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ABUNDANCE AND RECOVERY OF SPHALERITE AND FINE COAL FROM MINE WASTE IN ILLINOIS

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ABSTRACT

A million tons of marketable coal and 1100 tons of zinc are estimated to be present in a coal mine refuse deposit in west-central Illinois. In the 45 acres covered by the fan-shaped slurry deposit, the coal content was found to increase radially outward from the discharge pipe toward the settling pond, while the zinc content decreased. The maximum coal content was found 600 feet from the discharge pipe. The bulk of the zinc, 95 percent, occurs in a 450-foot radius from the discharge pipe.

The Humphreys spiral concentrator separated clean coal and heavy mineral concentrates from refuse fan samples. There was an effective increase in the zinc content of the heavy mineral concentrate by an average of 324 percent. The total carbon content in the coal concentrate increased an average of 72 percent. The best coal concentrate contained 97 percent coal and only 3 percent discrete mineral particles. Chemical analyses showed this coal concentrate to contain 2.6 percent total sulfur and 9 percent ash.

INTRODUCTION

Resource investigations of zinc in sphalerite-bearing coals in west-central Illinois show that the in situ zinc content of three coals mined ranges from about 0.05 percent to 0.09 percent (Cobb et al., 1978). The highest concentrations of zinc, up to 0.5 percent, occur locally in disturbed areas of the coal beds characterized by faults, slips, fractures, and clastic intrusions. Undisturbed portions of the coal usually contain less than 0.005 percent zinc.

Zinc is present in the coal as a sulfide mineral, sphalerite (ZnS with up to 1 percent cadmium). Sphalerite occurs as fillings in fractures, cleats, and faults, and as crystal aggegates in clastic dikes which intrude the coals. The occurrence of sphalerite in coals and the relative ease with which the sphalerite can be reduced in the coal by specific gravity techniques is discussed by Hatch et al. (1976), who speculated that recoverable quantities of sphalerite could be present in some existing coal refuse deposits.

The west-central Illinois mining district (Fulton, Knox, Peoria, and Stark Counties) has an estimated coal resource of 7500 million tons (Smith and Berggren, 1963) occurring in three seams: the Colchester (No. 2), Springfield (No. 5), and Herrin (No. 6). With a zinc concentration of 0.05 to 0.09 percent, the coals in this area contain several million tons of zinc.

The annual raw coal production from this area is about 10 million tons. This raw coal is crushed, washed, and screened in preparation processes. The coarse-sized refuse is hauled to gob piles, and the fine-sized refuse is slurried and discharged into impoundments. A survey of surface-mined land in Illinois (Haynes and Klimstra, 1975) lists 1,018 acres of uncovered slurry deposits and 858 acres of uncovered gob deposits in the west-central Illinois district.

Our investigation was conducted to evaluate the potential recovery of zinc and fine coal from waste material resulting from the coal preparation process. Random sampling of slurry and gob deposits from different mines in the area shows the concentration of sphalerite in refuse (tables 1 and 2). The zinc content of these gob samples ranges from 0.001 percent to 0.6 percent and that of slurry samples from 0.001 percent to 2.3 percent. Table 3 shows the zinc content of washed coal to vary from 0.007 percent to 0.025 percent. In this report, the refuse fan portion of a slurry deposit was selected for detailed study of its physical characteristics, composition, and reprocessing.

METHODS

Samples were collected from the refuse fan by auger from three bore holes and by shovel from 42 surface sites (fig. 1). Traverse A-A′, which contains three auger sites and eight surface samples, is the base line for the sample grid on figure 1. Selected samples were analyzed by the Analytical Chemistry Section at the Illinois State Geological Survey for zinc, cadmium, total carbon, total sulfur, and ash. Particle-size analyses and specific gravity separations were completed on selected samples.

All surface samples and spiral concentrate samples were analyzed for total carbon as an index of coal content. Elemental carbon represents about 70 percent of the total coal weight for Illinois coals from this area. A comparison of total carbon to organic carbon was made for the refuse fan samples. The results show that 3.0 percent or less of the carbon in the refuse is contributed by inorganic sources such as carbonate minerals. Float-sink tests of the refuse also show that less than 2 percent of the total carbon is contributed by bituminous shales.

Selected surface grid samples were processed by crushing and sizing to produce uniform material suitable as feed for a five-turn Humphreys spiral concentrator. Concentrates of fine coal and heavy minerals were produced and analyzed for total carbon and zinc.

SLURRY DEPOSITS

Coal mine slurry deposits vary in size and shape but most have three common elements: the discharge point, the fan-like deposit, and the settling pond.

At the discharge point, slurry is discharged into an impoundment. This point is usually not changed during the life of the impoundment but is periodically elevated as the thickness of the deposit increases.

Deposition of solids adjacent to the discharge point creates a fan-like deposit which is highest and thickest at the point of discharge and slopes away and thins toward the settling pond. As refuse is transported by the discharge stream, solids settle and build up the fan.

The surface of the refuse fan investigated (fig. 1) consists of about 45 acres of interconnected active and abandoned discharge channels that slope away into flat areas. The discharge channels are areas of rapidly moving water. These areas gradually spread out into lower gradient areas where the discharge water is slower moving. In the flat areas, bordered by water in the settling pond, the discharge water is slowest moving. In times of high water-level, the flat areas become submerged.

The settling pond is a major part of the slurry impoundment, encompassing about 65 acres. When discharge water accumulates, fine suspended matter is allowed to settle in the pond. The volume and composition of this material were not determined in this study. Water is recycled from the settling pond back to the preparation plant.

The physical features of the slurry deposit within the impoundment constantly change shape and position, responding to variation in the slurry discharge load, to build-up of the deposit, to bulldozing for control of channel development, and to the position of the water line.

REFUSE FAN

The refuse material discharged into the impoundment is not a typical sediment. It is composed of different types of minerals that have wide ranges in specific gravity as well as wide particle-size ranges. A plot of median particle size of surface grid samples on the refuse fan (fig. 1) with distance from the discharge pipe (fig. 2) shows an actual increase in the median size away from the discharge point. The refuse-fan samples do not show a progressive decrease in particle size away from the discharge pipe as might be expected in situations where the velocity of the transporting water decreases away from a point source. This is due to the fact that particles are transported in moving water according to both their specific gravity and their size. In the refuse fan, most of the higher density materials of both large and small particle size are deposited nearest the discharge pipe, while most low specific gravity, large particles and many high

Table 1. Zinc and cadmium in grab samples of coarse-grained refuse (gob).

