APPENDIX 4
Selenium

Abstract

Although the permittee asserts that its mining activities will not result in excess selenium (Se) being released into surface waters, the arguments to support that assertion are contradicted by evidence from previous mining in the area, including from other mines operated by the permittee. Abundant selenium exists in the coal deposits proposed for mining at the project site. From the analysis of Se in the coal beds of West Virginia, coals containing the highest selenium concentrations in West Virginia are in a region of south central West Virginia, which includes the region of the proposed Spruce No. 1 mine within the Coal River watershed. Conditions that make selenium bioavailable, or be able to be absorbed by living organisms, occur at mine sites in adjacent mines operated by Mingo Logan / Arch Coal, the permittee for the Spruce No. 1 mine. Though selenium is an essential element for animal nutrition, the behavior of Se is unusual in that it also acts to cause adverse effects on reproductive success (including developmental abnormalities), which have been linked to declines in vertebrate populations (Chapman et al., 2009). The information available does not demonstrate that the company can effectively distinguish material requiring isolation from water from those that have low selenium and might be used in valley fills. Furthermore, the permittee does not provide convincing evidence that water will not interact with these exposed deposits or that the selenium will be removed when the coal is removed. Thus, EPA believes that available information demonstrates that significant levels of selenium will be released by the Spruce No. 1 Mine.

A4.1. Fate of Selenium in the Environment

Selenium naturally exists in different oxidation states including oxyanions [selenate (SeO_4^{2-}) and selenite (SeO_3^{2-})], reduced selenium [selenide (Se^{2-})] and elemental selenium (Se). Selenate and selenite oxyanions, common in oxidizing environments such as the potentially exposed mine materials in valley fill areas, are the most mobile and toxic of the selenium species. The presence of aluminum (A1) and/or iron (Fe) oxides in the solid phase may result in substantially higher Se sorption as selenide (Se^{2-}) oxidizes to selenite (Se^{4+}) which could then sorb to FeO(OH). However, given the potentially alkaline nature of the mine materials from the proposed Spruce No. 1 mine, specific adsorption of selenium species onto geologic (or discharged fill) materials is not likely to play an important role in reducing Se mobility. This is because any near-field Se plume in the excess spoil material disposed into valleys will be sufficiently alkaline to greatly reduce the number of anion exchange sites for the Se oxyanions. Oxidation of the selenite to the highly mobile selenate could then take place. Also, given the depositional history and nature of formation of the rocks above and below the coal layers in West Virginia coal formations, significant concentrations of sulfates are expected in these valley-filled materials. Some of the sulfates will form as the metal sulfides in the valley-filled materials are exposed to the environment. Sulfates are known to compete with Se oxyanions for mineral adsorption sites making the Se oxyanions more available for leaching to surface waters and other environments.

While Se oxyanions have been reported to have lower potential for bioaccumulation in fish and other aquatic organisms, a reducing environment that may be induced in streams could reduce the oxyanions to forms that could easily bioaccumulate in aquatic species. A more desired outcome would be to decrease Se mobility in the materials present in valley fills, which would require a reducing environment. It is well known that reduction of Se is largely controlled by microbial processes (Février et al., 2007). In the excess spoil, we expect the subsurface to be physically complex and redox environments (at the microscale), and associated metabolic processes, to be heterogeneously distributed in both space and time. In particular, within the deeper deposits, oxygen is less available resulting in a chemically reducing environment.

A4.2. Predicting Fate of Se in Valley Fills

In the absence of mechanistic physical, chemical, and microbiological models, empirical models of Se partitioning between subsurface compartments is the most readily available method for predicting how Se will behave in these materials. The K_d parameter for Se (and indeed for other toxic metals that may be present in the valley fills) is an important parameter to estimate the potential for the adsorption of dissolved contaminants in contact with soil. K_d (L/kg) is typically defined as the ratio of the contaminant concentration associated with the solids (mg/kg) to the contaminant concentration in the surrounding aqueous solution (mg/L) when the system is at equilibrium. It is recognized that generic or default K_d values in the literature can result in significant errors when used to evaluate contaminant migration or site-remediation options. Hence site-specific K_d values derived using site-specific data are preferable. However, in the absence of such data, relevant published values may be used. Consequently, EPA conducted a literature survey for partition coefficients of Se. The following criteria and guidelines developed by EPA (USEPA, 2005b) were used to evaluate the published K_d values.

a) Use “whole” natural media for determination of K_d in natural media systems (meaning the rejection of K_d values from studies using pure mineral phases or treated soils).

b) Use low total metal concentrations (i.e., if K_d were determined at sites with multiple total metal concentrations, K_d values corresponding to the lowest metal concentrations where K_d is less likely to depend on metal concentrations where chosen).

c) Use pH values in the natural range of 4-10 (given the expected pH values of soils and rock formations that will comprise the valley fill).

d) Partition coefficients with no organic chelates (e.g., EDTA) in the extractant.

e) Where multiple K_d values are presented for a system due to experimental variation of pH or other parameters, choose K_d values corresponding to the conditions most closely approximating the geologic conditions of the materials that may comprise the valley fill.

The effective range of Se-K_d values in the ambient vadose zone of sediments is 0 to 0.78 L/kg (Kaplan & Serne, 1995). A K_d of zero means Se is entirely associated with the solution phase with a very high potential of being released into surface and/or ground waters. Using a conservative estimate of 2 mg/kg (or 2,000 µg/kg) in the valley-filled materials and the maximum estimated K_d of 0.78 L/kg, at equilibrium; we would expect 0.88 mg/kg (or 880 µg/kg) to remain adsorbed on the solid phase and 1.12 mg/L (or 1,120 µg/L) to be released into the soil solution. If we assume 1µg = 1 mL (which is reasonable for dilute systems), then 1,120 µg/mL in solution is equivalent to 1,120 parts per million (ppm). This is 224 times the 5 ppm criterion for Se in receiving streams. The precise amount that will end up in receiving streams or groundwater will require further modeling. However, this may be a realistic assumption given that the 2 mg/kg used in this example is half of the mean Se concentration reported for WV coals (see next section). Some horizons above and below the coal beds have also been reported to have more than 2 mg/kg. As indicated previously, soil microbial activity may increase the Se K_d. This will happen if mobile Se oxyanions are reduced to species that would readily adsorb on the solid phase and decrease the mobility of Se.

Evidence is lacking that would demonstrate that Se in the materials to be deposited in the Spruce No. 1 Mine valley fills would be immobile and pose no environmental threat. This would require the development of comprehensive and predictive models that quantify the anticipated dynamics of the biogeochemical systems including variations in the redox processes operating at the microscale in the proposed materials that will comprise the valley fills.

A4.3. Differences in Geologic Environment

The selenium content of West Virginia coals has been thoroughly examined and these data are available at the West Virginia Geological and Economic Survey (WVGES) website (http://www.wvgs.wvnet.edu/www/datastat/te/index.htm) and are summarized in Figure A4.1. From a total of 845 samples, Se concentrations are reported to range from non-detects to 21.3 mg/kg with a mean concentration of 4.2 mg/kg and standard deviation of 2.83 mg/kg.

