Chapter DB

DATABASE CREATION AND RESOURCE EVALUATION METHODOLOGY

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INTRODUCTION

The objectives of the coal resource assessment of the Fort Union Formation and equivalent rock units in the northern Rocky Mountains and Great Plains region are: (1) compile the information needed to assess selected coal beds and zones of the Fort Union Formation and its equivalent formations that are potentially mineable in the next few decades; (2) identify clean and compliant coal that meets standards of the Environmental Protection Agency for sulfur, ash, and trace elements of environmental concern; (3) create a publicly available digital database of this coal that can be rapidly accessed and analyzed to provide information critical to decision-making by government, industry, and the public; and (4) produce widely available digital products accessible in a variety of interpretive and interactive forms. In order to accomplish these objectives, it was necessary to create a computerized database that contains a vast amount of geographic, stratigraphic, and analytical information. Data were stored, retrieved, manipulated, and analyzed utilizing StratiFact software (GRG Corporation, 1996). This software consists of a relational database manager and a geographic information system (GIS).

The data were acquired through cooperation with the U.S. Bureau of Land Management, State geological surveys, U.S. Office of Surface Mining, and coal companies. The USGS National Coal Resources Data System (NCRDS) also provided digital data. Proprietary and non-proprietary data from these sources consist of drill-hole information and coal quality and coal geochemical analyses provided to the USGS as hard copies or in digital format. The data from hard copies were entered manually using spreadsheet software (for example, Access, QuattroPro, and Excel). The digital files were transformed into processible formats (ASCII) and downloaded into the StratiFact database manager. When all datasets

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from each drill hole were edited, correlated, and checked for quality control, the completed StratiFact database was queried to retrieve information to generate digital files for processing in other software (for example, ARC/INFO, ArcView, earthVision) for calculation of coal resources.

DATABASE CONSTRUCTION

Data for the Fort Union Formation and equivalent units were obtained mainly from drill holes and subordinately from measured sections in outcrops used as control points. Data from 18,207 drill holes were collected from government and private industry sources for this assessment. More than seventy-five percent of these drill holes are from coal exploratory drilling and development, and the rest are from oil and gas exploration. Thus, the basic entity of the database is a drill hole bored vertically from a surface location. Information from this drill hole is either in the form of driller's or geologist's lithology logs from rotary drill cuttings or cores, and geophysical logs (for example, gamma ray, density, neutron, resistivity, and spontaneous potential). The digital files of the geophysical logs are not included in the database.

The geophysical logs, which make up a large part of the drill-hole information, require special analysis to measure the thickness of coal beds and related rocks. The precision and accuracy of measurement of thickness of coal beds and adjacent rocks on geophysical logs depend on the speed of logging, scale of the log, type of log, type of equipment, and instrument settings (Vaninetti and Thompson, 1982; Wood and others, 1983). Perhaps the most important part of the log analysis is the ability of the user to identify the top and bottom of the beds by using the points of inflection and mid-point of inflection methods (Wood and others, 1983, p. 55). The points of inflection method requires picking the top and bottom of the beds where the curves change directions. The mid-point inflection method requires picking the top and bottom of the beds at points midway between the points of inflection and the initial peak. Thus, the value and accuracy of the geophysical logs in measuring the thickness of coal beds and adjacent rocks varies with the experience of the users. However, because the Fort Union coal beds are very thick, the “operator’s error” with the use of either method is considered negligible. In addition, the mining practice for these thick coal beds is to discard some of the top of the bed and leave the bottom of the bed in place during mining, both of which consist commonly of a “dirty” coal or carbonaceous shale considered uneconomic.

The basic information required for the StratiFact database manager from each drill hole includes: (1) point identification and geographic location; (2) stratigraphy; and (3) depth-based coal analytical data. More information on file designs or configuration of the database manager can be found in the guide to StratiFact published by GRG Corporation (1996).

