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GEOLOGICAL SURVEY

Sphalerite in coals from southeastern Iowa, Missouri, and southeastern Kansas

By

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Open-file report 76-796
1976

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

Sphalerite in coals from southeastern Iowa, Missouri, and southeastern Kansas

by

Joseph R. Hatch[1/], Matthew J. Avcin[2/], W. Keith Wedge[3/], and Lawrence L. Brady[4/]

Abstract

Zinc and cadmium determinations on 174 samples of coal from southeastern Iowa, Missouri, and southeastern Kansas and observation of minerals in cleat-fillings in the field are indicative of three large areas of sphalerite mineralization. The distribution of the secondary sphalerite appears to be related to the proximity of the coal to several of the major lead-zinc mining districts of Missouri and to two major structural features of the Midcontinent region: the 38th-parallel lineament, and the Mississippi River arch. Local variations in the amount of sphalerite appear to be related to cleat frequency and to the thickness of these fractures in the coal. Core samples from Iowa show an increase in the amount of cadmium relative to zinc in stratigraphically higher coals. Coals having high zinc and cadmium contents are also enriched, relative to other United States coals, in antimony, cobalt, copper, lead, molybdenum, nickel, and silver.

1/ U.S. Geological Survey, Denver, Colo.

2/ Iowa Geological Survey, Iowa City, Iowa

3/ Missouri Division of Geology and Land Survey, Rolla, Mo.

4/ Kansas Geological Survey, Lawrence, Kans.

Introduction

During the course of a State Geological Survey-U.S. Geological Survey cooperative effort to collect and chemically analyze representative coal samples from the United States, unusually high zinc and cadmium contents were noted in many samples from southeastern Iowa, northeastern, north-central and southwestern Missouri, and southeastern Kansas. High zinc and cadmium concentrations in coal from northwestern and southeastern Illinois have previously been described by Gluskoter, Hatch, and Lincahl (1973) and Hatch, Gluskoter, and Lindahl (1976), who attributed the high values to sphalerite mineralization along cleats in the coal. Because of possible environmental and technological problems and because of the potential for economical recovery of the two metals from coal, additional sampling and field investigations were conducted by personnel from the U.S. Geological Survey, the Iowa Geological Survey, the Missouri Division of Geology and Land Survey, and the Kansas Geological Survey. Preliminary results of these investigations are summarized in this report.

Coal analyses

Descriptive and analytical data for 174 coal samples from the Western region of the Interior coal province are divided into sets from southeastern Iowa-northeastern Missouri, north-central Missouri, and southwestern Missouri-southeastern Kansas (fig. 1). All coal samples were ashed at 525°C and the percent of ash was determined gravimetrically. Cadmium and zinc contents in ash were determined by atomic absorption spectrometry. The cadmium and zinc concentrations in whole coal were calculated from analyses of coal ash. The methods used in sampling and in chemical analysis of the coal are described in Swanson and Huffman (1976).

Locations, brief descriptions, percent of ash, and cadmium and zinc contents in parts per million (ppm) in both coal ash and whole coal for 91 southeastern Iowa-northeastern Missouri coal samples are listed in Table 1. The distribution of samples from this area is shown in Figure 2. Similiar information for 27 north-central Missouri and 56 southwestern Missouri-southeastern Kansas coal samples is listed in Tables 2 and 3 and illustrated in Figures 3 and 4, respectively. For reference, the stratigraphy of the principal coal beds of Missouri and Kansas is shown in Figure 5. The stratigraphy of Iowa coal beds is discussed in Landis and Van Eck (1965).

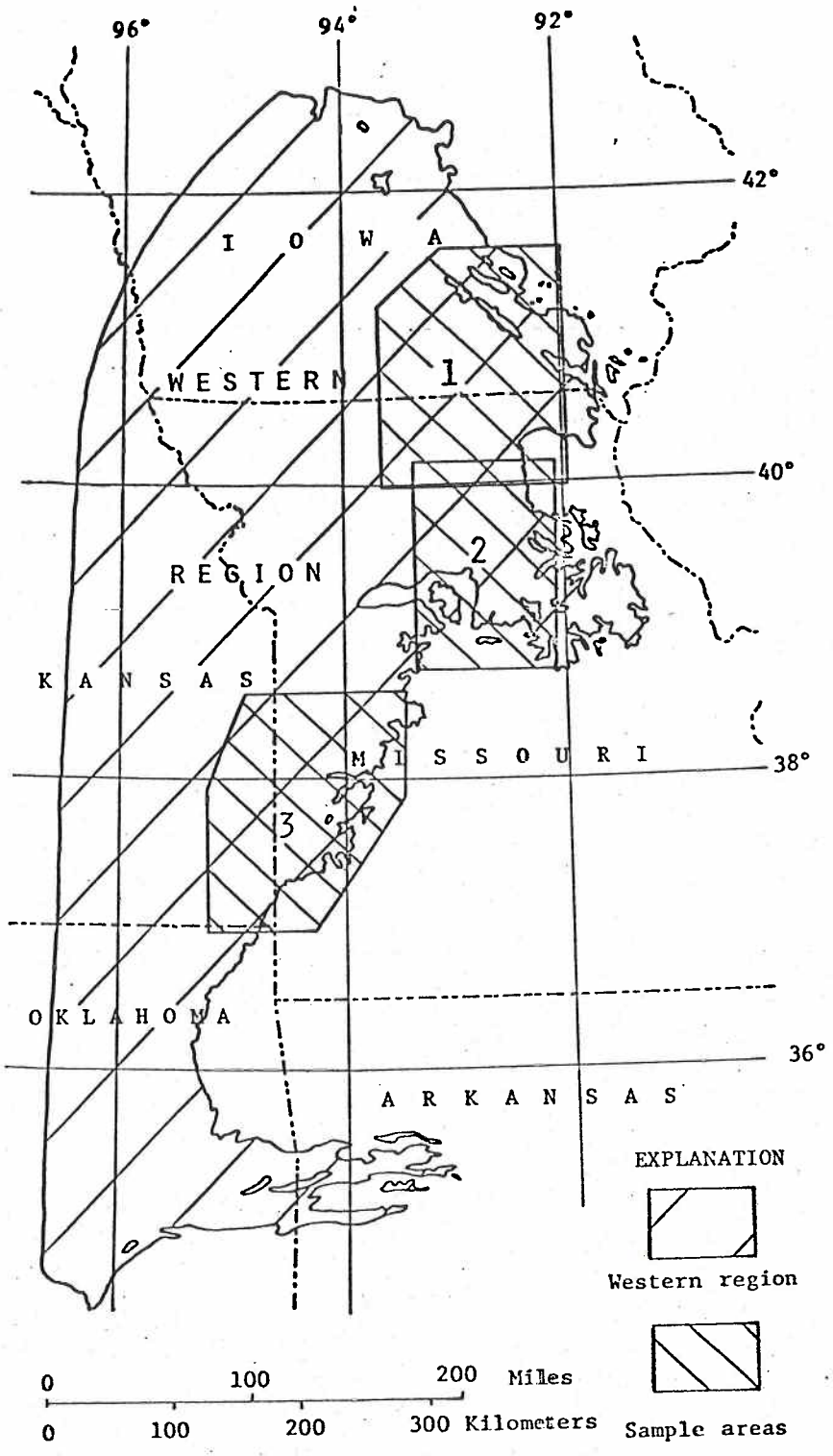

Figure 1.--Map of the Western region of the Interior coal province showing the locations of areas discussed in the text: 1 = southeastern Iowa-northeastern Missouri, 2 = north-central Missouri, and 3 = southwestern Missouri-southeastern Kansas.

