The Abundance of Zinc and Cadmium in Sphalerite-bearing Coals in Illinois

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COVER PHOTO: Sphalerite gash veins in the Herrin (No. 6) Coal of Knox County, Illinois. The actual distance across the field is one-half inch (13 mm). For details see figure 5e, page 6.

Cobb, James C
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Contents

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ABSTRACT

Coals in four Illinois Counties (Fulton, Knox, Peoria, and Stark) are enriched in zinc and cadmium. These coals are the Danville (No. 7), Herrin (No. 6), Springfield (No. 5), and Colchester (No. 2) Coal Members. The zinc and cadmium enrichment is attributed to the presence of sphalerite, the principal ore mineral of zinc. The sphalerite is an epigenetic mineral occurring mainly as an open-space filling in fractures in the coals. This 4-county area contains approximately 7 x 10^9 tons (6.3 x 10^9 metric tons) of coal resources. The sphalerite, which is distributed in the coals, is a potential source for zinc and, to a lesser extent, cadmium as a by-product of the coal production.

Sphalerite was identified in the coal in fractures, cleats, tension gashes, shears, pyrite nodules, cell lumens of fusinite, and crystal aggregates in clastic dikes. Sphalerite was also observed in phosphate nodules in the black shales overlying some of the coals.

Five methods of sampling were used to determine zinc and cadmium concentrations in the coals. The sampling methods were bench, column, composite auger, composite face channel, and composite face grid. Large variability in the data from the five methods precluded their being distinguished from one another by the Student's t test. On the basis of minimum variance, the composite face grid sample was selected as the most appropriate method for sampling these coal seams for zinc and cadmium.

A strong positive correlation exists between high concentrations of zinc and cadmium and the degree of local structural disturbance of the coal. Disturbances in the seams include clastic dikes, faults, shears, and fractures, all of which may contain sphalerite.

Estimates of the potential tonnage of zinc in the coals of this area range from 3 to 14 million tons and for cadmium 30 to 100 thousand tons.

INTRODUCTION

The zinc industry is the world's fourth largest metal-producing industry after steel, aluminum, and copper, respectively (Bush, 1979). The principal by-product of the zinc industry is cadmium, which is also an essential industrial metal. The exponential rise in zinc consumption during the past several decades and fewer new ore discoveries have encouraged scientific interest in "unconventional" sources of zinc. Sphalerite-bearing coals represent an unconventional source of both zinc and cadmium.

Some coals in eastern and western regions of the Interior Province are enriched in zinc and cadmium. The zinc and cadmium enrichment of these coals is restricted to certain areas of Illinois, Iowa, Kansas, and Missouri, and to a lesser extent in Oklahoma and Nebraska (Cobb et al., 1979; and Hatch, 1979). This report describes the occurrences and distribution of sphalerite in coals of an area of west-central Illinois. An estimate of the potential of the zinc and cadmium as a by-product of coal production is presented.

The five types of sampling methods used in this study were auger, bench, column, composite face channel, and composite face grid. A comparison of the results obtained from these methods was made. Statistical methods were used to assess the abundance of zinc and cadmium in the coal of the study area.

Other reports dealing with trace elements and mineral matter in coal have provided essential background data for the present study. Zubovic (1960) was one of the first to report sphalerite in the Herrin (No. 6) Coal of Illinois. The earliest report of sphalerite in clastic dikes of the Springfield (No. 5) Coal was by Roe (1934). Gluskoter, Hatch, and Lindahl (1973) identified sphalerite in coals of Illinois and classified northwestern, northeastern, and southeastern areas of the Illinois Basin Coal Field as unusually enriched in zinc and cadmium. They found that cadmium occurs in solid solution with zinc in the sphalerite from coal. Ruch, Gluskoter, and Shimp (1974) demonstrated that cadmium is enriched by a factor of 14.4 in coals of Illinois over the crustal abundance (Taylor, 1964). Ruch, Gluskoter, and Shimp (1974) also determined that a high positive correlation exists for zinc and cadmium ($r = 0.93$). They also determined that the zinc and cadmium were in solid solution in sphalerite and that sphalerite is not uniformly distributed within the Illinois Basin Coal Field but is concentrated in northwestern and southeastern Illinois.

Hatch, Gluskoter, and Lindahl (1976) mapped the regional distribution of zinc and cadmium in the Illinois Basin Coal Field. They discussed some of the field relationships of sphalerite in coal and showed a paragenesis for the mineralization. They also speculated that recoverable quantities of sphalerite may be present in existing coal refuse piles.

Hatch et al. (1976) reported high concentrations of zinc and cadmium in samples of coal from Kansas, Iowa, and Missouri. Wedge, Bhatia, and Rueff (1976) reported analyses of sphalerite-bearing coals in Missouri.

Cobb et al. (1979) investigated the sphalerite in a slurry refuse deposit at a mine in the study area. About one thousand tons of zinc were estimated to be present in the slurry deposit; 95 percent of the zinc was believed to be concentrated within a 450-foot radius of the point of discharge into the deposit. The maximum concentration of zinc determined from samples of slurry waste in the study area was 2.36 percent.

GEOLOGY OF STUDY AREA

The study area, consisting of Fulton, Knox, Peoria, and Stark Counties, is in the northwestern part of the Illinois Basin Coal Field (fig. 1). This area was selected for study because of the previously demonstrated high zinc and cadmium concentrations in the coals (Ruch, Gluskoter, and Shimp, 1974; Hatch, Gluskoter, and Lindahl, 1976; and Gluskoter et al., 1977) and because of the numerous and accessible exposures of the coal. Seven mines operating 17 pits were active during the investigation. These mines produced coal from the Colchester (No. 2), Springfield (No. 5), and Herrin (No. 6) Coal Members of the Carbondale Formations. The Danville (No. 7) Coal Member, though exposed in highwalls, was not being produced and was not included in the sampling program.

The study area lies in a stable tectonic region known as the Western Shelf. The strata dip gently southeast toward the center of the basin at less than 20 feet per mile (3.6 m per km). Minor structural disturbances of the coal such as fractures, faults, and warping of the strata are common.

Although the region has been mostly stable tectonically, Damberger (1970 and 1973) has described disturbance features in the coal seams that may have been generated by seismic activity. These features have been referred to as the "white top" disturbance and clastic dikes.

Pennsylvanian strata, overlain by Pleistocene glacial deposits, range in thickness from 0 to 600 feet (0 to 180 m) and cover nearly all of the study area. The Pennsylvanian strata are made up largely of sandstones and shales, but thin limestones and coals are scattered throughout (fig. 2). The total thickness of sedimentary strata overlying the Precambrian basement ranges from 3,600 to 5,100 feet (1,100 to 1,600 m). Figure 3 is a general stratigraphic section showing the principal lithologies from the Precambrian to the Quaternary.

SPHALERITE IN COAL

Sphalerite is principally found as a deposit filling a previously open space in the coal. It is also a replacement after pyrite. Types of structures in coal that contain sphalerite include cleats, vertical fractures, gash veins, shear fractures, pyrite concretions, fusinite cell lumens, and clastic dikes. Vertical fractures appear to be the main sphalerite-bearing structures.

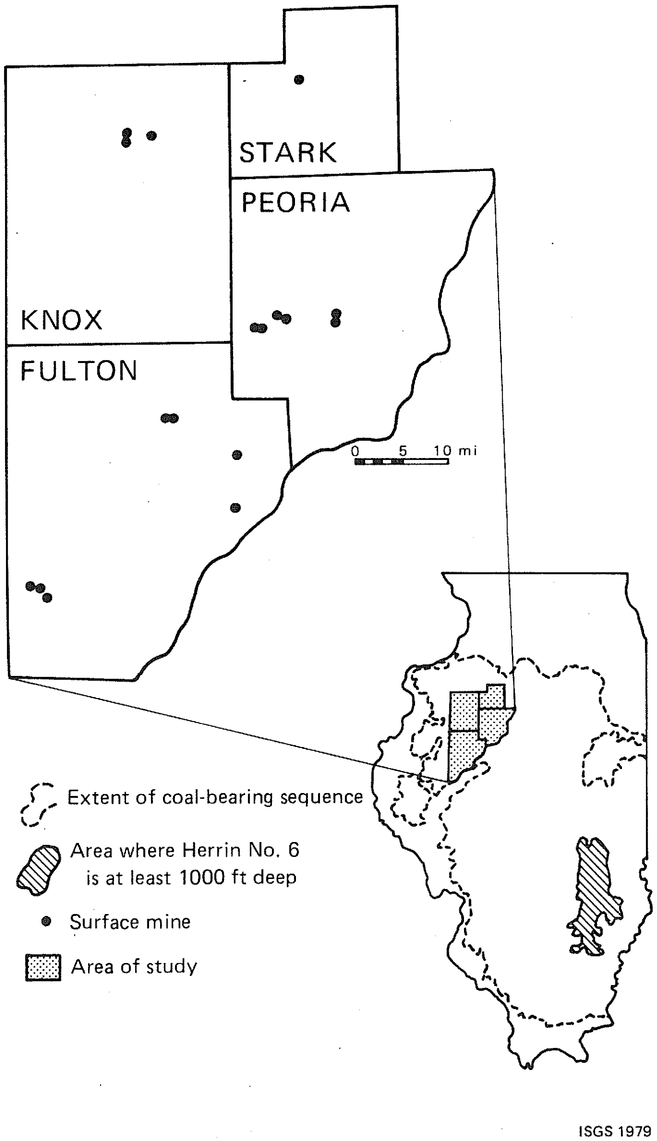


Figure 1. The Illinois Basin Coal Field and location of the study area.

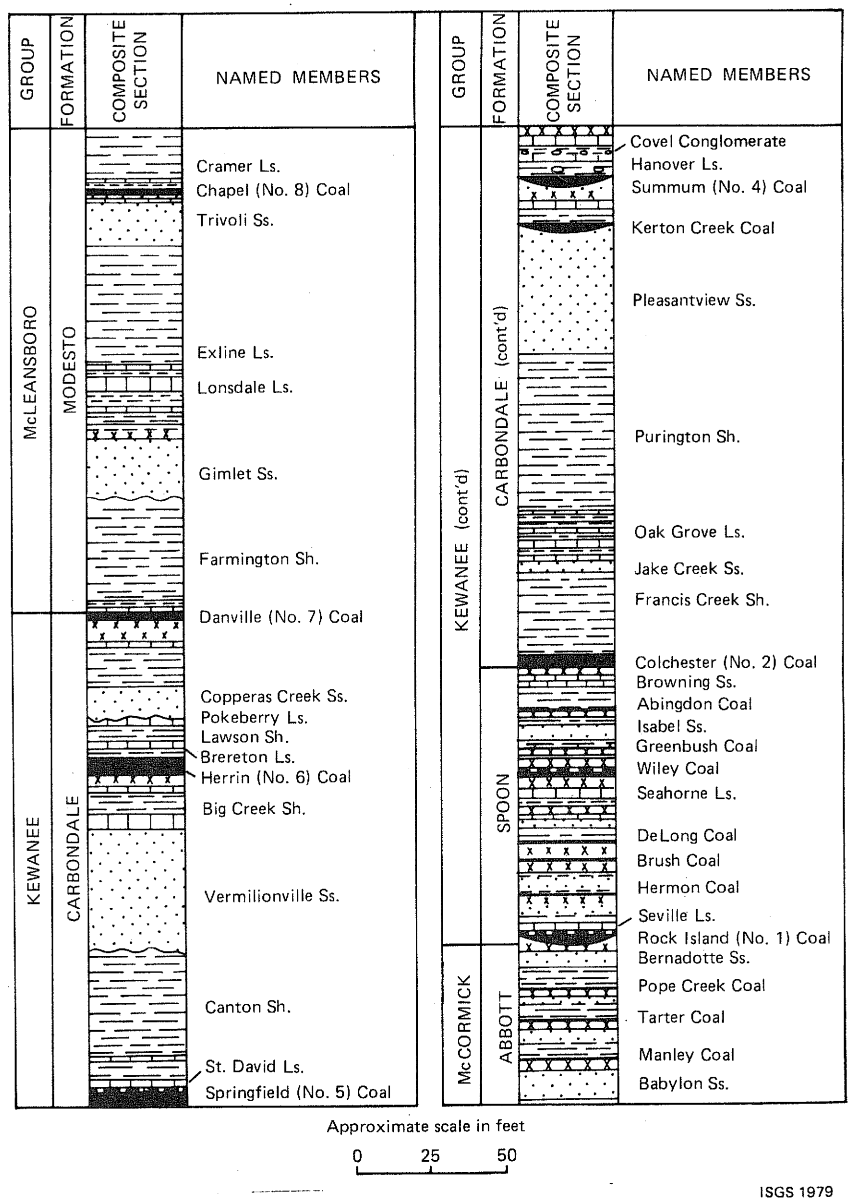


Figure 2. Composite section of Pennsylvanian strata in western Illinois (from Smith and Berggren, 1963).

The coal cleat contains sphalerite as thin veins with smooth, straight walls. The veins rarely exceed .125 inch (3.2 mm) in width (fig. 4a and b). Sphalerite in cleats commonly is associated with kaolinite, pyrite, and calcite. The filling within cleats separates easily from the coal into thin plates of the minerals.

The vertical fractures may occur en echelon (fig. 4c) or may cut across large portions of the seam (fig. 4d). They are usually perpendicular to the coal bedding and extend from a few inches to several feet in all directions. They are usually from .125 to .75 inch (3 to 19 mm) in width, although a few may be up to 1 inch (25 mm) in width (fig. 4d).

