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A geostatistical case study in West Virginia: All coals are not the same

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ABSTRACT

In reporting coal reserve and resource estimates, geologists and engineers have long reported quantity of coal classified among the distance-based categories described in the U.S. Geological Survey Circular 891 (1983). Although this tabulation of coal volumes apparently gives an expression of uncertainty in the resource or reserve, it is nonquantitative at best, and ignores among several factors the spatial variability of a particular coal under study. Seam thickness for three coals, the Pittsburgh, Eagle, and No. 2 Gas coals were extracted from a large database in West Virginia. Variograms were computed, models fitted visually, and sequential Gaussian simulation was used to compute multiple realizations of coal thickness at each location on a regular grid. Variances about the estimates of coal bed thickness at each grid location were compared among the three datasets. Both variograms and uncertainty about the estimated means are different among the three coals to the extent that normalized average variance for "measured" coal was double for the No. 2 Gas relative to the Eagle Seam, and intermediate for the Pittsburgh Coal. These results provide empirical evidence of the limitations inherent in the classification of coal tonnage into distance classes as a proxy for actual calculation of uncertainty.

1. Introduction

For reasons of practicality and clarity, geologists and engineers in the United States have reported coal reserve and resource estimations by using the method of the U.S. Geological Survey (Wood et al., 1983: "Circular 891"). Expressing uncertainty in resource estimation is difficult in the context of "how much coal is available" or "how many years of coal are still in the ground", when the questioner usually wants a simple answer, perhaps a single number. Yet we know that the quantity of a natural resource is uncertain until actually mined, picked, or harvested.

The method of Circular 891 (Wood et al., 1983) provided that answer, but sacrificed flexibility. The method described in this publication classifies an estimate of coal resource at a location according to whether it lies within a particular distance from an observed value. "Measured" coal is within 0.25 mi; "Indicated" between 0.25 and 0.75 mi; and "Inferred" between 0.75 and 3.00 mi of an observed value of coal thickness. Allocating coal quantities into distance-based categories recognized that uncertainty increases with distance from observed values. However, these specified distances remain constant from coal to coal without regard to spatial continuity in thickness or other variables for a particular deposit. Some coal beds simply retain a similar thickness over comparably long distances relative to other coals, dependent upon such factors as patterns of deposition, subsequent erosion, and chemistry.

At face value, classification of coal tonnage among uncertainty classes makes some sense and provides an easily-understood way of expressing how much coal is almost certainly to be present i.e., "measured", how much is reasonably likely to be found: "indicated", and how much is fairly speculative: "inferred." This approach suffers from at least two drawbacks. First, it does not provide a statistical distribution for computing a more meaningful prediction, such as the much-utilized expression of uncertainty into, for instance, the quantity of a resource one is almost certain to obtain with a probability of 90% i.e., "p-90" and the quantity that is only 10% probable, "p-10". Second, it is completely insensitive to the spatial continuity of a particular coal deposit. In the case of a coal seam manifesting low variability in thickness across large distances, we might consider measured and indicated coal tonnage to be almost certain. In contrast, there could be high uncertainty in the tonnage calculated in even the measured category for a coal varying greatly over small distances.

Olea et al (2011) also argue the shortcomings of the approach in circular 891, demonstrating its limitations in properly expressing uncertainty for lignite beds in Texas (USA), and proposing an alternative based on standard geostatistical methodology. Implicit, however, is the assumption that coals do indeed differ stratigraphically and geographically. Otherwise, the circular 891 approach could be adjusted or modified to fit the geostatistical approach; after all, both recognize the increase in uncertainty with distance from observations for estimating reserves or resources. This is not possible in part because as this paper illustrates, coal seams do vary in spatial continuity and demand a geostatistical approach.

This paper illustrates the variability among coal seams of an important variable–coal thickness–even within a single coal basin. We

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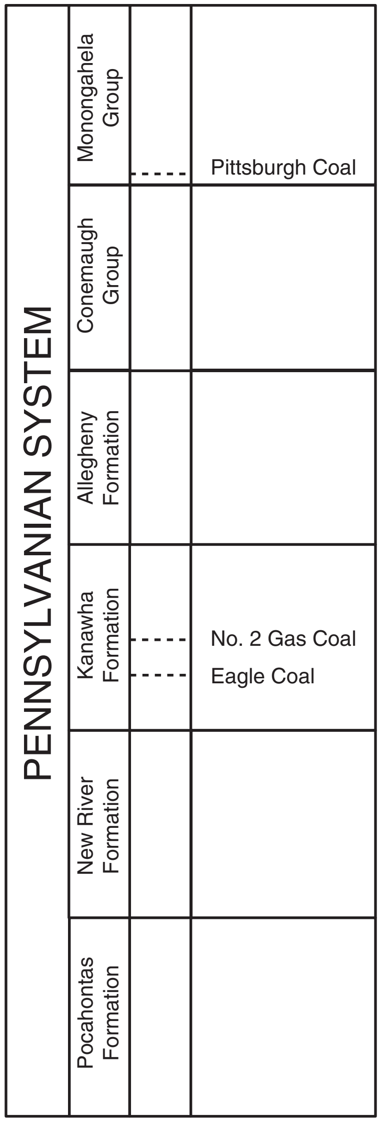

Fig. 1. Stratigraphic column of Pennsylvanian groups and formations in West Virginia and stratigraphic positions of coal seams discussed in this paper.

have selected as examples three coal beds in West Virginia that differ in variability in coal thickness over distance. West Virginia is the second largest producer of coal in the United States, and the three coal seams selected, Pittsburgh, Eagle, and No. 2 Gas, have been mined for many decades.

