UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TRACE METALS IN SURFACE WATER AND STREAM SEDIMENTS OF HEALY AND LIGNITE CREEK BASINS, ALASKA

By Bruce Parks

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Multiply inch-pound unit	by	to obtain SI unit equivalent
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
ton per day per square mile [$(ton/d)/mi^2$]	0.3503	megagram per day per square kilometer [$(Mg/d)/km^2$]
degree Fahrenheit (°F)	(°F-32) 0.555	degree Celsius (°C)
micromho per centimeter at 25° Celsius (µmho/cm at 25°C)	1	microsiemens per centimeter at 25° Celsius (µS/cm at 25°C)
British thermal unit (BTU)	1,055	joule (J)

Other abbreviations in this report are:

mg/L, milligram per liter
µg/L, microgram per liter
µg/g, microgram per gram
µm, micrometer
ppm, parts per million

Note: National Geodetic Vertical Datum of 1929 (NGVD of 1929), the reference surface to which relief features and altitude data are related, and formerly called mean sea level, is herein called sea level.

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ABSTRACT

Coal has been strip-mined in the Healy and Lignite Creek basins of the Nenana coal field. Trace metals concentrations are low in Healy Creek, but are higher in the Lignite Creek basin. Concentrations of trace metals increase as Healy Creek and Sanderson Creek (in the Lignite basin) flow past mined areas, but effects of coal mining cannot be distinguished from those due to a change in lithology or coal outcrop burning. Metals are typically concentrated on the suspended sediment. The source of the trace metals on sediment and in the water is probably the fine-grained Tertiary rock of the coal-bearing group. Local coals do not contain high levels of trace metals. Concentrations of dissolved and suspended trace metals in water and total-recoverable trace metals in the bed material do not present an environmental hazard in the Healy and Lignite Creek basins at this time. Mining does not appear to have had any appreciable effect on the quality of ground water in the basins.

INTRODUCTION

Purpose

Coal can adsorb trace metals during coalification, then release them into the environment when the coals are weathered and exposed to erosion. Trace metals in materials associated with the coals also can be released as these materials are disturbed during mining. The purpose of this study was to determine the concentration, distribution, and possible sources of selected trace metals in surface water and stream sediments of the Healy Creek and Lignite Creek basins in the Nenana coal field, Alaska.

Acknowledgment

The author wishes to thank Dorothy E. Wilcox for her contributions to this report. Ms. Wilcox, who has since resigned from the Geological Survey, conducted field investigations and collected and made preliminary analyses of the data that are the basis of this paper.

Location

The Nenana coal field, the smallest of Alaska's three major coal basins, lies in central Alaska about 200 mi north of Anchorage and 80 mi south of Fairbanks (fig. 1). The coal-bearing strata lie in a belt about 80 mi long and from 1 to 30 mi wide (Wahrhaftig and others, 1969) which parallels the northern foothills of the Alaska Range. The Healy Creek and Lignite Creek basins are the two principal coal-producing areas in the Nenana coal field. The two creeks flow from the center of the coal field westward to the Nenana River, which flows northward into the Tanana River at Nenana.