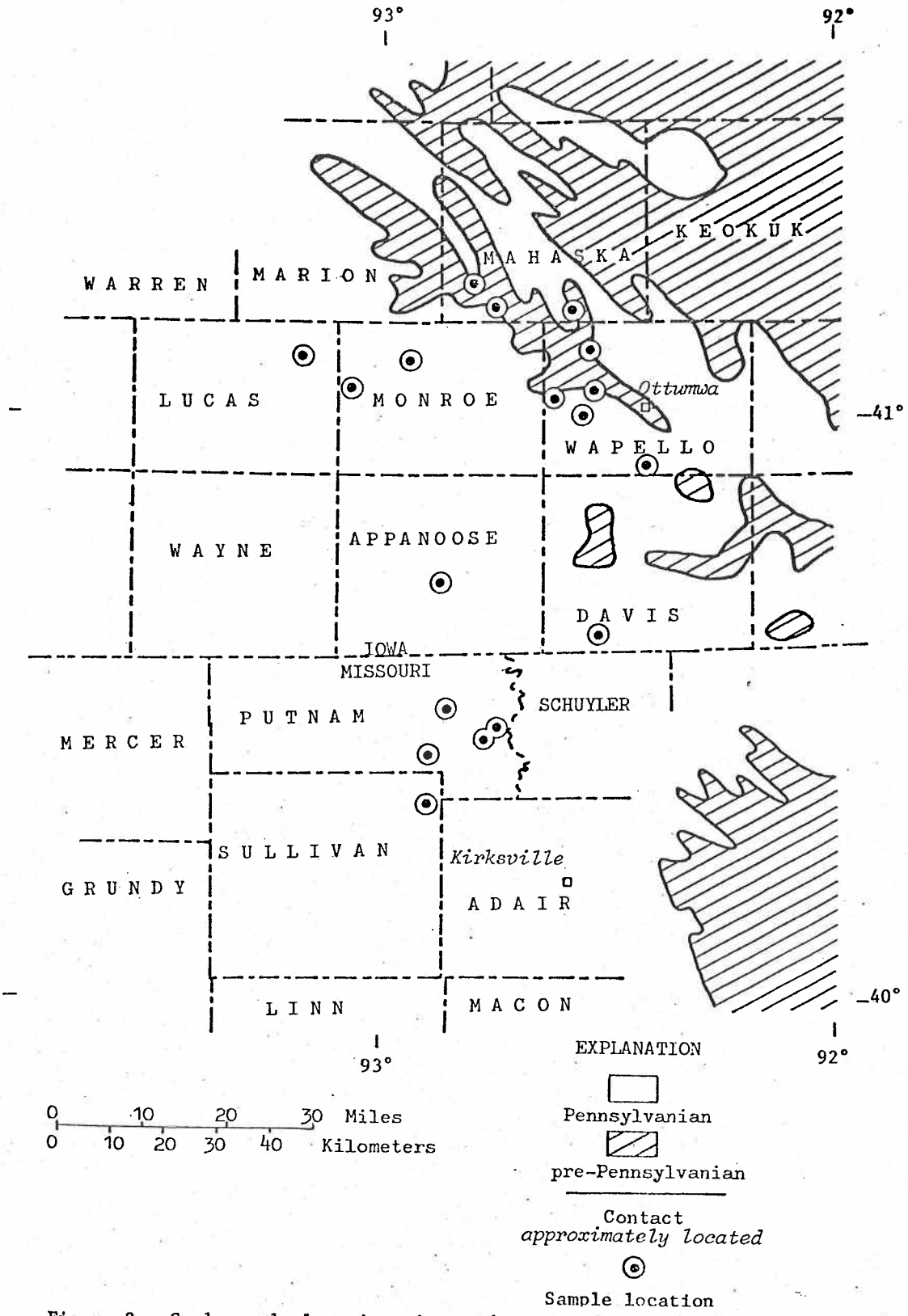

Figure 2.--Coal sample locations in southeastern Iowa and northeastern Missouri.

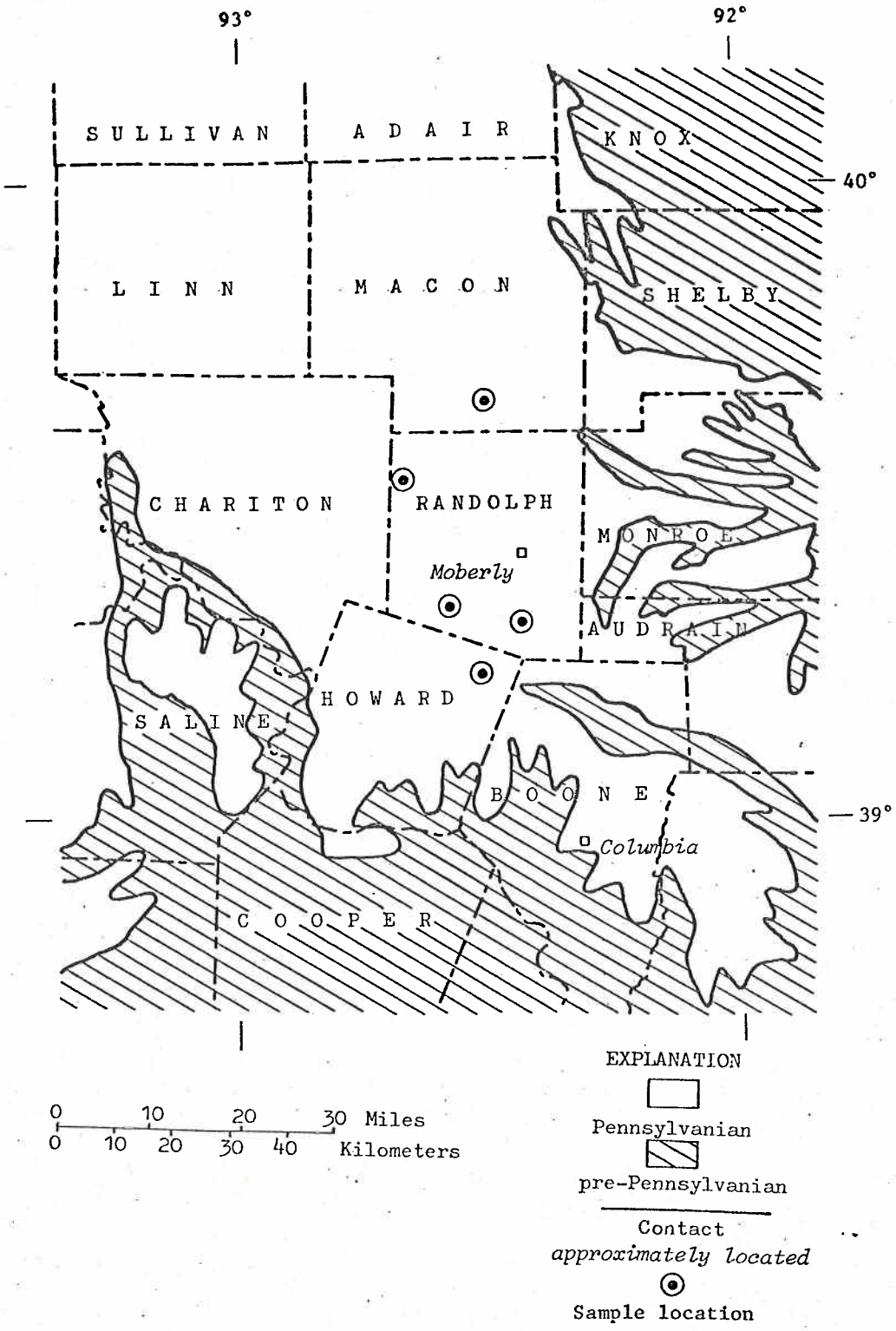

Figure 3.--Coal sample locations in northcentral Missouri.

