HYDROGEOCHEMICAL DATA OF COAL STRIP-MINE SPOIL NEAR MACON IN NORTH-CENTRAL MISSOURI

By Dennis C. Hall

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CONVERSION FACTORS

For readers who prefer to use metric units, conversion factors for terms used in this report are listed below.

Multiply inch-pound unit	By	To obtain metric unit
foot	0.3048	meter
mile	1.609	kilometer

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows: F=9/5 °C + 32.

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ABSTRACT

Hydrologic and geochemical data were collected in or near abandoned strip mines in the vicinity of Macon, Missouri, during 1984 as part of a U.S. Geological Survey regional coal-spoil-geochemistry study. The data, presented in tables, include water-quality analyses of selected wells; analyses of X-ray crystallography and sulfur content of spoil; analyses of paste extract and batch-mixed extract; and analyses of cation-exchange capacity of spoil-material samples. The data may be useful to predict processes controlling composition of ground water in coal strip-mine spoil in a pyrite-carbonate rich, humid environment.

INTRODUCTION

Two reports (Hall and Davis, 1986; and Hall, in press) include descriptions of the hydrology and geochemistry of abandoned coal strip-mine spoil and associated aquifers in the Macon-Huntsville area of north-central Missouri (fig. 1). Climatic, geologic, and hydrologic settings are described in detail in these reports. This report presents data supplemental to previously published reports.

WELLS AND COAL STRIP-MINE SPOIL SITES

Well Q (fig. 1) was completed in glacial drift. Wells 4, 6, 12, 13, and 15 (figs. 1 and 2) were completed in spoil. Well 21 (fig. 2) was completed in alluvium, and well T (fig. 2), a manually dug well, was completed in glacial drift. Wells with identifying numbers were drilled by the U.S. Geological Survey. Well Q was owned by Associated Electric Cooperative, Inc. Well T was owned by H.S. and C.S. Phillips of Macon. Spoil sample sites (fig. 2) were located in spoil produced during 1968.

APPROACH AND RESULTS

Water samples from selected wells were analyzed onsite for specific conductance, pH, water temperature, and bicarbonate and carbonate concentrations (tables 1 and 2 at the back of this report). If a hydrogen sulfide odor was detected, samples were analyzed onsite for hydrogen sulfide concentration. If no odor was detected, samples were analyzed onsite for dissolved-oxygen concentration. Samples also were analyzed by the U.S. Geological Survey Central Laboratory in Denver, Colorado, for selected common- and trace-constituent concentrations. Water samples were filtered through a 0.45-micrometer filter. In addition, water samples analyzed for calcium, magnesium, sodium, silica, aluminum, iron, and manganese were filtered through a 0.10-micrometer filter.

Spoil material was collected below the leached zone (about 4 feet or deeper) at three sites. At each site, three samples were collected from manually dug holes; one near the base of the spoil, one near the top of the spoil, and one midway between the base and the top. Duplicate samples also were collected at one site to provide a basis for determining repeatability of laboratory analyses. The spoil-sample identifiers consist of four characters: The first letter pertains to the State, the first number is the arbitrary mine number, the next letter is the sample-site designation, and the final number is the vertical location number at a site (1 is base of slope, 2 is midslope, and 3 is top of slope). The letter "D" after the four-character spoil-sample identifier indicates duplicate sample; the letter "S" after the four-character spoil-sample identifier indicates a sample split in the laboratory. Nine spoil-material samples, not including duplicates, were collected and analyzed (tables 3 to 6 at the back of this report).