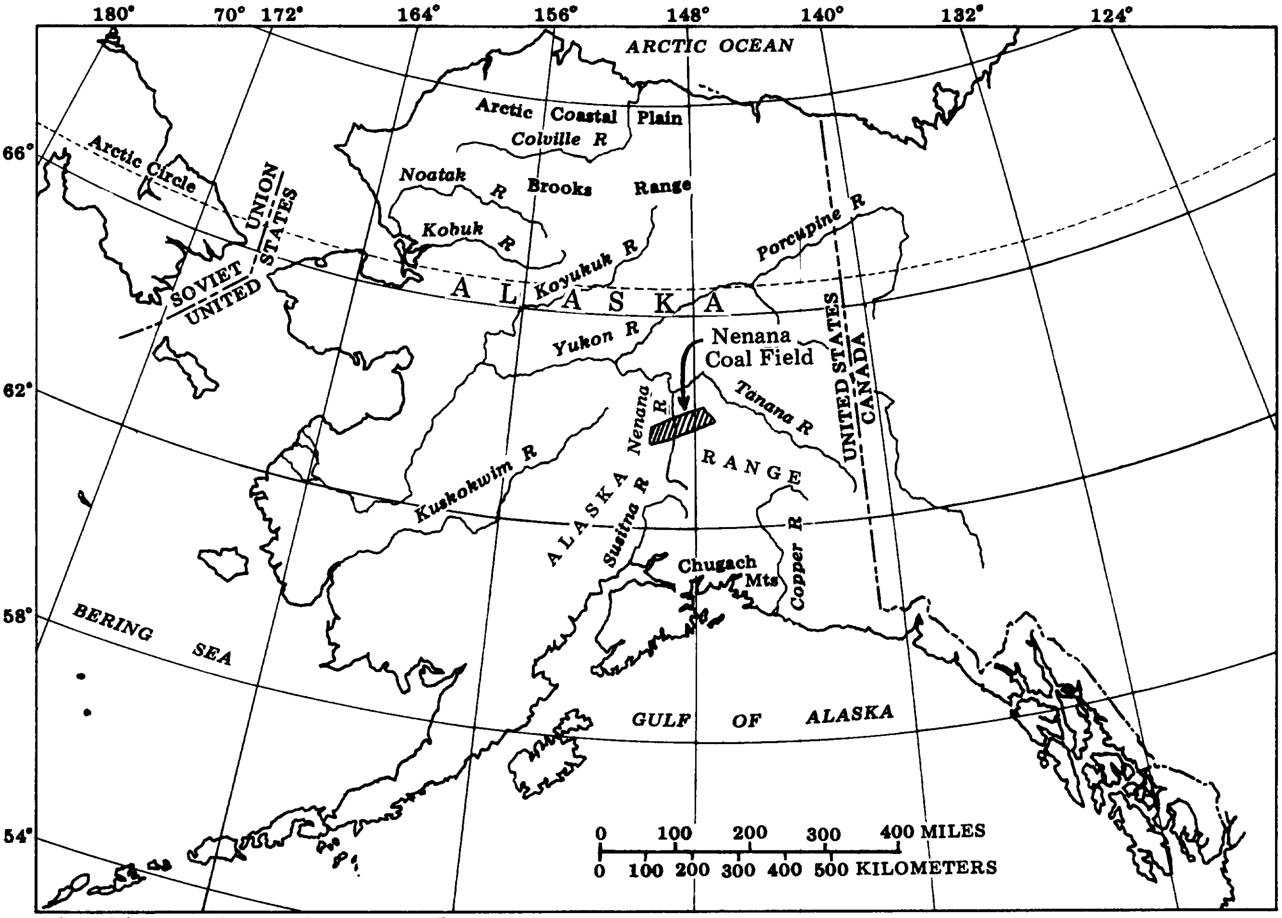


Figure 1.--Location of the Nenana coal field.

Geology

The Healy and Lignite Creek basins are underlain by Precambrian or Paleozoic metamorphic rocks (Wahrhaftig, 1970). In the lower part of the Healy Creek basin and most of the Lignite Creek basin, this basement rock is unconformably overlain by coal-bearing strata of Tertiary age (fig. 2). The coal-bearing material crops out along Healy and Lignite Creeks; in many areas it is overlain by the Nenana Gravel of Tertiary age and by Quaternary deposits.

The coal-bearing formations, which range in age from Oligocene to Miocene, are in east-west striking synclines and are mainly poorly consolidated terrestrial quartz sandstones, siltstones, and claystones, interbedded with coal. Although some abrupt lateral facies changes are present, other strata form thick, laterally persistent beds. Some beds break down easily to cause landslides.

Coal of the Nenana field ranges in thickness from thin partings to beds up to 100 ft thick. Much of the coal is blocky-fractured and sub-bituminous with a low (0.2 percent average) sulfur content, average ash content of 10 percent, and moisture content of 24 percent. Average BTU content is 8030 for Healy Creek coals and about 9000 for Lignite Creek coals (National Research Council, 1977).