In addition to evidence described above indicating the high selenium concentrations in nearby coal deposits, the coal beds of the Allegheny and Upper Kanawha Formations exhibit high Se concentrations compared to coal beds both lower and higher in the geologic sequence. Formation cores analyzed by USGS (Paybins et al., 2000; Neuzil et al., 2005) show similar trends. The coal beds to be mined at the Spruce No. 1 Mine include 5-Block of the Allegheny Group and down to the Upper Stockton coal bed in the eastern portion of the project area. In the western portion of the project area, the mine plan would extract coal through the Middle Coalburg coal bed. These coal beds are enriched in Se as evidenced by Se distribution data in the Spruce No. 1 Mine column (DT0417) provided in the NPDES permit application (Figure A4.2). Due to space limitations, the profile has been modified to show only coal beds encountered during drilling and the rocks above and below the coal beds that may be removed and deposited in valley fills during mining. Similar Se distributions in Coalburg coal and Winifrede coal at the Bull Creek Mine (Figure A4.3) were also reported by Vesper et al. (2008).

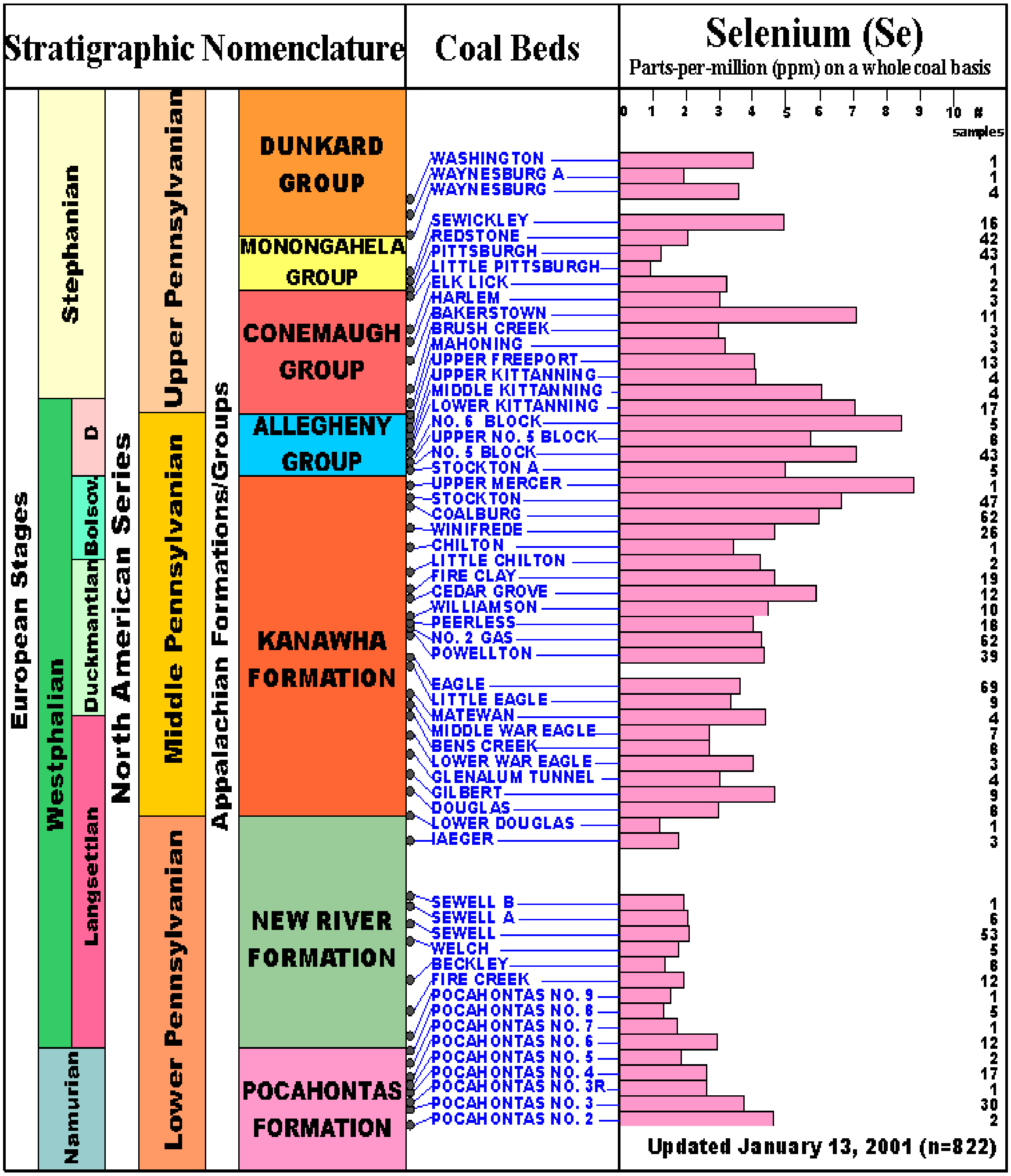
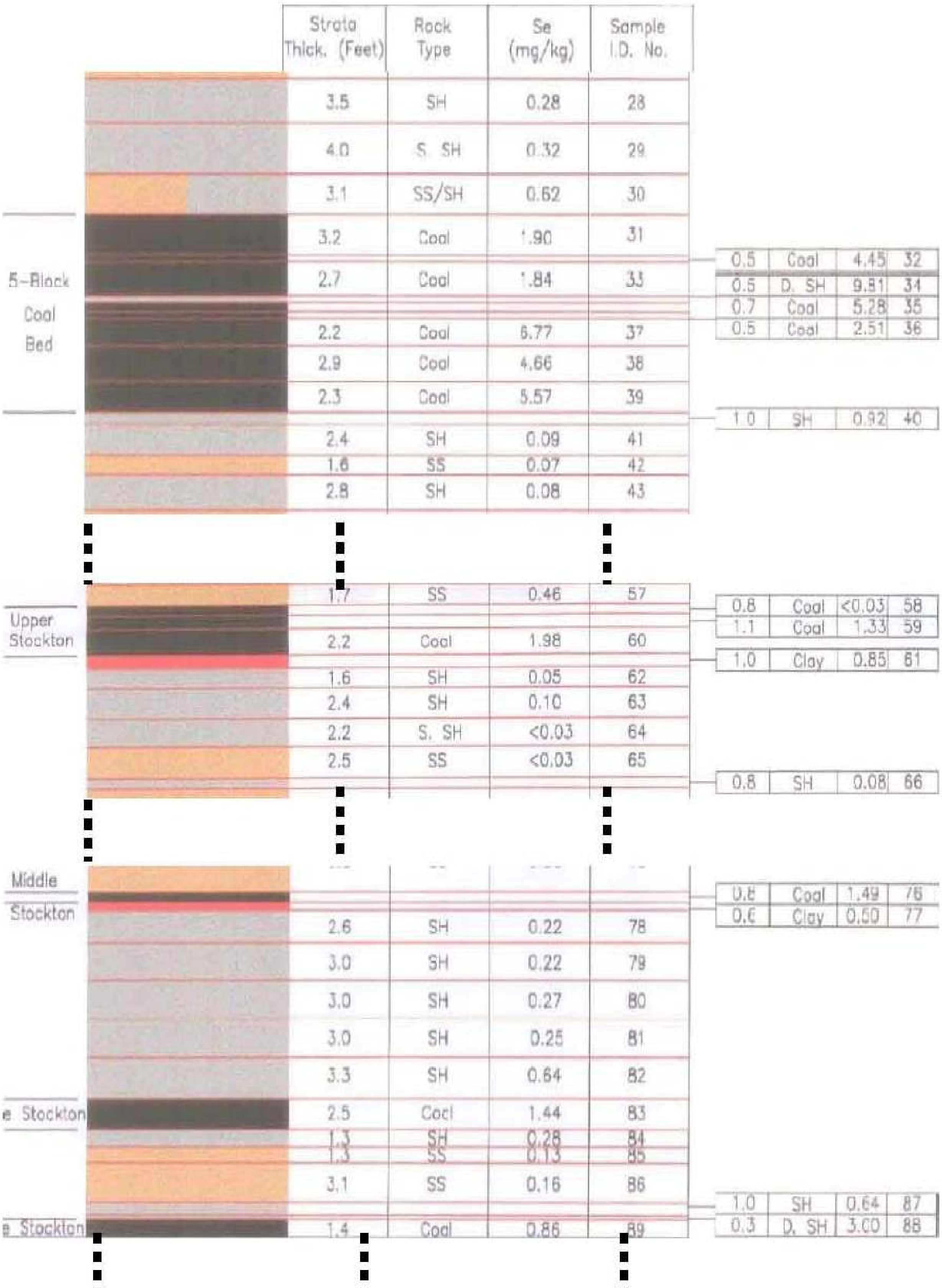