Coal	Sample Type	Zinc (%)	Cadmium (%)
6	gob pile	0.006	0.0001
6	gob pile	0.090	0.0007
5 & 6	gob pile	0.520	0.0006
5 & 6	prep. plant	0.440	0.0002
5 & 6	prep. plant	0.640	0.0007
5 & 6	prep. plant	0.230	0.0021
5 & 6	prep. plant	0.050	0.0004
5	prep. plant	0.220	0.0032
5	prep. plant	0.150	0.0018
5	prep. plant	0.100	0.0011
5	prep. plant	0.010	0.0002
5	gob pile	0.330	0.0031

Table 2. Zinc and cadmium in grab samples of fine-grained refuse deposits (slurry wastes)

Coals	Zinc (%)	Cadmium (%)
6	0.130	0.0015
6	0.270	0.0025
5	0.650	0.0071
5	0.320	0.0038
5	0.410	0.0048
5	0.010	0.0001
2	1.750	0.0190
2	2.360	0.0280
2	0.110	0.0013

Table 3. Zinc and cadmium in washed coal samples.

Coal	Sample description	Zinc (%)	Cadmium (%)
5 & 6	coal (3 in. - 6 in.)	0.010	0.0001
5 & 6	coal (1¼ in. - 3 in.)	0.020	0.0001
5 & 6	coal (3/4 in. - 1¼ in.)	0.007	0.0001
5	coal (1½ in.)	0.025	0.0005

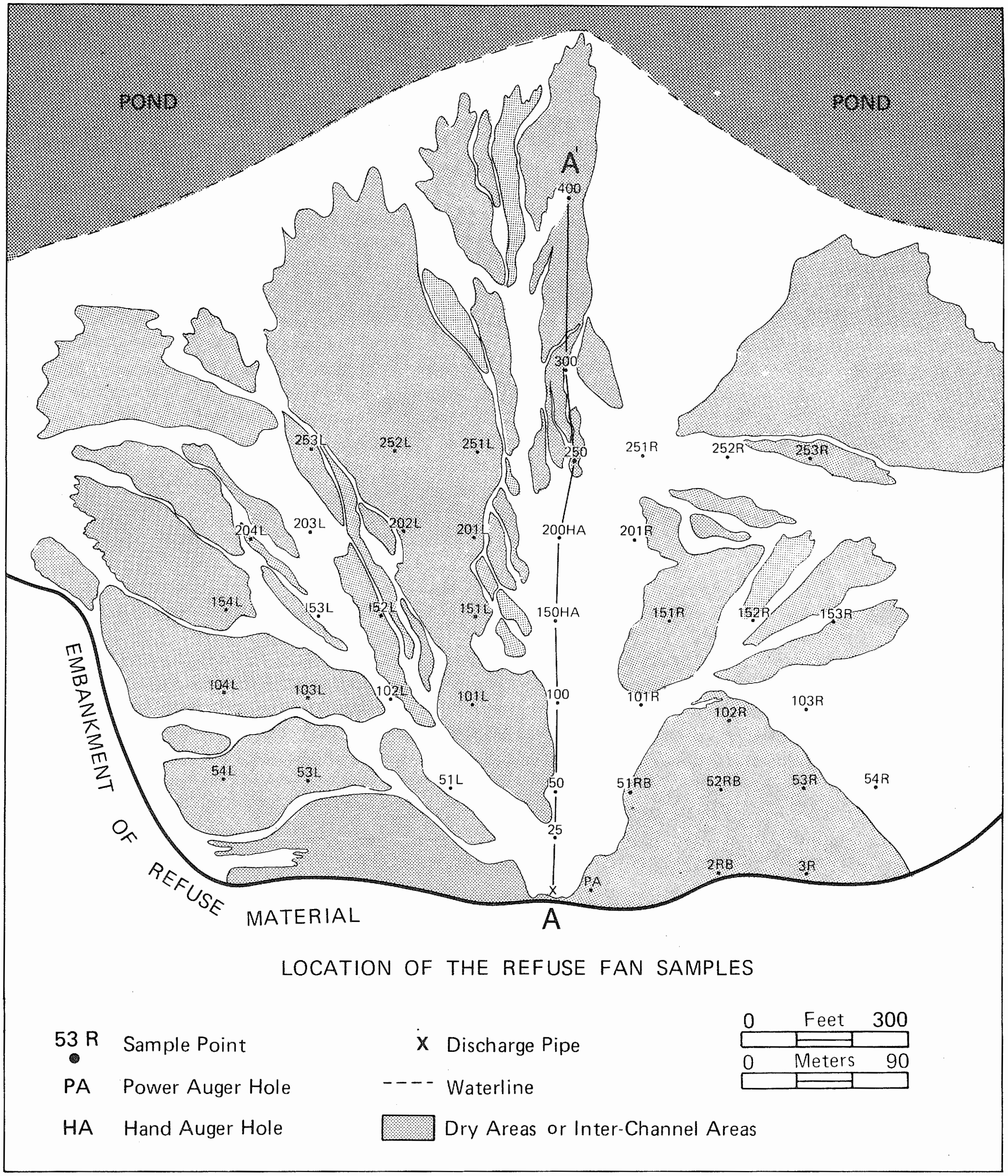

Figure 1. Plan view of slurry deposit and location of samples.

specific gravity, small particles are deposited in an intermediate area. Most low specific gravity, small particles are deposited farther away in the area adjacent to the settling pond.

The above specific gravity and particle-size relationships are demonstrated on figure 3, where a proximal sample is compared in detail to a more distant one. Figure 2 shows that the median particle size of 51 RB is finer than that of 103L, even though 51 RB is closer to the discharge pipe than 103L. Figure 3 shows that although 103L is coarser than 51 RB, it contains much more coal and much less high specific-gravity material than 51 RB. This relationship holds for material in every size fraction. For example, coarser particle fractions (5 to 18 mesh) in sample 103L are composed of 77 to 89 weight percent coal particles while the same coarse fractions in sample 51 RB contain only 11 to 27 weight percent coal. Therefore, the coarsening in median particle size away from the discharge pipe as illustrated in figure 2 is due to the longer distances that coal particles can be transported, whereas high specific gravity particles of smaller size, such as rock fragments, pyrite, sphalerite, quartz, calcite, and others, settle out closer to the discharge pipe.