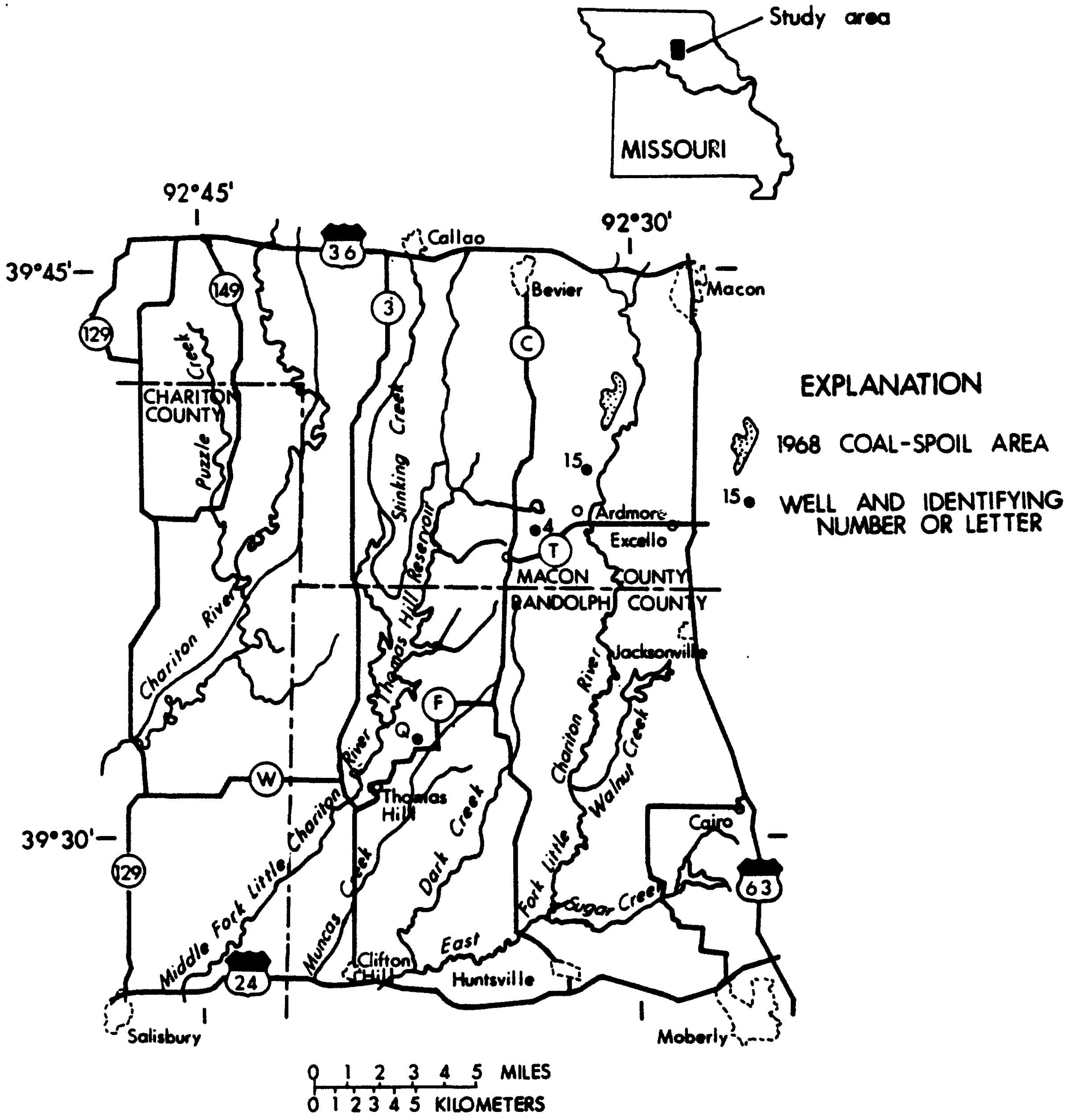

Figure 1.--Study area, 1968 coal-spoil area, and wells 4, 15, and Q.