Figure A4.1. Selenium by coal bed in West Virginia coals


Strata Thick. (Feet)
Rock Type
Se (mg/kg)
Sample I.D. No.
3.5 SH 0.28 28
4.0 S. SH 0.32 29
3.1 SS/SH 0.62 30
3.2 Coal 1.90 31
0.5 Coal 4.45 32
2.7 Coal 1.84 33
0.5 D. SH 9.81 34
0.7 Coal 5.28 35
0.5 Coal 2.51 36
5-Block Coal Bed
2.2 Coal 6.77 37
2.9 Coal 4.66 38
2.3 Coal 5.57 39
1.0 SH 0.92 40
2.4 SH 0.09 41
1.6 SS 0.07 42
2.8 SH 0.08 43
1.7 SS 0.46 57
0.8 Coal <0.03 58
1.1 Coal 1.33 59
Upper Stockton
2.2 Coal 1.98 60
1.0 Clay 0.85 61
1.6 SH 0.05 62
2.4 SH 0.10 63
2.2 S. SH <0.03 64
2.5 SS <0.03 65
0.8 SH 0.08 66
Middle Stockton
0.8 Coal 1.49 76
0.6 Clay 0.50 77
2.6 SH 0.22 78
3.0 SH 0.22 79
3.0 SH 0.27 80
3.0 SH 0.25 81
3.3 SH 0.64 82
e Stockton
2.5 Coal 1.44 83
1.3 SH 0.28 84
1.3 SS 0.13 85
3.1 SS 0.16 86
1.0 SH 0.64 87
0.3 D. SH 3.00 88
e Stockton
1.4 Coal 0.86 89

	1.2	SH	1.94	90				
					0.6	Carb	0.88	91
	3.6	S. SH	0.22	92				
	4.4	SS	0.07	93				
	4.3	SS	<0.03	94				
	3.1	SH	0.29	95				
	1.2	D. SH	6.63	96				
Lower Stockton	2.0	Coal	1.37	97				
					0.4	Clay	4.00	98
	5.0	S. SH	0.24	99				
	4.0	SH	0.16	100				
	3.0	Clay	0.28	101				
	1.9	SH	0.12	102				
	2.2	SH	0.04	103				
	2.8	SH	0.16	104				
	1.6	S/Carb	0.51	105				
	3.4	SH	0.14	106				
	3.0	SH	0.14	107				
	3.0	SH	0.13	108				
	3.0	SH	0.11	109				
	3.0	SH	0.11	110				
	3.0	SH	0.10	111				
	3.0	SH	0.18	112				
					1.0	SH	0.86	113
Upper Coalburg	2.4	Coal	1.20	114				
	1.2	SH	0.30	115				
					0.9	D. SH	1.23	116
Upper Coalburg	2.1	Coal	1.29	117				
					0.7	SH	0.36	118
	3.3	SH	0.42	119				
Upper Coalburg	2.7	Coal	3.44	120				
	3.7	S. SH	0.35	121				
	3.1	SH/SS	0.20	122				
	4.9	SS	0.08	123				
	5.0	SS	0.27	124				
Middle Coalburg	3.5	Coal	1.01	125				
					1.0	SS/SH	0.14	126
	2.5	S. SH	0.22	127				
	2.6	SH	0.18	128				