MAIN DISCHARGE CHANNEL

Samples along the A-A′ traverse (fig. 1) are in the main discharge channel. Analyses of these samples substantiate the specific gravity and particle-size trends previously described. Figures 4 and 5 show total carbon and zinc analyses along the traverse, which can be discussed in terms of its proximal medial, and distal portions.

The proximal portion extends from the discharge pipe to sample 150. The material in this portion is about 65 percent rock fragments and carbonate and silicate grains, about 20 percent coal, and about 15 percent sulfide grains. A large portion of fines is attributed to the disintegration of claystone and shale fragments. Figure 4 shows the total carbon to be consistently low; in contrast, figure 5 shows the total zinc to be high in this portion.

The medial portion extends from sample 150 to sample 200. The material in this portion is about 22 percent rock fragments, carbonate and silicate particles, about 77 percent coal, and only about 1 percent sulfide mineral particles. The particle size of this material is slightly coarser than that of the proximal portion, which is attributed to a decrease in transport capacity of the discharge stream sufficient to increase deposition of the larger coal particles. Figure 4 shows a corresponding sharp increase in total carbon in this portion; in contrast, figure 5 shows an extreme decrease in total zinc. Thus the discharge stream becomes depleted in sphalerite in the same interval where coal deposition becomes dominant.

The distal portion extends from sample 200 to sample 400. The material in this portion is about 24 percent mud, rock fragments, carbonate and silicate particles; about 75 percent coal; and less than 1 percent sulfide mineral particles. The particle size of this material is coarsest in the upstream portion and gradually decreases toward the settling pond, suggesting a normal particle-size sorting and deposition from a discharge stream that is decreasing in velocity. Figure 4 shows the total carbon to be high throughout this portion with a slight decrease toward the settling pond, probably reflecting increasing percentages of fines. The

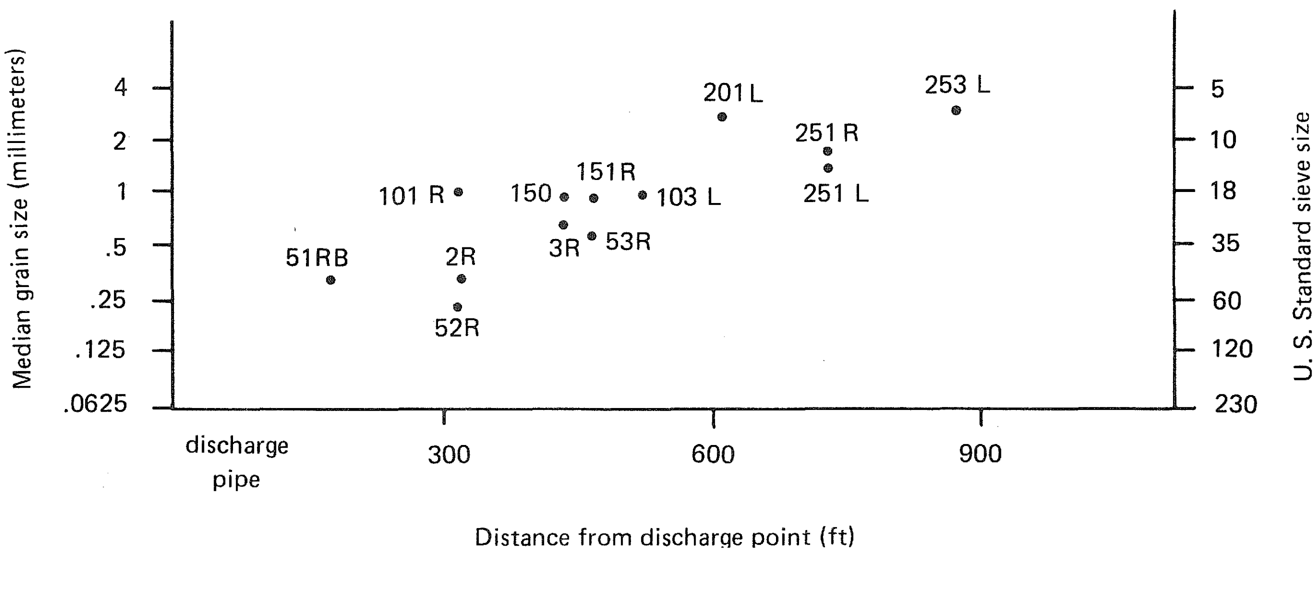

Figure 2. Increase in slurry particle size with increasing distance from the discharge pipe.

continued extremely low total zinc (fig. 5) substantiates the depletion of sphalerite in the medial and distal portions of the discharge channel.

A subsurface dimension is added to traverse A-A′ by the analyses of samples from the three auger borings shown on figure 1. Variations with depth for zinc, cadmium, and total carbon in these samples are shown on table 4. The sudden vertical fluctuations in the three constituents shown in table 4 are attributed to changes in the major discharge channel. As the major discharge channel shifts across the fan and the competence of the discharge stream decreases over a site, an increase in carbon and corresponding decrease in zinc is expected.

LOBATE FEATURES

All of the samples in the grid shown on figure 1 were analyzed for zinc, cadmium, and total carbon, thus adding an areal dimension to traverse A-A′. These results correspond to the trends found along traverse A-A′. Figures 6 and 7 are maps of zinc and total carbon concentrations at the surface of the refuse fan.

The surficial distribution of zinc (sphalerite) was found to be concentrated near the discharge pipe and to decrease outward in lobate patterns that coincide with the major discharge channels (fig. 6). The surficial pattern of cadmium distribution, for which all samples were also analyzed, is similar to that of zinc except that the concentration of cadmium is about 1.0 percent of that of zinc. The highest zinc value of 0.74 percent was from a grab sample 25 feet from the discharge pipe. The zinc content decreases rapidly at distances greater than 450 feet. The general pattern of zinc distribution shown in figure 6 is attributed to the high specific gravity of sphalerite and to the inability of the discharge streams to effectively transport sphalerite particles more than 450 feet from the discharge pipe. The extension of lobes left and right of the discharge pipe is a result of periodic bulldozing of material away from the area adjacent to the discharge pipe. This process controls excessive buildup of refuse in that area and controls the tendency of the discharge streams to meander left or right.

