GEOCHEMICAL AND GEOHYDROLOGICAL CHARACTERISTICS OF BEDROCK AND SPOIL FROM TWO METHODS OF MINING AT A RECLAIMED SURFACE COAL MINE, CLARION COUNTY, PA, USA[1]

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Abstract: Two methods of mining caused subtle differences in geochemical and geohydrological characteristics of spoil at a reclaimed surface coal mine in western Pennsylvania. A dragline was used in the southern area of the mine, and bulldozers and front-end loaders were used in the northern area. Mining methods used in the intervening, middle area are uncertain. In general, overburden at the mine consisted of sideritic gray shale and siltstone. Calcareous zones were laterally discontinuous. However, a 1.2-m thick stratum of pyritic shale above the mined coal was laterally continuous and had total sulfur (S) concentrations >2.5 weight percent (wt %). Regardless of mining methods, pyritic material in backfill is inverted relative to its stratigraphic sequence in bedrock. Where bulldozers and front-end loaders were used, the pyritic shale was selectively handled and buried in compacted layers above the water table, and only low-S (<0.2 wt %) material was buried near the pit floor. Where the dragline was used, high-S (≥0.5 wt %) material was placed near the surface, but above intermediate-S material. In the middle area, where mining methods are uncertain, high-S material was randomly distributed, near the surface and on the pit floor, within the zone of water-table fluctuation. In the northern and middle areas, mass-weighted average S in spoil was comparable to that in premining bedrock. In contrast, average neutralization potential of spoil was about one-third of that of premining bedrock, possibly because of preferential weathering of carbonates in shallow bedrock (premining) or spoil. Despite differences in mining methods, hydraulic conductivities for spoil were similar among the northern, middle, and southern areas, ranging from $10^{-8.2}$ to $10^{-3.0}$ meters per second (m/s), with median hydraulic conductivities from $10^{-3.8}$ to $10^{-3.6}$ m/s. Hydraulic conductivities for spoil were not always greater than those for underlying bedrock.

Introduction

Geochemical and geohydrological characteristics of spoil at surface coal mines can vary because of differences in mining methods and equipment. This paper describes the geochemical and geohydrological characteristics of bedrock and spoil at a reclaimed surface coal mine in the bituminous field of western Pennsylvania and evaluates effects of two different mining methods on these characteristics.

The study area is a reclaimed surface coal mine in southern Clarion County, Pa. (fig. 1) that consists of 44.5 hectares covering two adjoining hilltops. The middle and lower Kittanning coals were mined during 1980-86 (Glover 1987). In the southern area of the mine, where calcareous materials were widespread, a dragline with a 34.4-m^3 bucket was used to remove overburden and to backfill the mine. In contrast, in the northern area, where calcareous strata were present only locally, bulldozers and front-end loaders were used for mining and backfilling, and in particular to selectively handle a 1.2-m thick stratum of pyritic, carbonaceous shale overlying the lower Kittanning coal. The selectively handled pyritic material was compacted with the mining equipment in layers, or pods, on lifts composed of low-S spoil at least 3 m thick on the pit floor, so that the pods would be above the anticipated post-mining water table. In addition, in the northern area, a total of 56 megagrams (tonnes) of limestone per hectare was added to the backfill near the surface and to the pit floor. The boundary between areas where the different mining methods were used is not known precisely. Hence, a middle area, between the southern and northern areas, was included in the investigation. The middle and northern areas are separated by an unmined hilltop. This unmined area is a 60-m-wide right-of-way for a natural-gas pipeline, which runs north-south through the mine (fig. 1).

Methods

Initially, records were reviewed from Pennsylvania Department of Environmental Resources (PaDER) and C&K Coal Company files, which included premining geologic logs, geochemical data for drill cuttings, and mining activities. Later, subsurface drilling, sampling, and testing were conducted to evaluate variations in geochemical and geohydrological characteristics of bedrock and spoil across the reclaimed area. Premining boreholes were drilled by