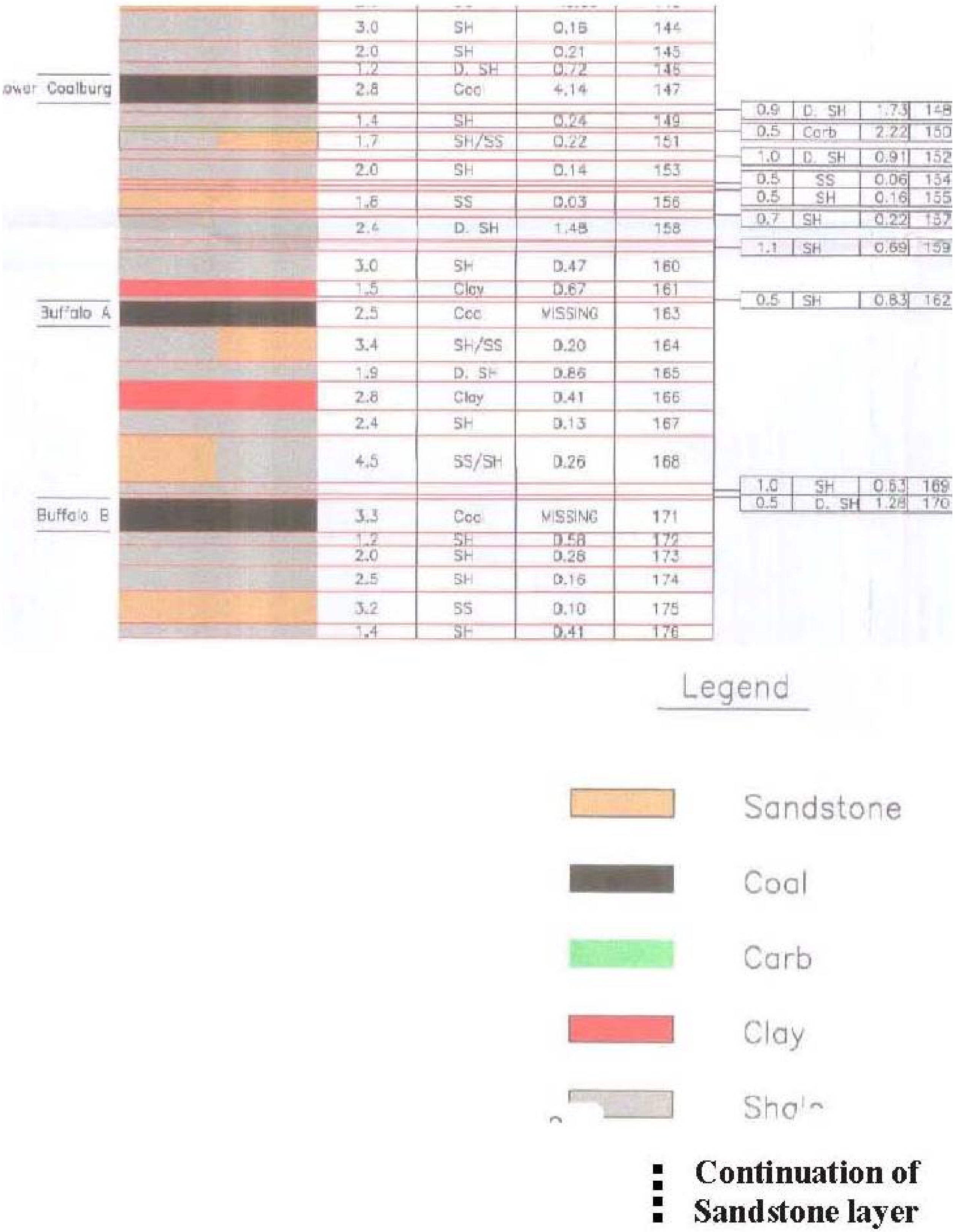


Figure A4.2. Geologic column DT0417

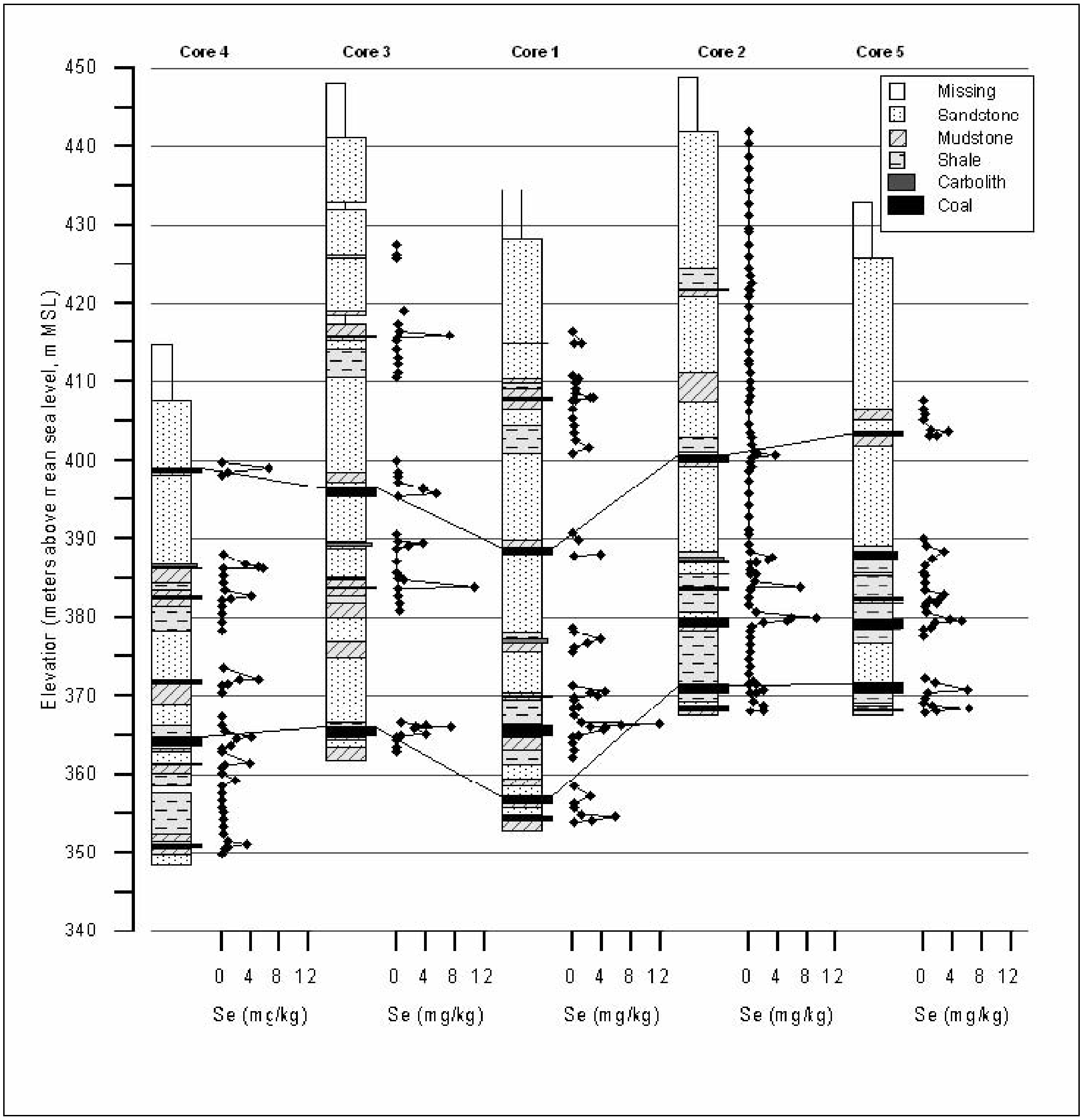


Figure A4.3. Se distribution in Coalburg coal (upper line) and Winifrede (lower line) coal, both of the Kanawa Formation (Boone County) at the Bull Creek Mine (Vesper, 2008)

A summary review of rock cores and corresponding cross sections for the Dal-Tex mine complex including the Gut Fork mine (Figures A4.4 and A4.5) compared to the proposed Spruce No 1 Mine (Figure A4.6) is provided in Table A4.1. Figure A4.7 shows the geologic cross section locations across the Gut Fork mine (I & II) and Spruce No. 1 mine (III & IV). Table A4.1 indicates that for the most part, the formations are repeated from the Dal-Tex mine complex to the proposed Spruce No. 1 Mine location. Indeed as stated by the permittee, the same coal beds will be developed for the Spruce No 1 mine as for the Dal-Tex mine. Also, these coal bed sequences are similar to those described in the literature for southern West Virginia coal bed sequences (Figure A4.1) and the geologic column for the proposed Spruce No. 1 Mine (Figure A4.2). Essentially, all the formations in the Dal-Tex complex that had in the past showed high Se levels and have led to environmental releases outlined in the Final Determination and Appendix 1 are present in the Spruce No. 1 Mine complex. According to the Se data in the rock core column, many of the rock formations above and below the coal beds also contain high levels of Se. For example, the shale rock above the Lower Stockton contains Se as high as 6.63 mg/kg. This rock layer may need to be removed to extract the Stockton seam and may contribute to Se releases.