The surficial distribution of total carbon in the refuse fan contrasts to that of the zinc distribution (figs. 6 and 7). The total carbon content ranged from less than 20 percent within a 25 foot radius of the discharge pipe to greater than 60 percent at distances greater than 450 feet. The low specific gravity of coal allows it to be transported much farther from the discharge pipe than the more dense mineral particles in the slurry. Figures 6 and 7 demonstrate that lobes of higher zinc and lower carbon concentrations extend outward from the discharge pipe for larger distances along the present major discharge channel than currently exist along the minor discharge channels.

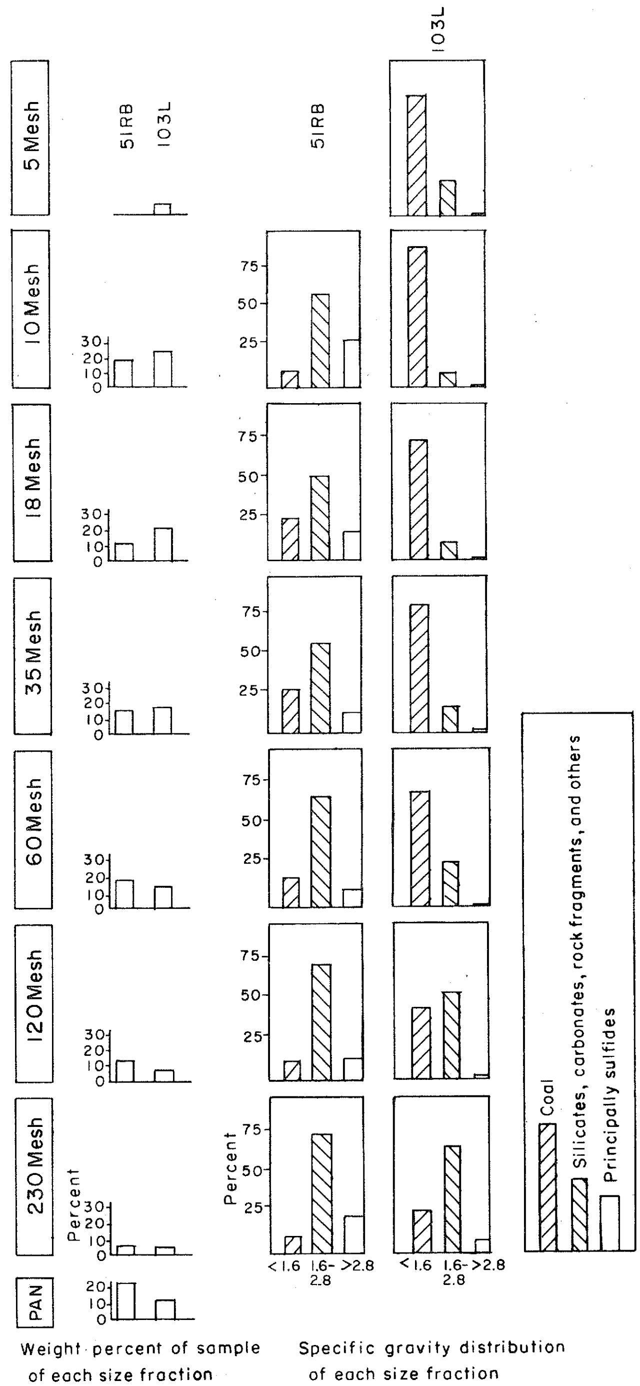

Figure 3. Particle-size and specific gravity distributions of two selected slurry samples.

EVALUATION OF THE SLURRY DEPOSIT

It is difficult to estimate the tonnage of material in the slurry deposit studied because of incomplete data on the thickness of the deposit. The area of the slurry deposit was previously surface mined, and the shape of the bottom surface is not known. It is possible that the bottom has ridges from the old spoil piles. We estimate that the refuse fan contains almost 2 million tons of material, which

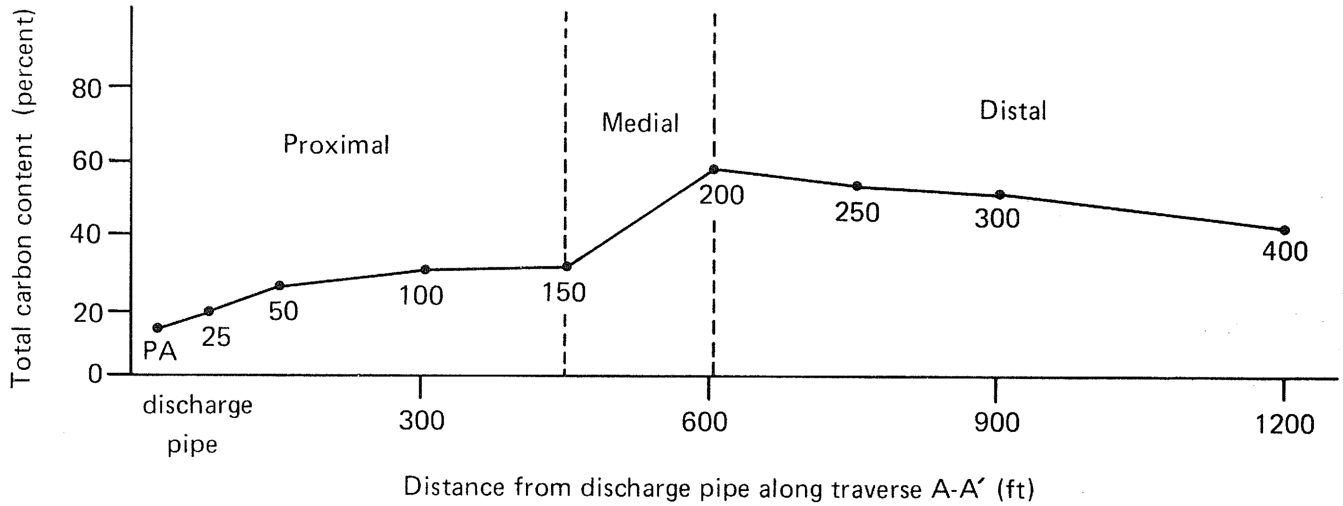

Figure 4. Trend in carbon content along traverse A-A′.