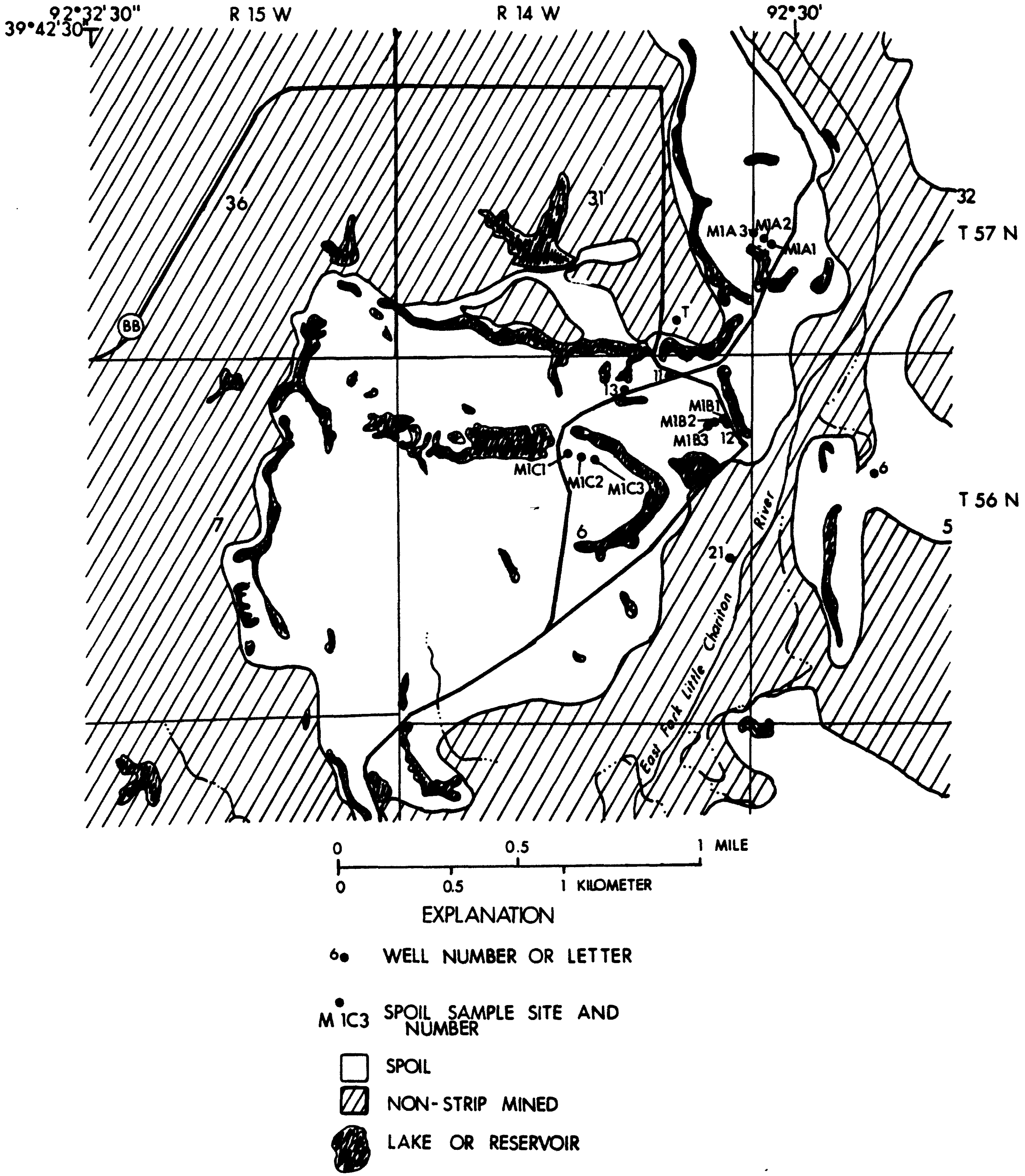

Figure 2.--Wells and spoil sample-collection sites in and near 1968 coal-spoil area.

Each sample was air dried and thoroughly mixed. The sample then was split and part of the sample was sent to the U.S. Geological Survey Geologic Division Laboratory for crushing and grinding. The crushed and ground samples were analyzed for whole-rock and clay mineralogy using X-ray diffraction analysis by the North Dakota Mining and Mineral Resources Research Institute, Grand Forks, North Dakota; for sulfur content by the Geologic Division Laboratory; and for paste-extract composition and cation-exchange capacity (Sanduval and Power, 1977, p. 4-9) by the Minnesota Valley Testing Laboratories, Inc., Bismarck, North Dakota. Distilled water was added to crushed and ground spoil material in a weight ratio of 1:1. After 24 hours of equilibration the samples were centrifuged and the extract was filtered through a 0.1-micrometer filter. The extract was then analyzed. Cation-exchange capacity was determined by adsorption of ammonium ion to spoil from a saturated ammonium-nitrate solution.

