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Project Summary

Mineral Matter and Trace Elements in the Herrin and Springfield Coals, Illinois Basin Coal Field

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This study investigated the variability and regional distribution of chemical elements and mineral impurities in *Springfield and Herrin Coals*—the two principal coal beds mined in the Illinois Basin Coal Field.

Analytical determinations were made for 67 elements and related chemical parameters and for 8 mineralogical components in 102 newly collected samples. The resulting data were combined with data previously obtained for 128 other samples.

The greatest variation of elemental concentrations in the Herrin Coal, found within benches in vertical sections through the seam, is due to changes in the mineral composition of the respective benches. The variability of elements in channel samples also differs from area to area in the Illinois Basin; most important is the variation of the chalcophile metals associated with the mineral pyrite (FeS_2). Metals of environmental concern decrease in relative variability (standard deviation/mean) in the following order: Cd, Zn, As, Pb, and Sb. All other such metals vary in lesser amounts (standard deviation/mean generally less than 1).

The mean concentration (in ppm) of these and other metals in both coals decreases in the following order: Pb (28), Cr and Ni (18), Cu (12.5), As (11), Mo (9.2), and Se (2.4). All other trace metals of environmental concern average less than 2.4 ppm. Sulfur averages 3.5 percent and has a comparatively low variability (standard deviation/mean of 0.35).

Washability tests confirm that elements associated with the mineral matter can be more easily removed from the coal than can organic-associated elements. Estimates of the average concentration (in ppm) in washed coals are: Pb and Ni (17), Cr (15), Cu (9), Mo (5), As (4), Se (2), Th (1.7), Cd (<1.5), and Be (1.4). All other metals of environmental concern are estimated to average less than 1 ppm in washed coals.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction and Summary

Coal provides about 20 percent of the energy consumed in the U.S.; about 70 percent of the coal produced in 1980 (some 600 million tons) was used for electric power generation. Two coal beds (seams), the Herrin Coal Member and the Springfield Coal Member, extend over much of the Illinois Basin Coal Field, which includes southwestern Indiana and western Kentucky. These two seams account for more than 90 percent of the coal produced from the coal field and about 73 percent of the resources remaining in the field. It is expected that large quantities of coal will continue to be mined from these two coals.

The National Research Council Panel on Trace Element Geochemistry of Coal

Resource Development Related to Health has identified 33 elements commonly found in coals to be of potential environmental concern. The primary objective of this study was to compile a data base on the characteristics and distribution of these and other elements in the two seams throughout the Illinois Basin Coal Field. Because of the expected association of many of these elements with mineral matter in the coals, another major objective was to investigate the mineralogical composition of the coals, and evaluate the results in terms of the elemental composition.

Other study objectives were: (1) to determine local and regional variations of chemical and mineral components in the two most important commercial seams in the Illinois Basin; (2) to assess the abundance and variation of the trace elements of environmental concern; and (3) to investigate the spatial distribution of the trace elements and mineral components throughout the coals to facilitate prediction of the properties of the two coals in unexplored areas of the basin.

Analytical Methods

Methods used for the analytical determinations include standard coal chemical tests, atomic absorption, instrumental and radiochemical neutron activation analyses, x-ray fluorescence, energy dispersive x-ray, optical emission, ion selective electrode, low-temperature ashing, x-ray diffraction, and scanning electron microscopy.

Variation of Elemental Concentrations

The elemental composition of layers (benches) within the Herrin (observed in 23 bench samples from four locations in a single mine) differs considerably from top to bottom within the seam. The variations in concentration (represented by the ratio of the maximum/minimum compositional values exclusive of the shale partings present) differ from element to element. Of those elements of potential environmental concern, Ba varied most in its concentration in the Herrin—up to 34 times its minimum value. Concentrations of other elements, in decreasing order of maximum/minimum (ratio), are: As and Zn (17), Tl (16), Li (15), and Sb, Th, and Pb (10). All other elements of environmental concern have smaller variations in concentration. However, nearly all samples in the bench study sets were so low in U and Cd (<1 and <1.3 ppm, respectively), that precise variations of these elements could not be determined.