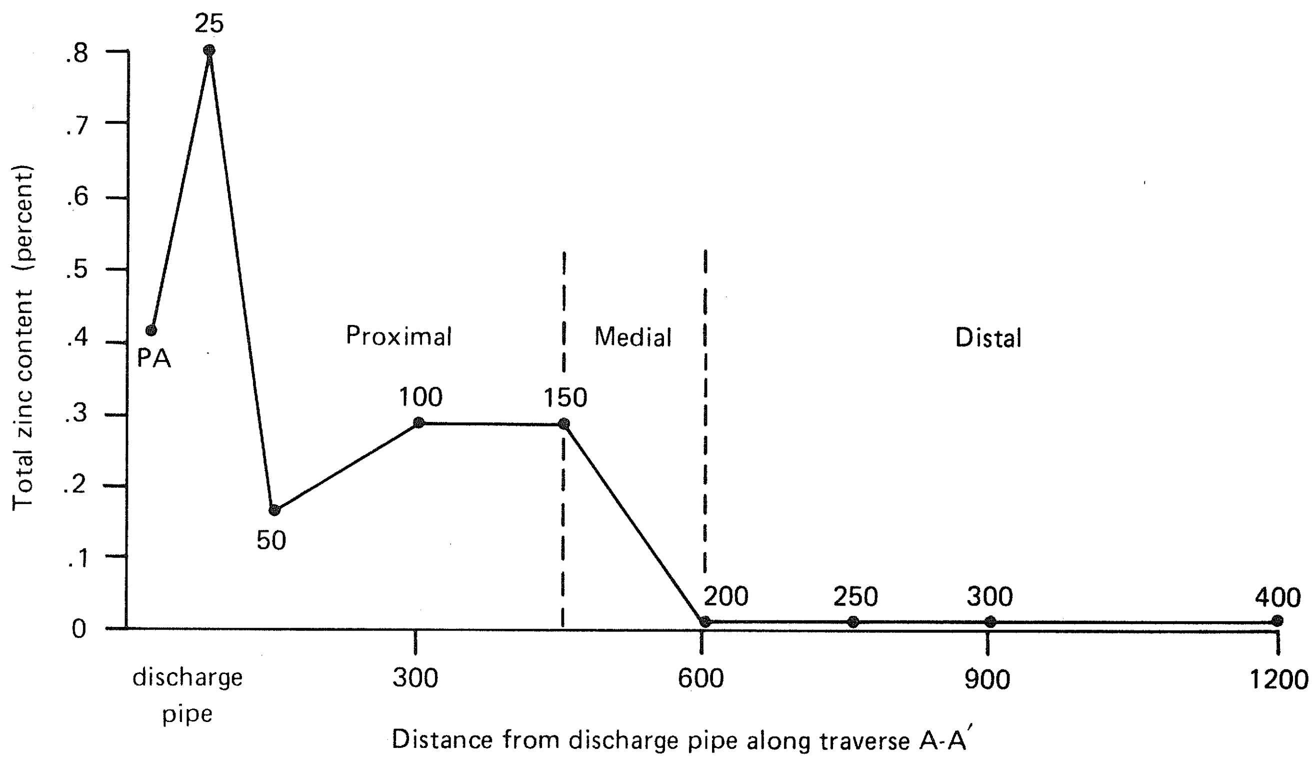

Figure 5. Trend in zinc content along traverse A-A′.

Table 4. Zinc, cadmium, and total carbon concentrations in auger hole samples[a]

Power auger hole 1				Hand auger hole 150				Hand auger hole 200			
Depth (ft)	Zinc (%)	Cadmium (%)	Carbon (%)	Depth (ft)	Zinc (%)	Cadmium (%)	Carbon (%)	Depth (ft)	Zinc (%)	Cadmium (%)	Carbon (%)
0 - 1.0	.15	.002	17								
1.0 - 2.5	.19	.003	19								
2.5 - 4.0	.25	.005	21								
4.0 - 5.0	.30	.005	20	0-5	.03	.001	51	0-5	.02	.001	59
5.0 - 7.5	.17	.003	26								
7.5 - 10.0	.18	.003	27	5-9	.11	.002	32	5-9	.04	.001	47
10.0 - 12.5	.05	.001	38								
12.5 - 15.0	.08	.001	39	9-13	.01	.0004	55	9-13	.01	.0004	64
15.0 - 17.5	.10	.002	12	13-17	.03	.0007	45	13-17	.04	.001	50
17.5 - 20.0	.20	.003	22								
20.0 - 22.5	.10	.002	38								
22.5 - 25.0	.17	.002	31	17-23	.12	.002	41				
25.0 - 26.5	.10	.003	35								
26.5 - 27.5	.09	.002	30								

[a]Locations shown in figure 1.

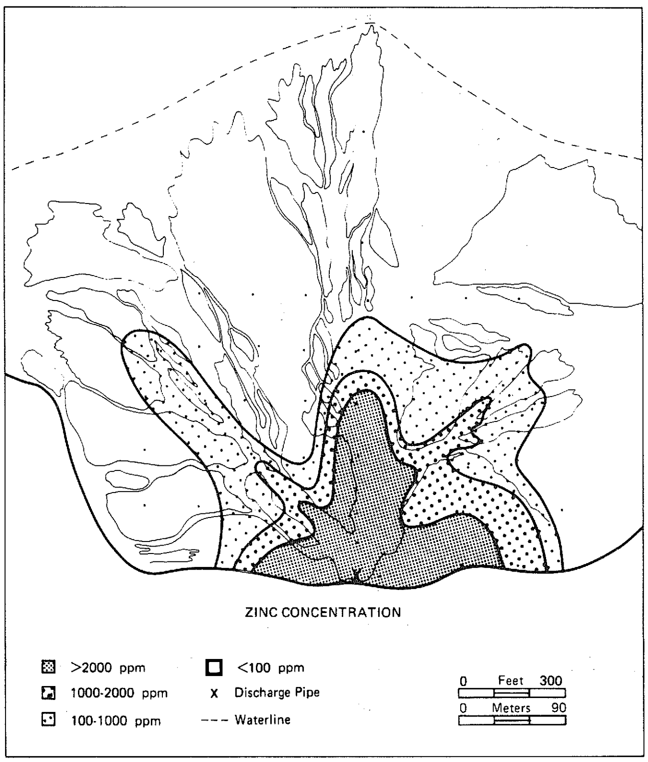

Figure 6. Zinc concentration in the slurry deposit.