In plan view these veins may be straight or curved (fig. 5a), are usually rough, and may split into veinlets that die out. The vertical fracture patterns include fanning and feathering (fig. 5b). Coal seam contacts, partings in the seam (including pyrite and shale layers), and coal banding control the continuity and structure of the veins. Veins do not always show preferred orientation, although locally they can strike parallel to each other (fig. 5c).

SYSTEM	DOMINANT LITHOLOGY	THICKNESS (ft)
Quaternary	Glacial drift	0-200
Pennsylvanian	Sandstone, siltstone, shale, limestone, and coal	0-600
Mississippian	Limestone	0-500
Devonian	Dolomite, limestone, shale	0-275
Silurian	Dolomite	0-400
Ordovician	Dolomite and limestone	1150-1500
Cambrian	Sandstone	200-2700
Precambrian	Granite	

ISGS 1979

Figure 3. Generalized stratigraphic section of the study area.

Another occurrence of sphalerite in coal is in gash veins, which are mineralized tension fractures (fig. 5d and e). Gash veins are wedge shaped in vertical profile and are commonly in association with shears–openings from the termination of shear fractures. Gash veins may be en echelon and have pinnate fractures diagonally between them (fig. 5e). The shear fractures are often mineralized and clay filled. Sphalerite crystals often occur within the clay fillings (fig. 5e).

Hatch, Gluskoter, and Lindahl (1976) first described the sphalerite veins in coals of this area. They suggested a paragenesis for the veins that was divided into three stages: a sulfide stage with pyrite and sphalerite; a silicate stage with quartz and kaolinite; and a carbonate stage with calcite. Five steps in the deposition of sphalerite were defined on the basis of color.

Cobb and Russell (1976) described sphalerite veins and sphalerite from clastic dikes in coal. They identified sphalerite growth bands and analyzed these bands for their iron and cadmium content by using the electron microprobe.

Cobb and Krausse (1979) described sphalerite gash veins in coal and included details of the mineral deposition. The contemporaneity of some structures in coal was determined by a comparison and correlation of their mineral fillings.

A sphalerite vein from the Colchester (No. 2) Coal shows relationships between pyrite, sphalerite, and calcite (fig. 6a). The pyrite occupies a small part in the center of the vein. Its edges are corroded, and it has been partially replaced by sphalerite. Multibanded sphalerite occupies most of the vein. These bands are vertical, parallel to the vein walls, and are defined by their color. Calcite occupies some of the veinlets that branch from the vein.

Common sphalerite color bands include one which is purple and composed of abundant, closely spaced purple lamellae and another which is pale yellow (fig. 6b and 6c). Results of opening a vertical fracture are evident in figure 6c. Splittting, fanning, and spreading apart of the coal is seen. A sharp contact between the band with purple lamellae and the yellow band is seen in the center of the vein. Sphalerite in a gash vein is shown in figure 6d. In this gash vein the yellow sphalerite band has a sharp, erosional contact on both sides with the band containing purple lamellae and, in the lower portion, the yellow band replaces the band with purple lamellae.

Clastic dikes containing sphalerite were observed in the Colchester (No. 2), Springfield (No. 5), Herrin (No. 6), and Danville (No. 7) Coals (fig. 7a). The matrix material filling clastic dikes is generally clay-rich, sandy silt that contains abundant coal fragments (fig. 7b). Damberger (1970 and 1973) has described clastic dikes in the coals in the study area and discussed their origin. The sphalerite is found in coarsely crystalline aggregates (fig. 7c) and single crystals.

Sphalerite from clastic dikes is multibanded (fig. 7d). The growth bands can be seen in successive layers that are

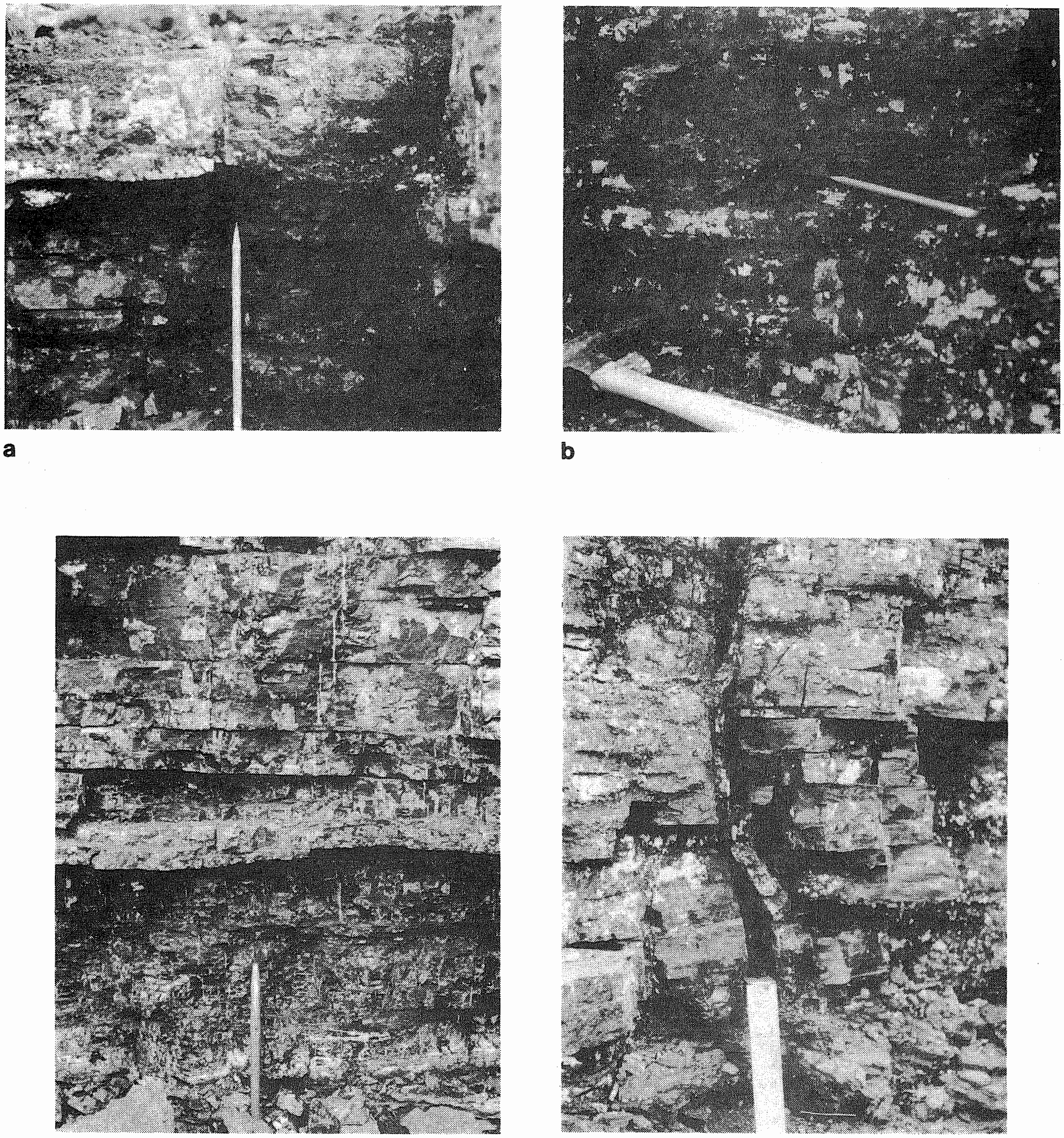


Figure 4. Sphalerite veins in coals. (a) Sphalerite filling a cleat in the Colchester (No. 2) Coal; (b) Sphalerite filling a cleat in the Herrin (No. 6) Coal; (c) Sphalerite veins en echelon in the Springfield (No. 5) Coal; (d) Sphalerite vein in the Danville (No. 7) Coal.

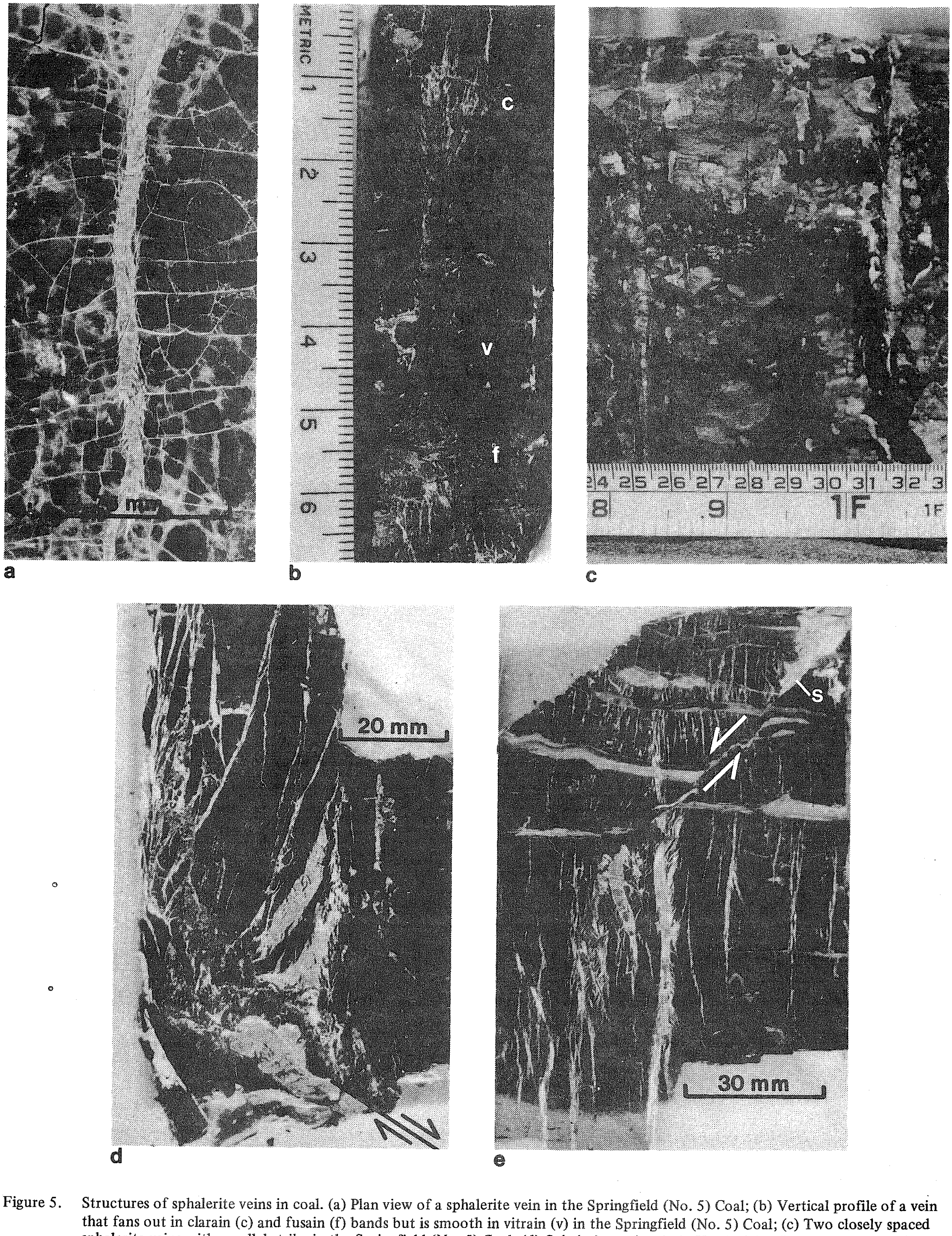


Figure 5. Structures of sphalerite veins in coal. (a) Plan view of a sphalerite vein in the Springfield (No. 5) Coal; (b) Vertical profile of a vein that fans out in clarain (c) and fusain (f) bands but is smooth in vitrain (v) in the Springfield (No. 5) Coal; (c) Two closely spaced sphalerite veins with parallel strike in the Springfield (No. 5) Coal; (d) Sphalerite gash vein in Herrin (No. 6) Coal; (e) Sphalerite gash veins and sphalerite crystals (s) in clay matrix of a shear fracture in the Herrin (No. 6) Coal.