Variations in the elemental composition of the whole coals seam were measured by the mean and standard deviation (SD) of analytical results on individual whole-coal (channel equivalent) samples that represent the entire thickness of the bed at each collection site. The means and SDs of the elemental composition of the two coal seams are given in Table 1. Comparison of the means for the two indicates that they are, on the average, quite similar; however, they do depart from this trend in some important aspects in some places in the coal field. The tabulated averages show that S is only slightly higher in the Springfield than the Herrin. The differences (Table 1) in the averages for Zn, Ba, and P between the Springfield and the

Table 1. Mean Concentration and Standard Deviation (SD) of Elements in Herrin and Springfield Coals

		Herrin			Springfield					Herrin			Springfield		
Element	Units	Mean	SD	Sam.[a]	Mean	SD	Sam.[a]	Element	Units	Mean	SD	Sam.[a]	Mean	SD	Sam.[a]
Ag	ppm	0.06	0.04	35	0.06	0.04	29	Mn	ppm	54.4	39.	68	56.1	39.4	50
Al	%	1.37	0.35	68	1.12	0.41	50	Mo	ppm	9.3	5.5	68	9.1	5.2	50
As	ppm	8.	19.	68	14.5	14.6	50	Na	ppm	828.	770.	68	596.	613.	49
B	ppm	127.	39.	59	108.	39.	50	Ni	ppm	19.8	8.7	68	15.1	7.0	50
Ba	ppm	86.	105.	52	230.	547.	31	P	ppm	80.	198.	68	80.	95.	50
Be	ppm	1.5	0.7	68	1.5	0.7	50	Pb	ppm	28.1	35.2	68	27.5	30.7	50
Br	ppm	12.8	7.2	61	11.9	8.5	43	Rb	ppm	17.6	6.4	57	15.3	7.6	40
Ca	%	0.7	0.4	68	0.7	0.5	50	S	%	3.46	1.26	68	3.66	1.24	50
Cd	ppm	2.2	9.5	15	1.3	4.5	48	Sb	ppm	0.91	0.91	68	1.15	0.7	50
Ce	ppm	15.4	7.8	57	13.8	9.2	40	Sc	ppm	2.96	0.88	57	2.38	1.27	40
Cl	%	0.18	0.17	63	0.16	0.16	47	Se	ppm	2.35	1.16	68	2.56	1.5	50
Co	ppm	6.0	2.9	68	4.4	2.2	50	Si	%	2.72	0.67	68	2.34	0.65	50
Cr	ppm	20.2	8.6	68	15.9	6.4	50	Sm	ppm	1.38	0.67	57	1.4	1.2	40
Cs	ppm	1.3	0.5	57	1.1	0.5	40	Sr	ppm	36.5	36.	52	28.8	26.	31
Cu	ppm	12.8	4.4	68	12.2	10.2	50	Ta	ppm	0.16	0.06	57	0.16	0.12	40
Dy	ppm	1.1	0.4	57	1.1	0.8	40	Tb	ppm	0.19	0.09	49	0.19	0.14	36
Eu	ppm	0.28	0.12	57	0.3	0.2	40	Th	ppm	2.33	0.79	57	1.95	1.19	40
F	ppm	70.9	31.8	68	62.9	26.7	50	Ti	%	0.07	0.02	68	0.06	0.02	50
Fe	%	1.87	0.74	68	2.04	0.92	50	Tl	ppm	0.9	0.9	44	1.3	1.5	21
Ga	ppm	4.2	2.3	68	3.4	1.6	50	U	ppm	1.6	1.4	57	1.3	0.9	40
Ge	ppm	5.0	4.5	68	6.1	3.5	50	V	ppm	29.3	10.1	68	32.3	23.8	50
Hf	ppm	0.57	0.2	57	0.51	0.19	40	W	ppm	0.55	0.4	57	0.6	0.7	40
Hg	ppm	0.16	0.11	68	0.17	0.11	48	Yb	ppm	0.58	0.2	57	0.5	0.3	40
I	ppm	1.4	0.9	45	1.3	1.2	22	Zn	ppm	310.	809.	68	164.	214.	50
In	ppm	0.1	0.08	57	0.1	0.1	40	Zr	ppm	38.9	27.9	58	30.7	26.	43
K	%	0.18	0.04	68	0.18	0.09	50	Ash	%	12.3	2.6	68	11.7	2.3	50
La	ppm	7.64	3.7	57	7.13	4.2	40								
Li	ppm	21.1	17.3	21	10.9	8.0	19								
Lu	ppm	0.11	0.05	57	0.12	0.09	40								
Mg	%	0.05	0.02	68	0.04	0.03	50								