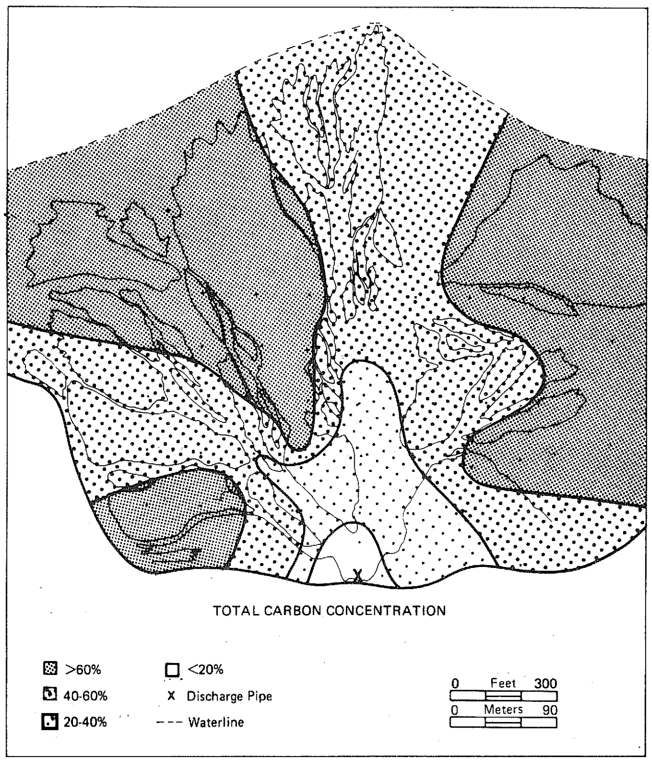

Figure 7. Carbon concentration in the slurry deposit.

assumes that the bottom of the deposit is level. Approximately 1 million tons of this material is estimated to be coal. Additional coal may be present in the settling pond. There are an estimated 1,100 tons of zinc in the slurry deposit. About 95 percent of the zinc is estimated to be deposited within a 450-foot radius of the discharge pipe. These tonnages suggest that under favorable economic conditions coal and zinc could be reclaimed from this slurry deposit.

A calculation based on the estimates of total tonnages of refuse and zinc in the fan gives an average zinc concentration of about 0.07 percent zinc. This value is similar to the zinc content in the raw coal, which suggests that a greater proportion of the zinc may be going from the preparation plant to the gob pile than to the slurry deposit. A materials balance was calculated to demonstrate the redistribution of zinc in the products of coal preparation and to provide an estimate of the average zinc concentration in gob. The concentrations of zinc in raw coal (0.06 percent) and washed coals (0.015 percent) are averages of several samples. The percentages of the products of coal preparation were obtained from records of the annual operation of the preparation plant. The materials balance may be expressed as follows:

$$\text{raw coal}\left[\frac{120\text{ lb zinc}}{100\text{ tons raw coal}}\right] \rightarrow \text{washed coal}\left[\frac{21\text{ lb zinc}}{69\text{ tons washed coal}}\right] + \text{slurry}\left[\frac{8\text{ lb zinc}}{6\text{ tons slurry refuse}}\right] + \text{gob}\left[\frac{91\text{ lb zinc}}{25\text{ tons gob refuse}}\right]$$

A comparison of the zinc concentration in gob derived by the materials balance (0.18 percent) compares favorably to an average of the results of five gob samples (0.16 percent) collected at the mine. It appears that most of the sphalerite is rejected with gob early in the preparation process while a significant portion is rejected with the slurry. Consideration should be given to the incorporation of sphalerite-concentrating circuits into the existing as well as new coal processing plants in this district.

RECOVERY OF SPHALERITE AND COAL

In the second phase of this study, an investigation was made to determine the feasibility of recovering both sphalerite and coal from the slurry deposit. The Humphreys spiral concentrator was used to produce first-stage concentrates of heavy minerals and coal. The spiral concentrator was selected for three reasons: (1) its demonstrated ability to recover fine coal from washer wastes (Browning, 1977), (2) its effective application in cleaning < 0.25-inch coal (Hubbard et al., 1950), and (3) its effectiveness in removing pyrite from coal when used in fine-coal desulfurization (Zellinger and Deurbrouck, 1976). Advantages of such an application of the spiral concentrator include its low initial cost, low operating cost, and the direct correlation between laboratory test results and full scale operation.

The theory of Humphreys spiral operation is described by Gleeson (1945). Basically the Humphreys spiral is a set of either five or six spiral-shaped troughs. The solids fed into the spiral circuit are pumped to the top of the spiral column where they are expelled as a slurry into the trough. Gravity, centrifugal force, and friction between the channel bottom and water create currents which tend to move dense particles to the center of the spiral, where they are removed by a series of splitting ports. Less dense particles tend to move to the outside of the trough and are collected at the bottom of the spiral.

Spiral feed was prepared following the procedure outlined in figure 8. The particle-size distributions of the refuse samples used are shown in the cumulative curves in figure 9. The effects of crushing, screening, grinding, and washing on these samples are shown in the particle-size distribution curves of figure 10. After preparation, 100 percent of each sample passed through an 18-mesh screen and less than 15 percent passed through a 200-mesh screen. A roll mill was used for crushing, which reduced particle size without producing an excess of fines. A primary reason for crushing the samples was to liberate coal from denser mineral matter and particularly to liberate sphalerite from other, less dense minerals. Sphalerite commonly occurs in the refuse in fragments of coal vein filling.