The spoil material that was not crushed and ground was used in batch-mixing extractions (Davis, 1984). The extraction procedure was designed to simulate the effect of infiltration of precipitation on the spoil material in the unsaturated zone. Four batches of distilled water used for extraction water, A-D, were made, and used immediately to eliminate storage effects. The pH value of the water was adjusted to 4.70, the average pH of precipitation in the area (Turk, 1983), by adding concentrated hydrochloric acid. In these extractions, distilled water and spoil material were combined in weight ratios of 2:1 and 5:1 (water:spoil material). Mixing was accomplished by affixing the mixture bottles, which were filled to exclude oxygen, to a vertical wheel, 3 feet in diameter, rotating for 2 hours at three revolutions per minute. The mixtures then were allowed to settle and the water filtered through a 0.45-micrometer and a 0.10-micrometer filter after a total contact time of about 24 hours. Temperature, pH, and specific conductance were measured immediately after mixing and settling. The filtrate was analyzed by the U.S. Geological Survey Central Laboratory.

Results of analyses are given as follows: Physical properties and common- and trace- constituent concentrations in water from selected wells are given in tables 1 and 2. Minerals or mineral groups detected in spoil by X-ray diffraction are given in table 3. Analyses of sulfur in spoil material are given in table 4. Analyses of paste extracts, cation-exchange capacity, and batch-mixed extracts of spoil material are given in tables 5 and 6.

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Sanduval, F.M., and Power, J.F., 1977, Laboratory methods recommended for chemical analysis of mined-land spoil and overburden in western United States: U.S. Department of Agriculture, Agriculture Handbook 525, 31 p.

Turk, J.T., 1983, An evaluation of trends in the acidity of precipitation and the related acidification of surface water in North America: U.S. Geological Survey Water-Supply Paper 2249, 18 p.

HYDROGEOCHEMICAL DATA

Table 1.--Physical properties and common-constituent concentrations in water from selected wells

[Constituents are dissolved and concentrations are reported in milligrams per liter unless otherwise indicated; ft, feet; µS/cm, microsiemens per centimeter at 25 °C; °C, degrees Celsius; <, less than; --, no data]

Well number or letter	Aquifer zone	Date	Depth (ft)	Specific conductance (µS/cm)	pH (units)
4	Spoil	7-10-84	50.5	2,870	6.50
6	Spoil	7-11-84	56.1	4,350	6.70
12	Spoil	7-12-84	59.7	2,780	6.82
13	Spoil	7-12-84	47.1	1,940	7.00
15	Spoil	7-11-84	25.2	3,190	5.49
21	Alluvium	7-12-84	30.0	910	6.09
Q	Glacial drift	7-10-84	64.5	1,170	7.30
T	Glacial drift	7-13-84	14.6	326	7.42

Well number or letter	Water temperature (°C)	Dissolved oxygen	Hydrogen sulfide	Calcium	Magnesium	Sodium	Potassium
4	15.4	0.0	0.32	490	130	78	4.9
6	15.7	.0	2.7	590	330	310	18
12	17.4	.0	1.1	280	120	210	13
13	19.3	.0	.08	230	84	150	13
15	15.5	.0	.58	580	240	31	7.0
21	15.3	.0	.37	120	27	44	.6
Q	14.6	.0	4.7	--	--	--	--
T	15.1	6.2	.00	40	8.8	5.5	22

Table 1.--Physical properties and common-constituent concentrations in water from selected wells--Continued