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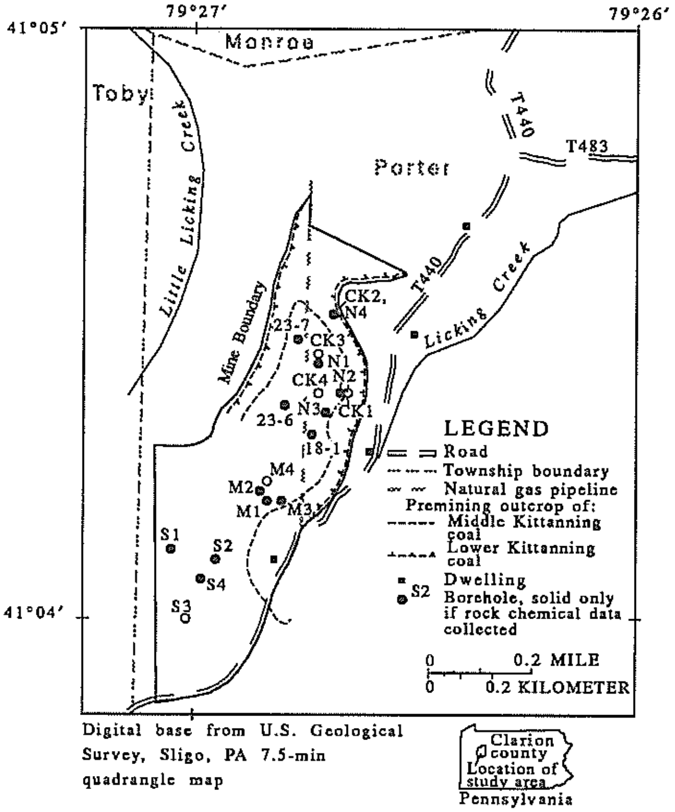
diamond-coring methods, and postmining boreholes by air-rotary methods, to collect rock samples and install ground-water monitoring equipment. Six boreholes (18-1, 23-6, 23-7, N1, CK3, and CK4 in fig. 1) were drilled in bedrock in or near the northern area through zones of maximum overburden thickness along a hilltop. Holes at locations CK1 and CK2 (fig. 1) were drilled in 1985, after mining. Clusters of boreholes identified with prefixes N, M, and S (fig. 1) were drilled in 1991, mostly through spoil, in the northern, middle, and southern areas, respectively. Rock samples from boreholes through spoil and bedrock were collected as composites over 1.5-m depth intervals.

Lithology of rock samples was determined, and most rock samples were analyzed for concentrations of total S and neutralization potential (NP) by methods of Sobek et al. (1978) for acid-base accounting. Mass-weighted averages for NP, maximum potential acidity (MPA), and net neutralization potential (NNP=NP-MPA) for each borehole and each of the three areas of the mine were calculated by methods of Smith and Brady (1990). Data for rock samples collected at the same depth at a borehole cluster were averaged for areal estimates. Major minerals in samples from borehole N1 (fig. 1) were identified by X-ray diffractometry (XRD; Whittig and Allardice 1986), which has a detection limit of about 1 to 5 percent. Lithostratigraphic correlation diagrams were constructed with premining and postmining data for lithology and rock chemical concentrations by use of the computer program StratiFact (Rosenlund et al. 1993). To facilitate correlation of horizons, the borehole data were adjusted to a common datum, the base of the lower Kittanning coal.



Digital base from U.S. Geological Survey, Sligo, PA 7.5-min quadrangle map

Figure 1. Location of boreholes at surface coal mine in southern Clarion County, PA.

Monitoring wells were installed in most boreholes. Wells were constructed of 5.1-cm diameter polyvinyl chloride pipe with a minimum of 3-m length slotted screen (Cravotta et al. 1994). Static water levels in wells were measured monthly by use of an electrical tape. Hydraulic conductivities were estimated for saturated intervals of the screened zones by use of slug-test methods of Bouwer and Rice (Bouwer 1989). A solid cylinder (slug) was submerged below the static water level in each well, and changes in hydraulic head during slug injection and withdrawal were measured with a submerged pressure transducer and recorded with a data logger. Methods of hydraulic testing and data reduction were reported by Hawkins and Aljoe (1991).

Geochemical Characteristics

Lithostratigraphic correlations, before mining (fig. 2), show vertical and lateral differences in overburden chemistry. Locally, the middle and lower Kittanning coalbeds dipped gently west-northwest and were separated by about 18 to 20 m of medium- to dark-gray shale that graded upward to siltstone and claystone. The middle Kittanning coal had a thickness of 0.6 to 0.8 m, and the lower Kittanning coal had a thickness of 0.45 to 0.6 m. A 1.2-m-thick stratum of high-S, pyritic, carbonaceous shale was immediately above the lower Kittanning coal (fig. 2, table 1). The shale and lower Kittanning coal had concentrations of total S >2.5 wt % and NP <10 grams as calcium carbonate per kilogram (g/kg $CaCO_3$). Most overburden horizons had concentrations of total S <1 wt % and NP <25 g/kg $CaCO_3$; however, some shale and siltstone were calcareous. High values of NP, up to about 125 g/kg $CaCO_3$, were associated with fossiliferous (brachiopods), gray shale between the lower and middle Kittanning coalbeds.