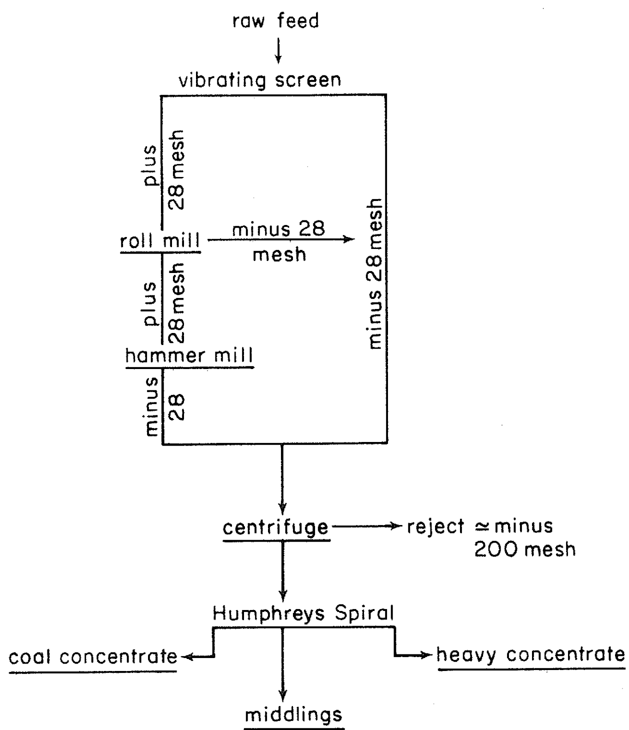

Figure 8. Flowsheet of raw slurry preparation and spiral concentration.

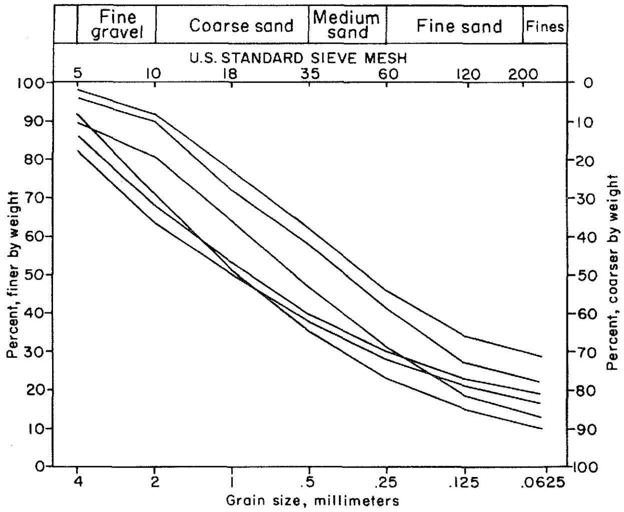

Figure 9. Particle-size distributions of raw slurry samples selected for spiral tests. Each line represents a separate slurry sample.

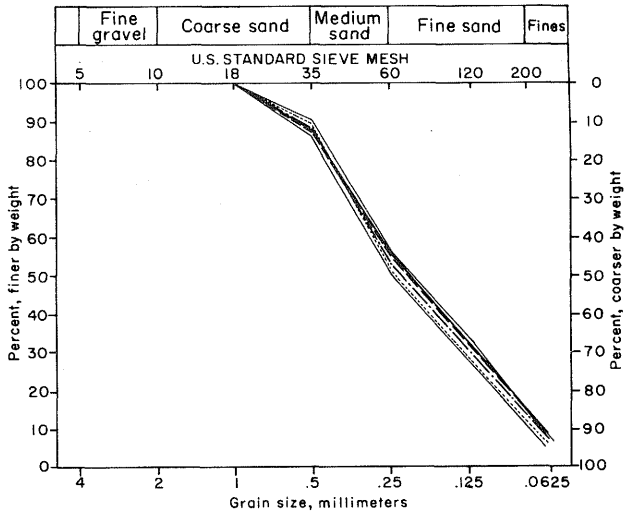

Figure 10. Particle-size distributions of spiral feed. Each line represents a separate spiral sample.

The spiral feed was cleaned of fines by pumping it through a centrifuge. Analyses of the rejected fines showed zinc concentrations to range from 0.01 percent to 0.12 percent, while the plus 230-mesh material for the same samples ranged from 0.05 percent to 0.45 percent.

The recoverability of zinc and coal on the Humphreys spiral was investigated in batch tests (Humphreys Engineering Co., 1952). The purpose of these tests was to simulate a first-stage concentration with the products intended to proceed to other unspecified secondary and tertiary stages. Tests were run on 12 to 16.5 lb. (5.5 to 7.5 kg) of prepared material. The feed was circulated in the Humphreys spiral until constant conditions were observed. The splitting ports were then adjusted to obtain maximum recovery of coal in the light concentrate and maximum recovery of heavy minerals in the heavy concentrate. Samples of the coal concentrate, middlings, and heavy concentrate were collected and analyzed. Float-sink tests were performed on the concentrates and the percentages of zinc, total carbon, ash, and total sulfur were determined for some of the samples. Results of selected float-sink tests are compared with data on the unprocessed samples in table 5.

Batch tests on the spiral concentrator show that the zinc content was increased by an average of 324 percent in the heavy concentrates, which ranged from a 150 to a 900 percent increase. The highest zinc value found in a heavy concentrate was 0.45 percent. Float-sink tests revealed that the heavy concentrates are predominantly 1.6 to 2.8 specific gravity material (74 to 84 percent), while the greater than 2.8 specific gravity fraction, which contains most of the zinc, is 14 to 22 percent. Other methods would be required to further separate the sphalerite from pyrite and other high specific gravity particles.

In these batch tests, the total carbon content was increased by an average of 72 percent in the coal concentrates. The coal concentrates contained 9 to 18 percent ash and 2.6 to 3.5 percent total sulfur. The maximum total sulfur reduction from the refuse fan material to the light concentrate was from 7.5 to 3.0 percent. Float-sink tests showed that coal concentrates contained between 85 and 97 percent coal (less than 1.6 specific gravity), with 3 to 17 percent mineral grains (rock fragments, silicates, carbonates, and others), and 1 percent or less sulfides.

These first-stage batch tests demonstrate the feasibility of producing both coal and zinc-rich concentrates using a spiral concentrator. Further concentration, using gravity or chemical techniques, could significantly improve the results.