Well number or letter	Bicarbonate	Carbonate	Sulfate	Chloride	Fluoride	Silica
4	770	0	1,400	4.0	0.4	18
6	800	0	2,700	7.0	.4	14
12	450	0	1,400	4.2	.3	8.5
13	300	0	950	3.5	.3	7.3
15	74	0	2,300	2.2	.5	20
21	140	0	400	3.8	.2	26
Q	660	0	--	--	--	--
T	150	0	32	4.3	.3	7.8

Well number or letter	Dissolved solids (calculated sum)	Nitrite, as nitrogen	Nitrite plus nitrate, as nitrogen	Ammonia, as nitrogen	Ammonia plus organic nitrogen, as nitrogen
4	2,500	<0.01	<0.01	0.76	0.70
6	4,360	<.01	.13	1.8	1.9
12	2,260	<.01	<.10	1.7	1.8
13	1,590	.07	.66	2.5	2.3
15	3,220	<.01	<.10	1.2	1.1
21	691	.01	.13	.27	.7
Q	--	--	--	--	--
T	195	<.01	1.5	.08	1.0

Well number or letter	Phosphorus	Orthophosphate, as phosphorus
4	<0.01	0.01
6	.42	.35
12	<.01	.01
13	.34	--
15	.01	.02
21	.01	<.01
Q	--	--
T	.42	--

Table 2.--Trace-constituent concentrations in water from selected wells

[Constituents are dissolved and concentrations are reported in micrograms per liter, unless otherwise indicated; <, less than; --, data not determined]

Well number or letter	Date	Aluminum	Boron	Iron	Manganese	Molybdenum
4	7-10-84	10	230	1,800	2,500	1
6	7-11-84	<10	1,100	3,900	4,200	18
12	7-12-84	20	740	700	1,600	14
13	7-12-84	50	610	160	1,100	5
15	7-11-84	310	360	7,200	13,000	<1
21	7-12-84	20	60	2,700	4,800	<1
Q	7-10-84	--	--	--	--	--
T	7-13-84	30	90	27	17	<1

Well number or letter	Selenium	Strontium	Tritium, (tritium units)
4	<1	1,800	16.2
6	<1	8,600	--
12	<1	430	23.4
13	<1	3,200	--
15	<1	790	29.2
21	<1	460	23.2
Q	--	--	26.7
T	1	160	--

Table 3.--Minerals or mineral groups detected by X-ray diffraction in spoil material

[Units are in percent by weight; spoil-sample identifier consists of four characters: The first letter pertains to the State, the next number is the arbitrary mine number, the next letter is the sample-site designation, and the final number is to the vertical location number at a site (1 is base, 2 is midway, and 3 is top); "D", duplicate sample; <, less than. Analyses were made by the North Dakota Mining and Mineral Resources Research Institute, Grand Forks, North Dakota.]

Spoil-sample identifier	Mixed-layer clays	Smectite	Chlorite	Muscovite illite	Kaolinite	Gypsum	Quartz
M1A1	12	<1	7	6	17	4	25
M1A2	29	<1	7	5	9	6	23
M1A3	1	<1	16	12	30	6	29
M1B1	4	<1	10	4	13	22	21
M1B1-D	7	<1	13	6	23	17	21
M1B2	21	<1	3	2	4	13	24
M1B2-D	1	<1	12	9	28	10	23
M1B3	3	<1	9	9	25	6	24
M1B3-D	1	<1	16	8	26	6	22
M1C1	4	<1	15	15	32	1	24
M1C2	1	10	12	6	28	<1	29
M1C3	4	3	19	11	15	7	21

Spoil-sample identifier	Potassium feldspar	Plagioclase feldspar	Dolomite	Calcite	Pyrite	Total
M1A1	1	5	<1	15	<1	92
M1A2	1	5	<1	3	<1	88
M1A3	<1	6	<1	5	<1	105
M1B1	1	5	1	10	<1	91
M1B1-D	<1	3	1	8	<1	99
M1B2	1	4	1	19	<1	92
M1B2-D	1	6	<1	17	<1	107
M1B3	<1	4	<1	18	<1	98
M1B3-D	<1	4	2	17	<1	102
M1C1	<1	6	<1	2	<1	99
M1C2	4	6	1	5	<1	102
M1C3	1	4	<1	11	<1	96