DRILL-HOLE LOCATION AND STRATIGRAPHIC DATA

The drill-hole identification is typically a unique hole number or a hole name. Drill-hole location coordinates were entered in coordinate systems (Universal Transverse Mercator system, latitude and longitude system, or state plane survey). Drill-hole elevation data were entered as part of the location format. The rock types (for example, coal, sandstone, siltstone, mudstone, etc.) were entered along with the top and bottom depth of the lithology and lithology name. A “rock” name was entered when the lithology between the coal is either undifferentiated sandstone, siltstone, and mudstone or unidentified. Additionally, the stratigraphic data contain formation names (for example, Fort Union Formation), subdivisions labeled as coal zones (for example, Wyodak-Anderson) consisting of one or more coal beds, and unassessed zones above and below this zone. The assessed and unassessed zones are identified according to the names of coal beds contained within the zones and/or members of the formation in which they exist. A drill hole may penetrate one or more stratigraphic formations or members of a formation that contain alternating coal beds and rock types. The coal beds are recognized by standard nomenclature and may exist in one or more members and in a formation.

COAL ZONE

Throughout a basin of coal deposition, individual coal beds may either thicken or thin, merge or split into thinner beds separated by rock units (for example, sandstone, siltstone, mudstone), or pinch out. Coal splits into two or more beds that gradually thin or pinch out or interfinger with clastic rocks. Thus, a “zone” or an interval of coal beds and interbedded rock units will contain coal in one or more beds, and this “zone” is more correlatable over a wide area than are the component coal beds.

The term coal zone is used in this investigation to define related coal beds that are in stratigraphic proximity to each other but may not be all as one unit. Coal-zone names are either adopted from accepted nomenclature or are selected from the coal-bed names that are inclusive, from bottom to top of the interval, of contained coal beds. Figure DB-1 is a diagrammatic representation of variation of a coal zone that reflects the study areas in the Powder River, Williston, Hanna, Carbon, and Greater

Green River Basins. A coal zone in these basins typically contains from one to as many as eleven coal beds (for example, Wyodak-Anderson coal in the Powder River Basin). As exemplified by the Wyodak-Anderson coal zone in the Powder River Basin, the coal beds, from west to east, are split by fluvial deposits, merge into one thick bed, resplit, and remerge into another thick bed (fig. DB-1). In addition, the associated coal beds thin westward and pinch out or abut against "want areas" or fluvial channel deposits. In this example, separate coal beds may exist within the coal zone at some places, but some beds may be missing elsewhere. In addition, a coal zone in one area may be interconnected with the same coal zone in an adjoining area by either a coal bed at the top, in the middle, or at the bottom of the coal zone (fig. DB-2). Thus, the laterally juxtaposed coal zone forms either a series of "onlapping" or "zigzagging" patterns (fig. DB-2) throughout the basin of deposition. Consequently, because of very complicated correlation and non-correlation of coal beds within the coal zone, the coal resource assessment is more easily performed on the coal zone rather than on the coal bed. The continuity of the coal zone over a large area makes it more amenable to more accurate calculations of coal resources than would assessment of individual beds.

CORRELATION

The coal zone is established in order to correlate in detail the various coal beds and associated rock types. Correlation of coal beds is guided by the regional and local geologic structures and lithofacies association or depositional settings of associated rock types. That is, differences in depths of coal beds may be explained by the structural dip of rocks and/or by structural faults and folds (Whitacker and others, 1978; Broadhurst and Simpson, 1983; Weisenfluh and Ferm, 1984). In addition, occurrences of coal beds near the surface may be controlled by ancestral (for example, glacial) and modern (for example, river) erosion. More importantly, the environments and related processes at the time of deposition or accumulation of the coal beds (as peat deposits) influenced their lateral extent or continuity (Wanless, 1955; Ferm, 1970; Ferm and Staub, 1984; Flores, 1986). That is, highly dynamic environments such as deltas and rivers, which laterally switched back and forth (avulsion process) during their existence, are prone to develop very discontinuous associated peat swamps that form coal. This process of avulsion makes correlation of coal beds difficult unless it is aided by very closely spaced drill holes. In general, inactive areas associated with these environments, such as floodplains, interdeltas, and abandoned deposits, are prone to development of associated laterally extensive peat swamps and subsequent coal beds. This allows uncomplicated correlation of coal beds requiring less closely spaced drill holes. However, when these environments were overrun by rivers and/or deltas, the accumulation of associated peat deposits was interrupted, resulting in nondeposition of coal beds. Once these rivers and deltas shifted elsewhere (for example, topographic low areas) the same area may have been reoccupied by peat swamps and the coal deposition may resume. These processes may explain the variable continuity of the coal beds as well as their splitting and merging to form coal zones within the same area of deposition. When these processes are repeated contemporaneously basinwide, the result is “onlapping” and “zigzagging” of coal beds and zones. Thus, continuity of coal beds and/or zones and associated rock types is a function of their depositional environments, and the degree of reliability of correlation is determined by the spacing of drill holes that indicate the lateral variations imposed by these geological factors.