[a]Number of samples.

Herrin are not significant considering the large variation between samples from the same seam—as indicated by the relatively high SDs for these elements.

Other elements in whole coal samples that also have high variations relative to the mean assay in both seams are As, Cd, In, and Pb. Sb is more variable in the Herrin Coal than in the Springfield, and Be and W are more variable in the Springfield Coal. Cr, F, Hg, Mo, Ni, Se, S, and U have low variabilities, relative to the mean, in both coals.

The high variations for these elements are due in large part to the patterns of regional distribution (Table 2). In the Herrin Coal, As, Cd, Cu, Pb, and Zn all show a pattern of relatively high concentration in the northwestern part of the coal field (northwestern Illinois). The data also confirm previous reports of coal relatively low in S in areas of the Herrin Coal adjacent to the Walshville channel in southern Illinois and in areas of the Springfield adjacent to the Galatia channel in southeastern Illinois/southwestern Indiana.

Table 2 also gives the mean concentrations, common ranges, and maximum concentrations of the elements of environmental concern in both beds. All trace elements of environmental concern average less than 28 ppm (Pb) in the raw-unwashed coal samples. Data on elements of environmental concern in the two Illinois Basin coals are summarized and compared with data on coals from other areas in Table 3.

Implications of Results for Washed Coal Products

The compositional data in Table 1 are based on channel samples (major mineral parting excluded) and therefore apply to coal from the mine after a minimal amount of cleaning. Of interest are the elemental concentrations of coal products after washing in modern coal preparation

Table 2. *Concentration of Chemical Elements and Mineral Matter of Environmental Concern in Samples of Herrin (H) and Springfield (S) Coals and Trends in Regional Distribution*