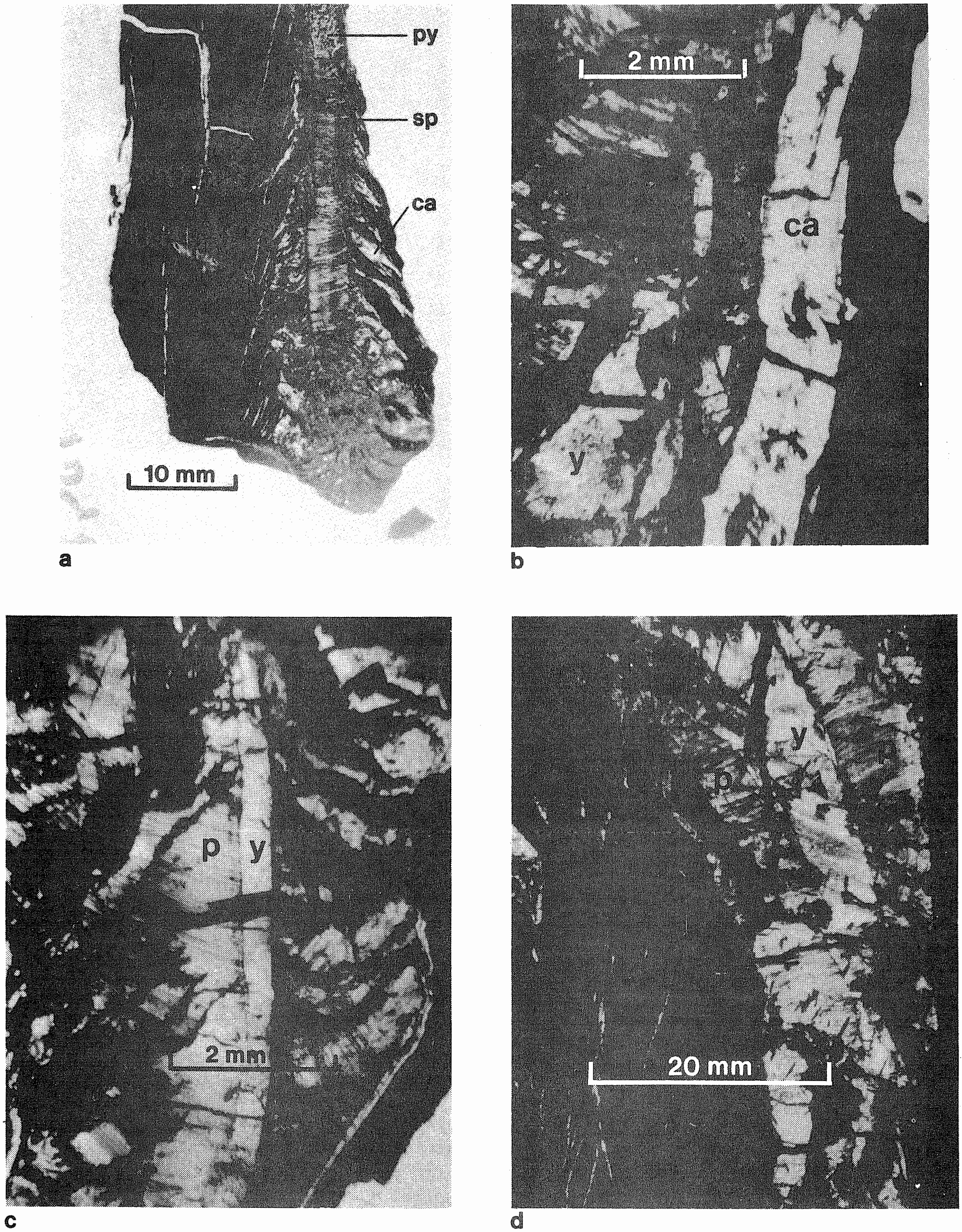


Figure 6. Sphalerite vein fillings. (a) Partial paragenesis (pyrite-sphalerite-calcite) in a vein in the Colchester (No. 2) Coal; (b) Sphalerite color banding of yellow (y) and purple (p) and calcite (ca) in the Herrin (No. 6) Coal; (c) Sphalerite color bands yellow (y) and purple (p) in the Springfield (No. 5) Coal; and (d) Sphalerite color bands yellow (y) and purple (p) in a gash vein in the Herrin (No. 6) Coal.

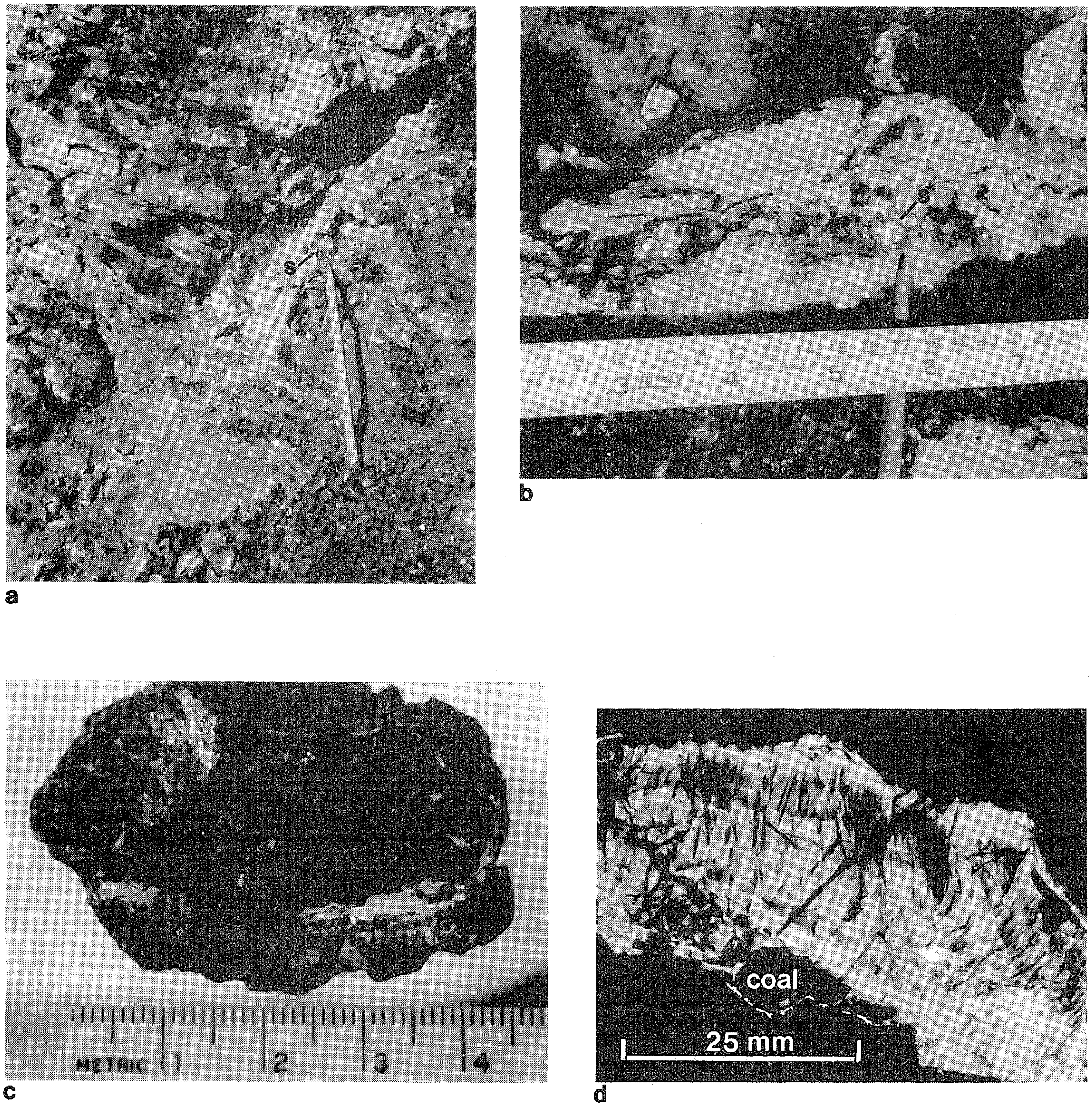


Figure 7. Sphalerite in clastic dikes. (a) Clastic dike in Colchester (No. 2) Coal and sphalerite crystals (s); (b) Plan view of clastic dike at top of Herrin (No. 6) Coal and sphalerite crystal (s); (c) Sphalerite crystal aggregate from clastic dike in Herrin (No. 6) Coal; (d) Photomicrograph of sphalerite crystal from clastic dike showing color banding.

distinguished by color and texture. In many of the aggregates the sphalerite encloses coal particles and the growth bands are concentric around the coal-sphalerite boundary. Nucleation probably commenced at the coal contact and growth of the crystal proceeded outward in successive bands. The nucleation and growth of large, banded crystals suggests that the sphalerite was precipitated under generally static conditions from solutions of very low supersaturation.

Other occurrences of sphalerite are in pyrite nodules as a replacement after pyrite (fig. 8a), a filling in cell lumens in fusinite (fig. 8b), in phosphate nodules in black shales overlying the coal seams (fig. 8c), and in fault surfaces (fig. 8d).

Sphalerite from coal contains fluid-filled inclusions (fig. 9a and b). Roedder (1979) first determined homogenization and freezing temperatures for sphalerite fluid inclusions from the Illinois Herrin (No. 6) Coal. Homogenization temperatures ranged from 90° to 102°C for sphalerite taken from vertical veins and 82° to 96°C for sphalerite from clastic dikes. The freezing temperatures determined by Roedder (1979) indicate a 21 percent equivalent NaCl solution for the inclusion fluids suggesting that the sphalerite was deposited from a brine.

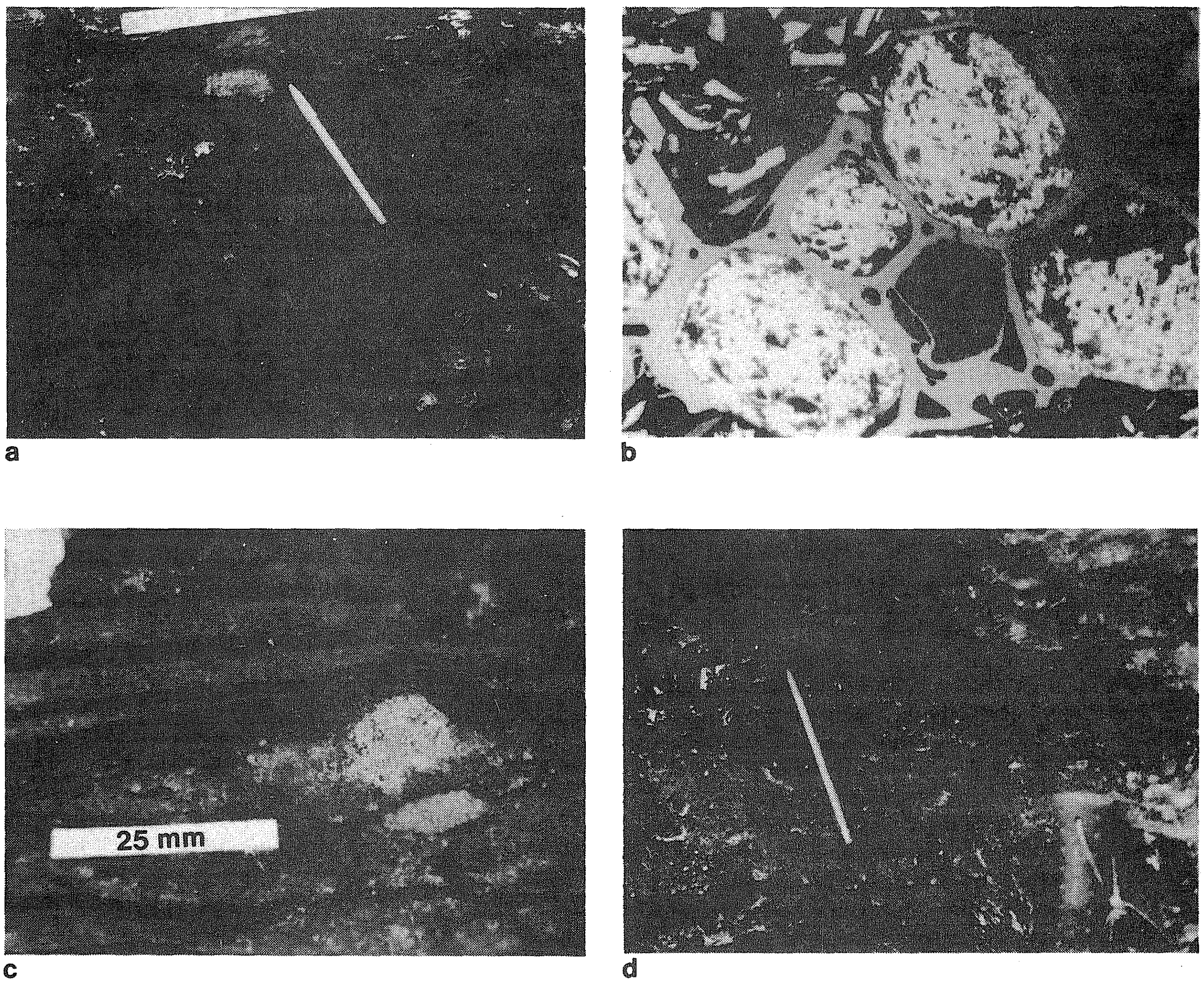
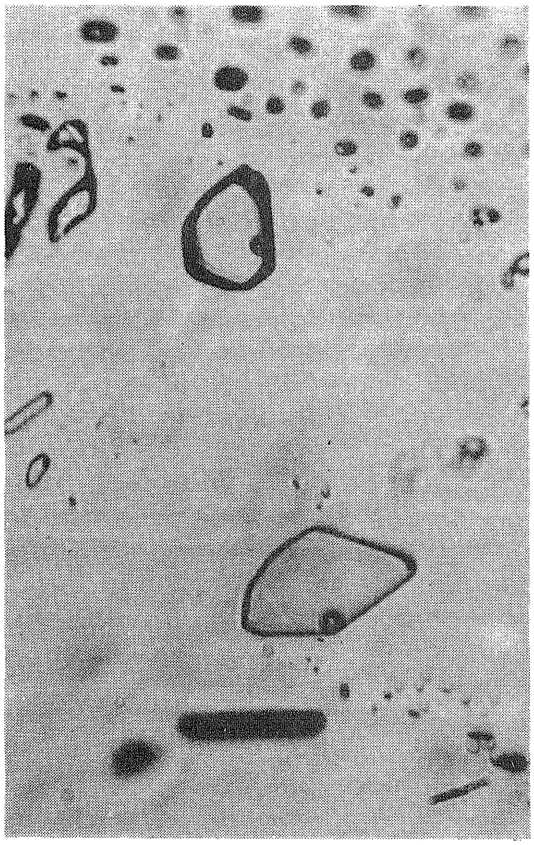


Figure 8. Other occurrences of sphalerite. (a) Sphalerite with pyrite nodule in Colchester (No. 2) Coal; (b) Sphalerite filling cell lumens in fusinite in Herrin (No. 6) Coal, long dimension of the cell lumen in the lower left is 0.01 mm; (c) Sphalerite in phosphate nodule in black shale above Springfield (No. 5) Coal; (d) Sphalerite on fault surface in Herrin (No. 6) Coal.