Table 1.--Sample locations, descriptions, and ash, cadmium, and zinc contents in 91 bituminous coal samples of Pennsylvanian age from southeastern Iowa and northeastern Missouri

[Except where noted, each sample represents the entire thickness of the bed. The coals were ashed at 525°C. L after a value means less than the value shown. Values indicated by an asterisk may have been significantly reduced by removal of a small part of the core for mineralogical studies]

U.S.G.S. Sample No.	County, State	Description			Ash %	Coal ash		Whole coal	
		Coal bed (B) or formation (F)	Sample type	Thickness (meters)		Cd ppm	Zn ppm	Cd ppm	Zn ppm
D166027	Mahaska, Iowa	(F) Cherokee	Face Channel	1.2	23.7	2	1,480	0.5	351
D166028	--do--	--do--	--do--	1.2	25.5	6	3,000	1.5	765
D166029	--do--	--do--	Run-of-Mine	------	15.5	13	7,800	2.0	1,210
D166030	--do--	--do--	Face Channel	1.5	15.1	4	1,500	.6	226
D166031	--do--	--do--	--do--	1.5	20.0	1 L	1,080	.2L	216
D166032	--do--	--do--	--do--	1.2	20.9	1 L	292	.2L	61.0
D166033	--do--	--do--	--do--	1.2	17.9	8	2,400	1.4	430
D166034	--do--	--do--	Run-of-Mine	------	21.9	1 L	52	.2L	11.4
D166035	Monroe, Iowa	--do--	Face Channel	1.2	21.0	1 L	188	.2L	39.5
D166036	--do--	--do--	--do--	1.2	12.8	1 L	364	.1L	46.6
D166037	--do--	--do--	Run-of-Mine	------	14.2	2	2,240	.3	318
D166038	--do--	--do--	--do--	------	15.3	2	1,740	.3	266
D166039	Lucas, Iowa	--do--	--do--	------	18.3	1 L	740	.2L	135
D166040	--do--	--do--	--do--	------	29.3	1 L	260	.3L	76.2
D166041	Wapello, Iowa	--do--	Face Channel	.9	17.2	85	32,000	14.6	5,500
D166042	--do--	--do--	--do--	.9	16.2	33	11,000	5.3	1,780
D166043	--do--	--do--	Run-of-Mine	------	11.2	28	7,800	3.1	874
D176169	--do--	--do--	Core	.33	16.2	1 L	64	.2L	10.4
D176170	--do--	--do--	--do--	.20	18.5	1 L	64	.2L	11.8
D176171	--do--	--do--	--do--	.20	29.5	165	14,200	48.7	4,190
D176172	--do--	--do--	--do--	.41	25.6	58	8,840	14.8	2,260
D176173	--do--	--do--	--do--	.46	27.9	1	200	.3	55.8
D176174	--do--	--do--	--do--	1.57	20.1	64	17,500	12.9	3,520
D176175	--do--	--do--	--do--	.46	16.6	18	6,000	3.0	996
D176176	--do--	--do--	--do--	.43	22.2	1 L	60	.2L	13.3
D176177	--do--	--do--	--do--	1/.28	16.6	1 L	60	.2L	10.0
D176178	Appanoose, Iowa	--do--	--do--	.28	30.4	328	17,600	99.7	5,350
D176179	--do--	--do--	--do--	.38	18.4	1 L	97	.2L	17.8
D176180	--do--	--do--	--do--	.36	10.3	22	960	2.3	98.9
D176181	--do--	--do--	--do--	.53	18.1	4	210	.7	38.0
D176182	--do--	--do--	--do--	.22	41.6	1	476	.4	198
D176183	--do--	--do--	--do--	.41	29.4	68	11,000	20.0	3,250
D176184	--do--	--do--	--do--	.22	22.5	1 L	182	.2L	40.9
D176185	--do--	--do--	--do--	.25	32.0	1 L	42	.3L	13.4
D176186	--do--	--do--	--do--	.27	34.2	5	1,360	1.7	465
D176187	Mahaska, Iowa	--do--	--do--	1.45	12.6	6	2,800	.8	353
D176188	Wapello, Iowa	--do--	--do--	1.52	25.3	1	176	.3	44.5
D176189	--do--	--do--	--do--	2/.68	24.9	1 L	58	.2L	14.4
D176190	--do--	--do--	--do--	.15	45.9	1 L	46	.5L	21.1
D176191	--do--	--do--	--do--	.25	12.8	73	6,120	9.3	783

Table 1.--Sample locations, descriptions, and ash, cadmium, and zinc contents in 91 bituminous coal samples of Pennsylvanian age from southeastern Iowa and northeastern Missouri--Continued

U.S.G.S. Sample No.	County, State	Description			Ash %	Coal ash		Whole coal	
		Coal bed (B) or formation (F)	Sample type	Thickness (meters)		Cd ppm	Zn ppm	Cd ppm	Zn ppm
D176192	Wapello, Iowa	(F) Cherokee	Core	0.79	17.0	437	30,400	74.3	5,170
D176193	--do--	--do--	--do--	3/.96	37.8	35	3,480	13.2	1,320
D176194	--do--	--do--	--do--	.34	31.5	1	130	.3	41.0
D176195	--do--	--do--	--do--	.43	10.7	1 L	95	.1L	10.2
D176196	--do--	--do--	--do--	.71	23.7	1 L	66	.2L	15.6
D176197	--do--	--do--	--do--	.30	16.4	9	2,720	1.5	446
D176198	--do--	--do--	--do--	1.07	29.2	1 L	54	.3L	15.8
D176199	--do--	--do--	--do--	1.32	16.2	1 L	44	.2L	7.1
D176200	--do--	--do--	--do--	.15	30.1	188	60,000	56.6	18,000
D179838	Davis, Iowa	--do--	--do--	.64	11.6	1 L	76	.1L	8.8
D179839	--do--	--do--	--do--	.15	49.8	1 L	111	.5L	55.3
D179840	--do--	--do--	--do--	.29	11.8	9	1,450	1.0	171
D179841	--do--	--do--	--do--	.84	20.6	26*	4,540*	5.4*	935*
D179842	--do--	--do--	--do--	.18	68.8	1 L	40	.7L	27.5
D179843	Wapello, Iowa	--do--	--do--	.28	38.6	1 L	120	.4L	46.3
D179844	--do--	--do--	--do--	.26	32.9	22	7,400	7.2	2,430
D179845	--do--	--do--	--do--	.18	38.7	23	7,350	8.9	2,840
D179846	--do--	--do--	--do--	.36	35.6	3*	1,370*	1.1*	488*
D179847	--do--	--do--	--do--	.36	12.7	120*	9,300*	15.2*	1,180*
D179848	--do--	--do--	--do--	.20	7.9	14	1,000	1.1	79.0
D179849	--do--	--do--	--do--	.13	21.8	1 L	320	.2L	69.8
D179850	--do--	--do--	--do--	.97	13.0	4	1,035	.5	134
D179851	--do--	--do--	--do--	.33	5.7	35*	2,200*	2.0*	125*
D179852	--do--	--do--	--do--	.83	10.6	93*	6,250*	9.9*	663*
D179853	--do--	--do--	--do--	.30	32.8	5	1,250	1.6	410
D179854	--do--	--do--	--do--	.99	24.6	1 L*	370*	.2L*	91.0*
D179855	--do--	--do--	--do--	1.93	13.4	1 L	970	.1L	130
D179856	--do--	--do--	--do--	.53	32.0	4	2,560	1.3	819
D172323	Sullivan, Mo.	(B) Lexington	Face Channel	.94	12.4	32	1,400	4.0	174
D172327	Putnam, Mo.	--do--	--do--	.86	14.9	117	14,800	17.4	2,210
D172328	--do--	--do--	--do--	.50	12.8	200	22,800	25.6	2,920
D172329	--do--	--do--	--do--	.81	13.3	580	39,600	77.1	5,270
D172330	--do--	--do--	--do--	.81	15.9	32	2,940	5.1	467
D178763	--do--	--do--	Bench Channel	.58 (upper)	10.8	93	7,600	10.0	821
D178764	--do--	--do--	--do--	.34 (lower)	10.8	1 L	308	.1L	33.3
D178765	--do--	--do--	--do--	.58 (upper)	17.3	133	17,500	23.0	3,030
D178766	--do--	--do--	--do--	.34 (lower)	8.0	1 L	99	.1L	7.9
D178767	--do--	--do--	--do--	.55 (upper)	10.7	47	5,350	5.0	572
D178768	--do--	--do--	--do--	.36 (lower)	7.5	1 L	153	.1L	11.5
D178769	--do--	--do--	--do--	.55 (upper)	10.2	28	3,420	2.9	349