Bedrock samples from borehole N1 were further analyzed for major minerals and concentration of total carbon to indicate possible mineralogic forms of S and NP (table 1). Pyrite (FeS_2) was the predominant S-bearing mineral and siderite ($FeCO_3$) was the predominant carbonate mineral. Some siderite-bearing shale and siltstone also contained

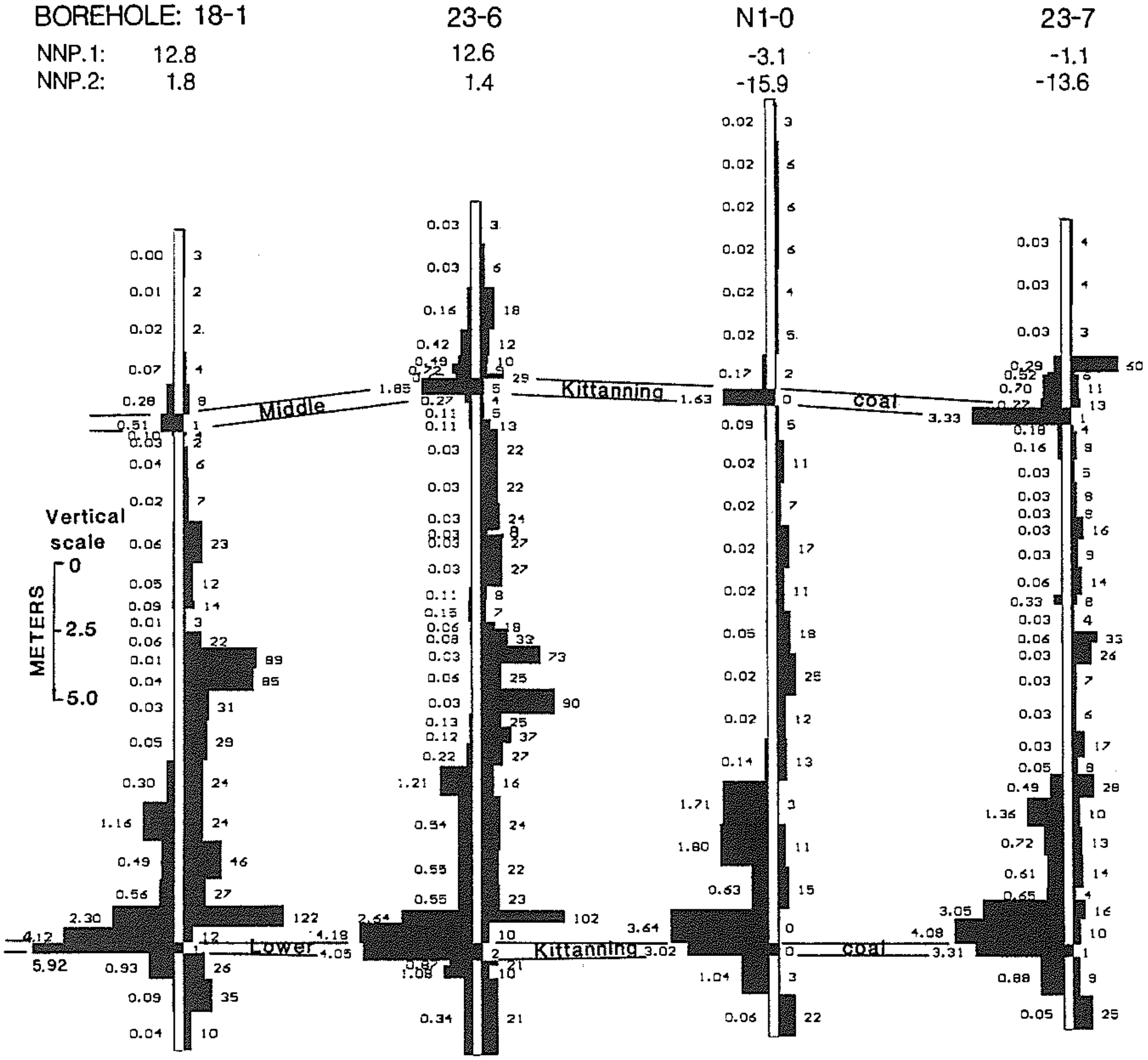


Figure 2. Lithostratigraphic correlations and rock-chemical variations for premining conditions. Datum is base of lower Kittanning coal. Values for column-weighted net neutralization potential computed using a factor of 31.25 (NNP.1) and of 62.5 (NNP.2) are shown below borehole number (see footnote 3 in table 2). Borehole locations shown in figure 1. For explanation of symbols, see "KEY" in figure 3.

manganosiderite [$(Fe,Mn)CO_3$], calcite ($CaCO_3$), and dolomite [$CaMg(CO_3)_2$]. Overburden and coal in the upper 12 m penetrated by borehole N1 lacked detectible sulfide and carbonate minerals and had lower concentrations of total S and NP than deeper strata, probably as a result of near-surface weathering. High concentrations of total S in the middle Kittanning coal at 11-m depth were probably from organic-S forms, because S-bearing minerals were not detected by XRD.