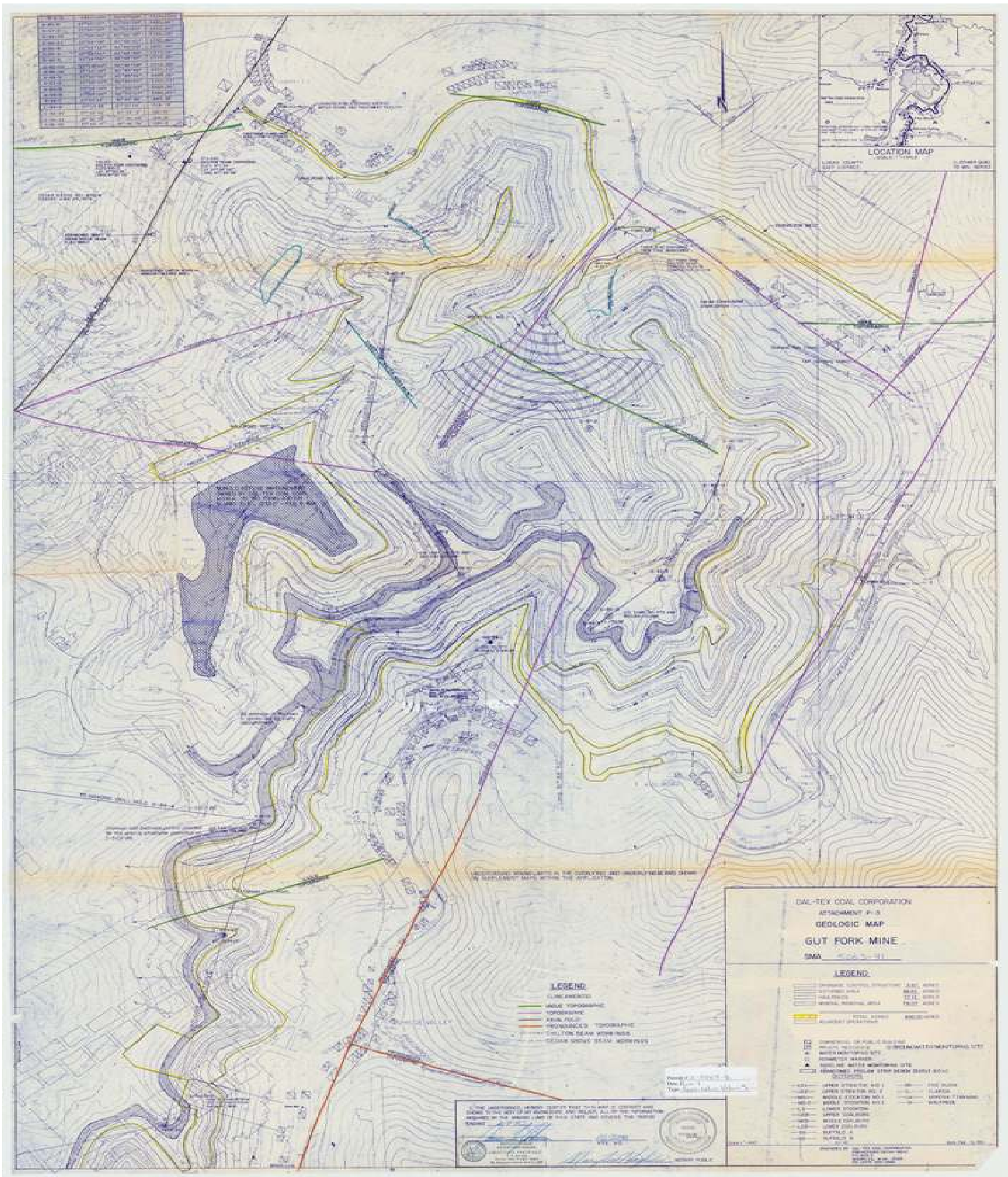


Figure A4.4. Gut Fork mine Geologic Map

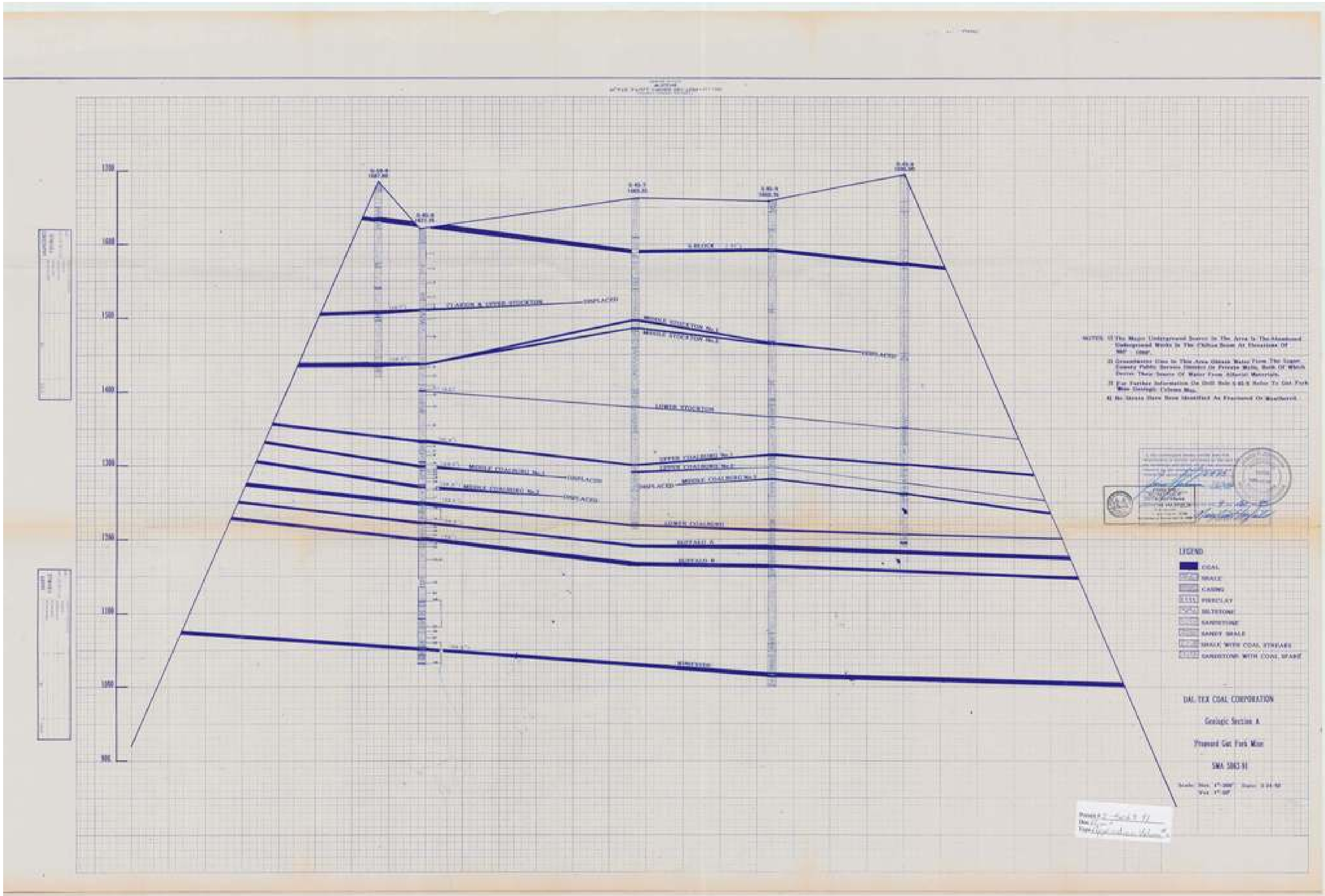


Figure A4.5. Gut Fork mine Geologic Section

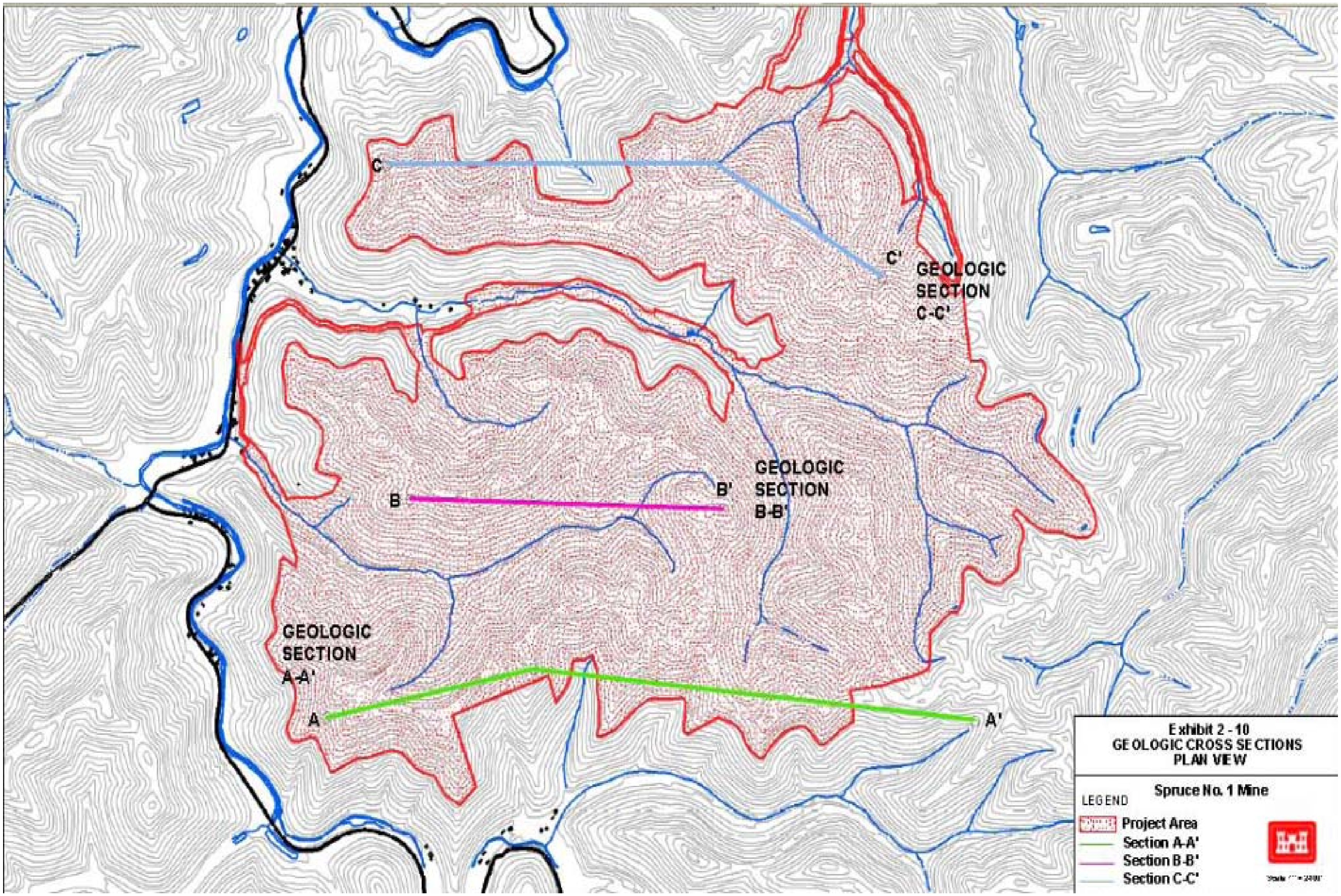


Figure A4.6. Spruce No. 1 Mine cross-section locations

Table A4.1. Sequences of rock cores and coal beds on a NW-SE cross section through the Dal-Tex mines (Gut Fork, Rockhouse mines) and proposed Spruce No. 1 mine. ***(Note: Coal beds are in black; Se data is for the Spruce No 1 mine)***

Rickhouse Mine	Gut Fork Mine	Spruce No 1	Se (mg/kg)
	Casing		
	Sandstone	Sandstone	0.02 – 0.20
	Shale	Shale	0.07 – 0.62
5-Block	**5-Block**	**5-Block**	**1.84 – 9.8**
	Shale	Shale	0.08
	Sandstone	Sandstone	0.03 – 0.46
Clarion	**Clarion / Upper Stockton**	**Upper Stockton**	**0.85 – 1.98**
		Clay (1’)	0.85
	Shale	Shale	0.03 – 0.10
	Sandstone	Sandstone	0.03 – 0.36
	Middle Stockton No. 1	**Middle Stockton (0.8’)**	**1.49**
		Clay (0.6’)	0.5
		Shale (15’)	0.22 – 0.64