Table 1.--Sample locations, descriptions, and ash, cadmium, and zinc contents in 91 bituminous coal samples of Pennsylvanian age from southeastern Iowa and northeastern Missouri--Continued

U.S.G.S. Sample No.	County, State	Description			Ash %	Coal ash		Whole coal	
		Coal bed (B) or formation (F)	Sample type	Thickness (meters)		Cd ppm	Zn ppm	Cd ppm	Zn ppm
D178770	Putnam, Mo.	(B) Lexington	Bench Channel	0.40 (lower)	9.1	2	363	0.2	33.0
D179385	--do--	--do--	--do--	.56 (upper	13.9	100	8,100	13.9	1,130
D179386	--do--	--do--	--do--	.30 (lower)	16.3	1L	80	.2L	13.0
D179387	--do--	--do--	--do--	.53 (upper)	8.0	60	4,700	4.8	376
D179388	--do--	--do--	--do--	.28 (lower)	8.5	1L	110	.1L	9.4
D179389	--do--	--do--	--do--	.56 (upper)	10.8	640	57,000	69.1	6,160
D179390	--do--	--do--	--do--	.30 (lower)	8.6	4	360	.3	30.9
D179391	--do--	--do--	--do--	.56 (upper)	11.2	7	1,700	.8	190
D179392	--do--	--do--	--do--	.28 (lower)	10.6	1L	1,100	.1L	117
D179393	--do--	--do--	--do--	.52 (upper)	12.0	320	19,000	38.4	2,280
D179394	--do--	--do--	--do--	.25 (lower)	7.2	9	930	.6	67.0

1/ Includes parting 0.08 m thick.

2/ Includes parting 0.15 m thick.

3/ Includes parting 0.07 m thick.

Table 2.--Sample locations, descriptions, and ash, cadmium, and zinc contents in 27 bituminous coal samples of Pennsylvanian age from northcentral Missouri

[Except where noted, each sample represents the entire thickness of the bed. The coals were ashed at 525°C. L after a value means less than the value shown]

U.S.G.S. Sample No.	County, State	Description			Ash %	Coal ash		Whole coal	
		Coal bed (B) or formation (F)	Sample type	Thickness (meters)		Cd ppm	Zn ppm	Cd ppm	Zn ppm
D172324	Macon, Mo.	(B) Mulky	Face Channel	0.41	14.5	1L	72	0.1L	10.4
D172325	--do--	--do--	--do--	.48	11.3	2	260	.3	29.4
D172326	Randolph, Mo.	(B) Bevier-Wheeler	--do--	1.12	14.9	2	252	.3	37.5
D173799	--do--	--do--	--do--	1.04	15.9	12	1,600	1.9	254
D174654	Macon, Mo.	--do--	--do--	.94	12.7	1L	68	.1L	8.6
D174655	--do--	--do--	--do--	.86	17.2	1L	55	.2L	9.5
D178757	Howard, Mo.	--do--	--do--	.85	15.7	110	13,100	17.3	2,060
D178758	Randolph, Mo.	--do--	--do--	1.01	9.2	6	800	.6	73.6
D178759	--do--	--do--	Bench Channel	.91 (upper)	20.7	1L	86	.2L	17.8
D178760	--do--	--do--	--do--	.24 (lower)	14.7	1L	132	.1L	19.4
D178761	--do--	--do--	--do--	.91 (upper)	13.1	1L	301	.1L	39.4
D178762	--do--	--do--	--do--	.27 (lower)	19.3	1L	234	.2L	45.2
D179892	Macon, Mo.	(B) Mulky	Face Channel	.51	8.4	1	169	.1	14.1
D179893	--do--	--do--	--do--	.51	9.7	1	151	.1	14.6
D179894	--do--	(B) Bevier-Wheeler	Bench Channel	.48 (upper)	14.3	2	151	.2	26.6
D179895	--do--	--do--	--do--	.30 (lower)	14.8	1L	110	.1L	16.3
D179896	--do--	--do--	--do--	.25 (upper)	19.2	1	109	.2	20.9
D179897	--do--	--do--	--do--	.28 (lower)	10.9	50	6,100	5.4	665
D179898	Randolph, Mo.	--do--	--do--	.73 (upper)	14.7	1L	60	.1L	8.8
D179899	--do--	--do--	--do--	.46 (lower)	16.8	2	165	.3	27.7
D179900	--do--	--do--	--do--	.84 (upper)	12.0	1L	92	.1L	11.0
D179901	--do--	--do--	--do--	.46 (lower)	12.0	6	451	.7	54.1
D179975	Howard, Mo.	--do--	--do--	.70 (upper)	18.7	1L	130	.2L	24.3
D179976	--do--	--do--	--do--	.18 (lower)	25.7	680	74,000	175	19,000
D179977	--do--	--do--	--do--	.61 (upper)	18.9	22	2,100	4.2	397
D179978	--do--	--do--	--do--	.30 (lower)	13.1	160	15,400	21.0	2,020
D179979	Randolph, Mo.	--do--	--do--	.94 (upper)	10.5	17	2,000	1.8	210