Table 4.--Analyses of sulfur content in spoil material

[Units are in percent by weight; spoil-sample identifier consists of four characters: The first letter pertains to the State, the next number is the arbitrary mine number, the next letter is the sample-site designation, and the final number is to the vertical location number at a site (1 is base, 2 is midway, and 3 is top); "D", duplicate sample; <, less than]

	Spoil-sample identifier						
Constituent	M1A1	M1A2	M1A3	M1B1	M1B1-D	M1B2	M1B2-D
Total sulfur	0.97	0.72	0.95	1.89	1.94	1.41	1.31
Sulfate sulfur	.19	.32	.19	1.14	1.01	.59	.65
Sulfide sulfur	.48	.24	.51	.58	.68	.66	.50
Organic sulfur (calculated)	.30	.16	.25	.17	.25	.16	.16

	Spoil-Sample identifier				
Constituent	M1B3	M1B3-D	M1C1	M1C2	M1C3
Total sulfur	0.99	0.89	0.36	<0.01	1.72
Sulfate sulfur	.41	.33	.09	.03	.30
Pyritic sulfur	.48	.45	.15	<.01	1.21
Organic sulfur (calculated)	.10	.11	.12	.00	.21

Table 5.--Analyses of paste-extract and cation-exchange capacity of spoil material

[Sample identifier consists of four characters: The first letter pertains to the State, the next number is the arbitrary mine number, the next letter is the sample-site designation, and the final number is the vertical location number at a site (1 is base, 2 is midway, and 3 is top); "D", duplicate sample; "S", sample split in laboratory; μS/cm, microsiemens per centimeter at 25° Celsius; mg/L, milligrams per liter; meq/100g, milliequivalents per 100 grams; <, less than. Analyses were made by the Minnesota Valley Testing Laboratories, Inc., Bismarck, North Dakota]

Spoil-sample identifier	Paste extract pH (units)	Specific conductance (μm/cm)	Extract solution				Cation-exchange capacity using ammonium acetate (meq/100g)
			Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Sulfate (mg/L)	
M1A1	7.02	3,180	440	50	4.1	260	1.0
M1A2	7.35	2,750	520	56	2.9	430	1.1
M1A3	7.57	4,000	520	48	12	480	1.9
M1B1	7.42	1,290	500	43	2.1	710	1.7
M1B1-S	7.40	1,300	500	45	2.0	700	
M1B1-D	6.95	4,110	470	40	2.2	1,100	1.8
M1B1-DS	7.01	4,160	480	40	2.3	1,100	1.8
M1B2	7.36	2,840	590	21	1.3	780	1.6
M1B2-D	7.31	2,920	570	20	1.3	800	1.4
M1B3	7.62	1,750	640	41	1.3	520	1.4
M1B3-S	7.60	1,770	640	40	1.4	540	1.3
M1B3-D	7.42	3,620	290	28	1.2	440	1.7
M1B3-DS	7.41	3,580	280	30	1.2	460	1.6
M1C1[a]	7.00	3,440	140	31	4.1	120	1.8
M1C2	7.41	2,950	230	23	5.6	92	1.9
M1C3	7.52	3,350	150	13	1.0	130	1.1

[a] Extract also analyzed for aluminum (<100), arsenic (<1), iron (5.6), lead (<1), manganese (77), and zinc (168), in micrograms per liter.