		Whole-coal samples			Estimated average for washed coals	Regional distribution in the Illinois Basin Coal Field[a]
	Units	Mean	Common range	Maximum		
CHEMICAL ELEMENTS						
[b]As	ppm	11	2-20	61	4	H: ≥6 clustered in NW and SO IL S: >10 mostly along Galatia channel
Be	ppm	1.5	1.1-1.9	3.9	1.4	H & S: no apparent trends
[b]Bo	ppm	118	40-200	225	113	H: somewhat higher values in W IL S: somewhat lower values along the Galatia channel
[b]Cd	ppm	1.5	<5.	65	<1.5	H: >5(?) clustered in NW and SE IL S: >5(?) clustered in NW and SE IL
Cr	ppm	18	14-22	60	15	H & S: no apparent trends
Cu	ppm	12.5	7-17	67	9	H: higher values in NW IL S: no apparent trend
F	ppm	68	10-125	262	50	H & S: no apparent trends
[b]Pb	ppm	28	11-45	206	17	H: >50 mostly in NW, EC and SE IL S: >30 mostly in SE IL
[b]Hg	ppm	0.16	0.1-0.2	0.71	0.13	H: >0.2 mostly in NW IL S: >0.3 (few), scattered
[b]Mo	ppm	9.2	6-12	29	5	H & S: no apparent trends
Ni	ppm	18	14-22	46	17	H: higher values in NW IL S: no apparent trends
[b]Se	ppm	2.4	2-3	8.5	2	H & S: no apparent trends
Ag	ppm	0.06	0.04-0.08	0.18	0.04	Insufficient data
[b]S	%	3.5	2.8-4.2	8.4	2.6	H: lower values in certain areas near Walshville channel S: lower values in certain areas near Galatia channel
Tl	ppm	1.0	0.3-2.2	7.2	0.5	H & S: no apparent trends
Th	ppm	2.2	1.7-2.7	7.6	1.7	H: >3 scattered S: >2 scattered
U	ppm	1.5	0.5-2.9	9.3	1.5	H & S: no apparent trends
MINERAL MATTER						
Calcite ($CaCO_3$)	%	1.3	0.8-1.8	5.2	-	H & S: no apparent trends
Clays (Al-Silicates)	%	8.5	7.2-9.8	19.1	-	H & S: no apparent trends
Pyrite (FeS_2)	%	3.4	2.4-4.4	11.6	-	H & S: same as sulfur above
Quartz (SiO_2)	%	2.3	1.8-2.8	5.4	-	H & S: no apparent trends
Ash (750°C)	%	12.1	9-15	22.9	-	H: lower values in areas near Walshville channel and in KY S: lower values in certain areas near Galatia channel and in KY
LTA	%	15.5	12-19	28.1	-	H & S: same as Ash above

[a]H=Herrin Coal; S=Springfield Coal; NW=northwestern; EC =east central; SE=southeastern; SO=southern; W=western.
[b]Elements of greatest potential environmental concern; all other chemical elements listed are of moderate potential concern.

plants. In such plants in the Illinois Basin, about 70-85 percent of the raw coal mined at many sites is recovered for marketing from washing plants. Computations utilizing an 80 percent weight recovery were applied to the four sets of washability tests conducted for this study, and the average reduction for the various elements was determined (Table 4). Although there was appreciable variation of reduction of certain elements in the four sets, the averages listed provide useful trends.

One group of elements, classified as inorganic (mineral)-associated elements, shows an average reduction of from 40 to 75 percent. In contrast, other elements classified as organic-associated elements show average reductions of 0 to 8.6 percent. The middle group, classified as mixed-associated elements, show intermediate reductions from 15 to 30 percent. These predicted reductions of elemental concentrations allow estimates to be made of the concentrations expected in washed coals from the two seams investigated. These estimated concentrations are shown in Table 4.

Departures from these average concentrations are likely to exist in marketed coals from the Illinois Basin. The range of departures is likely to be of the order of the standard deviation observed for the elements (Table 1). Departures are likely to be the greatest for those elements in the mixed- and organic-associated groups, and not so great for elements in the inorganic association classification, because of the ease of removal of the heavy minerals, especially pyrite. Typically, half of the pyrite occurring in Illinois coals is removed by washing to the 80 percent recovery level. Thus, elements associated with pyrite (As, Ba, Cd, Pb, and Zn) are not expected to show as wide a variation in concentration in washed coals as they do in the channel samples tested.

Conclusions and Recommendations

Predicted concentrations of elements of potential environmental concern in coals that have been washed by float/sink methods are quite low, except for S (Table 4). The concentration of those elements that are associated with high density minerals including pyrite, especially As, Ba, Li, Mn, Mo, Pb, Tl, and Zn, will be much lower in washed than in raw coals. These metals, however, will be concentrated in the waste materials from coal preparation plants, thus presenting some problems regarding their disposal. Investigation of the extent of the concen-

Table 3. *Generalized Comparisons of Average Elemental Concentrations in Herrin and Springfield Coals with Those in Other U.S. Coals*[a]