	Middle Stockton No. 2	**Middle Stockton (2.5’)**	**1.44**
		Shale	0.28
		Sandstone	0.13 – 0.16
		Shale	0.6 - 3.0
		Middle Stockton (2.6’)	**0.86 – 1.4**
		Carbonates (0.6’)	**0.88**
	Shale	Shale	0.22
	Sandstone	Sandstone	0.07
	Shale	Shale	0.9 – 6.63
Lower Stockton	**Lower Stockton**	**Lower Stockton**	**1.3**
		Clay	4.0
	Shale	Shale	0.16 – 2.4
		Clay	0.28
		Shale	0.04 – 0.16
		Carbonates	**0.51**
		Shale	0.10 – 0.86
	Sandstone		
	Upper Coalburg No. 1	**Upper Coalburg**	**1.2**
	Shale	Shale	0.3 – 1.23
	Upper Coalburg No. 2	**Upper Coalburg**	**1.29**
		Shale	0.42
		Upper Coalburg	**3.44**
	Shale	Shale	0.20 – 0.35
	Sandstone	Sandstone	0.08 – 0.27
Middle Coalburg	**Middle Coalburg No. 1**	**Middle Coalburg**	**1.01**
	Shale	Shale	0.18 – 0.22
	Sandstone	Sandstone	0.03 – 0.08
		Shale	0.16 – 0.72
	Middle Coalburg No. 2		
	Shale		
	Sandstone		
	Lower Coalburg	**Lower Coalburg**	**4.14**
	Shale	Shale	
	Sandstone	Sandstone	
	Buffalo A	**Buffalo A**	MISSING
	Shale	Shale	
		Clay	