Regardless of the mining method used, backfilled spoil at the mine tends to be inverted relative to the stratigraphic sequence in bedrock, and unweathered material containing substantial concentrations of total S and NP commonly was placed near the land surface (fig. 3). Substantial lateral variations in total S concentrations also were produced, as indicated by cuttings from adjacent boreholes N2-0 and N2-2, N3-0 and N3-2, M1-0 and M1-2, and M2-0 and M2-2 (fig. 3), which were drilled about 1.5 m apart for installation of nested lysimeters and wells (Cravotta et al. 1994). In the northern area, where bulldozers and loaders were used, high-S (≥0.5 wt %) materials were placed near

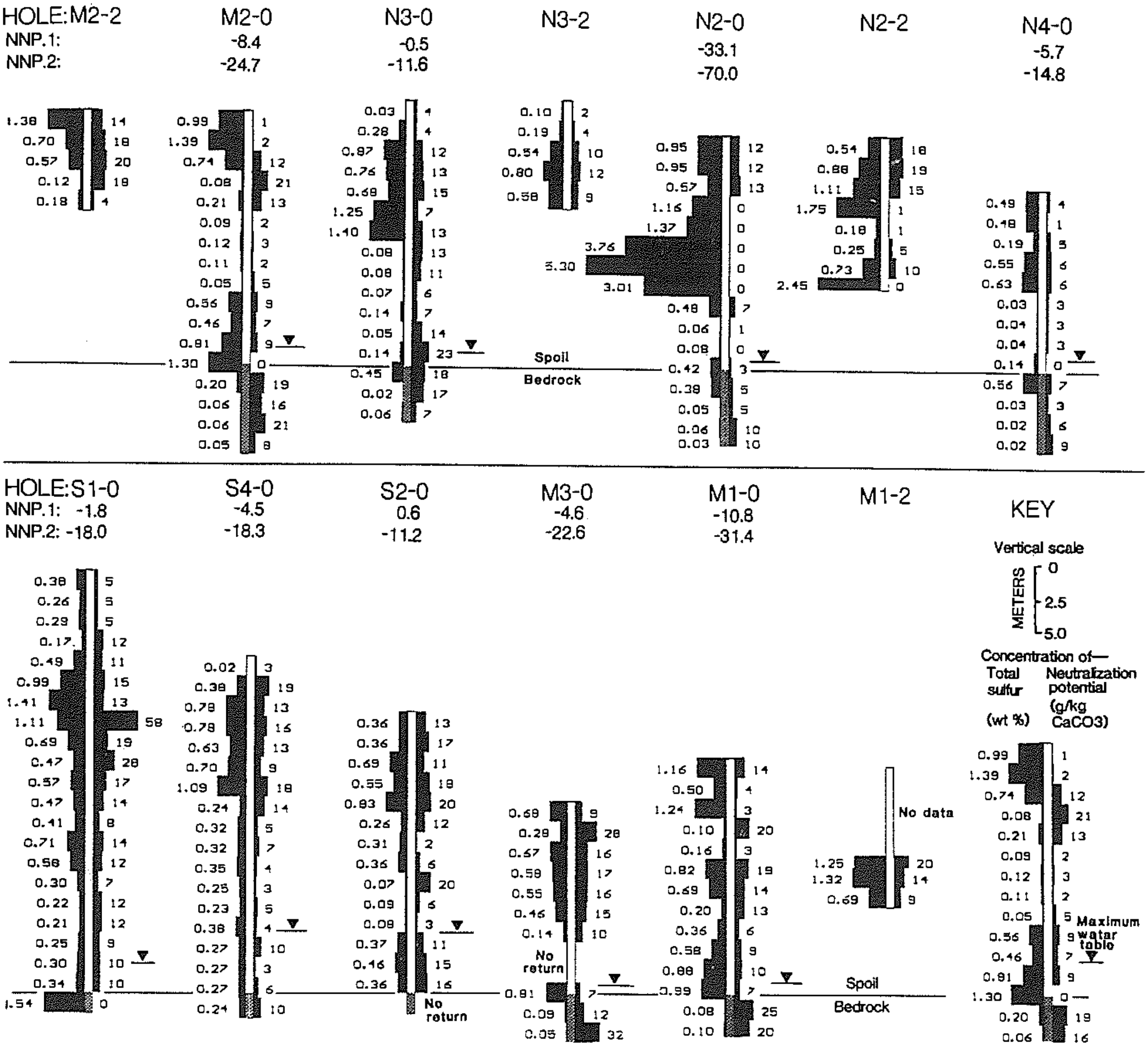


Figure 3. Lithostratigraphic correlations and rock-chemical variations for postmining conditions. Datum is base of lower Kittanning coal. Values for column-weighted net neutralization potential computed using a factor of 31.25 (NNP.1) and of 62.5 (NNP.2) are shown below borehole number (see footnote 3 in table 2). Borehole locations shown in figure 1. Boreholes identified with suffix "-0" or "-1" drilled through lower Kittanning coal horizon and "-2" drilled to less than 11 m depth.

the land surface to 13.7 m depth (fig. 3) and were generally underlain by a minimum of 6 m of low-S (<0.2 wt %) material. High-S materials in the northern area, including a pyritic pod that was penetrated by boreholes N2-0 and N2-2 (fig. 3), were placed more than 6 m above the pit floor. In the southern area, where a dragline was used, high-S materials also were placed near the surface, but underlying materials had intermediate S (0.2 to 0.5 wt %) concentrations. In the middle area, pyritic, high-S materials were randomly distributed from the surface to the pit floor.

Summaries of the acid-base account (ABA) for premining bedrock and postmining spoil data are reported as mass-weighted averages for each area (table 2). Two values of MPA were computed by multiplying total S concentration, in weight percent, by factors of 31.25 (MPA.1; Sobek et al. 1978) and 62.5 (MPA.2; Cravotta et al. 1990). On the basis of bedrock data for the northern and middle areas, average MPA computed by a factor of 31.25 was less than average NP and resulted in positive values of average NNP. Premining bedrock data were not available for the southern area. On the basis of spoil data, MPA computed by either factor resulted in negative values for average NNP for all areas, which could indicate a relative deficiency of alkaline-producing materials (Cravotta et al. 1990). Average NNP for spoil generally decreased northward across the mine (fig. 2, table 2).