Metal	Average concentration in Herrin and Springfield coals is:	than the reported average concentration in coals mined from:
As, Be, and Cu	somewhat lower:	U.S. bituminous and Appalachian
	somewhat higher:	Northern Great Plains and Rocky Mountains
Cd and Cr	about the same (as):	U.S. bituminous, Appalachian, and Northern Great Plains
	somewhat higher:	Rocky Mountains
Ni	about the same (as):	U.S. bituminous and Appalachian
	somewhat lower:	Rocky Mountains
	somewhat higher:	Northern Great Plains
Pb	somewhat higher:	all others
Hg and Sb	about the same (as):	all others

[a]*Only metals of potential environmental concern are included in this comparison.*

Table 4. *Estimated Average Concentration of Elements of Environmental Concern in Washed Coals*

	Average concentration in whole-coal, ppm	[a]Average Reduction in washed coals, %	Estimated average concentration in washed coals, ppm
INORGANIC ASSOCIATED ELEMENTS			
[b]As	11.	60	4.
Ba	140.	41	83.
[b]Cd	1.5	?	<1.5
Li	16.	44	9.
Mn	55.	62	21.
[b]Mo	9.2	44	5.
[b]Pb	28.	40	17.
Tl	1.0	55	0.5
Zn	250.	75	63.
MIXED ASSOCIATED ELEMENTS			
Ag	0.06	30	0.04
Co	5.	20	4.
Cr	18.	16	15.
Cu	12.5	30	9.
F	68.	27	50.
[b]Hg	0.16	21	0.13
Na	731.	16	614.
[b]S	3.5(%)	27	2.6(%)
[b]Se	2.4	15	2.
Sr	33.	16	28.
Th	2.2	21	1.7
ORGANIC ASSOCIATED ELEMENTS			
B	118.0	3.9	113.
Be	1.5	6.5	1.4
Br	12.0	0	12.
Ge	5.5	0	5.5
Ni	18.	4.5	17.
Sb	1.0	6.0	0.9
U	1.4	0	1.4
V	31.6	8.6	29.

[a]*Calculated at the 80% recovery of coal from washability results.*
[b]*Metals of greatest environmental concern.*

tration of these metals in coal wastes and their environmental impact in Illinois would be beneficial.

High S levels are a serious problem to the coal industry in the Illinois Basin. Except for a few Herrin samples, the coal contains too much S to meet existing emission requirements for use in newly constructed electric power plants that do not have desulfurization facilities. To illustrate this problem, the total S value "expected" for washed coal (27 percent reduction) was calculated, then converted to pounds SO_2 per million Btu.

Results for the samples from the Herrin are plotted in Figure 1; those from the Springfield, in Figure 2. These maps show that, for washed coals from the Herrin, only four samples (from locations adjacent to the southern end of the Walshville channel) could be considered for compliance with a 1.2 lb $SO_2/10^6$ Btu (512 ng SO_2/J) emission limit. The maps illustrate the condition of total combustion for which no SO_2 is removed at the power plant and all of the S in the washed coal is converted to SO_2. None of the samples tested from the Springfield coal, calculated to the washed coal basis, yield less than 1.2 lb $SO_2/10^6$ Btu.