Palynology has been applied throughout the assessment region to provide a biostratigraphic (“palynostratigraphic”) framework for correlation of coal beds and zones. A palynostratigraphic zonation was developed from reference sections in selected outcrops, coal mines, and cores that are correlated to subsurface drill-hole data. The Fort Union Formation and equivalent rocks were divided into six palynostratigraphic zones designated P1 (lowermost Paleocene) through P6 (uppermost Paleocene) by Nichols (1994; 1996). The palynostratigraphic zonation is the basis for age determinations of individual coal beds and zones, and for correlations of coal-bearing rocks between basins in the assessment region.

COAL ANALYTICAL DATA

Each coal sample locality and/or drill hole is identified by a unique number and name. When possible the original location number and name were retained from the drill hole where the coal sample was collected. Location coordinates were recorded in Universal Transverse Mercator, latitude and longitude, and state plane coordinate systems. The coal analytical data consist of proximate and ultimate analyses from drill holes and mine locations. Guidelines for sampling to ascertain the rank and chemical, mineralogical, petrographic, and geophysical and physical properties of coal are discussed by Swanson and Thompson (1976). The proximate analysis includes the moisture, volatile matter, fixed carbon, and ash contents (on an as-received, moisture-free or dry, and ash-free basis). The ultimate analysis consists of the hydrogen, carbon, nitrogen, sulfur, oxygen, and ash contents (on an as-received, moisture-free or dry, and ash-free basis). The calorific or heat value (Btu/lb), forms of sulfur (sulfate, pyritic, and organic), and chemistry/mineralogy of the ash (for example, aluminum, calcium, manganese, potassium, silicon, and/or sodium oxides) are also included. Prescribed methods for analyses of these physical and chemical properties of the coal are discussed in American Society for Testing and Materials (1997).

The geochemical dataset includes the 12 trace elements of environmental concern named in the 1990 Clean Air Act Amendments (antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, selenium, and uranium). These data were entered in a spreadsheet format and each data entry includes the name of the coal bed or zone from which the coal sample was collected. The coal quality and geochemistry data from each sample location was linked to either the actual drill hole from which the sample was taken or to the nearest stratigraphic drill hole using the point identification number and the name of the coal bed/zone. This method relates the coal quality and geochemistry data to the coal stratigraphy, permitting spatial analysis and ultimately the use of coal quality (for example, rank, total sulfur, SO_2 per million Btu) in reporting the coal resources.

COAL RESOURCE EVALUATION METHODOLOGY

Coal resource evaluation employs digital computer technology (for example, software), similar to manual methods, for isopaching and planimetering coal beds and zones, and overburden to categorize and calculate quantities of coal. These manual and computer methods determine the thickness and volume of coal, overburden thickness of rocks above the coal, and reliability categories; however, the computer method is deemed more efficient, more readily repeatable, more detailed, and faster than the manual method. Detailed methods for data preparation and computer calculation of coal resources for the assessed Fort Union and equivalent coal in the Powder River Basin is discussed by Ellis and others (1999; in press). See specific chapters in this CD-ROM for a general discussion of the methodology used to assess the coal resources of other basins in this study (Williston Basin WN;

Greater Green River Basin GN; Hanna and Carbon Basins HN). The coal resource evaluations in these basins consist of estimating the volumetrics of 18 coal beds and zones (Wyodak-Anderson, Rosebud, Knobloch, Harmon, Hansen, Hagel, Beulah-Zap, Ferris 23, 25, 31, 50, and 65, Hanna 77-79 and 81, Johnson-107, and Deadman coal beds or zones). These selected Tertiary coal beds and zones, except the Knobloch and Johnson-107, were mined and produced more than 30 percent of the total U.S. coal production in 1997. Thus, these selected coal deposits are important to development in the next few decades.

