Chemical characterization of coal-bearing strata using down-hole prompt gamma ray spectroscopy wireline logging: a status report

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Abstract

The U.S. Geological Survey, in cooperation with the West Virginia Geological and Economic Survey, West Virginia University, and Schlumberger Oilfield Services, has undertaken a program to develop a methodology that chemically characterizes coal-bearing strata in a rapid, accurate, and cost-effective manner. The methodology under development utilizes a prompt gamma ray spectroscopy tool in down-hole wireline logging. The spectroscopy tool routinely analyzes for the elements Ca, S, Fe, Ti, K, and Si, of which S and Ca can be used for an acid-base accounting determination. The tool provides a continuous chemical analysis record of the formation surrounding the drill hole, thereby eliminating significant errors that are introduced by sampling and other analytical techniques. Preliminary results indicate that the tool provides high quality elemental concentration logs that should greatly improve chemical characterization of coal-bearing strata including data for improved accuracy in acid/base accounting determinations.

Introduction

The U.S. Geological Survey, in cooperation with the West Virginia Geological and Economic

Survey, Schlumberger Oilfield Services and Environmental Technologies, and the West Virginia University Department of Geology and Geography (WVUDGG) and the National Mine Land Reclamation Center (WVUNMLRC), initiated a program to apply oil and gas industry well logging techniques to the chemical characterization of coal-bearing strata. The methodology is based on down-hole chemical analyses using prompt gamma ray spectroscopy, hereinafter referred to as geochemical logging. The objective of the program is to develop a methodology that chemically characterizes coal-bearing strata in a rapid, accurate, and cost effective manner using wireline logging techniques. Standard analytical procedures generally involve coring, core sampling, and chemical analysis of core samples. In contrast, the geochemical logging technique may only require wireline logging of drill holes. The logging provides continuous chemical analyses, top to bottom, of a drill hole thereby eliminating sampling bias and error as well as errors associated with sample preparation and analyses. The spectroscopy tool routinely analyzes for the elements Ca, S, Fe, Ti, K, and Si. Calcium and S values can be used for acid/base accounting (ABA) which is the accepted method for predicting acid drainage from reclaimed surface coal mines. Acid/base accounting is based on the stoichiometric relationships between pyrite (FeS_2) and calcite ($CaC0_3$) concentrations in overburden. Calculated ABA predictors include neutralization potential (NP), maximum potential **acidity (MPA),** and net neutralization potential (NNP). Weight percent calcium from geochemical logging may be recalculated as neutralization potential (NP) because calcium primarily occurs in carbonate minerals, principally CaC03, with only trace amounts occurring in other minerals such as feldspars and clays. Weight percent sulfur can be recalculated as pyrite (FeS_2) and MPA. The NP and MPA values are then used to calculate NNP. Data generated by wireline logging, therefore, may be directly applied to problems such as ABA.

Methods

in order to compare acid/base accounting data generated by wire line logging with conventional analytical methods, a study site was sought having a variety of rock types and chemistries. In a collaborative effort, the participants defined the study requirements and selected a site near the eastern edge of the bituminous coal field approximately 10 miles northeast of the town of Davis, Tucker County, West Virginia. The region has a long history of coal production from strata that are known to have significant stratigraphic and regional variations in mineralogy and chemistry.

The top 29 feet of the core drill hole was cased and a 650-foot core was extracted from the base of the casing to the bottom of the hole at the study site. Upper and Middle Pennsylvanian coal-bearing strata were cored. The stratigraphic interval cored was from the approximate stratigraphic horizon of the Upper Pennsylvanian Bakerstown Coal bed in the Conemaugh Formation down through the Middle Pennsylvanian Allegheny Formation to the top of Pottsville Formation. The core was described at the wellsite using standard driller's log descriptions. The core was boxed and transported to core curation facilities at the West Virginia Geological and Economic Survey where it was further geologically described. The core was divided into one foot increments. Each one foot increment was cut in half longitudinally. One half was archived for future reference and the other half was cut in half again into quarters of the original core. One complete set of one foot long quarter samples was submitted to WVUDGG analytical laboratories where each sample was ground to -200 mesh and prepared for mineralogical and chemical analyses. The second set of quarter core samples were selectively sampled for an ABA analyses. Two-hundred eighty-eight samples out of six-hundred fifty were selected from the second set of quarters by a consulting firm that has extensive experience in core sampling for ABA. Samples selected from the second set of quarters were also submitted to WVUDGG for chemical and mineralogical analyses. All samples submitted to WVUDGG are being subjected to ABA determinations plus they are being analyzed for the same elemental suite as in geochemical logging. The core sampling protocol was designed for a three-way comparison of ABA data generated among 1) chemical and mineralogical analyses of the total core using one foot increments, 2) chemical and mineralogical analyses of selected samples of core using ABA sampling procedures, and 3) down hole geochemical logging analyses. Preliminary data from samples of the total core and geochemical logging are presented herein.