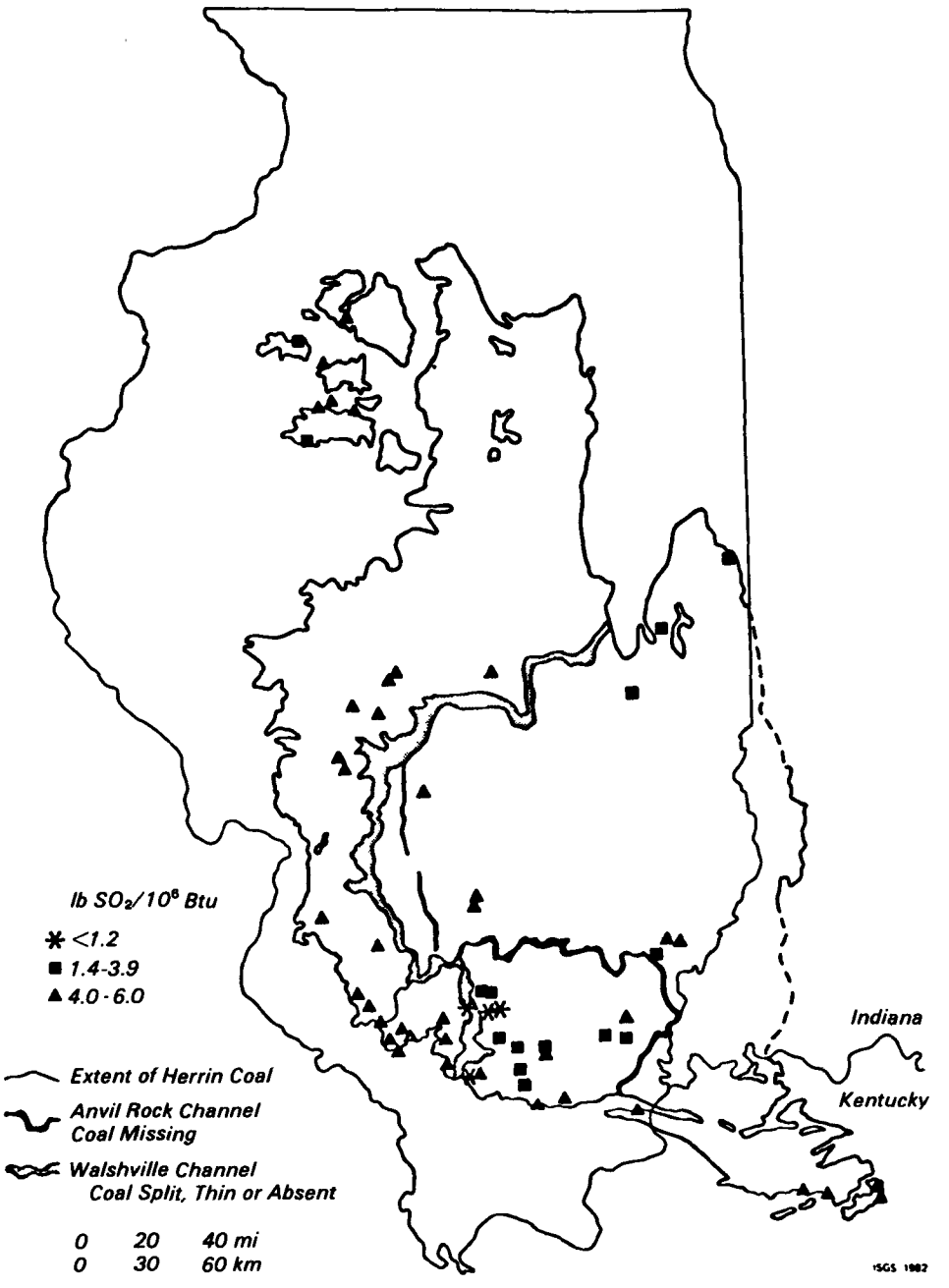

Figure 1. *Distribution of sulfur in Herrin Coal, expressed in lb $SO_2/10^6$ Btu adjusted to a washed coal basis.*