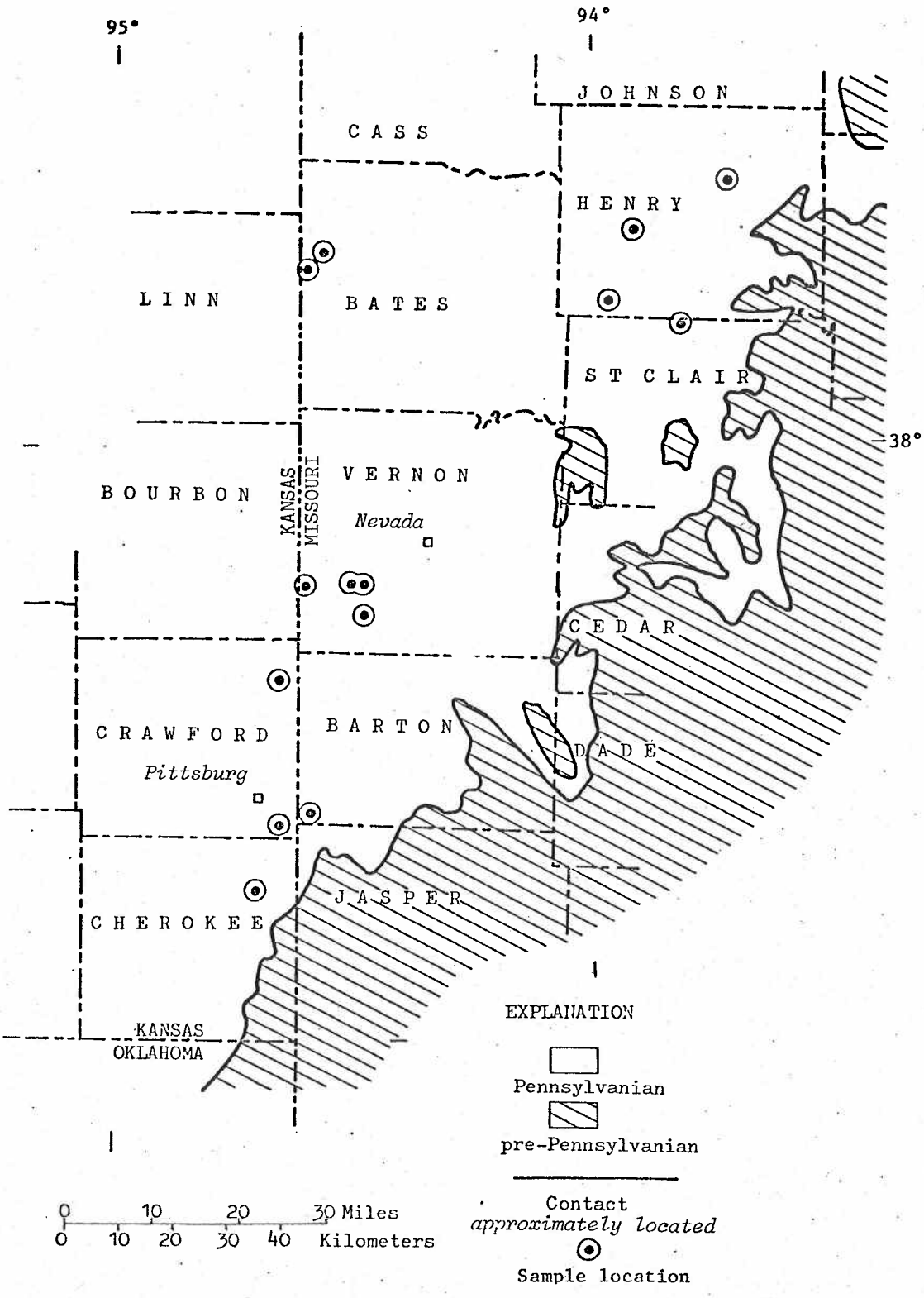

Figure 4.--Coal sample locations in southwestern Missouri and southeastern Kansas.

Table 3.--Sample locations, descriptions, and ash, cadmium, and zinc contents of 56 bituminous coal samples of Pennsylvanian age from southwestern Missouri and southeastern Kansas

[Each sample represents the entire thickness of the bed. The coals were ashed at 525°C. L after a value means less than the value shown]

U.S.G.S. Sample No.	County, State	Description			Ash %	Coal ash		Whole coal	
		Coal bed (B) or formation (F)	Sample type	Thickness (meters)		Cd ppm	Zn ppm	Cd ppm	Zn ppm
D173800	Henry, Mo.	(B) Croweburg	Face Channel	0.47	8.1	60	5,200	4.9	421
D173801	--do--	--do--	--do--	.46	6.5	1L	600	.1L	39.0
D173802	--do--	(B) Fleming	--do--	.30	18.1	7	1,280	1.3	232
D173803	--do--	--do--	--do--	.33	31.7	3	1,050	1.0	333
D173804	--do--	(B) Tebo	--do--	.50	15.6	1L	460	.2L	71.8
D173805	--do--	--do--	--do--	.46	9.0	90	10,000	8.1	900
D173806	--do--	(B) Weir-Pittsburg	--do--	1.58	19.0	1L	50	.2L	9.5
D173807	--do--	(B) Mulky	--do--	.23	8.0	1L	190	.1L	15.2
D173808	--do--	--do--	--do--	.36	5.8	2	340	.1	19.7
D174656	Bates, Mo.	(B) Mulberry	--do--	.84	19.5	130	9,400	25.4	1,830
D174657	--do--	--do--	--do--	.94	18.1	325	24,600	58.8	4,450
D174658	Barton, Mo.	(B) Rowe	--do--	.41	22.8	1L	82	.2L	18.7
D174659	--do--	--do--	--do--	.50	15.5	1L	130	.2L	20.1
D174660	--do--	(B) Drywood	--do--	.33	15.4	1L	110	.2L	16.9
D174661	--do--	--do--	--do--	.33	14.7	1L	84	.1L	12.3
D175940	Vernon, Mo.	(B) Croweburg	--do--	.30	17.8	2	448	.3	79.7
D175941	--do--	--do--	--do--	.28	16.0	1L	190	.2L	30.4
D175942	--do--	(B) Fleming	--do--	.36	17.0	65	16,400	11.0	2,790
D175943	--do--	--do--	--do--	.36	14.8	180	29,000	26.6	4,290
D179877	Barton, Mo.	(B) Drywood	--do--	.29	15.1	1L	131	.2L	19.8
D179878	--do--	--do--	--do--	.29	16.1	1L	94	.2L	15.1
D179879	--do--	(B) Rowe	--do--	.36	17.1	1L	116	.2L	19.8
D179880	--do--	--do--	--do--	.37	16.1	1L	108	.2L	17.4
D179881	St. Clair, Mo.	(B) Riverton (?)	--do--	.36	24.2	1L	75	.2L	18.2
D179882	Vernon, Mo.	(B) Mineral	--do--	.43	17.0	55	5,100	9.4	867
D179883	--do--	--do--	--do--	.48	12.7	120	24,500	15.2	3,110
D179884	--do--	(B) Fleming	--do--	.38	14.2	130	24,200	18.5	3,440
D179885	--do--	--do--	--do--	.38	13.9	8	1,900	1.1	264
D179886	--do--	(B) Croweburg	--do--	.24	17.4	1L	119	.2L	20.7
D179887	--do--	--do--	--do--	.25	14.1	1L	222	.1L	11.3
D179888	Bates, Mo.	(B) Mulberry	--do--	.71	21.7	700	62,000	152	13,500
D179889	--do--	--do--	--do--	.71	23.8	20	1,900	4.8	450
D179890	Henry, Mo.	(B) Croweburg	--do--	.46	5.7	230	18,000	13.1	1,030
D179891	--do--	--do--	--do--	.46	7.6	400	37,000	30.4	2,810
D179980	--do--	(B) Tebo	--do--	.56	16.7	150	20,000	25.0	3,340
D179981	--do--	--do--	--do--	.48	12.8	100	12,400	12.8	1,590
D179982	--do--	(B) Weir-Pittsburg	--do--	.33	15.1	1L	92	.2L	13.9
D179983	--do--	--do--	--do--	.30	23.3	1L	127	.2L	29.6
D177984	--do--	(B) Tebo	--do--	.49	21.1	91	11,300	19.2	2,380
D179985	--do--	--do--	--do--	.36	23.3	39	4,800	9.1	1,120

Table 3.--Sample locations, descriptions, and ash, cadmium, and zinc contents of 56 bituminous coal samples of Pennsylvanian age from southwestern Missouri and southeastern Kansas--Continued