		Shale	
Buffalo B	**Buffalo B**	**Buffalo B**	MISSING
	Shale	Shale	
	Sandstone	Sandstone	
	Shale	Shale	
	Sandstone	Sandstone	
	Winifrede	**Winifrede**	
		Sandstone	
		Chilton	

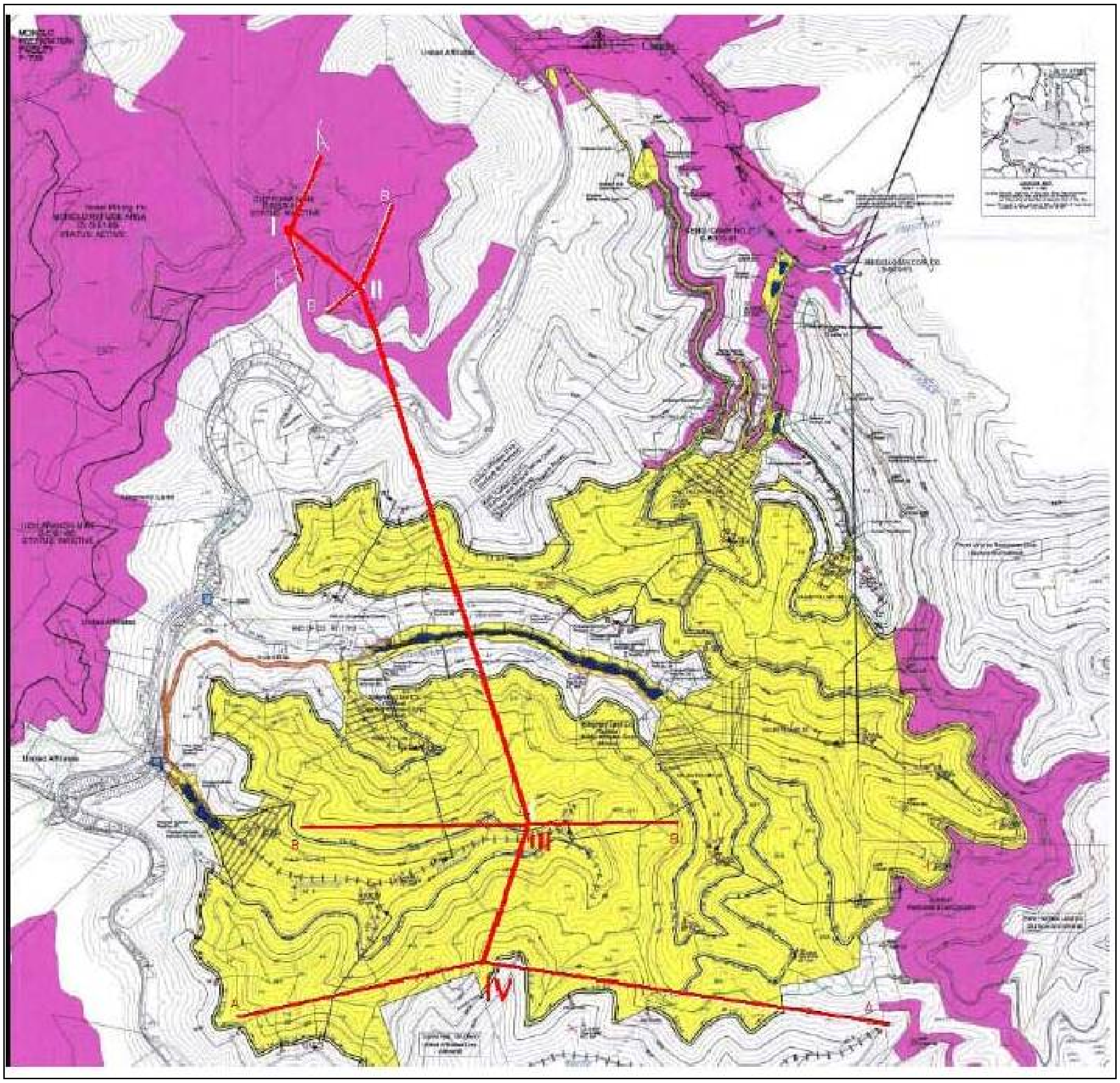


Figure A4.7. Geologic cross section locations across the Gut Fork mine (I), Rockhouse mine (II), and Spruce No 1 mine (III & IV)

A4.4. Differences in Mining Practices and Materials Handling

The permittee has maintained that mining within the Buffalo coal bed in the proposed Spruce No 1 mine will be limited to incidental contour mining and therefore will not result in the kind of environmental degradation that resulted from the Dal-Tex mountain top mining project which lies adjacent to the Spruce No. 1 mine. According to the permittee, there will be less active operating areas and hence less incremental disturbance with the proposed Spruce No. 1 mine. The permittee also contends that enhanced erosion control, sedimentation control, and selective handling of acidic or Se-bearing overburden material make EPA's comparison of the Dal-Tex mine and Spruce No. 1 Mine inappropriate. As discussed below, EPA does not find the permittee's evidence to be credible or convincing.

A4.4.1. Segregation of high Se materials

The permittee is proposing to selectively handle high Se bearing materials. However, the permit's Special Conditions and the permittee have not adequately described how the operator will distinguish in the course of intense operations which layers to remove and handle separately and which to dispose of without special handling. Adequately testing each layer in the field to achieve this result is extremely difficult. For example, a test at a specific location may indicate that the rock materials above and/or below the coal bed would be suitable for disposal without selective handling. However, due to the heterogeneous nature of the rock formation, the permittee cannot necessarily use this information to demonstrate that rock materials 100' (or less) away can also be disposed of in the same way without being tested. Microscale spatial differences in Se occurrence and concentrations make it difficult to predict a priori which drilled locations will have high Se concentrations above and below the coal beds. In addition, while Se is highest in coals and rocks that are adjacent to the coals, not all units close to the coal beds are high in Se and not all units away from the coal are low in Se (Figure A4.8). Even correlations with sulfur (S) and total organic carbon (TOC) are not always strong. Also, extraction data indicates that both organic and sulfide principal component analysis (PCA) show no single trend for Se (Vesper et al., 2008). Hence, these parameters are unreliable as indicators for Se occurrence.