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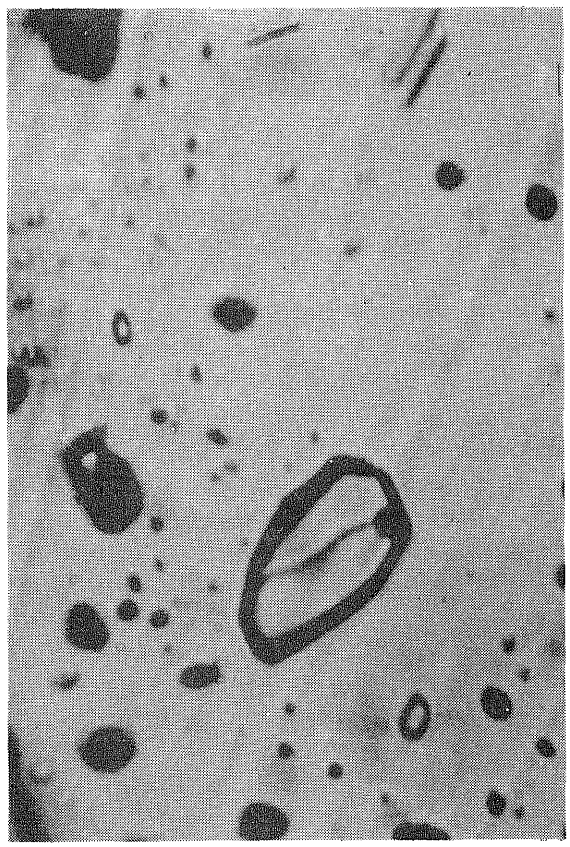

b

Figure 9. Fluid-filled inclusions in sphalerite from coal. (a) Two-phase fluid inclusion in sphalerite from the Colchester (No. 2) Coal, long dimension of large inclusion is 112 μm; (b) Two-phase fluid inclusion in sphalerite from the Herrin (No. 6) Coal, long dimension of large inclusion is 122 μm.

COLLECTION, PREPARATION, AND ANALYSIS OF COAL FOR ZINC AND CADMIUM CONTENT

Sample collection

The method of sampling has an important bearing on information derived from samples. Selection of an appropriate method of sampling depends on the distribution of the component of interest within the host. The coal seams in this study are considered to be the host for the sphalerite, which contains the zinc and cadmium of interest. Because of its nature as an open-space filling, sphalerite in coal is distributed in a somewhat erratic pattern.

Methods of sampling coal such as bench, channel, and composite face channel are useful for establishing its bulk composition according to standard methods of coal analysis (ASTM, 1977). These sampling methods are also useful for mapping variations in some major constituents of coal such as carbon, sulfur, moisture, ash, and volatile matter (Schopf, 1960). To assess the abundance of other constituents, however, such as zinc and cadmium, a method must be chosen that provides representative weighting to both disturbed and undisturbed parts of the coal seam. Some coal sampling explicitly avoids areas where the coal is unusually disturbed or where the coal contains a high percentage of mineral matter, as in clastic dikes.

We compared standard coal sampling methods in order to evaluate their appropriateness, then used these methods to estimate the zinc and cadmium content of the coal. The methods are described as follows.

Bench. A sample from the coal face is taken in vertical segments determined by natural breaks in the coal bedding, such as partings or pyrite layers. The benches vary in height from 6 to 10 in. (152 to 254 mm) and are about 6 in. (152 mm) in width.

Column. A sample of the entire coal seam is obtained by cutting a channel approximately 6 inch (152 mm) wide down the coal face. All material cut from the seam is included in the sample; no mineral partings are excluded.

Composite face channel. A sample of the coal seam is taken that exludes mineral partings or nodules more than 3/8 inch (9.5 mm) in thickness. Channels are cut at three places on the coal seam and the material is combined into a composite sample. This follows a procedure used by the Illinois State Geological Survey and is based on a technique described by Holmes (1918).

Composite face-grid. A sample of the coal face is taken by measuring a 20-foot wide (6.1 m) length of the coal face and placing a grid with intersections at foot intervals on the coal face. A hand-size chunk of the face is removed from each grid intersection. All material thus removed is combined into a single composite sample.

Composite auger sample. A composite sample of all cuttings was collected from each auger hole in a series of ten holes, each 8 inches (203 mm) in diameter and spaced 1.5 feet (457 mm) apart. In some cases analyses were made of the cuttings from each hole for purposes of comparison of the variability between the holes.

Discussion. The composite face-grid method was used because it could cover a larger proportion of the coal seam than other methods and have a greater likelihood that both disturbed and undisturbed conditions of the seam would be weighted in sampling.

The auger method has little bias in site selection because the coal face is not observed before selection of the drilling site. Auger holes were drilled at even intervals along a line and as a result unbiased weighting was given to both disturbed and undisturbed conditions of the coal seam.

Observations made during sampling show that of the 55 samples collected during this study, 17 samples were collected from disturbed areas in the seam, 11 from undisturbed sites, and 19 from areas large enough to include a mixture of undisturbed and disturbed coal. The coal seam condition for 8 other samples was not recorded.

Procedures for the preparation and chemical analysis of the samples are given in appendix A. The locations of samples, the names of mine and coal companies, the identification of the coal seam mined, the sampling methods, and the sample numbers are listed in appendix B. The data are most complete for the Herrin (No. 6) and Springfield (No. 5) Coals; limited exposures prevented more comprehensive sampling of the Colchester (No. 2) Coal. From the standpoint of the different sampling methods, the data are most numerous for the bench, column, composition face channel, and composite face grid, and least numerous for the composite auger samples.

Distribution of zinc and cadmium in coal

The highly variable distribution of zinc and cadmium in coal was demonstrated by a series of auger samples spaced 50 feet (15 m) apart in the Herrin (No. 6) Coal. The results show variations in zinc and cadmium laterally in the seam (fig. 10). The highest zinc and cadmium concentrations were from auger holes that were closest to the disturbed coal, in this case clastic dikes. The lowest values occurred within the relatively undisturbed parts of the seam.

Similar variations in the zinc and cadmium concentrations were found in the Springfield (No. 5) Coal (fig. 11). The auger holes in the Springfield Coal were 1.5 feet (.5 m) apart and encountered only one clastic dike. The highest zinc and cadmium values were clustered in the vicinity of the clastic dike.

A series of auger samples was collected from a part of the Herrin (No. 6) Coal that was uniform in thickness and had no apparent disturbances (fig. 12). The zinc and cadmium values were consistently low.

The difficulty of representative sampling of coal for its zinc and cadmium content is shown by a sequence of coordinated composite face-grid and bench samples. Three sites were selected at random along a .5 mile (0.8 km) exposure. Twenty-foot lengths (6.1 m) of the seam were measured for the composite face-grid samples at sites spaced at least 300 feet (90 m) apart. Bench samples were taken within the measured areas of composite face-grid sample. Figure 13 shows the results of this coordinated sampling.

The results from the composite face-grid samples have a narrow range from 762 to 1,048 μg/g zinc. This narrow range results from the large area covered by the sample, which eliminates localized extreme high and low values. The results obtained from the bench samples have a large range from 6 to 14,940 μg/g zinc. The large variability between the bench samples emphasizes this danger—for samples with limited coverage of the seam, undue weight might be placed on samples from either mineralized or nonmineralized portions of the seam. A comparison of the bench set results with the corresponding composite face-grid results illustrates the necessity of sampling large areas of the coal seams (fig. 13).

Figures 14a and b are the arithmetic frequency distributions for the sample results. The distribution of undisturbed, disturbed, and mixed seam conditions is also shown. The results of samples collected from undisturbed coal are clustered near the origin; those from disturbed coal range outward to the highest values. Results from samples from a mixture of disturbed and undisturbed seam conditions are predominantly within the intermediate portion of the graph.

Ahrens (1954a and b) suggested that the lognormal distribution is one of the most common distributions in natural populations of trace elements in many rock types. The arithmetic frequency distributions for zinc and cadmium (figs. 14a and b) exhibit positive skewness. This skewness is indicative of a lognormal frequency distribution. Because of the lognormal distribution in the data for zinc and cadmium concentrations, several methods of statistical analysis will be used in this paper.

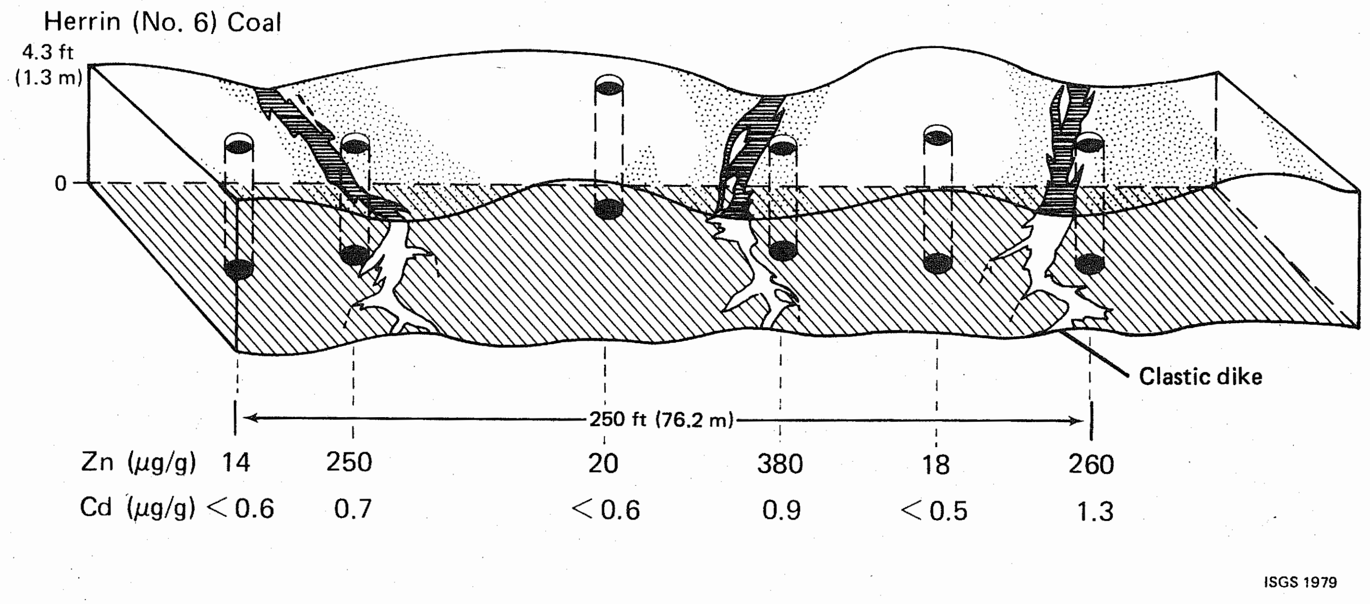

Figure 10. Results of auger sampling in disturbed and undisturbed coal of the Herrin (No. 6) Coal.

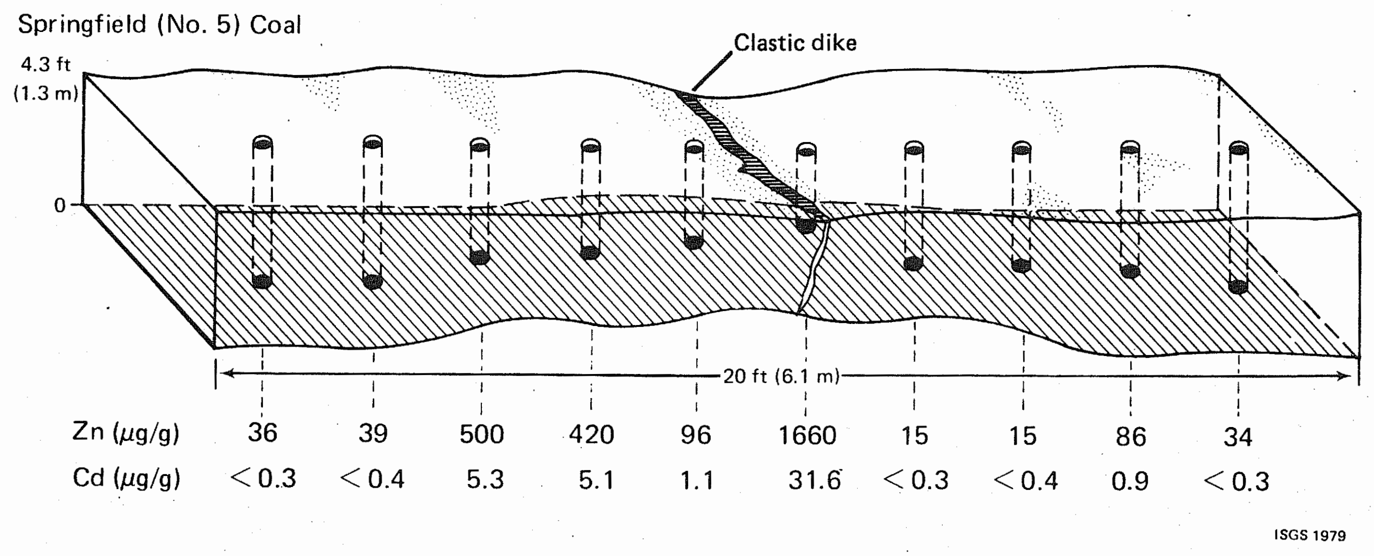

Figure 11. Results of auger sampling in disturbed and undisturbed coal of the Springfield (No. 5) Coal.