Differences between average NNP for premining bedrock and postmining spoil (table 2) in the northern and middle areas are a result of lower average NP for spoil, roughly one-third of that for bedrock in each area. In contrast, average MPA for spoil is similar to that of bedrock. Differences in chemical compositions and minerals in bedrock and spoil probably are an artifact of sampling, reflecting effects of topographic positions of boreholes and premining weathering profiles. Boreholes in bedrock generally were at locations about 10 m higher elevation than comparable boreholes downslope in spoil. A stratum would be expected to be less weathered at greater depths, and calcareous strata generally were situated above high-S strata. Differences between bedrock and spoil also could result from accelerated weathering of carbonates relative to sulfides during the postmining period. However, elevated concentrations of sulfate and alkalinity in ground water from the spoil were observed, which indicates that oxidation of pyrite was active and probably promoted carbonate dissolution (Cravotta et al. 1994).

Table 1. Mineral and chemical content of bedrock samples from borehole N1.

[+ major; ? possible trace; - not detected; < less than; wt %, weight percent; g/kg, grams $CaCO_3$ per kilogram]

Sample depth interval[1]	Lithology[2]	Quartz[3]	Illite	Chlorite	Calcite	Dolomite	Siterite	Mn-siderite	Pyrite	Total sulfur (wt %)	Total carbon (wt %)	Neutralization potential (g/kg)
0.0-1.5	SS+SH	+	+	+	-	-	?	-	-	<0.05	0.11	3
1.5-3.0	SH	+	+	+	-	-	?	-	-	<.05	.16	6
3.0-4.6	SH	+	+	+	-	-	-	-	-	<.05	.14	6
4.6-6.1	SH	+	+	+	-	-	-	-	-	<.05	.39	6
6.1-7.6	SS+SH	+	+	+	-	-	+	-	-	<.05	.22	4
7.6-9.1	SH	+	+	+	-	-	?	-	-	<.05	.35	5
9.1-10.4	ST+SH	+	+	+	-	?	?	-	-	.17	1.04	2
10.4-11.0	CO	+	-	+	-	-	-	-	-	1.63	68.09	-3
11.0-12.2	UC	+	+	+	-	-	+	-	-	.09	.71	5
12.2-13.7	UC	+	+	+	?	?	+	+	-	<.05	.76	11
13.7-15.2	UC	+	+	+	?	+	+	+	-	<.05	.54	7
15.2-16.8	SH+ST	+	+	+	?	+	+	+	-	<.05	2.07	17
16.8-18.3	SH+ST	+	+	+	-	?	+	+	?	<.05	1.76	11
18.3-19.8	SH+ST	+	+	+	+	+	+	+	-	.05	1.02	18
19.8-21.3	SH	+	+	+	+	+	+	+	-	<.05	.68	25
21.3-22.9	SH	+	+	+	-	-	+	+	?	<.05	.42	12
22.9-24.4	SH	+	+	+	+	+	+	+	-	.14	1.87	13
24.4-25.9	SH	+	+	+	-	-	+	-	+	1.71	2.28	3
25.9-27.4	SH	+	-	+	?	+	+	+	+	1.80	2.38	11
27.4-29.0	SH	+	+	+	?	+	+	+	+	.63	2.17	15
29.0-30.2	SH+CO	+	+	+	-	+	?	-	+	3.64	4.15	-5
30.2-30.6	CO	+	+	-	-	-	-	-	+	3.02	69.08	-2
30.6-32.0	UC	+	+	+	-	-	?	-	+	1.04	.61	3
32.0-33.5	UC	+	+	-	-	?	+	+	?	.06	.96	22
33.5-35.1	UC	+	+	+	?	?	-	-	-	<.05	.32	6