U.S.G.S. Sample No.	County, State	Description			Ash %	Coal ash		Whole coal	
		Coal bed (B) or formation (F)	Sample type	Thickness (meters)		Cd ppm	Zn ppm	Cd ppm	Zn ppm
D176045	Crawford, Kans.	(B) Croweburg	Face Channel	0.30	20.0	1	256	0.2	51.2
D176046	--do--	--do--	--do--	.33	17.4	1L	146	.2L	25.4
D176047	--do--	--do--	--do--	.28	13.6	1L	174	.1L	23.7
D176048	--do--	(B) Mineral	--do--	.43	13.2	1L	298	.1L	39.3
D176049	--do--	--do--	--do--	.43	13.2	1	348	.1	45.9
D176050	--do--	(B) Rowe	--do--	.46	16.4	1L	120	.2L	19.7
D176051	--do--	--do--	--do--	.46	16.1	1L	184	.2L	30.5
D176052	--do--	--do--	--do--	.51	18.2	1L	183	.2L	33.3
D176053	Cherokee, Kans.	--do--	--do--	.36	16.1	1L	88	.2L	14.2
D176054	--do--	--do--	--do--	.36	16.1	1L	90	.2L	14.5
D180069	Crawford, Kans.	--do--	--do--	.46	18.8	1L	204	.2L	38.4
D180070	--do--	(B) Dry Wood	--do--	.30	11.5	8	770	.9	85.9
D180071	--do--	(B) Rowe	--do--	.43	17.9	1L	89	.2L	15.9
D180072	--do--	(B) Dry Wood	--do--	.30	20.9	77	25,500	16.0	5,330
D180073	--do--	(B) Rowe	--do--	.41	13.9	1.5	1,020	.2	142
D180074	--do--	(B) Dry Wood	--do--	.30	32.3	490	158,000	.158	51,000

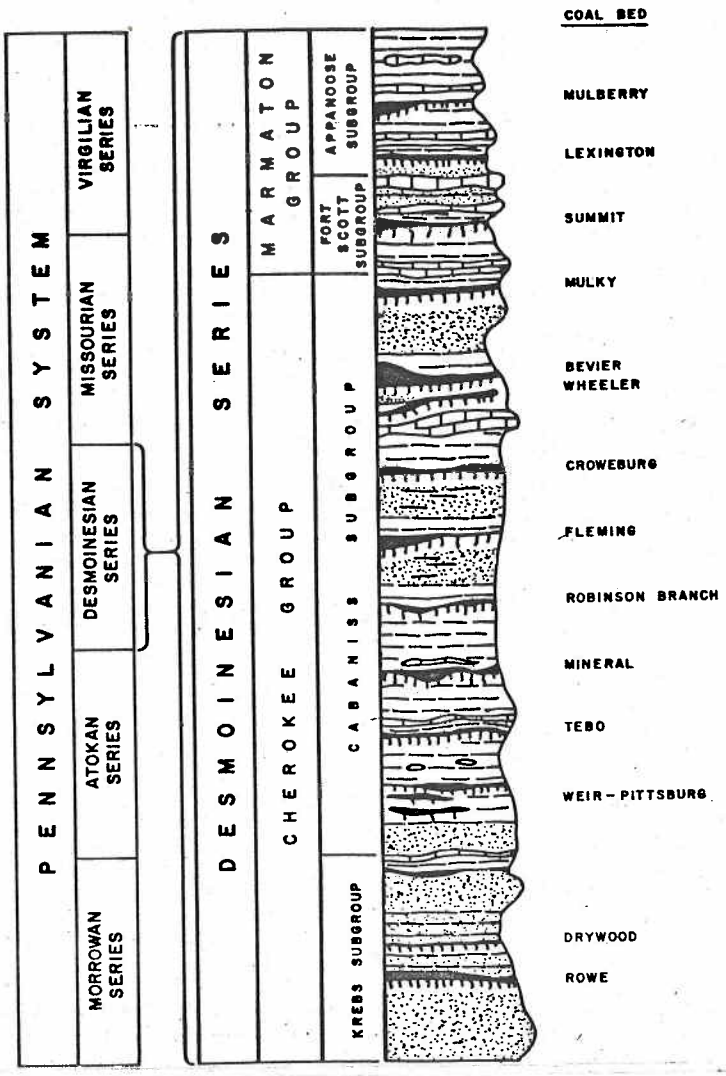

Figure 5.--Stratigraphy of the principal coal beds of Missouri and equivalent Cherokee coal beds in Kansas (Robertson, 1971, figure 4).

Zinc and cadmium analyses on a whole-coal basis for all samples from the three states are summarized in Table 4. For Missouri and Kansas the summaries are by county and by coal bed. In Iowa correlations between coal beds encountered in the different cores and for the coal beds sampled in mines are lacking; for this reason, cadmium and zinc analyses of Iowa coals are summarized by county and by two bed-thickness categories--beds $\geq$0.46 m ($\approx$18 inches) and beds <0.46 m thick.

Field studies

Field studies in both strip and underground coal mines in southeastern Iowa and northeastern and southwestern Missouri, and studies of core samples from southeastern Iowa show that the zinc occurs as sphalerite. This mineral occurrence in the Western Interior region coal is very similiar to the occurrences described in the Eastern Interior region by Hatch, Gluskoter, and Lindahl (1976). The sphalerite is in mineralized vertical fractures (cleats) in the coal, and is associated with calcite, kaolinite, and pyrite. In southeastern Iowa and northeastern Missouri, barite has been observed in association with the sphalerite. The vertical fractures range up to 1.5 cm across and are discontinous in both the horizontal and vertical directions in the coal; the vertical terminations are commonly at prominent fusain bands. These minerals generally completely fill the fractures. However, in Bates County, Missouri, open or unfilled fractures as much as 0.5 cm across have been observed. Most of the sphalerite is pale to medium yellow. The only other color observed in hand specimens is pale purple.

Table 4.--Average zinc and cadmium concentrations in whole coal samples from southeastern Iowa, Missouri and southeastern Kansas; summarized by County

[L after a value means less than the value shown. Missouri and Kansas coal analyses are summarized by bed. Since correlations of coal beds between core holes in Iowa are lacking, Zn and Cd concentrations are summarized in two thickness categories, beds ≥0.46 meters (18 inches) and beds <0.46 meters thick]

State	County	Thickness category or bed name	No. of samples	Whole coal Cd ppm	Whole coal Zn ppm
Southeastern Iowa - northeastern Missouri					
Iowa	Mahaska	≥0.46 m	9	0.8	403
Iowa	Lucas	≥0.46 m	2	.2L	106
Iowa	Monroe	≥0.46 m	4	.2	168
Iowa	Wapello	≥0.46 m	18	7.7	1,180
		<0.46 m	21	8.1	1,590
Iowa	Appanoose	≥0.46 m	1	.7	38
		<0.46 m	8	15.6	1,180
Iowa	Davis	≥0.46 m	2	2.7	472
		<0.46 m	3	.7L	85
Missouri	Putnam	Lexington	22	18.1	1,600
Missouri	Sullivan	--do--	1	4.0	174
Northcentral Missouri					
Missouri	Macon	Mulky	4	0.2	17.1
		Bevier-Wheeler	6	1.0	125
Missouri	Randolph	--do--	12	.5	67
Missouri	Howard	--do--	5	43.5	4,700
Southwestern Missouri - southeastern Kansas					
Missouri	Henry	Mulky	2	0.1L	17.5
		Croweburg	4	12.1	1,080
		Fleming	2	1.2	283
		Tebo	6	12.4	1,567
		Wier-Pittsburg	3	.2L	17.7
Missouri	St. Clair	Riverton (?)	1	.2L	18.2
Missouri	Bates	Mulberry	4	60.2	5,060
Missouri	Vernon	Croweburg	4	.2L	40.5
		Fleming	4	14.3	2,700
		Mineral	2	12.3	1,990
Missouri	Barton	Drywood	4	.2L	16.0
		Rowe	4	.2L	19.0
Kansas	Crawford	Croweburg	3	.2L	33.4
		Mineral	2	.1L	42.6
		Dry Wood	3	58.3	18,800
		Rowe	6	.2L	46.6
Kansas	Cherokee	--do--	2	.2L	14.4

Field observations indicate considerable variations in the distribution of sphalerite. In a multibed mining operation (relatively common in the Western region of the Interior province), one of the beds may have a relative abundance of filled fractures containing sphalerite, while an underlying or overlying coal bed may lack visible sphalerite. In Vernon County, Missouri, for example, the Croweberg coal bed is stratigraphically 6 to 9 meters above the Fleming bed; abundant sphalerite is observed in the Fleming bed but is apparently lacking in the overlying Croweberg. Analyses D175940 through D175943, and D179884 through D179887 (table 3) confirm this observation. A second example is in Henry County, Missouri, where the Tebo bed is stratigraphically 1.5 to 6 meters above the Weir-Pittsburg bed. In this area, however, the geologic conditions are reversed: sphalerite is readily observed in the upper bed (Tebo) and apparently lacking in the lower bed (Weir-Pittsburg). Analyses D173804 through D173806, and D179980 through D179983 (table 3) again confirm the field observations.