Table 6.--Constituent concentrations in batch-mixing extraction water and spoil-material extract solution

[Constituents are dissolved and concentrations are reported in milligrams per liter, unless otherwise indicated; sample identifiers A through D are extractant water, and 1 through 22 are extract solution; "S", duplicate extracts of split sample; spoil-sample identifiers consist of four characters: The first letter pertains to the State, the next number is the arbitrary mine number, the next letter is the sample-site designation, and the final number is the vertical location number at a site (1 is base, 2 is midway, and 3 is top); "D", duplicate sample; µS/cm, microsiemens per centimeter at 25 °Celsius; °C, degrees Celsius; µg/L, micrograms per liter; <, less than; --, not applicable]

Extractant-water sample identifier	Date	Specific conductance (µs/cm)	pH (units)	Water temperature (°C)
A	6-07-84	10	4.72	26.1
B	6-12-84	8	4.70	26.0
C	6-14-84	8	4.72	27.0
D	6-19-84	9	4.73	26.5

Extractant-water sample identifier	Calcium	Magnesium	Sodium	Potassium	Bicarbonate
A	0.10	0.08	<0.2	<0.2	<1
B	.20	<.01	<.2	.1	<1
C	.20	.20	.4	.1	<1
D	.10	.05	.2	.1	<1

Extractant-water sample identifier	Carbonate	Sulfate	Chloride	Fluoride
A	0	<0.2	0.8	<0.1
B	0	<.2	.9	.1
C	0	<.2	.9	.1
D	0	<.2	.9	.1

Table 6.--Constituent concentrations in batch-mixing extraction water and spoil-material extract solution--Continued

Extractant-water sample identifiers	Silica	Dissolved solids (calculated)	Aluminum	Boron	Iron	Manganese	Strontium
A	<0.01	2.6	0.01	<0.01	<0.003	<0.001	0.0007
B	<.01	1.3	.02	<.01	<.003	<.001	.001
C	<.01	1.9	.02	<.01	<.003	<.001	.002
D	<.01	1.4	.01	<.01	.004	<.001	.002

Extract-solution sample identifiers	Date	Extractant water	Spoil-sample identifier	Mixing ratio by weight (water:material)
1	6-07-84	A	M1A1	2:1
1-S	6-07-84	A	M1A1	2:1
2	6-07-84	A	M1A1	5:1
2-S	6-07-84	A	M1A1	5:1
3	6-12-84	B	M1A2	2:1
4	6-12-84	B	M1A2	5:1
5	6-12-84	B	M1A3	2:1
6	6-12-84	B	M1A3	5:1
7	6-12-84	B	M1B1	2:1
8	6-12-84	B	M1B1-D	2:1
9	6-12-84	B	M1B1	5:1
10	6-12-84	B	M1B1-D	5:1
11	6-12-84	B	M1B2	2:1
12	6-12-84	B	M1B2-D	2:1
13	6-12-84	B	M1B2	5:1
14	6-12-84	B	M1B2-D	5:1
15	6-14-84	C	M1B3	2:1
15-S	6-14-84	C	M1B3	2:1
16	6-14-84	C	M1B3	5:1
16-S	6-14-84	C	M1B3	5:1
17	6-19-84	D	M1C1	2:1
18	6-19-84	D	M1C1	5:1
19	6-19-84	D	M1C2	2:1
20	6-19-84	D	M1C2	5:1
21	6-19-84	D	M1C3	2:1
22	6-19-84	D	M1C3	5:1

Table 6.--Constituent concentrations in batch-mixing extraction water and spoil-material extract solution--Continued

Extract-solution sample identifiers	Specific conductance (µS/cm)	pH (units)	Water temperature (°C)	Calcium	Magnesium	Sodium
1	2,840	7.55	26.0	460	160	23
1-S	2,840	7.57	26.0	510	170	26
2	1,680	7.48	26.0	270	78	11
2-S	1,680	7.50	26.0	260	76	11
3	2,770	7.62	25.3	570	160	9.7
4	2,140	7.78	25.4	360	72	4.0
5	2,910	7.74	25.4	430	160	78
6	1,720	7.83	25.3	250	71	33
7	2,890	7.54	25.6	470	150	8.9
8	2,960	7.54	25.7	520	170	11
9	2,610	7.59	25.8	560	92	6.3
10	2,610	7.60	25.8	510	93	5.7
11	2,540	7.50	25.9	570	74	2.9
12	2,530	7.52	25.9	540	71	2.9
13	2,300	7.63	25.9	500	39	2.0
14	2,310	7.62	25.9	530	42	2.0
15	2,310	7.68	25.8	490	110	3.3
15-S	2,680	7.63	26.7	530	110	3.3
16	2,150	7.77	25.7	490	72	2.2
16-S	2,280	7.75	26.5	500	63	2.3
17	1,650	7.44	26.3	240	70	18
18	750	7.85	26.3	96	28	8.3
19	912	7.77	26.5	140	19	24
20	450	7.89	26.4	63	8.6	12
21	2,640	7.54	26.6	550	110	3.7
22	1,890	7.56	26.5	380	54	1.9