[1] Composite sample of drill cuttings from depth interval, in meters from surface, at location of borehole N1 (figs. 1-2).

[2] Lithology determined by hand-specimen analysis: SS = sandstone; ST = siltstone; SH = shale; CO = coal; UC = underclay.

[3] Minerals identified in all samples were combined under the heading, "Quartz." These include quartz, microcline, albite, muscovite, and kaolinite.

Geohydrological Characteristics

Spoil at the mine does not always have greater hydraulic conductivity than premining or underlying bedrock (table 3). Hydraulic conductivities of spoil were more than an order of magnitude greater than those of bedrock at nests N4, M1, M4, and S2; however, conductivities of spoil were slightly less than those of bedrock at nests N2, N3, and M3. Backfill produced by bulldozers and loaders would be expected to have a more uniform particle-size distribution, similar or greater compaction, and lesser hydraulic conductivity than that produced by the dragline (Phelps and Saperstein 1982; Phelps 1983). Air circulation commonly was lost in shallow spoil during drilling in the southern area; however, no air losses occurred in the northern area, indicating greater compaction from bulldozers and loaders than from a dragline. Nevertheless, hydraulic conductivities for saturated mine spoil were similar among the three areas (table 3). For saturated spoil, hydraulic conductivities were from $10^{-8.2}$ to $10^{-3.0}$ m/s, with medians of $10^{-3.8}$ to

$10^{-3.6}$ m/s in each area. The similarity in median hydraulic conductivities of spoil could result from similar lithologies and piping and settling processes (Pionke and Rogowski 1982), by which fines are transported downward and large voids fill or collapse. Mine spoil in the southern area is several years older than that in the northern area, so a longer time has elapsed for these processes to occur.

To avoid contact between acid-forming materials and ground water, the mining plan for the northern area required placement of pyritic materials at least 3 m above the pit floor, so that they would be above the postmining water table. During January-December 1992, saturated thickness of spoil in the northern area ranged from 0.2 to 3.0 m, and across the mine ranged from 0.2 to 6.9 m (table 3). Borehole data for the northern area indicated that pyritic materials were always above the water table (fig. 3). In the southern area, borehole data generally indicated that high-S material was buried above the water table. In the middle area, high-S materials were buried both in the unsaturated zone and on the pit floor (fig. 3). High-S material on the pit floor in the middle area generally is more than 1.5-m thick and lies within the zone of water-table fluctuation.

Table 2. Acid-base-account summaries of area-weighted overburden chemical data.
[Values in g/kg as $CaCO_3$; --, no data; values in parentheses include 56 Mg/ha limestone as alkaline addition.]

Sample type[1]	Neutralization potential (NP)	Maximum potential acidity 31.25[2] (MPA.1)	Net neutralization potential[3] (NNP.1)	Maximum potential acidity 62.5[2] (MPA.2)	Net neutralization potential[3] (NNP.2)
		Northern area			
Bedrock	21.43 (21.59)	18.67	2.76 (2.92)	37.34	-15.91 (-15.75)
Spoil	7.83	15.06	-7.23	30.12	-22.29
		Middle area			
Bedrock	26.95	14.28	12.67	28.56	-1.61
Spoil	8.55	17.05	-8.50	34.10	-25.55
		Southern area			
Bedrock	--	--	--	--	--
Spoil	10.58	12.99	-2.41	25.97	-15.39

[1] Bedrock samples from boreholes 18-1, 23-6, 23-7, and N-1 (fig. 1). Spoil samples from boreholes N2, N3, N4, M1, M2, M3, S1, S2, and S4 (fig. 1). Northern area: 23-6, 23-7, N1, N2, N3, and N4. Middle area: 18-1, 23-6, M1, M2, and M3. Southern area: S1, S2, and S4.