Sphalerite mineralization commonly is concentrated in coal that is well cleated. In Bates County, Missouri, the top half of the Mulberry coal bed is well cleated and contains abundant sphalerite, but the bottom half of the bed lacks cleats and contains no apparent sphalerite.

Discussion

On the basis of analytical data listed in Tables 1, 2, and 3 and summarized in Table 4, three areas with high concentrations of zinc and cadmium in the coal can be demonstrated. The first area includes Mahaska, Monroe, Wapello, Appanoose, and Davis Counties, Iowa, and Putnam County, Missouri; the second area includes Henry, Bates, and Vernon Counties, Missouri, and Bourbon and Crawford Counties, Kansas; and the third area is in Howard County, Missouri. The boundaries of these three areas will be more clearly defined as additional samples are analyzed.

The distribution of these areas of mineralization in coal appears to be related to the proximity of the coal to several of the major lead-zinc mining districts of Missouri and to two major structural features of the Midcontinent area--the 38th-parallel lineament and the Mississippi River arch. (See figure 6 for locations,) The 38th parallel lineament, along which are located many major lead, zinc, and fluorite ore deposits (Heyl, 1972), is projected to pass through Vernon, and just south of Bates, and Henry Counties, Missouri, and into Bourbon County, Kansas. The importance of the Mississippi River arch and other closely related structures, principally the Linoln fold, is indicated by the mineralization of coal on each flank of the structural high--the occurrence in northwestern Illinois to the east and the occurrences in southeastern Iowa and northeastern and north-central Missouri to the west.

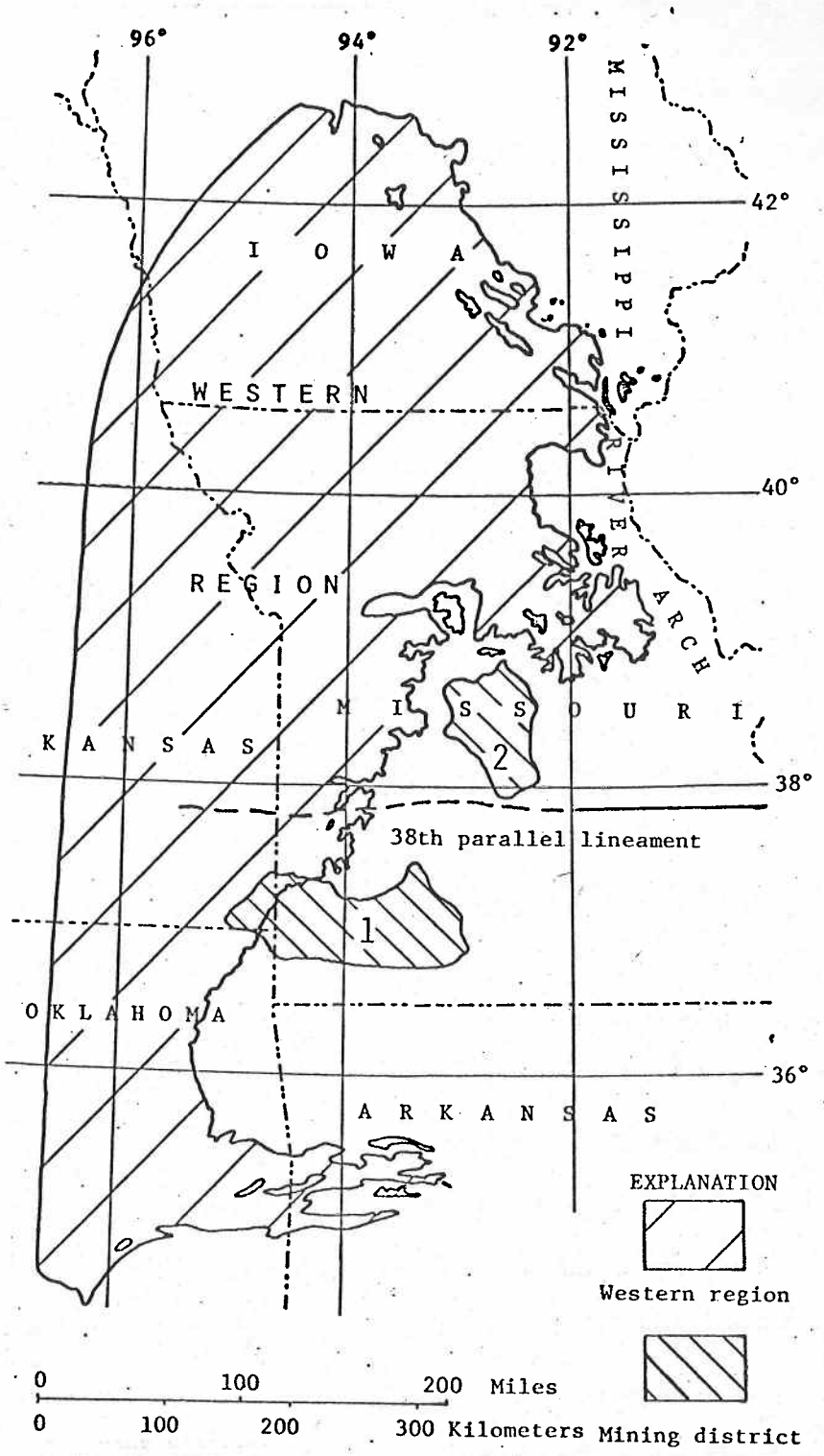

Figure 6.--Approximate locations of major structures and mining districts mentioned in the text. [1. = Tri-State mining district, and 2 = Central Missouri mining district]

The analytical data listed and summarized in Tables 1 through 4 also demonstrate the high variability of cadmium and zinc contents in coal, not only for a bed on a regional scale, but also because beds within a mine and between parts of the same bed. The Croweberg coal bed in Crawford County, Kansas (U.S.G.S. Sample Nos. D176045, D176046, and D176047, table 3), and Vernon County, Missouri (U.S.G.S. Sample Nos. D175940, D175941, D179886, and D179887, table 3) has low concentrations of both zinc and cadmium; but to the northeast, in Henry County, Missouri (U.S.G.S. sample nos. D173800 through D173803, D179890 and D179891, table 3), the concentrations of zinc are increased by a factor of 20 and those of cadmium are increased by a factor of 40. The three samples of the Dry Wood coal bed from Crawford County, Kansas (U.S.G.S. Sample Nos. D180070, D180072, and D180074, table 3) are from the same mine; the cadmium content of these three coal samples (whole-coal basis) ranges from 0.9 to 158 ppm, and the zinc content ranges from 85.9 to 51,000 ppm. Analyses of samples D178763 through D178770, and D179385 through D179394 (table 1), which are bench samples, of the upper and lower parts of the Lexington coal bed from Putnam County, Missouri, show that the cadmium content of the upper bench is greater by as much as a factor of 230 than that of the lower bench, and the zinc content in the upper bench is greater by as much as a factor of 380 than that of the lower bench. In all nine sets of bench samples from this coal bed, the zinc and cadmium contents of the upper bench are greater than those in the lower bench. The reverse is true in the Bevier-Wheeler coal bed of Macon, Randolph, and Howard Counties, Missouri,

where the lower bench is enriched in zinc and cadmium when compared to the upper bench. Analyses of samples D179759 through D178762, D179894 through D179901, and D179975 through D179979 (table 2) show that the cadmium content of the lower bench is greater by as much as a factor of 875 and that the zinc content in the lower bench is greater by as much as a factor of 780. In all except one of the eight sets of bench-channel samples from the Bevier-Wheeler coal, zinc and cadmium contents are greater in the lower bench than in the upper.