Based on EPA's analysis of Discharge Monitoring Reports (DMRs) from nearby mines for selenium, as noted in Appendix 1, the Dal-Tex mine and discharges associated with current Spruce No. 1 operations in Seng Camp Creek are contributing discharges with selenium concentrations greater than 5 μg/L to downstream waters. These patterns are repeated and persistent. Especially in light of an outfall on the current project site contributing downstream selenium in excess of applicable water quality criteria, speculative statements regarding materials handling approaches do not negate the complex and pervasive selenium geology described above.

The practice of mountaintop coal mining disturbs large volumes of rock with huge quantities of overburden removed. Given the nature of Se distribution in these overburden materials, it is extremely difficult to demonstrate how an effective on-site separation of high Se-bearing overburden materials will be performed without testing all materials within two to four feet above and below the coal beds. The permittee's materials handling plan does not contemplate an effective amount of core samples or other testing of geologic materials to identify areas of high selenium content that would effectively enable isolation of these materials.

A4.4.2. Exposure of Selenium to Water Sources

The permitee contends that there are no significant seeps or springs that would indicate potentially significant discharge from any coal seam or rock stratum to be encountered. This statement seems to be unfounded given earlier statements by the permittee about perched waters that may be encountered that may be aquifers and could produce significant discharges.

The permitee makes contradictory arguments regarding drainage to aquifers, claiming that aquifers are not present, but that those that are present will not be affected. For example, the permitee states that alluvial aquifers are typically below the valley floor and will be unaffected because all of the proposed mineral extraction will be conducted on coal beds that are above the valley floor. In cross-sections (Exhibits 2-11 to 2-13) provided by permittee, it is noted that there are several overlying perched aquifers which could recharge underlying formations including nearby alluvial aquifers during operations. The permittee repeatedly states that these perched aquifers "…would be considered insignificant" without providing any justification for the statement.

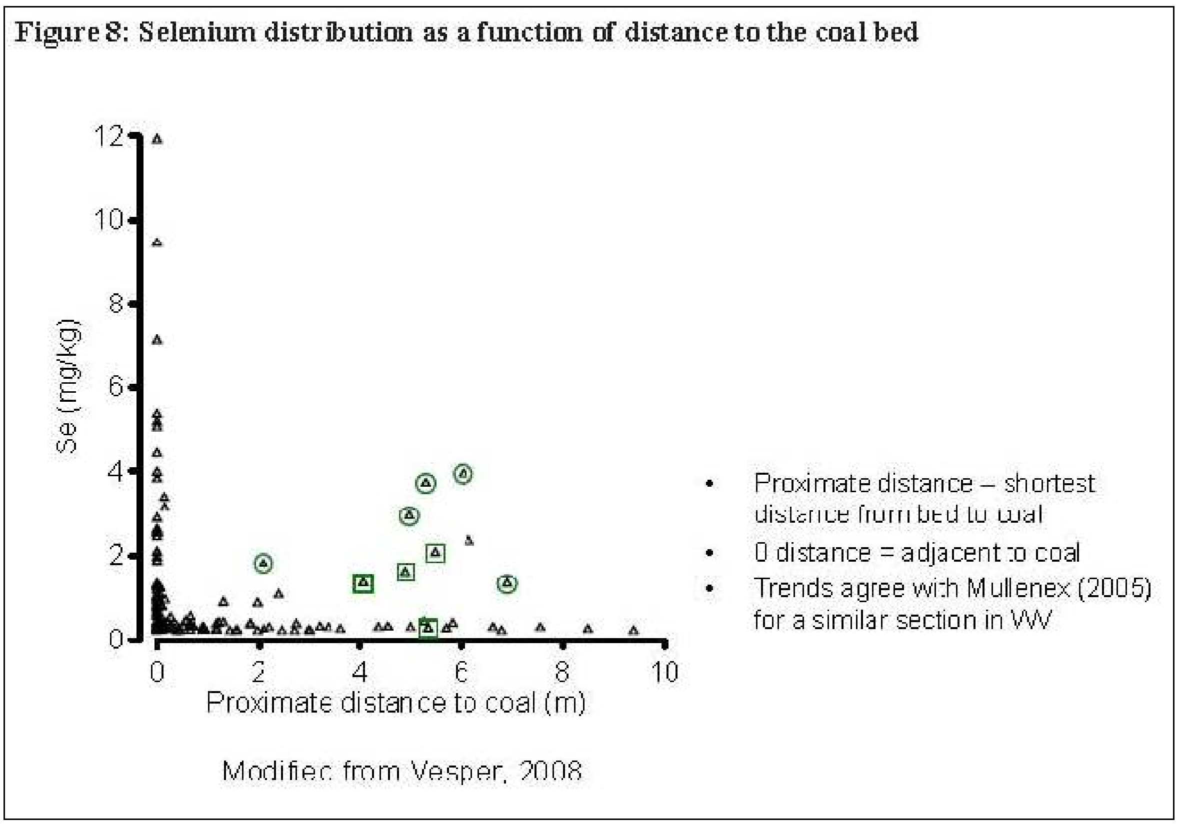


Figure A4.8. Selenium distribution as a function of distance to the coal bed

Further, the highly permeable backfill material is expected to decrease storm runoff and provide water to the alluvial aquifer. Given that this backfill material may leach constituents of concern, including selenium, salts, and metals, shallow groundwater contamination is likely. Such contamination would increase the potential for mobilized selenium to reach downstream waters. In addition, depending on the extent of backfill material, there may be reversals of flow direction over time such that the alluvial aquifer recharges surface water instead of the other way around and if the aquifer (or perched aquifer) is contaminated, it is plausible to conclude that surface water contamination could occur.

A4.4.3. Removal of Selenium When Coal Is Removed

The argument that the strata containing high levels of Se are the coal beds that will be removed is not strong. We know that elevated Se concentrations have been reported in Appalachian coals (Diehl et al., 2005; Vesper et al., 2008) and from streams that drain areas impacted by mining in southern West Virginia (Bryant et al., 2002; Ferreri et al., 2004; Vesper et al., 2004; Vesper et al., 2008) and areas impacted by coal surface mining and reclamation in Ohio (Bonta and Dick, 2003). Given that in surface mining nearly all of the coal is removed, the source of Se is more likely to be the associated strata disturbed by mining operations and the resulting fines that may coat streambeds.

Summary

EPA believes that the materials handling plan as permitted at the Spruce No. 1 mine will not fully prevent the release of elevated levels of selenium into streams or potentially potable aquifers, which will result in unacceptable concentrations of selenium. The evidence shows that there is abundant selenium in the coal deposits, and that conditions that make selenium bioavailable occur at mine sites in adjacent mines. The documentation does not demonstrate that the company can effectively distinguish material requiring isolation from water from those that have low selenium and might be used in valley fill. Furthermore, the permittee does not provide convincing evidence that water will not interact with these exposed deposits or that the selenium will be removed when the coal is removed. Thus, EPA believes that toxic levels of selenium will be released from the Spruce No. 1 Mine. For more details on the effects of bioavailable selenium on wildlife, and a more comprehensive description of high selenium concentrations at the Dal-Tex operation and associated with ongoing mining on the Spruce No. 1 project site in the Seng Camp Creek watershed, see Appendix 1.