VOLUMETRICS

In order to calculate the volume for each of the 18 coal beds and zones, it is necessary to determine the thickness and areal distribution of the coal. The volume of coal is calculated using these parameters and is then converted from acre-ft to short tons by factoring in the density (number of short tons per acre-ft for the apparent coal rank) of the coal. Thus the formula used for resource calculation is: short tons = acres x coal thickness x coal rank or density conversion factor (for example, 1,750 for lignite, 1,770 for subbituminous, 1,800 for bituminous, and 2,000 for semianthracite and anthracite) (Wood and others, 1983).

As described under the section on construction of the database, coal beds existing in vertical proximity were assigned to and correlated over large areas as a coal zone throughout their depositional extent. Throughout this extent an individual coal zone may contain one or more coal beds recorded in each drill hole. Thus, given the number of coal beds and their continuity per coal zone, a method was devised to measure and combine the net thickness of the coal beds of one zone at each data-point location. This method was applied after the coal beds in the coal zone were correlated, taking into account all the geological factors discussed under the section on database construction. Correlations defined the coal beds included in the coal zone and the elevations of the top and base of the coal zone. The amount of overburden (thickness of rocks above the coal zone) was calculated by subtracting the grid of the surface elevations from digital elevation models (DEMs) and the grid of the elevations of the top of the coal zone. As a part of this method, the rock in the coal zone from each drill hole was also divided into partings and splits as defined by Wood and others (1983). Rock partings exist when the thickness of the rock between coal beds in the zone is less than the thickness of the underlying and overlying coal beds. Rock splits exist when the thickness of the rock between the coal beds in the zone is more than the thickness of either the underlying or overlying coal beds. These criteria are tailored to the estimation of coal resources where a coal bed bifurcates into two or more beds, as in the coal zone. This classification is required in order to accurately calculate the net coal thickness of coal within a coal zone.

COAL RESOURCE CATEGORIES

A standardized and universally accepted method for reporting reliability categories of coal resources has been established for the U.S. Geological Survey (USGS) by Wood and others (1983). This coal resource classification system is an expansion of the system adopted by the U.S. Geological Survey (1976) and Averitt (1975) in reporting the 1974 U.S. coal resources. In 1976, the USGS and the U.S. Bureau of Mines modified the system used by Averitt (1975), which served as the standard reference for coal resource/reserve assessment by many Federal and State agencies. Our coal resource reporting categories generally follow the 1983 USGS methodology (Wood and others, 1983), but with the addition of coal quality.

The basic concept in the USGS coal resource classification system is based on the geologic assurance that it is directly related to the distance from drill holes (control points) where coal thickness and overburden are measured. The specified distances from drill holes (control points) are reliability circles: 0–0.25 mi radius for measured coal, 0.25–0.75 mi radius for indicated coal, 0.75–3.0 mi radius for inferred coal, and beyond 3 mi radius for hypothetical coal. Thus, the classification system is designed to quantify the amounts of coal (1) that are known or identified resources (measured, indicated, and inferred reliability categories), and (2) that remain to be identified (hypothetical reliability category). These distance reliability categories, as well as the net coal thickness category (2.5–5 ft, 5–10 ft, 10–20 ft, 20–40 ft, and >40 ft) and the overburden thickness category (0–100 ft, 100–200 ft, 200–500 ft, and 500–1,000 ft), are required for reporting resources for the Fort Union lignite and subbituminous coal (>500 ft is used because no or little overburden exceeds 1,000 ft). In addition, coal resources were reported by county, state, 7.5-minute quadrangle, Federal versus non-Federal surface and coal ownership, coal quality (using ash and sulfur contents, and pounds of SO_2/million Btu), and apparent coal rank (as indicated by moist, mineral-matter free Btu; American Society for Testing and Materials, 1997) categories. The coal resources reported by these categories do not include mined out and leased areas, and areas of burned coal and associated rocks or clinker. Also, coal resources of Indian tribal lands were not calculated.