Table 6.--Constituent concentrations in batch-mixing extraction water and spoil-material extract solution--Continued

Extract-solution sample identifiers	Potassium	Bicarbonate	Carbonate	Sulfate	Chloride	Fluoride
1	16	33	0	2,000	1.3	0.5
1-S	17	32	0	2,000	1.3	.5
2	9.6	26	0	1,000	1.1	.5
2-S	9.9	29	0	1,000	1.1	.5
3	5.6	36	0	1,800	1.1	.8
4	3.5	27	0	1,200	1.0	.7
5	19	33	0	1,900	1.3	.7
6	9.4	25	0	930	1.2	.6
7	2.1	33	0	1,900	2.3	.7
8	22	52	0	2,000	1.7	.7
9	12	36	0	1,600	1.0	.5
10	14	26	0	1,600	1.0	.6
11	18	58	0	1,600	1.4	.6
12	16	55	0	1,500	1.4	.7
13	10	38	0	1,400	1.0	.6
14	10	36	0	1,400	1.0	.6
15	21	31	0	1,400	1.0	.4
15-S	22	31	0	1,800	1.3	.4
16	14	19	0	1,300	1.0	.4
16-S	14	25	0	1,400	1.0	.4
17	6.2	85	0	910	1.5	1.0
18	3.7	52	0	340	1.2	1.0
19	.5	44	0	440	1.4	1.3
20	.4	37	0	180	1.2	1.5
21	20	34	0	1,800	1.1	1.7
22	11	26	0	1,200	1.1	.6

Table 6.--Constituent concentrations in batch-mixing extraction water and spoil-material extract solution--Continued

Extract-solution sample identifiers	Silica	Dissolved solids (calculated)	Aluminum	Boron	Iron	Manganese	Strontium
1	1.9	2,680	0.02	0.26	0.004	0.11	4.0
1-S	2.5	2,740	.02	.27	.032	.15	4.1
2	1.2	1,380	.02	.17	.004	.057	2.2
2-S	1.5	1,370	.02	.17	.005	.050	2.0
3	3.6	2,570	.02	.23	.033	.006	3.6
4	2.3	1,660	.03	.13	<.003	<.001	1.9
5	1.6	2,610	.01	.34	<.003	.009	3.7
6	1.2	1,310	.01	.21	.004	.008	2.0
7	2.3	2,550	.02	.30	<.003	.026	3.5
8	9.0	2,760	.02	.34	.004	.028	3.9
9	2.1	2,290	.01	.22	.009	.010	3.0
10	2.1	2,240	.01	.21	.009	.006	3.0
11	2.3	2,300	.01	.19	<.003	.007	2.1
12	2.2	2,160	.01	.18	.011	.011	2.0
13	1.6	1,970	.01	.13	<.003	.008	1.5
14	1.6	2,000	.02	.13	.009	.009	1.6
15	2.5	2,040	.02	.24	.005	.006	3.3
15-S	2.6	2,480	.03	.29	.017	.009	3.4
16	2.4	1,890	.02	.20	<.003	.008	2.8
16-S	2.1	2,000	.03	.20	.010	.008	2.7
17	2.1	1,290	.03	.19	.005	.017	1.2
18	1.5	506	.03	.10	.006	.002	.50
19	2.7	871	.02	<.01	<.003	<.001	.31
20	2.4	287	.03	<.01	.007	.002	.15
21	3.0	2,500	.02	.21	.007	.084	2.7
22	2.3	1,660	.03	.13	.006	.043	1.7