[2] Maximum potential acidity computed by multiplying mass-weighted total sulfur concentration by a factor of 31.25 (MPA.1) or 62.5 (MPA.2) according to methods of Cravotta et al. (1990).

[3] Net neutralization potential computed by subtracting maximum potential acidity from mass-weighted neutralization potential, i.e., NNP.1 = NP - MPA.1 and NNP.2 = NP - MPA.2, according to methods of Smith and Brady (1990).

Table 3. Well construction and hydraulic-conductivity data .
[Values in meters except where noted; --, no data]

Well name[1]	Latitude, north	Longitude, west	Lithology of screened interval[2]	Depth of screened interval	Ground surface elevation	Base of LK-coal elevation[3]	Ground-water head elevation		Values during June 1992[4]		
							Minimum	Maximum	Ground-water head	Saturated thickness	Hydraulic conductivity (m/s)
					Wells screened in spoil						
CK1-1	41°04'23"	79°26'39"	SH+CO?	7.6-14.1	449.75	435.65	--	--	--	--	--
CK2-1	41°04'31"	79°26'41"	SH+CO?	7.6-13.5	446.53	433.06	434.10	434.49	434.10	0.98	9.27E-04
N2-1	41°04'23"	79°26'40"	SH+UC	15.8-19.2	453.78	436.10	436.28	436.47	436.28	.18	6.55E-09
N3-1	41°04'21"	79°26'42"	SH+UC	18.3-21.6	455.15	435.03	435.87	436.20	435.87	.84	2.97E-04
N4-1	41°04'31"	79°26'41"	SH+UC	10.7-14.3	446.83	433.11	434.00	436.15	434.00	.88	1.61E-05
M1-1	41°04'12"	79°26'50"	CO+UC	16.5-19.7	450.32	432.34	433.00	434.45	433.64	1.30	2.79E-05
M2-1	41°04'13"	79°26'51"	CO+UC	17.1-20.4	451.07	431.87	433.19	434.45	433.62	1.75	6.37E-04
M3-1	41°04'12"	79°26'48"	SH+UC	12.5-15.8	446.93	432.29	433.03	434.31	433.47	1.17	1.84E-06
M4-1	41°04'14"	79°26'50"	SH+UC	23.5-26.5	457.60	432.30	433.21	435.07	433.53	1.23	4.27E-04
S1-1	41°04'07"	79°27'03"	SH+UC?	29.3-32.6	460.39	428.38	430.71	432.01	430.93	2.55	3.11E-04
S2-1	41°04'06"	79°26'57"	SH+UC?	18.9-22.3	451.40	430.06	433.11	434.52	433.70	3.64	8.17E-04
S3-1	41°04'00"	79°27'01"	CO+SH	26.5-30.2	461.60	432.65	433.29	434.58	434.41	1.76	1.17E-08
S4-1	41°04'04"	79°26'59"	SH+UC	22.6-26.8	455.69	430.09	434.86	436.96	435.02	4.93	1.00E-05

Table 3. Well construction and hydraulic-conductivity data--Continued.
[Values in meters except where noted; --, no data]