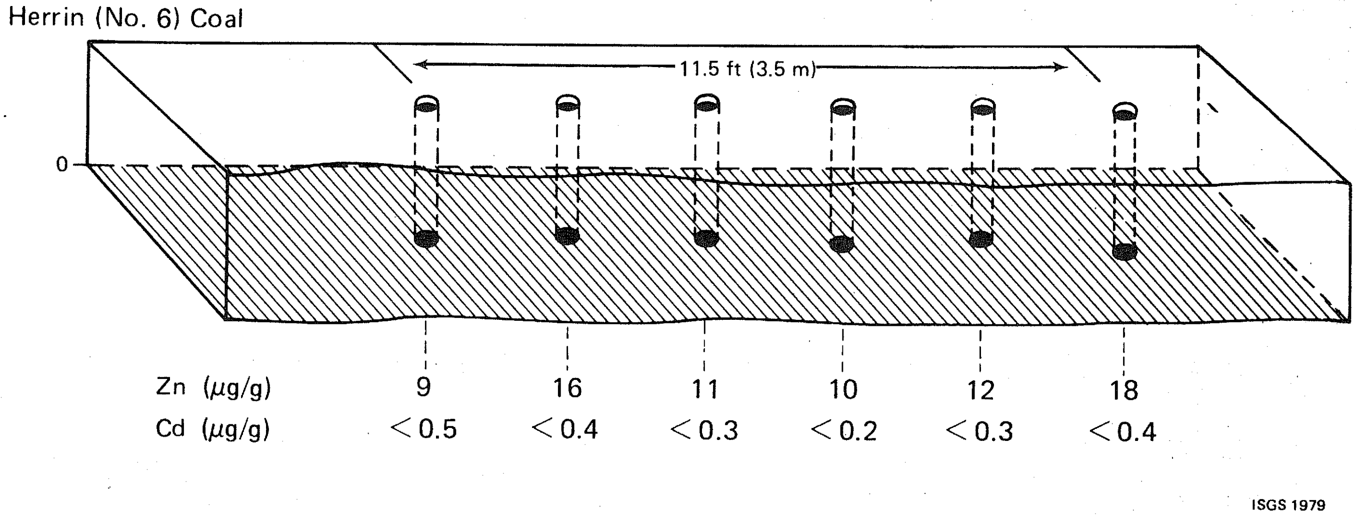

Figure 12. Results of auger sampling in an undisturbed part of the Herrin (No. 6) Coal.

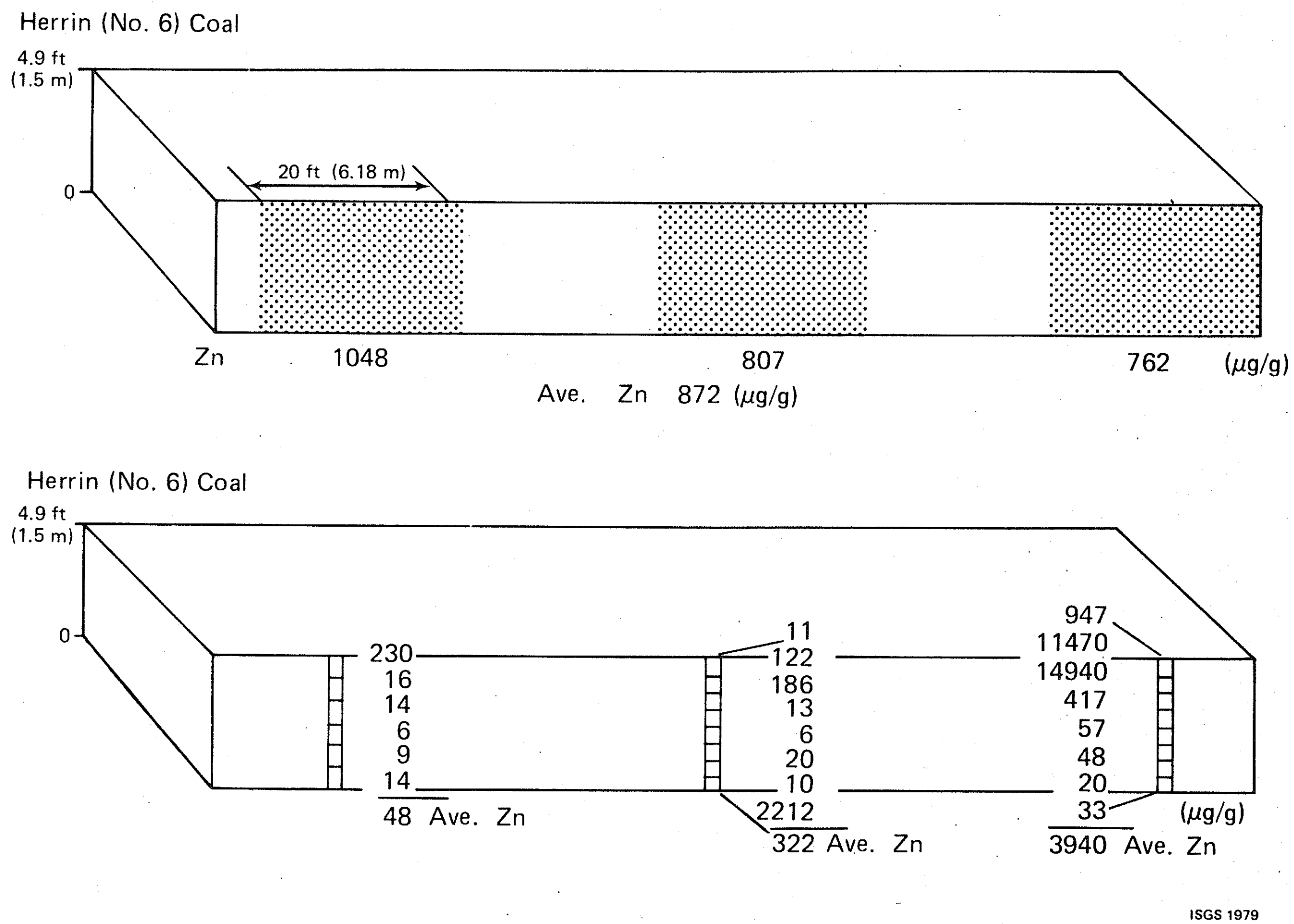

Figure 13. Results of composite face-grid and bench samples from the same sites in the Herrin (No. 6) Coal.

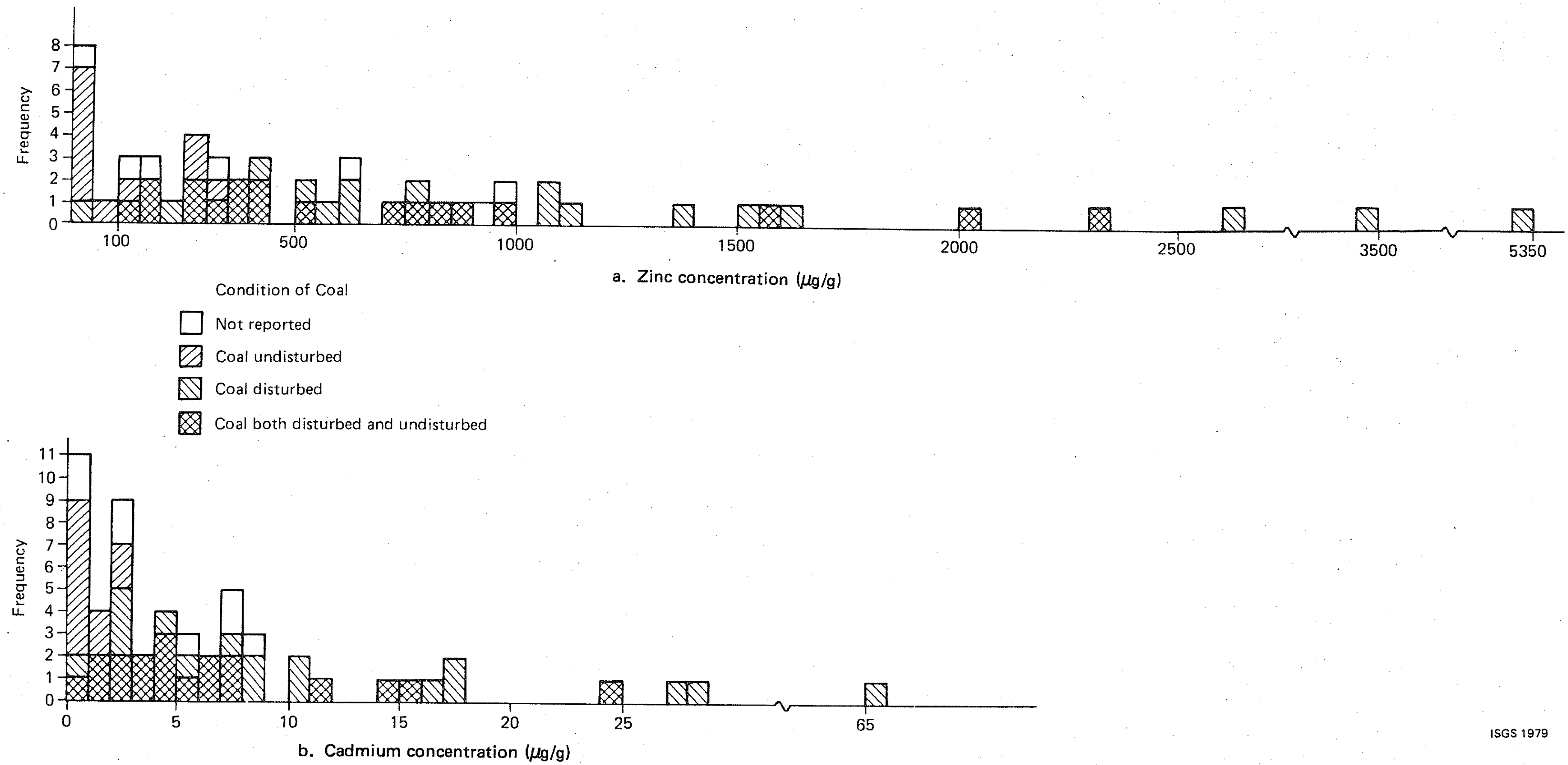

Figure 14. (a) Arithmetic frequency distribution of zinc in samples from undisturbed, disturbed, and mixed conditions of coal seams. (b) Arithmetic frequency distribution of cadmium in samples from undisturbed, disturbed, and mixed conditons of the coal seams.

An additional indicator for lognormality is to plot a cumulative frequency curve by using probability paper with a logarithmic ordinate. A lognormal distribution plots as a straight line on probability paper. Figures 15 and 16 show the plotted zinc and cadmium results. These plots consist of straight line segments with differing slopes. The line segments are interpreted as representing subpopulations of the zinc and cadmium distribution in coal. The line segments BC in both figures are composed of results from disturbed or mixed conditions of the seam, and the line segments AB are of results from undisturbed coal. In the plot for zinc (fig. 15) a third line segment DA is not identified.

Results from bench, column, composite face channel, composite face grid, and composite auger samples are displayed in tables 1 to 5. Statistical summaries of the data are presented for comparison of the five sampling methods in tables 6 and 7. The summary tables contain three measures of central tendency: arithmetic mean, geometric mean, and Sichel's t (not to be confused with Student's t) (Sichel; 1952). Also included are three measures of variation: standard deviation, geometric deviation, and the 90 percent confidence intervals for the arithmetic mean.

Data from the different sampling methods were paired for all possible combinations and were subjected to the Student's t test. At the 0.05 level of significance, there is no reason to reject the hypothesis that the arithmetic means for all the sampling methods have been taken from the same population. The inference from this is that because of the large variability in the data, the results cannot be distinguished from one another by the Student's t. Likewise, the Student's t test shows that at the 0.05 level of significance, there is no reason to reject the hypothesis that the mean zinc and cadmium concentrations for each of the three coal seams, Colchester, Springfield, and Herrin Coals, were taken from the same population.

Estimating zinc and cadmium resources in coal

A problem in estimating the abundance of the zinc and cadmium in coal arises because of their lognormal distribution. The sample arithmetic mean in a lognormal distribution may not be a good estimator of the population arithmetic mean. The population arithmetic mean is, however, the only unbiased estimate of abundance. Sichel's t statistic, which is a function of the geometric mean and geometric deviation, may be used to estimate the population arithmetic mean for lognormal distributions having few data (Sichel, 1952; and Miesch, 1967). According to Sichel (1952) this statistic is unbiased, possesses minimum variance, is not unduly influenced by occasional high values (when they occur among a set of low to moderate values), and lies nearer to the unknown true mean than any other statistic to which it is compared. These criteria support the use of Sichel's t in the present study.