COMPUTERIZED METHODS

Several computer software programs were utilized to create digital information for the calculation of the coal resources. ARC/INFO and ArcView software were used to create layers of spatial digital information or coverages (for example, state boundaries, counties, geological boundaries, mine and lease boundaries, quadrangle maps, clinker, point locations, etc.). These coverages are in Lambert Conformal Conic projection, Clarke Spheroid 1866, with parameters of first standard parallel of 33°, second standard parallel of 45°, and central meridian of 106°.

The computer method for calculating coal resources involved compensating for the irregular distribution (x and y values) of drill-hole data (dense versus sparse distribution) within the study basins. In order to compensate for this distribution, a rectangular grid was superimposed over the data area and a Z value (for example, top and bottom of coal beds, net thickness, etc.) was interpolated by computer. This gridding procedure was performed by using the earthVision software. Different grid sizes and algorithms were used to test either the “coarseness” or “fineness” of the grids in order to generate the appropriate isopach maps. Thus, resource calculations were accomplished by using grid nodes and sub-nodes values in the earthVision program (Ellis and others, 1999, in press; Roberts, 1998). Coal thickness isopach and overburden maps generated from this procedure were utilized to produce unioned coverages using ARC/INFO. These coverages are composed of combined layers or polygons of spatial information containing attributes (for example, counties, State, Federal versus nonFederal ownerships). After unioning all the coverages, the resulting coverage was clipped to the coal zone areal extent. The ARC/INFO union coverage polygon files were imported into earthVision for volumetric calculations (assigned in short tons). This method, which used the net coal thickness grid node and sub-grid node values of the coal thickness, was determined to be the most accurate method for estimation of coal resources by computer (Ellis and others, 1999; in press).

The coal resources are reported in tables, which contain rows such as overburden, coal thickness, and distance reliability categories. The tables also include columns such as coal quality (percent sulfur and ash), lbs SO_2/million Btu, and apparent coal rank. Coal resources within each of these categories are reported as short tons (in millions to billions) in two significant figures. Schuenemeyer and Power (in press) developed a procedure for the estimation of uncertainty or measurement of error in the volume of coal resources as a part of the USGS National Coal Resource Assessment.

CONCLUSIONS

After drill hole and outcrop data are obtained and entered into a database, the process of evaluating coal resources involves retrieving drill-hole data from the StratiFact database manager for each identified and correlated coal zone in each study basin. The data are used to create grids of measured values and finally to calculate coal tonnages (in millions to billions short tons) categorized according to specific intervals of depths or overburden, net thickness of coal, and degree of assurance of existence of the coal (relation of distribution and quantity of drill holes). Additional reporting categories include coal resources by counties, state, surface and subsurface ownerships, coal quality, and apparent coal rank. Coal tonnages are reported in Excel tables.