Well name[1]	Latitude, north	Longitude, west	Lithology of screened interval[2]	Depth of screened interval	Ground surface elevation	Base of LK-coal elevation[3]	Ground-water head elevation		Values during June 1992[4]		
							Minimum	Maximum	Ground-water head	Saturated thickness	Hydraulic conductivity (m/s)
					Wells screened in bedrock						
CK1-0	41°04'23"	79°26'39"	ST+CO	18.0-21.3	449.44	435.27	432.81	435.18	433.59	5.49	4.30E-08
CK2-0	41°04'31"	79°26'41"	SH+CO	17.4-21.3	446.53	433.06	432.34	432.60	432.34	7.15	8.32E-06
CK3-0	41°04'27"	79°26'43"	SH+CO	33.5-39.6	463.57	434.04	432.57	433.91	432.75	8.81	--
CK3-1	41°04'27"	79°26'43"	SH+CO	15.2-29.6	463.60	434.04	--	--	--	--	--
CK4-0	41°04'23"	79°26'43"	SH+CO	27.4-33.7	461.40	434.82	432.64	434.13	433.82	6.10	--
CK4-1	41°04'23"	79°26'43"	SH+CO	14.0-26.6	461.34	434.82	445.90	446.93	445.90	11.14	--
N1-0	41°04'26"	79°26'43"	UC	32.0-35.4	463.75	433.12	432.45	433.48	432.64	4.24	6.86E-06
N1-1	41°04'26"	79°26'43"	SH+UC	28.7-32.0	463.76	433.13	433.04	433.36	433.04	1.28	3.84E-08
N2-0	41°04'23"	79°26'40"	UC	20.1-23.3	453.88	436.20	433.47	434.63	433.63	3.06	1.90E-07
N3-0	41°04'21"	79°26'42"	UC	22.6-26.2	455.09	434.97	432.46	433.66	432.65	3.78	7.74E-04
N4-0	41°04'31"	79°26'41"	UC	14.6-19.8	446.77	433.05	432.39	433.47	432.41	5.46	9.39E-07
M1-0	41°04'12"	79°26'50"	UC	21.3-24.5	450.29	432.31	432.99	436.97	433.39	7.64	4.24E-09
M2-0	41°04'13"	79°26'51"	UC	22.6-25.9	451.10	431.90	433.45	434.42	433.45	8.26	--
M3-0	41°04'12"	79°26'48"	UC	18.3-21.3	446.90	432.27	432.89	434.57	433.64	8.07	1.09E-05
M4-0	41°04'14"	79°26'50"	UC	28.7-32.0	457.47	432.17	432.60	434.12	432.84	7.38	2.58E-06
S1-0	41°04'07"	79°27'03"	UC?	33.5-38.4	460.40	428.39	--	--	--	--	--
S2-0	41°04'06"	79°26'57"	UC?	24.1-27.4	451.48	430.15	424.83	427.78	426.17	2.12	2.36E-07
S3-0	41°04'00"	79°27'01"	UC+ST	32.0-35.4	461.88	432.93	427.44	433.01	432.36	5.83	--

[1] Well number indicates location (fig. 1): Prefix "CK" or "N," northern area; "M," middle area; "S," southern area. Suffix "-1," screened within horizon of mined coal; "-0," screened below horizon of mined coal.

[2] Lithology: CO = coal, UC = underclay, SH = shale, ST = siltstone. Queried where lithology uncertain because of incomplete return of drill cuttings or incomplete drill log.

[3] Base of lower Kittanning (LK) coal; in north area, base of the upper split. This elevation corresponds with the elevation of surface-mine floor where mine spoil is present.

[4] Saturated thickness corresponds with zone from ground-water surface down to the base of spoil or screen, if bedrock. Hydraulic conductivity reported using exponential notation, where 9.27E-04 = 0.000927 m/s.

Conclusions

Different methods of mining caused subtle differences in geochemical and geohydrological characteristics of spoil at a reclaimed surface coal mine in western Pennsylvania.

(1) In premining bedrock, a 1.2-m-thick stratum of pyritic shale above the lower Kittanning coal was laterally continuous across the mine. Overlying calcareous strata thinned or were absent in the northern area. Pyrite was the predominant S-bearing mineral; siderite, manganosiderite, and calcareous minerals including calcite and dolomite were the predominant carbonate minerals.

(2) Where bulldozer and loader (northern area) or dragline (southern area) methods were used to emplace backfill, pyritic, high-S materials generally were inverted relative to their stratigraphic sequence in bedrock and were placed above the post-mining water table. However, where mining methods are uncertain (middle area), high-S materials were randomly distributed from the surface to the pit floor, in the zone of water-table fluctuation.

(3) Placement of pyritic materials below a permanent water table would not have been practical at the mine because the saturated zone in spoil was locally <1 m thick. Also, because the saturated thickness of spoil exceeded 6 m in some areas, placement of pyritic materials on 3-m thick benches on the pit floor, as required by the mining plan, would not have been adequate to maintain unsaturated conditions within pyritic pods in some areas.

(4) Mass-weighted average concentration of maximum potential acidity (total S) in spoil was comparable to that in premining bedrock; however, average neutralization potential was about one-third that of bedrock. Differences in the composition of bedrock and spoil probably were an artifact of sampling and also could have resulted from accelerated weathering of carbonates relative to pyrite in spoil. Averages of net-neutralization potential for spoil in each area of the mine were negative and generally decreased northward, indicating a relative deficiency of calcareous minerals and potential for development of acidic ground-water quality, particularly in the northern area.

(5) Hydraulic conductivities of saturated spoil were not always greater than those of underlying bedrock. Hydraulic conductivities of spoil throughout the mine ranged from $10^{-8.2}$ to $10^{-3.0}$ m/s; median values were $10^{-3.8}$ to $10^{-3.6}$ m/s in each of the three areas. Similarity probably results from similar spoil lithologies, aging of the spoil, and effects of piping and settling in each area.

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