Two approaches have been taken in attempting to estimate the abundance of zinc and cadmium in the coals. The first approach takes advantage of the maximum amount of data available. The second approach takes into account the optimum sampling conditions of the composite face-grid method.

In the first approach the maximum number of data was used. This was justified by the results of the Student's t test where the data from the different sampling methods and the three different coal seams could not be differentiated. Sichel's t was calculated using the combined results of all 55 samples. These 55 results represent 12 bench sets, 11 column, 11 composite face channel, 14 composite face grid, and 7 composite auger samples. Sichel's t was calculated to be 1050 μg/g for zinc and 8.4 μg/g for cadmium. The values of 1050 μg/g zinc and 8.4 μg/g cadmium then will be used as the average concentrations for purposes of estimating the amounts of these metals in the coal seams studied. The central 90 percent confidence limits for these estimates are $680\ \mu g/g < t_{Zn} < 1985\ \mu g/g$ for zinc and $5.8\ \mu g/g < t_{Cd} < 14.0\ \mu g/g$ for cadmium.

In the second approach only those results from the composite face-grid samples were used because this method: (1) covered the largest proportion of the coal seams; (2) provided the most representative weighting of disturbed and undisturbed portions of the coal seam; (3) lessened the potential for collector bias; and (4) exhibited the minimum variance in its results. Sichel's t using the 14 data from the composite face-grid sampling methods was calculated to be 633 μg/g for zinc and 5.9 μg/g for cadmium. The central 90 percent confidence limits for these estimates are $470\ \mu g/g < t_{Zn} < 1069\ \mu g/g$ for zinc and $4.4\ \mu g/g < t_{Cd} < 9.8\ \mu g/g$ for cadmium. The values of 633 μg/g zinc and 5.9 μg/g cadmium will be used as the average concentrations of these metals for purposes of estimating their amounts in the coal seams of the study area.

The potential resource of zinc and cadmium in coals of the 4-county study area may be considered to be the product of the mapped resources of the coals considered here and the estimated abundance of these metals in the coal. The coal resources of the area are approximately 7 billion tons of mapped coal in the ground (Smith and Berggren, 1963). No attempt has been made here to estimate the uncertainity of the coal resources.

The potential metal resources based on the approach using all the available data are approximately 7 million tons for zinc and 60 thousand tons for cadmium. These resource estimates show a range, based on the 90 percent confidence intervals of the Sichel's t estimates, of 5 to 14 million tons for zinc and 40 to 100 thousand tons for cadmium.

The potential metal resources based on the approach using the data from the preferred sampling method, the composite face grid, are approximately 4 million tons for zinc and 40 thousand tons for cadmium. These resource estimates show a range, based on the 90 percent confidence intervals of the t estimates, of 3 to 7 million tons for zinc and 30 to 70 thousand tons for cadmium.

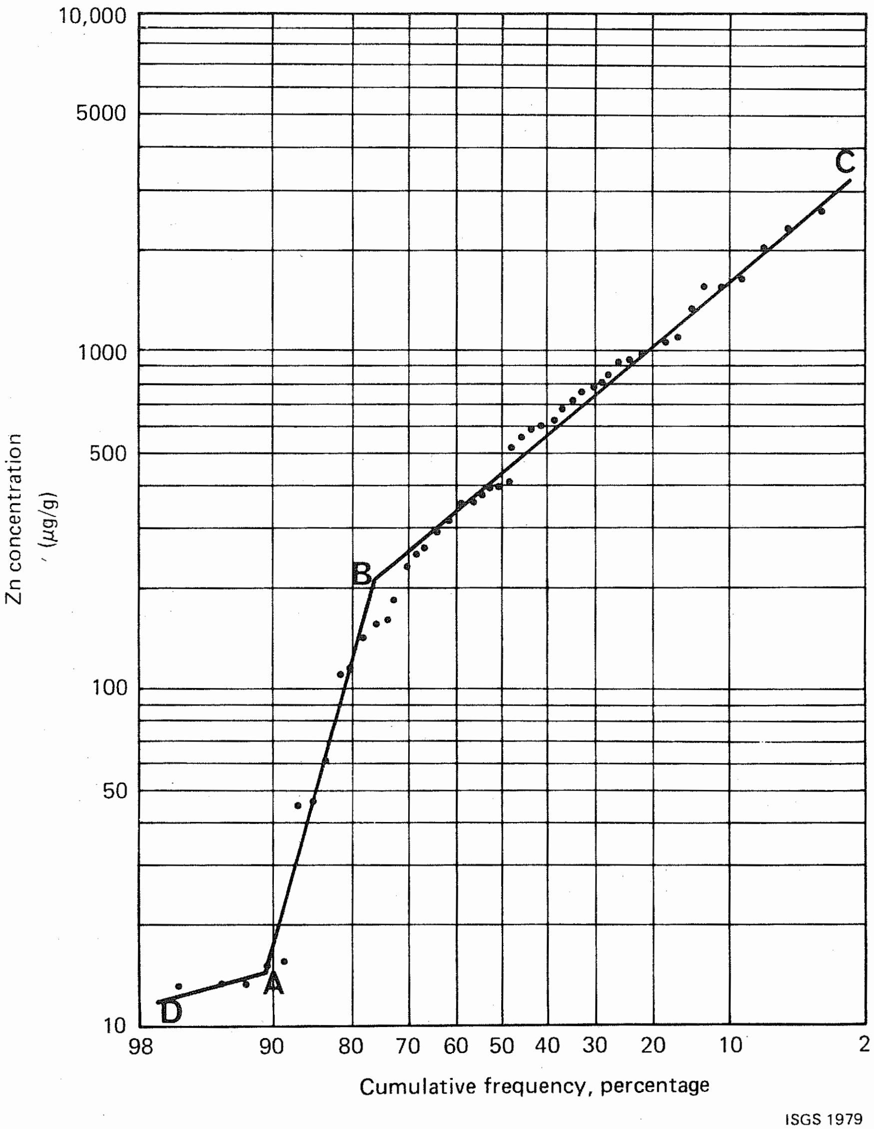

Figure 15. Cumulative frequency plot for zinc in samples.

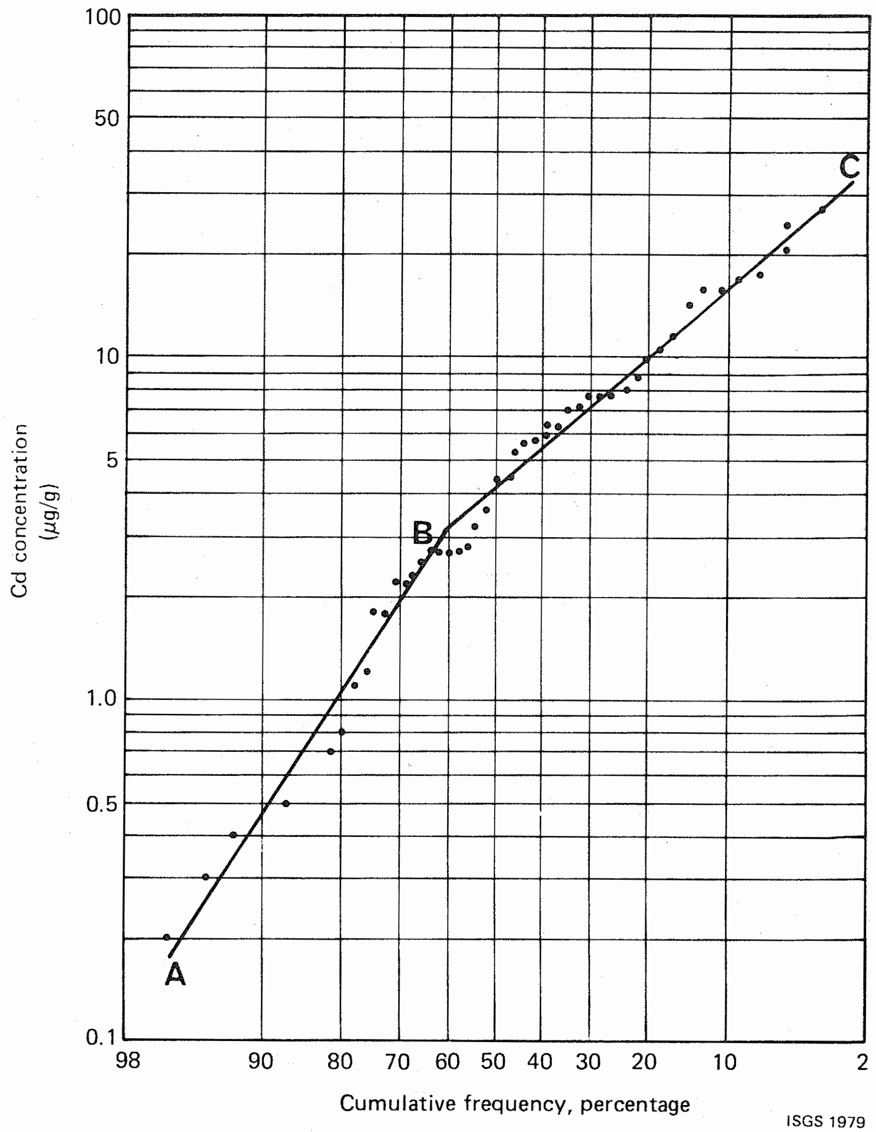

Figure 16. Cumulative frequency plot for cadmium in samples.

TABLE 1. Zinc and cadmium results for bench samples.

Sample number	Coal	Sample type[a]	Ash (%)	Zinc (μg/g)	Cadmium (μg/g)
C-19060	2	RK1	95.37	79	<3.1
C-19062	2	B1	6.52	5	<0.2
C-19063	2	B2	6.74	5	<0.2
C-19064	2	B3	5.87	6	<0.2
C-19065	2	B4	5.02	18	<0.2
C-19061	2	RK2	92.96	67	<2.8
		Average		8.5	<0.2
C-19079	5	B1	11.37	1770	19.4
C-19080	5	B2	10.77	7660	80.9
C-19081	5	B3	14.65	46	<0.3
C-19082	5	B4	16.92	14	<0.3
C-19083	5	B5	15.86	290	2.9
C-19084	5	B6	16.97	17	<0.3
		Average		1630	17.4
C-19227	5	B1	14.14	370	3.4
C-19228	5	B2	10.07	160	2.1
C-19229	5	B3	11.20	420	4.7
C-19230	5	B4	10.22	330	3.3
C-19231	5	B5	14.02	10	<0.3
C-19232	5	RK2	95.61	24	<2.2
		Average		260	2.7
C-18982	6	RK1	91.34	32	<2.8
C-18983	6	B1	7.95	230	1.8
C-18984	6	B2		16	<1.0
C-18985	6	B3	10.08	14	<0.3
C-18986	6	B4	6.30	6	<0.2
C-18987	6	B5	10.77	9	0.6
C-18988	6	B6	17.90	14	<0.5
C-18989	6	RK2	87.85	34	<2.7
		Average		48	0.7
C-19066	6	B1	11.73	6	<0.4
C-19067	6	B2	8.12	8	<0.3
C-19068	6	B3	7.09	9	<0.1
C-19069	6	B4P	62.11	14	<1.9
C-19070	6	B5	24.10	45	<0.4
C-19071	6	B6	22.42	12	<0.7
		Average		16	<0.6
C-19093	6	RK1	97.59	91	<2.5
C-19105	6	B1	9.95	950	11.1
C-19085	6	B2	10.35	11500	84.0
C-19086	6	B3	14.45	14900	117
C-19087	6	B4	7.74	420	3.4
C-19088	6	B5P	90.88	57	<1.6
C-19089	6	B6	11.83	48	0.3
C-19090	6	B7	13.41	20	<0.3
C-19091	6	B8	22.57	33	<0.5
C-19092	6	RK2	93.25	71	<2.4
		Average		3490	27.0
C-19094	6	RK1	90.90	42	<2.1
C-19095	6	B1	20.43	11	<0.5
C-19096	6	B2	11.94	122	0.5
C-19097	6	B3	15.18	186	0.5
C-19098	6	B4	9.21	13	<0.2
C-19099	6	B5	6.49	6	<0.2
C-19100	6	B6P	84.42	20	<1.9
C-19101	6	B7	15.03	10	<0.4

TABLE 1. *Continued.*

Sample number	Coal	Sample type[a]	Ash (%)	Zinc (μg/g)	Cadmium (μg/g)
C-19102	6	B8	13.44	2210	17.6
C-19103	6	RK2	90.56	43	<2.1
		Average		322	2.7
C-19211	6	RK1	96.60	71	<2.2
C-19212	6	B1	17.92	15	<0.4
C-19213	6	B2	11.03	34	<0.3
C-19214	6	B3	13.08	6180	55.7
C-19215	6	B4P	93.04	13	<2.2
C-19216	6	B5	27.12	11	<0.6
C-19217	6	B6	18.86	103	0.9
C-19218	6	RK2	97.36	40	<2.3
		Average		1060	10.0
C-19220	5	B1	11.29	8	<0.3
C-19221	5	B2	12.59	11	<0.3
C-19222	5	B3	13.76	28	<0.3
C-19223	5	B4	18.50	2390	23.6
C-19224	5	B5	12.49	470	4.6
C-19225	5	RK2	94.26	30	<2.2
		Average		580	5.8
C-19234	6	B1	28.98	2590	6.1
C-19235	6	B2	10.42	33	<0.2
C-19236	6	B3	8.50	61	0.8
C-19237	6	B4P	86.41	20	<2.0
C-19238	6	B5	10.80	7	<0.3
C-19239	6	B6	32.30	320	3.7
C-19240	6	RK2	86.63	15	<2.0
		Average		505	2.2
C-19246	6	RK1	86.84	31	<2.0
C-19241	6	B1	34.95	21	<0.8
C-19242	6	B2	14.05	18	<0.3
C-19243	6	B3	12.15	8	<0.3
C-19244	6	B4	18.76	14	<0.4
C-19245	6	RK2	94.17	34	<2.2
		Average		15	<0.5
C-19248	6	RK1	88.96	59	<2.1
C-19249	6	B1	14.55	8	<0.3
C-19250	6	B2	18.62	13	<0.4
C-19251	6	B3P	90.65	19	<2.1
C-19252	6	B4	8.79	14	<0.2
C-19253	6	B5	10.39	13	<0.2
C-19254	6	RK2	89.49	40	<2.1
		Average		13	<0.6

NOTE: Some shale and underclay samples are included.