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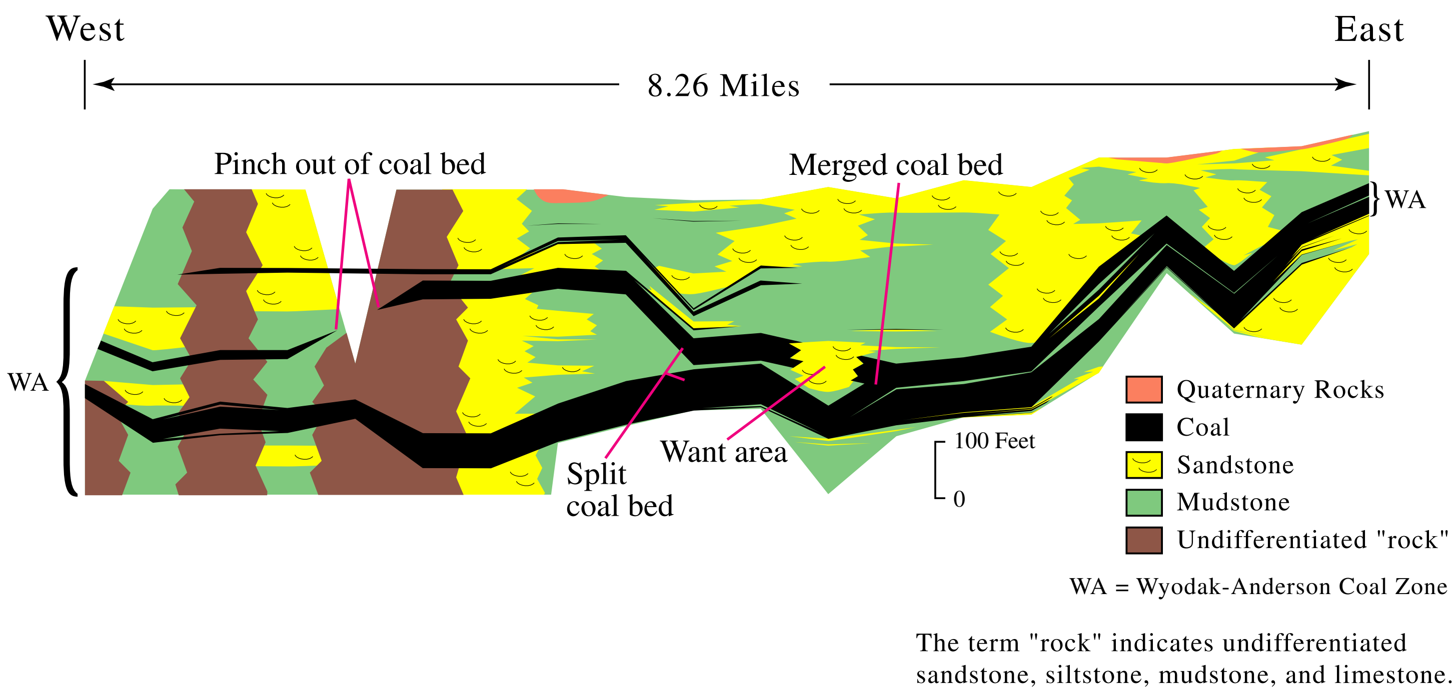

Figure DB-1. Cross section of the Wyodak-Anderson coal zone south of Gillette, Wyoming.

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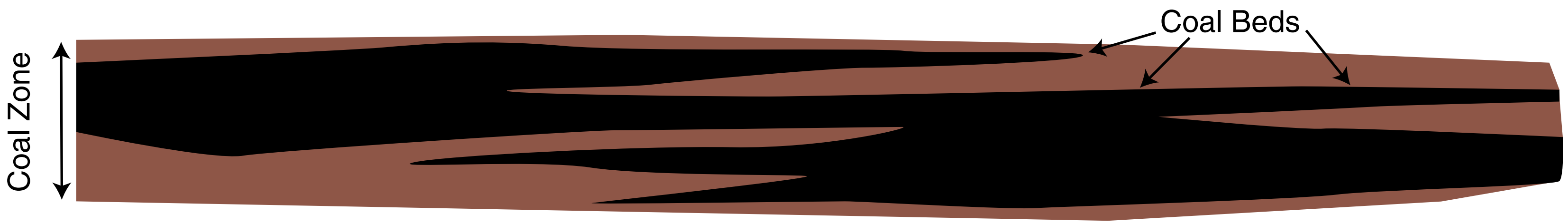

Undifferentiated "rock"
Coal

The term "rock" indicates undifferentiated
sandstone, siltstone, mudstone, and limestone.

Figure DB-2. Diagrammatic cross section of a series of interconnected coal zones and related coal beds. Not to scale.

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