CONCLUSIONS

1. Zinc in sphalerite-bearing coals of west-central Illinois is redistributed in preparation of plants from the raw coal into the products of coal preparation: coarse-sized refuse (gob), fine-sized refuse (slurry), and washed coal.

2. In a typical slurry deposit, particle size increases outward from the discharge pipe. This increase is due to large coal fragments which are carried longer distances in the discharge streams than are other particles such as rock fragments, silicate and carbonate grains, and sulfide grains.

3. The concentration of zinc within a 450-foot radius of the discharge pipe in the refuse fan studied is approximately 0.2 percent. The zinc content declined rapidly to less than 0.005 percent at a distances greater than 600 feet from the discharge pipe.

Table 5. A comparison of analyses of raw slurry and products from spiral tests.

	Raw slurry				Concentrate from batch spiral tests								
Sample	Zinc (%)	Total carbon (%)	Ash (%)	Total sulfur (%)	Spiral product	Wt%	Zinc (%)	Carbon (%)	Ash (%)	Sulfur (%)	Light[a] (%)	Middle[b] (%)	Heavy[c] (%)
Samples from within high zinc area (450-ft radius of discharge pipe)													
2R	.23	29	61	7.5	Light concentrate	21	.02	65	18	3.0	87	11	1
					Middlings	9							
					Heavy concentrate	70	.36				4	74	22
51R	.14	24	67	7.7	Light concentrate	13	.02	62	22	3.5	81	17	2
					Middlings	5							
					Heavy concentrate	82	.35					74	22
101R	.10	46	39	3.9	Light concentrate	35	.01	66	17	3.1	85	14	1
					Middlings	13							
					Heavy concentrate	52	.25				5	83	12
Samples from outside 450-ft radius													
53R	.003	59	26	3.2	Light concentrate	92	.003	69	9	2.6	97	3	0
					Middlings	5							
					Heavy concentrate	3	.07						
103L	.01	54	13	3.6	Light concentrate	69	.003	69	13	3.0	93	6	1
					Middlings	7							
					Heavy concentrate	24	.10				11	80	9
153L	.05	41	13	4.3	Light concentrate	41	.009	66	18	2.8	91	9	0
					Middlings	14							
					Heavy concentrate	45	.22				2	84	14

[a](< 1.6 specific gravity)
[b](1.6-2.8 specific gravity)
[c](> 2.8 specific gravity)

4. The total carbon concentration was lowest near the discharge pipe (less than 20 percent) but increased to over 60 percent 450 feet from the discharge pipe. A maximum total carbon concentration was found 600 feet from the discharge pipe.

5. Vertical fluctuations in the total carbon and zinc concentration of the refuse fan are interpreted as shifts in the major discharge channel.

6. The refuse fan was estimated to contain about 1 million tons of coal and 1100 tons of zinc. The concentration of zinc in the refuse fan was estimated to be about 0.07 percent; however, 95 percent of the zinc was concentrated within a 450- foot radius from the discharge pipe.

7. A materials balance or the redistribution of zinc from the raw coal to the wash coal, gob, and slurry indicates that about 3 times as much zinc is deposited in the gob as is deposited in the slurry deposit.

8. It appears that most of the sphalerite is rejected early in the preparation process while a significant portion of the sphalerite enters the slurry circuits. Consideration should be given to the incorporation of sphalerite-concentrating circuits into existing as well as new coal preparation plants in this district.

9. Batch tests on the Humphreys spiral concentrator produced an increase in the zinc content from the refuse fan material to the heavy concentrates by an average of 324 percent. The highest zinc value produced in a heavy concentrate was 0.45 percent.

10. The batch tests increased the total carbon content in the coal concentrates by an average of 72 percent. These

tests produced coal concentrates with up to 97 percent coal and only 3 percent discrete mineral particles. The coal concentrates contained between 2.6 and 3.5 percent total sulfur and 9 to 18 percent ash.

11. These batch tests demonstrate the feasibility of producing both coal and zinc-rich concentrates using a spiral concentrator. These tests were a first-stage concentration, and further separations by gravity or chemical techniques could significantly improve the results.

Acknowledgment

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REFERENCES

Browning, J. S., 1977, Recovering fine-size coal from Alabama surface mine washer wastes using the Humphreys spiral: Alabama Material Research Institute, Technical Report no. 2, 11 p.

Cobb, J. C., J. D. Steele, C. G. Treworgy, J. F. Ashby, and S. J. Russell, 1978, The geology of zinc in coals of the Illinois Basin: Illinois State Geological Survey, Final Report to the U. S. Geological Survey, Grant No. 14-08-001-6-249, 69 p.

Gleeson, G. W., 1945, Why the Humphreys spiral works: Engineering and Mining Journal, v. 146, no. 3, pp. 85-86.

Hatch, J. R., H. J. Gluskoter, and P. C. Lindahl, 1976, Sphalerite in coals from the Illinois Basin: Economic Geology, v. 71, no. 3, pp. 613-624.

Haynes, R. J., and W. D. Klimstra, 1975, Illinois lands surface mined for coal: Cooperative Wildlife Research Laboratory, Southern Illinois University, Carbondale, Illinois, 201 p.

Hubbard, Judson S., W. E. Brown, and M. Walker, 1950, The Humphreys spiral concentrator for cleaning minus ¼ inch coal: Proceedings, First International Coal Preparation Congress, Paris, France, paper E2, pp. 441-448.

Humphreys Engineering Co., 1952, The Humphreys spiral concentrator closed circuit test unit, manual of operating instructions, Bulletin No. 10A, 28 p.

Smith, W. H., and D. J. Berggren, 1963, Strippable coal reserves of Illinois, Part 5A–Fulton, Henry, Knox, Peoria, Stark, Tazewell, and parts of Bureau, Marshall, Mercer, and Warren Counties: Illinois State Geological Survey, Circular 348, 59 p.

Zellinger, J. E., and A. W. Deurbrouck, 1976, Physical desulfurization of fine-size coals on a spiral concentrator: U.S. Bureau of Mines, Report of Investigations No. 8152, 18 p.

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69. Industrial Minerals Publications of the Illinois State Geological Survey, through December 1978. 1979.
70. Illinois Mineral Industry in 1976 and Review of Preliminary Mineral Production Data for 1977. 1979.