[a]RK1 –Overlying shale (roof)
RK2 –Underclay
B1-B8 –Coal benches
B4P –Shale parting in seam
Average –Average of individual benches excluding roof shale and underclay

TABLE 2. Zinc and cadmium results for column samples.

Sample number	Coal	Ash (%)	Zinc (μg/g)	Cadmium (μg/g)
C-19210	6	18.66	1360	17.0
C-19219	5	22.70	610	4.3
C-19226	5	13.72	62	0.5
C-19233	6	26.59	1100	16.0
C-19256	6	15.88	690	5.3
C-19257	6	19.20	109	<0.4
C-19258	5	17.74	630	8.1
C-19418	2	7.56	1540	10.4
C-19421	5	13.50	410	2.7
C-19424	5	24.53	790	7.7
C-19426	6	26.93	240	2.3

TABLE 3. Zinc and cadmium results for composite face channel samples.

Sample number	Coal	Ash (%)	Zinc (μg/g)	Cadmium (μg/g)
C-14650	2	9.46	930	8.7
C-14774	5	12.82	960	7.2
C-15079	6	15.31	46	<0.2
C-15117	6	13.60	117	1.2
C-15125	6	13.07	620	7.8
C-15872	6	14.44	310	2.2
C-16264	5	12.53	159	2.7
C-16265	6	9.50	13	<0.4
C-16317	6	12.00	2670	28.0
C-16543	6	11.94	5350	65.0
C-16741	6	12.89	290	1.8

TABLE 4. Zinc and cadmium results for composite face grid samples.

Sample number	Coal	Ash (%)	Zinc (μg/g)	Cadmium (μg/g)
C-18979	6	10.98	1050	8.0
C-18980	6	9.08	810	7.0
C-18981	6	16.32	760	6.3
C-19072	6	15.15	980	15.6
C-19398	5	12.14	360	4.4
C-19399	5	16.19	540	5.9
C-19400	2	10.33	400	4.1
C-19401	2	7.92	400	2.8
C-19404	5	11.49	180	2.5
C-19415	6	16.18	380	3.2
C-19419	2	12.70	850	6.3
C-19422	5	13.48	250	1.8
C-19425	5	13.90	1570	11.7
C-19427	6	21.84	310	3.6

TABLE 5. Zinc and cadmium results for composite auger samples.

Sample number	Coal	Ash (%)	Zinc (μg/g)	Cadmium (μg/g)
C-18861-66	6	35.93	157	0.8
C-19436-43	5	20.86	290	4.6
C-19452-59	6	28.87	14	<0.4
C-19523	5	18.62	141	1.1
C-19524	5	19.67	710	7.8
C-19525	6	30.19	2320	14.7
C-19526	6	31.36	2020	24.7

TABLE 6. Summary of zinc data for all samples.

Sample	Coal	No. of samples	Arith. mean	Geom. mean	Estimated abundance Sichel's t	Std. dev.	Geom. dev.	90% conf. interval of arith. mean	Observed range
Bench	2	1	8						
	5	3	820	630		720	2.51		258-1630
	6	8	680	132		1190	8.84		13.4-3490
	All	12	660	155	951	1020	8.27	133-1192	9.5-3490
Column	2	1	1540						
	5	5	500	378		280	2.82		62-790
	6	5	700	497		540	2.86		109-1360
	All	11	680	486	763	490	2.77	418-950	62-1540
Composite face channel	2	1	930						
	5	2	560	391					159-960
	6	8	1180	294		1900	7.35		13-5350
	All	11	1040	344	1218	1690	5.77	117-1517	13-5350
Composite face grid	2	3	550	514		260	1.55		400-850
	5	5	580	424		570	2.31		180-1570
	6	6	710	649		310	1.67		310-1050
	All	14	630	530	633	390	1.86	445-814	180-1570
Composite auger	2	0							
	5	3	380	307		300	2.25		141-710
	6	4	1130	319		1210	11.28		14-2320
	All	7	810	314	1022	960	5.91	117-1517	14-2320
All	2	6	690	347	1212	540	6.54	263-1113	8.5-1540
	5	18	560	412	580	450	2.36	379-747	62-1630
	6	31	880	306	1318	1190	5.91	513-1242	13-5350
	All	55	750	342	1050	950	4.60	498-1010	8.5-5350

TABLE 7. Summary of cadmium data for all samples.

Sample	Coal	No. of samples	Arith. mean	Geom. mean	Estimated abundance Sichel's t	Std. dev.	Geom. dev.	90% conf. interval of arith. mean	Observed range
Bench	2	1	<0.2						
	5	3	8.6	6.5		7.7	2.47		2.7-17.4
	6	8	5.6	1.9		9.3	4.42		<0.5-27.3
	All	12	5.9	2.2	6.1	8.5	4.72	1.5-10.3	<0.2-27.3
Column	2	1	10.4						
	5	5	4.7	3.2		3.3	3.13		0.5-8.1
	6	5	8.2	4.2		7.8	4.74		<0.4-17.0
	All	11	6.8	4.1	8.1	5.7	3.55	3.7-9.9	<0.4-17.0
Composite face channel	2	1	8.7						
	5	2	5.0	4.4					2.7-7.2
	6	8	13.3	2.9		22.9	7.38		<0.2-65.0
	All	11	11.4	3.5	11.9	19.5	5.59	1.2-14.5	<0.2-65.0
Composite face grid	2	3	4.4	4.2		1.8	1.50		2.8-6.3
	5	5	5.3	4.2		3.9	2.08		1.8-11.7
	6	6	7.3	6.3		4.5	1.78		3.2-15.6
	All	14	5.9	5.0	5.9	3.8	1.83	4.1-7.8	1.8-15.6
Composite auger	2	0							
	5	3	4.5	3.4		3.4	2.76		1.1-7.8
	6	4	10.2	3.3		11.8	7.85		<0.4-24.7
	All	7	7.7	3.3	8.6	9.1	4.81	1.2-14.5	<0.4-24.7
All	2	6	5.4	3.3	7.3	3.8	4.29	2.4-8.4	<0.2-10.4
	5	18	5.5	4.1	5.8	4.2	2.36	3.8-7.2	0.5-17.4
	6	31	8.9	3.3	10.2	13.3	4.74	4.9-13.0	<0.2-65.0
	All	55	7.4	3.5	8.4	10.4	3.80	4.6-10.2	<0.2-65.0

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APPENDIXES

APPENDIX A

Sample Preparation

All samples were processed according to the following procedure:

(1) Crushed in a small jaw crusher;
(2) Split in a 1-inch riffler;
(3) Subjected to a secondary crushing in jaw crusher with jaws set to 1/16- to 1/8-inch opening;
(4) Split in an enclosed ¼-inch riffler;
(5) Weighed and placed in an air-dry pan and dried overnight;
(6) Dry weight was recorded;
(7) Crushed with a small roll crusher;
(8) Split in the riffler to obtain about 1 kg for reserve;
(9) Split from the remainder (in riffler) to obtain about 0.5 kg;
(10) 0.5 kg sample crushed in a Holems Mill to 60 mesh;
(11) Split in a riffler to obtain sample for analysis and bottled;
(12) Agitated for 30 minutes to ensure thorough mixing.

Chemical Preparation and Analysis

Cadmium and zinc in the coal samples were determined by using a Perkin-Elmer Model 306 atomic absorption spectrophotometer equipped with a Perkin-Elmer Model 056 recorder. A 4-inch long, single-slot, flathead burner with an air-acetylene flame was used for sample atomization. A Perkin-Elmer electrodeless discharge lamp and hollow cathode lamp were used in the determination of Cd and Zn, respectively. Corrections for nonatomic background adsorption were made simultaneously using a Perkin-Elmer deuterium arc background corrector.

All reagents used were ACS-certified reagent-grade chemicals; standard stock solutions were prepared from high-purity metals or compounds. Calibration standards prepared from diluted stock solutions contained the following matrix components: 1.4 percent v/v aqua regia (1:3:1, HNO_3:HCl:H_2O), 1 percent v/v 48 percent HF, and 1 percent w/v H_3BO_3.

About 2 grams of crushed and ground coal samples of approximately 60 mesh were placed in a 30-mL Vycor crucible and ashed in a muffle furnace at 500°C for 5 hours. The ash was then ground with a mullite mortar and pestle to approximately 200 mesh and stored in acid-washed glass vials. Approximately 0.1 g of ash, dried at 110°C for several hours, was transferred to an acid-washed 60 mL linear polyethylene bottle. The sample was treated with 1 mL of distilled HCl and heated to dryness on a steam bath. The sample was then wetted with 0.7 mL aqua regia, followed with addition of 0.5 mL of 48 percent HF. The bottle was capped tightly and placed on a steam bath for approximately 2 hours. The digested sample was treated with 10 mL of a 50-g/liter solution H_3BO_3 to complex the fluorine. The digested sample was transferred to a 50-mL Pyrex volumetric flask, diluted to volume with deionized water, and returned to the decomposition bottle for storage (Bernas, 1968; French and Adams, 1973; and Ruch, Gluskoter, and Shimp, 1974).

The analytical wavelengths used for the analyses were 228.8 nm for Cd and 213.9 nm for Zn. Calibration standards were in the range of 0.01 to 1.0 μg/mL for Zn. Where sample concentrations were greater than the upper limit of linear response, either the samples were diluted or the burner was rotated from its parallel orientation to bring all absorbance values within the range of linearity. The metal concentrations were calculated by solving for concentration in a calibration curve constructed from least squares, where absorbance was a function of concentration. A new calibration curve was calculated for each set of analyses.

Ruch, Gluskoter, and Shimp (1974) demonstrated that Cd and Zn are retained during ashing; neither element is reduced significantly by volatilization. The National Bureau of Standards certified values for coal sample SRM 1632 for Cd and Zn and 0.19 and 37 μg/g respectively; the values determined in this study were $<$ 0.23 μg/g for Cd and 36.7 μg/g for Zn. The average relative standard deviation for both Cd and Zn determinations by atomic absorption spectrometry in this study was 6 percent or less.

APPENDIX B.

TABLE A. Location of samples.

Sample no.	Coal bed	Sample type	County	Location	Mine name and company
C-19523	5[a]	Ca	Fulton	SE SE NW Sec. 6 T. 5 N., R. 5 E.	Buckheart Mine Freeman United Coal Co.
C-19524	5	CA	Fulton	SE NW NW Sec. 13 T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-19525	6[b]	CA	Peoria	NE NE SE Sec. 20 T. 9 N., R. 6 E.	Elm Mine Midland Coal Co.
C-19526	6	CA	Knox	NE SW SW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-14650	2[c]	CFC	Fulton	T. 4 N., R. 1 E	Buckheart Mine Freeman United Coal Co.
C-14774	5	CFC	Fulton	T. 5 N., R. 5 E	Buckheart Mine Freeman United Coal Co.
C-15079	6	CFC	Peoria	T. 9 N., R. 6 E.	Elm Mine Midland Coal Co.
C-15117	6	CFC	Peoria	T. 9 N., R. 6 E.	Elm Mine Midland Coal Co.
C-15125	6	CFC	Fulton	T. 13 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-15872	6	CFC	Fulton	T. 13 N., R. 6 E.	Allendale Mine Midland Coal Co.
C-16264	5	CFC	Fulton	T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-16265	6	CFC	Fulton	T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-16317	6	CFC	Peoria	T. 9 N., R. 6 E.	Elm Mine Midland Coal Co.
C-16543	6	CFC	Knox	T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-16741	6	CFC	Fulton	T. 12 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-18979	6	Gd	Peoria	NW SE NE Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-18980	6	Gd	Peoria	NE SE NE Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-18981	6	Gd	Peoria	NW SW NE Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-18982	6	RK1	Peoria	NW SW NE Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-18983	6	B1	Peoria	NW SW NE Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-18984	6	B2	Peoria	NW SW NE Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-18995	6	B3	Peoria	NW SW NE Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-18986	6	B4	Peoria	NW SW NE Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-18987	6	B5	Peoria	NW SW NE Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-18988	6	B6	Peoria	NW SW NE Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.

[a] Refers to Springfield (No. 5) Coal
[b] Refers to Herrin (No. 6) Coal
[c] Refers to Colchester (No. 2) Coal

APPENDIX B.