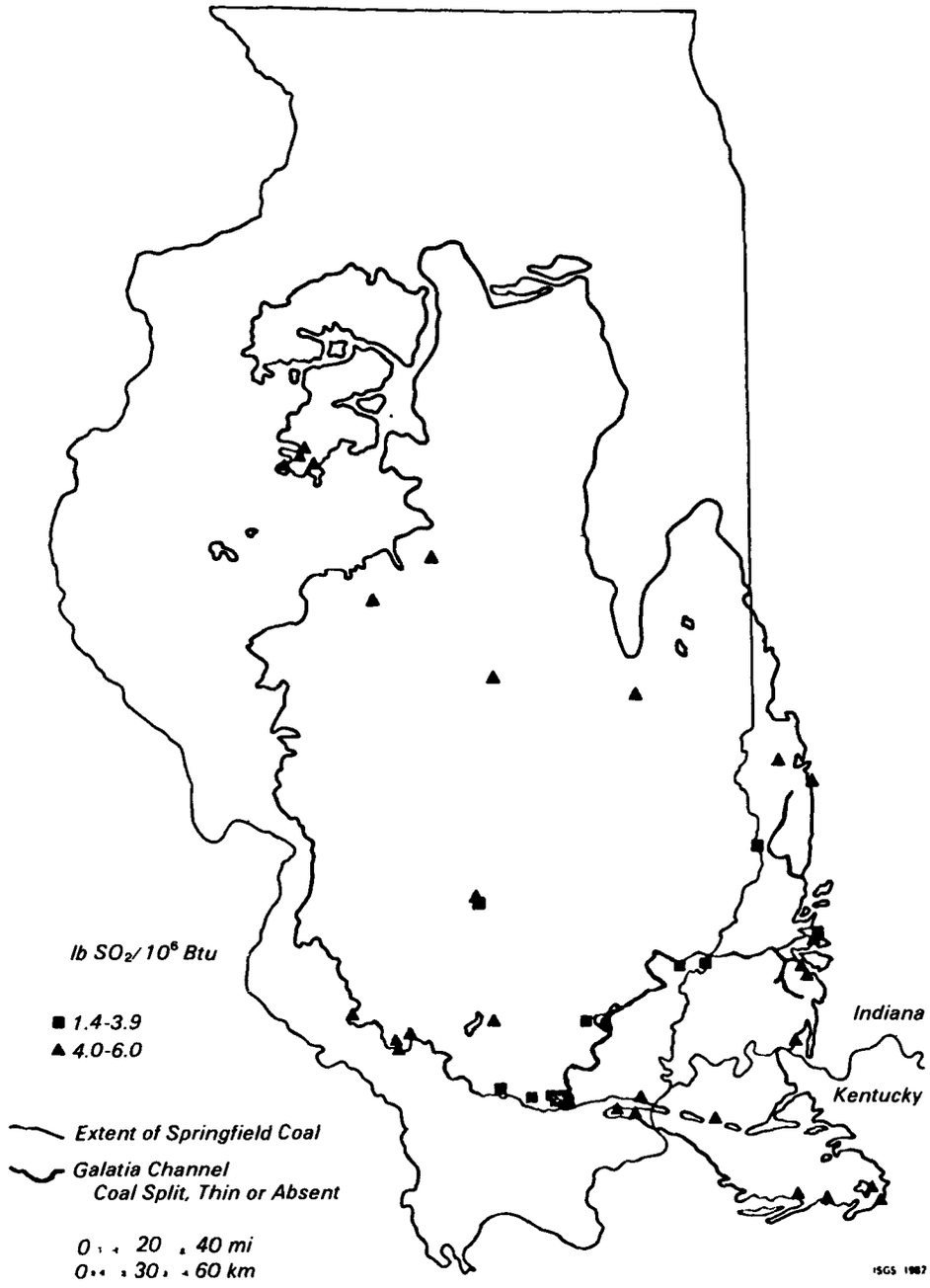

Figure 2. *Distribution of sulfur in Springfield Coal, expressed in lb $SO_2/10^6$ Btu adjusted to a washed coal basis. None of the samples converted to less than 1.2 lb $SO_2/10^6$ Btu.*

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The complete report, entitled "Mineral Matter and Trace Elements in the Herrin and Springfield Coals, Illinois Basin Coal Field," (Order No. PB 84-174 143; Cost: $16.00, subject to change) will be available only from:
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