The five-inch diameter of the geochemical logging tool required a larger diameter hole than provided by wire line coring. A second hole, six inches in diameter, was drilled specifically for geochemical logging by air rotary equipment approximately 20 feet from the core hole. Both the core hole and air rotary hole were logged using density, natural gamma, and resistivity tools. The geochemical logging system reported results every six inches, and outputs were adjusted to include calcite (CaC03) concentrations plus **NP, MPA, and NNP.** Coal beds are easily identified by wireline logs and they were excluded herein from ABA determinations because coal would be removed during mining.

Results

Preliminary laboratory results consist of sulfur (LECO sulfur analyzer) and calcite as determined by X-ray diffraction (XRD), on the total suite of one foot increment quarter core samples. The geochemical logging analyses consisted of continuous weight percent Si, Ca, Fe, Ti, and S, top to bottom of the hole. A comparison of the statistics from the geochemical logging data, chemical analyses for S, and XRD analyses for calcite is shown in Table 1.

Table 1. Comparison of the analytical data statistics for calcite and pyrite from geochemical logging (GL), chemical, and XRD analyses.

	$CaCO_3$ XRD	$CaCO_3$, GL	S S analyzer	S GL
Average	1.05	1.12	0.15	0.14
Standard deviation	4.69	3.10	0.33	0.35
Median	0.00	0.038	0.049	0.008
Minimum	0.00	0.021	0.00	0.004
Maximum	67.6	34.9	3.26	2.76
Number of samples	608	599	609	586

Comparison of all data from both the air rotary hole and the core reveals variation in calcium concentrations that would affect an ABA. Core XRD and geochemical logging data for calcium indicated that geochemical logging could have underestimated calcium with respect to the XRD data. The XRD data for Ca derived from the core increment samples appear to be consistent with drillers, geologists, density, resistivity, and natural gamma logs of the core and core hole. However, when the density, natural gamma, and resistivity logs of the two holes are compared it is clear that primary lithologies correlate between the two holes but the amount of calcite is very different. High XRD values for calcite (> 20 weight percent) in the core samples occur in sandstone intervals that correspond to calcareous intervals noted in geologists logs and to high resistivity values in the resistivity log. Stratigraphically equivalent intervals in the air rotary hole have low resistivity and they have low Ca values as determined by geochemical logging. The variation in calcite appears therefore to be related to lateral variation in calcite which easily accounts for the Ca differences in the geochemical logging and XRD data sets. It appears that both data sets are accurate and that spatial variability in calcite is high given the proximity of the drill holes.

The numerical comparison of the data for sulfur indicates that there is no significant difference in the average or standard deviation between the geochemical logging data from the air rotary hole and the chemical data from the core. Comparison of the median, minimum, and maximum values for sulfur indicates that either geochemical logging may slightly underestimate total sulfur or there are minor variations in sulfur concentrations between the two holes.

The cumulative ABA predictors for the core and geochemical logging are shown in Table 2. All ABA predictors were calculated without threshold values. A stoichiometric factor of 31.25 was used to calculate the MPA. The NNP value is equal to NP minus MPA.

Table 2. Acid/base accounting predictors from core samples and geochemical logging (GL).

	MPA,core	MPA, GL	NP, core	NP, GL	NNP, core	NNP, GL
Average	8.59	7.31	10.5	11.2	1.91	3.89
Standard deviation	16.1	25.8	46.9	31.0	48.2	40.6
Median	0	0.24	0	0.38	0	0.11
Minimum	0	0.14	0	0.21	-124	-321
Maximum	124	321	676	349	616	349
Number of samples	608	597	608	599	608	599

Conclusions

Preliminary data indicate that geochemical logging can provide a level of accuracy equivalent to chemical analyses of one foot increment samples of core. These data indicate that geochernical logging can be used successfully in chemical characterization of coal-bearing strata. The data can be used to address problems such as acid/base accounting in overburden characterization. Geochemical logging data allow acid/base accounting for part or all of a drill hole. The logging has the advantage of providing accurate data in a matter of minutes for an individual drill hole or any number of holes. The logging, therefore, offers a tremendous time savings because elemental concentration logs and acid/base computations can be provided at the wellsite. If further testing demonstrates that geochemical logging is as accurate as conventional chemical methods of overburden characterization, then geochemical. logging of air rotary holes may significantly reduce the need for coring. The project objectives of accuracy and rapid analysis appear to be met by geochemical. logging. The industry will have to address cost effectiveness. Additional drilling, logging, mineralogical, and chemical analyses at other sites in the Appalachian and Eastern Interior basins are ongoing to further evaluate geochemical logging as an improved methodology for chemical characterization of coal-bearing strata.