TABLE A. *Continued.*

Sample no.	Coal bed	Sample type	County	Location	Mine name and company
C-18989	6[b]	RK2	Peoria	NW SW NE Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-19054	2[c]	RK	Fulton	SE NE SW Sec. 15 T. 4 N., R. 1 E.	Sunspot Mine Amax Coal Co.
C-19055	2	RK	Fulton	SE NE SW Sec. 15 T. 4 N., R. 1 E.	Sunspot Mine Amax Coal Co.
C-19056	2	RK	Fulton	SE NE SW Sec. 15 T. 4 N., R. 1 E.	Sunspot Mine Amax Coal Co.
C-19057	2	RK2	Fulton	SE NE SW Sec. 15 T. 4 N., R. 1 E.	Sunspot Mine Amax Coal Co.
C-19060	2	RK1	Fulton	NW NE SW Sec. 15 T. 4 N., R. 1 E.	Sunspot Mine Amax Coal Co.
C-19061	2	RK2	Fulton	NW NE SW Sec. 15 T. 4 N., R. 1 E.	Sunspot Mine Amax Coal Co.
C-19062	2	B1	Fulton	NW NE SW Sec. 15 T. 4 N., R. 1 E.	Sunspot Mine Amax Coal Co.
C-19063	2	B2	Fulton	NW NE SW Sec. 15 T. 4 N., R. 1 E.	Sunspot Mine Amax Coal Co.
C-19064	2	B3	Fulton	NW NE SW Sec. 15 T. 4 N., R. 1 E.	Sunspot Mine Amax Coal Co.
C-19065	2	B4	Fulton	NW NE SW Sec. 15 T. 4 N., R. 1 E.	Sunspot Mine Amax Coal Co.
C-19066	6	B1	Knox	SW SE NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19067	6	B2	Knox	SW SE NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19068	6	B3	Knox	SW SE NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19069	6	B4P	Knox	SW SE NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19070	6	B5	Knox	SW SE NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19071	6	B6	Knox	SW SE NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19072	6	Gd	Knox	SW NE NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19073	6	RKP	Knox	SW SE NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19074	6	RKP	Knox	SW SE NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19075	2	B1	Fulton	NE NE SW Sec. 15 T. 4 N., R. 1 E.	Sunspot Mine Amax Coal Co.
C-19076	2	B2	Fulton	NE NE SW Sec. 15 T. 4 N., R. 1 E.	Sunspot Mine Amax Coal Co.
C-19077	2	B3	Fulton	NE NE SW Sec. 15 T. 4 N., R. 1 E.	Sunspot Mine Amax Coal Co.
C-19078	5[a]	RKC	Fulton	SW SE NW Sec. 6 T. 5 N., R. 4 E.	Buckheart Mine Freeman United Coal Co.
C-19079	5	B1	Fulton	SW SE NW Sec. 6 T. 5 N., R. 4 E.	Buckheart Mine Freeman United Coal Co.

[a] Refers to Springfield (No. 5) Coal
[b] Refers to Herrin (No. 6) Coal
[c] Refers to Colchester (No. 2) Coal

APPENDIX B.

TABLE A. *Continued.*

Sample no.	Coal bed	Sample type	County	Location	Mine name and company
C-19080	5[a]	B2	Fulton	SW SE NW Sec. 6 T. 5 N., R. 4 E.	Buckheart Mine Freeman United Coal Co.
C-19081	5	B3	Fulton	SW SE NW Sec. 6 T. 5 N., R. 4 E.	Buckheart Mine Freeman United Coal Co.
C-19082	5	B4	Fulton	SW SE NW Sec. 6 T. 5 N., R. 4 E.	Buckheart Mine Freeman United Coal Co.
C-19083	5	B5	Fulton	SW SE NW Sec. 6 T. 5 N., R. 4 E.	Buckheart Mine Freeman United Coal Co.
C-19084	5	B6	Fulton	SW SE NW Sec. 6 T. 5 N., R. 4 E.	Buckheart Mine Freeman United Coal Co.
C-19105	6[b]	B1	Peoria	NE SW NW Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-19085	6	B2	Peoria	NE SW NW Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-19086	6	B3	Peoria	NE SW NW Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-19087	6	B4	Peoria	NE SW NW Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-19088	6	B5P	Peoria	NE SW NW Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-19089	6	B6	Peoria	NE SW NW Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-19090	6	B7	Peoria	NE SW NW Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-19091	6	B8	Peoria	NE SW NW Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-19092	6	RK2	Peoria	NE SW NW Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-19093	6	RK1	Peoria	NE SW NW Sec. 28 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-19094	6	RK1	Peoria	SE SW NE Sec. 20 T. 9 N., R. 6 E.	Elm Mine Midland Coal Co.
C-19095	6	B1	Peoria	SE SW NE Sec. 20 T. 9 N. R. 6 E.	Elm Mine Midland Coal Co.
C-19096	6	B2	Peoria	SE SW NE Sec. 20 T. 9 N., R. 6 E.	Elm Mine Midland Coal Co.
C-19097	6	B3	Peoria	SE SW NE Sec. 20 T. 9 N., R. 6 E.	Elm Mine Midland Coal Co.
C-19098	6	B4	Peoria	SE SW NE Sec. 20 T. 9 N., R. 6 E.	Elm Mine Midland Coal Co.
C-19099	6	B5	Peoria	SE SW NE Sec. 20 T. 9 N., R. 6 E.	Elm Mine Midland Coal Co.
C-19100	6	B6P	Peoria	SE SW NE Sec. 20 T. 9 N., R. 6 E.	Elm Mine Midland Coal Co.
C-19101	6	B7	Peoria	SE SW NE Sec. 20 T. 9 N., R. 6 E.	Elm Mine Midland Coal Co.
C-19102	6	R8	Peoria	SE SW NE Sec. 20 T. 9 N., R. 6 E.	Elm Mine Midland Coal Co.
C-19103	6	RK2	Peoria	SE SW NE Sec. 20 T. 9 N., R. 6 E.	Elm Mine Midland Coal Co.

[a] Refers to Springfield (No. 5) Coal
[b] Refers to Herrin (No. 6) Coal
[c] Refers to Colchester (No. 2) Coal

APPENDIX B.

TABLE A. *Continued.*

Sample no.	Coal bed	Sample type	County	Location	Mine name and company
C-19104	6[b]	RK	Peoria	SE SW NE Sec. 20 T. 9 N., R. 6 E.	Elm Mine Midland Coal Co.
C-19210	6	C	Stark	SE NW NW Sec. 11 T. 13 N., R. 6 E.	Allendale Mine Midland Coal Co.
C-19211	6	RK1	Stark	SE NW NW Sec. 11 T. 13 N., R. 6 E.	Allendale Mine Midland Coal Co.
C-19212	6	B1	Stark	SE NW NW Sec. 11 T. 13 N., R. 6 E.	Allendale Mine Midland Coal Co.
C-19213	6	B2	Stark	SE NW NW Sec. 11 T. 13 N., R. 6 E.	Allendale Mine Midland Coal Co.
C-19214	6	B3	Stark	SE NW NW Sec. 11 T. 13 N., R. 6 E.	Allendale Mine Midland Coal Co.
C-19215	6	B4P	Stark	SE NW NW Sec. 11 T. 13 N., R. 6 E.	Allendale Mine Midland Coal Co.
C-19216	6	B5	Stark	SE NW NW Sec. 11 T. 13 N., R. 6 E.	Allendale Mine Midland Coal Co.
C-19217	6	B6	Stark	SE NW NW Sec. 11 T. 13 N., R. 6 E.	Allendale Mine Midland Coal Co.
C-19218	6	RK2	Stark	SE NW NW Sec. 11 T. 13 N., R. 6 E.	Allendale Mine Midland Coal Co.
C-19219	5[a]	C	Fulton	SE SW NW Sec. 13 T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-19220	5	B1	Fulton	SE SW NW Sec. 13 T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-19221	5	B2	Fulton	SE SW NW Sec. 13 T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-19222	5	B3	Fulton	SE SW NW Sec. 13 T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-19223	5	B4	Fulton	SE SW NW Sec. 13 T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-19224	5	B5	Fulton	SE SW NW Sec. 13 T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-19225	5	RK2	Fulton	SE SW NW Sec. 13 T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-19226	5	C	Fulton	SE SW NW Sec. 13 T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-19227	5	B1	Fulton	SW NE NE Sec. 13 T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-19228	5	B2	Fulton	SW NE NE Sec. 13 T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-19229	5	B3	Fulton	SW NE NE Sec. 13 T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-19230	5	B4	Fulton	SW NE NE Sec. 13 T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-19231	5	B5	Fulton	SW NE NE Sec. 13 T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-19232	5	RK2	Fulton	SW NE NE Sec. 13 T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-19233	6	C	Knox	NW NE NE Sec. 10 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.

[a] Refers to Springfield (No. 5) Coal
[b] Refers to Herrin (No. 6) Coal
[c] Refers to Colchester (No. 2) Coal

APPENDIX B.

TABLE A. *Continued.*

Sample no.	Coal bed	Sample type	County	Location	Mine name and company
C-19234	6[b]	B1	Knox	NW NE NE Sec. 10 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19235	6	B2	Knox	NW NE NE Sec. 10 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19236	6	B3	Knox	NW NE NE Sec. 10 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19237	6	B4P	Knox	NW NE NE Sec. 10 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19238	6	B5	Knox	NW NE NE Sec. 10 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19239	6	B6	Knox	NW NE NE Sec. 10 T. 12 N., R. 5 E.	Mecco Mine Midland Coal Co.
C-19240	6	RK2	Knox	NW NE NE Sec. 10 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19241	6	B1	Knox	NW SE NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19242	6	B2	Knox	NW SE NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19243	6	B3	Knox	NW SE NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19244	6	B4	Knox	NW SE NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19245	6	RK2	Knox	NW SE NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19246	6	RK1	Knox	NW SE NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19248	6	RK1	Knox	SE NW NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19249	6	B1	Knox	SE NW NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19250	6	B2	Knox	SE NW NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19251	6	B3P	Knox	SE NW NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19252	6	B4	Knox	SE NW NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19253	6	B5	Knox	SE NW NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19254	6	RK2	Knox	SE NW NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19256	6	C	Peoria	SE NW NE Sec. 19 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-19257	6	C	Peoria	SE SW NE Sec. 20 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-19258	5[a]	C	Peoria	SE SE NE Sec. 20 T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-19260	5	Slr	Fulton	pond Sec. 4 T. 7 N., R. 4 E.	Norris Mine Consolidation Coal Co.
C-19398	5	Gd	Fulton	SW NE NE Sec. 13 T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.

[a]Refers to Springfield (No. 5) Coal
[b]Refers to Herrin (No. 6) Coal
[c]Refers to Colchester (No. 2) Coal

TABLE A. *Continued.*

Sample no.	Coal bed	Sample type	County	Location	Mine name and company
C-19399	5[a]	Gd	Fulton	NW SE NW Sec. 13 T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-19400	2[c]	Gd	Fulton	NW SE NW Sec. 16 T. 4 N., R. 1 E.	Sunspot Mine Amax Coal Co.
C-19401	2	Gd	Fulton	NW NW SW Sec. 15 T. 4 N., R. 1 E.	Sunspot Mine Amax Coal Co.
C-19402	5, 6[b]	Gob	Peoria	prep. plant T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-19403	5, 6	Gob	Peoria	prep. plant T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-19415	6	Gd	Stark	SE NW NW Sec. 11 T. 13 N., R. 6 E.	Allendale Mine Midland Coal Co.
C-19418	2	C	Fulton	SE SW NE Sec. 16 T. 4 N., R. 1 E.	Sunspot Mine Amax Coal Co.
C-19419	2	Gd	Fulton	SE SW NE Sec. 16 T. 4 N., R. 1 E.	Sunspot Mine Amax Coal Co.
C-19420	2	Gb	Fulton	SE SW NE Sec. 16 T. 4 N., R. 1 E.	Sunspot Mine Amax Coal Co.
C-19421	5	C	Fulton	NW SW NW Sec. 6 T. 6 N., R. 5 E.	Buckheart Mine Freeman United Coal Co.
C-19422	5	Gd	Fulton	NW SW NW Sec. 6 T. 6 N., R. 5 E.	Buckheart Mine Freeman United Coal Co.
C-19423	5	Gb	Fulton	NW SW NW Sec. 6 T. 5 N., R. 5 E.	Buckheart Mine Freeman United Coal Co.
C-19424	5	C	Fulton	NW SW NE Sec. 13 T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-19425	5	Gd	Fulton	NW SW NE Sec. 13 T. 7 N., R. 3 E.	Norris Mine Consolidation Coal Co.
C-19426	6	C	Knox	NW SW NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19427	6	Gd	Knox	NW SW NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19428	6	Gb	Knox	NW SW NW Sec. 12 T. 12 N., R. 3 E.	Mecco Mine Midland Coal Co.
C-19429	5, 6	Gob	Peoria	prep. plant T. 9 N., R. 5 E.	Elm Mine Midland Coal Co.
C-19520	5	Slr	Fulton	pond Sec. 24 T. 6 N., R. 4 E.	Buckheart Mine Freeman United Coal Co.
C-19521	5	Slr	Fulton	pond Sec. 24 T. 6 N., R. 4 E.	Buckheart Mine Freeman United Coal Co.
C-19528	5	Slr	Fulton	pond Sec. 4 T. 3 N., R. 1 E.	Sunspot Mine Amax Coal Co.

[a]Refers to Springfield (No. 5) Coal
[b]Refers to Herrin (No. 6) Coal
[c]Refers to Colchester (No. 2) Coal

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