This paper utilizes variogram analysis and conditional simulation to compare and contrast spatial continuity of these coal seams. Variograms are calculated and contrasted visually for each coal bed. For each dataset, variogram models and sequential Gaussian simulation are used to compute multiple realizations of coal bed thickness from which mean and variance are computed for each location on a regular grid. Estimation variances for grid cells classed as 'measured', 'indicated', and 'inferred' are averaged and these mean values are compared.

2. Geologic and economic setting

Coal resources in West Virginia are divided into a northern, high-ash, high-sulfur field and a southern low-ash, low-sulfur field separated by a hinge line. This hinge line formed in response to sediment infilling of a foreland basin located at the edge of the mid-continental craton following thrust loading during the Allegheny orogeny. A narrow foreland budge area separated the more southeastern rapidly subsiding basin from a more stable northern cratonic margin. Coal rank and quality can be attributed to climatic, depositional and structural conditions which governed coal swamp architecture and thus ash yield and sulfur content.

The Pittsburgh Coal is the basal unit of the Monongahela Group of the Upper Pennsylvanian Subsystem (Fig. 1). It was formed in an aggrading and prograding coastal plain within a foreland basin during a depositional hiatus which allowed a huge peat mire to accumulate in a wet, topogenous to ombrogenous, but planar coal swamp. The resultant current coal horizon extended from present day Pittsburgh, PA, south through central West Virginia, extending over 11,000 mi^2 through 53 counties in Pennsylvania, West Virginia, Ohio and Maryland (Tewalt et al., 2000). One of the most prolific producing coal seams in the United States, the Pittsburgh seam produced 32.3 million tons of coal in 2008, 19.7% of total production for the state. In 2008 the top 4 producing underground mines and 5 of the top ten mines were in the Pittsburgh seam. Production in 2011 was 37.8 million tons, 27% of the total production. The Pittsburgh was first mined commercially in the 1760s. The original mineable extent of the Pittsburgh Coal extended from Pittsburgh, Pennsylvania, into central West Virginia. Much of the original extent in Monongalia, Marion and Harrison counties have been exploited while deeper reserves lie to the west into Wetzel county, WV. The majority of the Blacksville Quadrangle has been mined, averaging about 7.5 ft thick throughout the quadrangle and ranging between 61.2 and 117.6 in. in thickness with partings varying from 0.0 to 9.0 in.

Many Kanawha Formation coals–including the Eagle and No. 2 Gas–have been interpreted to have been formed as domed peats in a seasonal wet–dry paleoenvironment similar to peats forming in

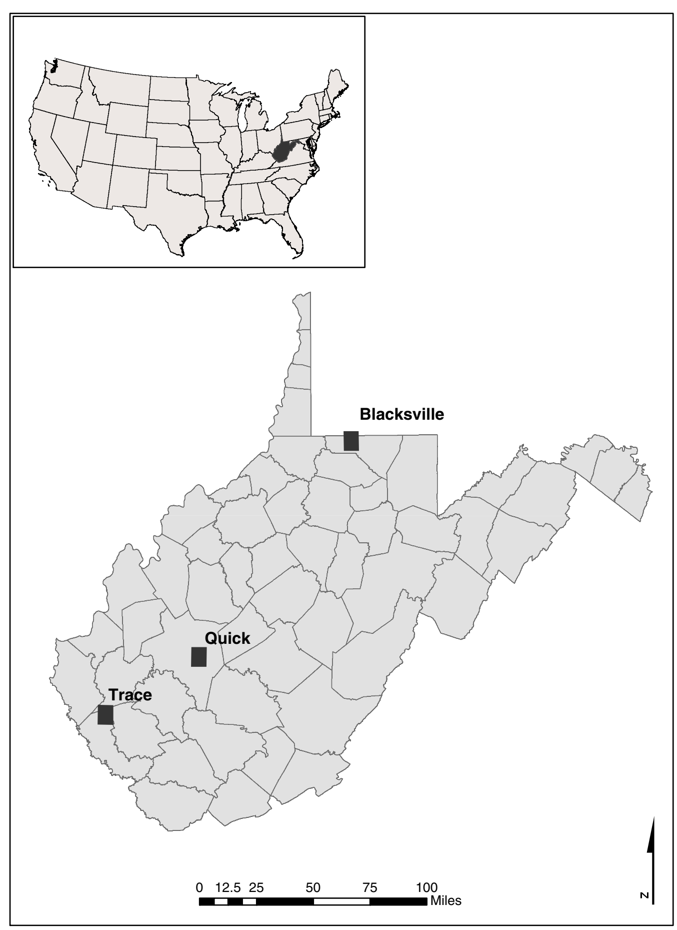

Fig. 2. Index map of the three 1:24,000 quadrangles discussed in this paper.