As listed in Table 5 and illustrated in Figure 7, the Zn/Cd molar ratio in coal in cores from Appanoose and Wapello Counties, Iowa, increases appreciably with depth. This trend, observed in five core holes, indicates a differentiation in the ore-bearing solutions. A possible salinity control for these changes in molar ratios is suggested by the work of Mookherjee (1962).

In addition to the ash, cadmium, and zinc analyses listed for the 174 coal samples from the Western Interior region, analytical data for 40 other major, minor, and trace elements are available for each sample. Seventy-five of the complete analyses have been published (Swanson and others, 1976; Wedge, Bhatia, and Rueff, 1976), and the analyses for the other 99 samples are in the U.S. Geological Survey's files. Although the high zinc and cadmium concentrations are the principal topic of this report, some other chalcophile elements, including antimony, cobalt, copper, lead, molybdenum, nickel, and silver, are commonly present in relatively high amounts. Antimony is found in concentrations up to 300 ppm in coal ash (D179851); cobalt, 700 ppm (D179843); copper, 520 ppm (D176178); lead, 2,770 ppm (D173807); molybdenum, 1,000 ppm (D179847); nickel, 1,500 ppm (D179843); and silver, 15 ppm (D179847). These relatively high (for coal) concentrations suggest that through detailed petrographic studies, additional sulfide phases such as chalcopyrite, galena, or millerite may be identified.

Table 5.--Depths from the surface (in meters) and the zinc/cadmium mole ratios for 40 coal samples from five core holes in Wapello and Appanoose Counties, Iowa

[Data are from Table 1, hole number CP-10 is in Appanoose County. The other four holes are in Wapello County. Qualified cadmium values (L) prevented calculation of the Zn/Cd mole ratio for some samples. The Zn/Cd ratio for sample D176182 is not plotted in figure 7]

Hole No.	Sample No.	Depth (meters)	moles Zn / moles Cd	Hole No.	Sample No.	Depth (meters)	moles Zn / moles Cd	Hole No.	Sample No.	Depth (meters)	moles Zn / moles Cd
CP-7	D176169	33.3	---	CP-21	D176189	23.4	---	CP-28	D179851	17.0	108
	D176170	45.5	---		D176190	40.2	---		D179852	29.5	115
	D176171	50.4	148		D176191	50.9	144		D179853	46.9	430
	D176172	58.9	261		D176192	56.0	120		D179854	55.2	---
	D176173	62.8	345		D176193	58.3	170		D179855	64.4	---
	D176174	69.8	469		D176194	60.3	223		D179856	69.5	1100
	D176175	76.9	572		D176195	65.7	---				
	D176176	87.8	---		D176196	73.5	---				
	D176177	98.7	---		D176197	80.1	515				
					D176198	95.2	---				
CP-10	D176178	74.0	93		D176199	96.9	---				
	D176179	79.6	---		D176200	107.8	548				
	D176180	85.1	76								
	D176181	93.6	91	CP-32	D179847	7.5	134				
	D176182	109.9	818		D179848	18.0	123				
	D176183	118.5	278		D179849	35.7	---				
	D176184	123.8	---		D179850	54.1	445				
	D176185	129.5	---								
	D176186	142.2	468								

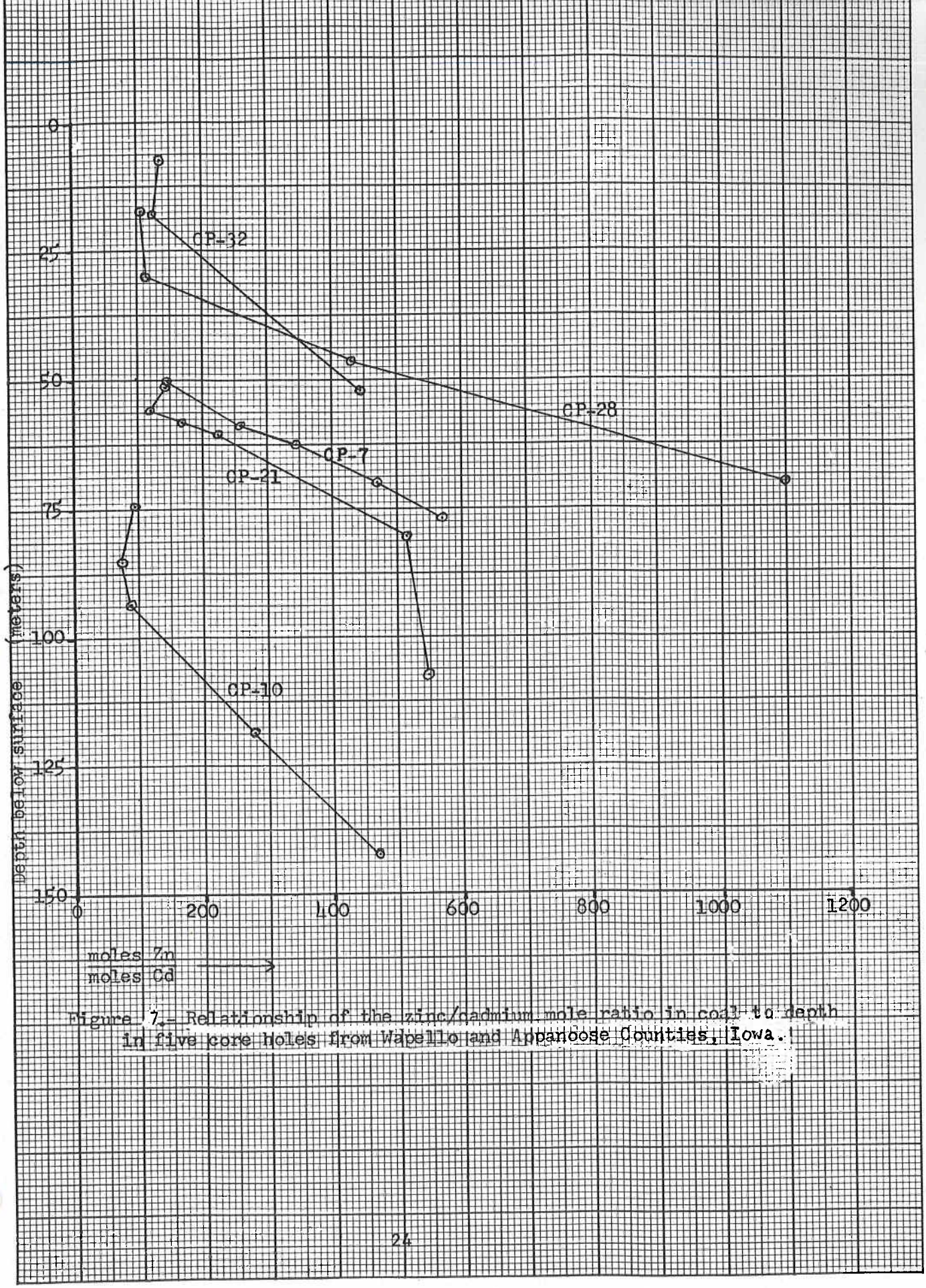

Figure 7.- Relationship of the zinc/cadmium mole ratio in coal to depth in five core holes from Wapello and Appanoose Counties, Iowa.

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