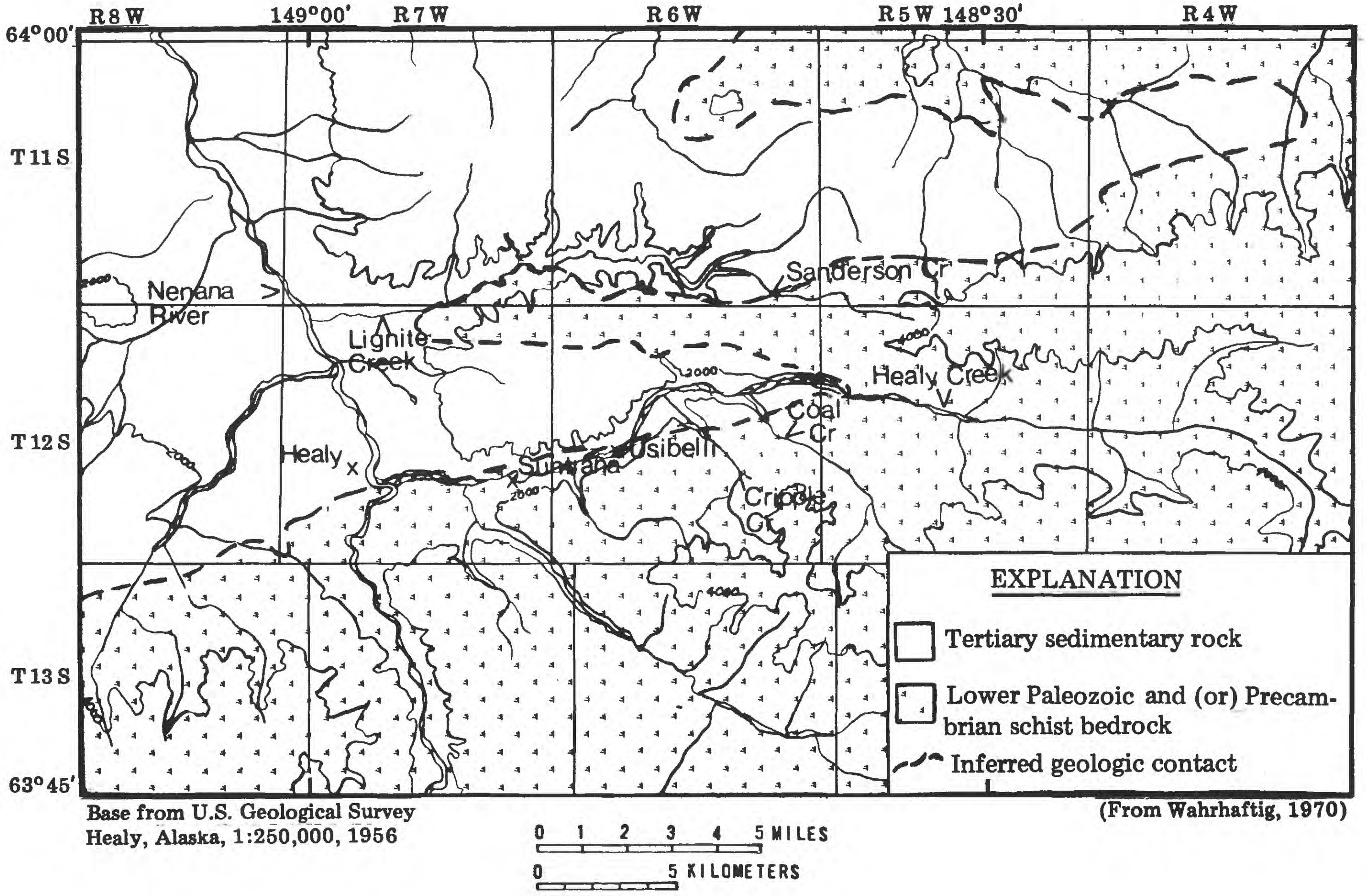


Figure 2.--Generalized bedrock geology in a part of the Nenana coal field.

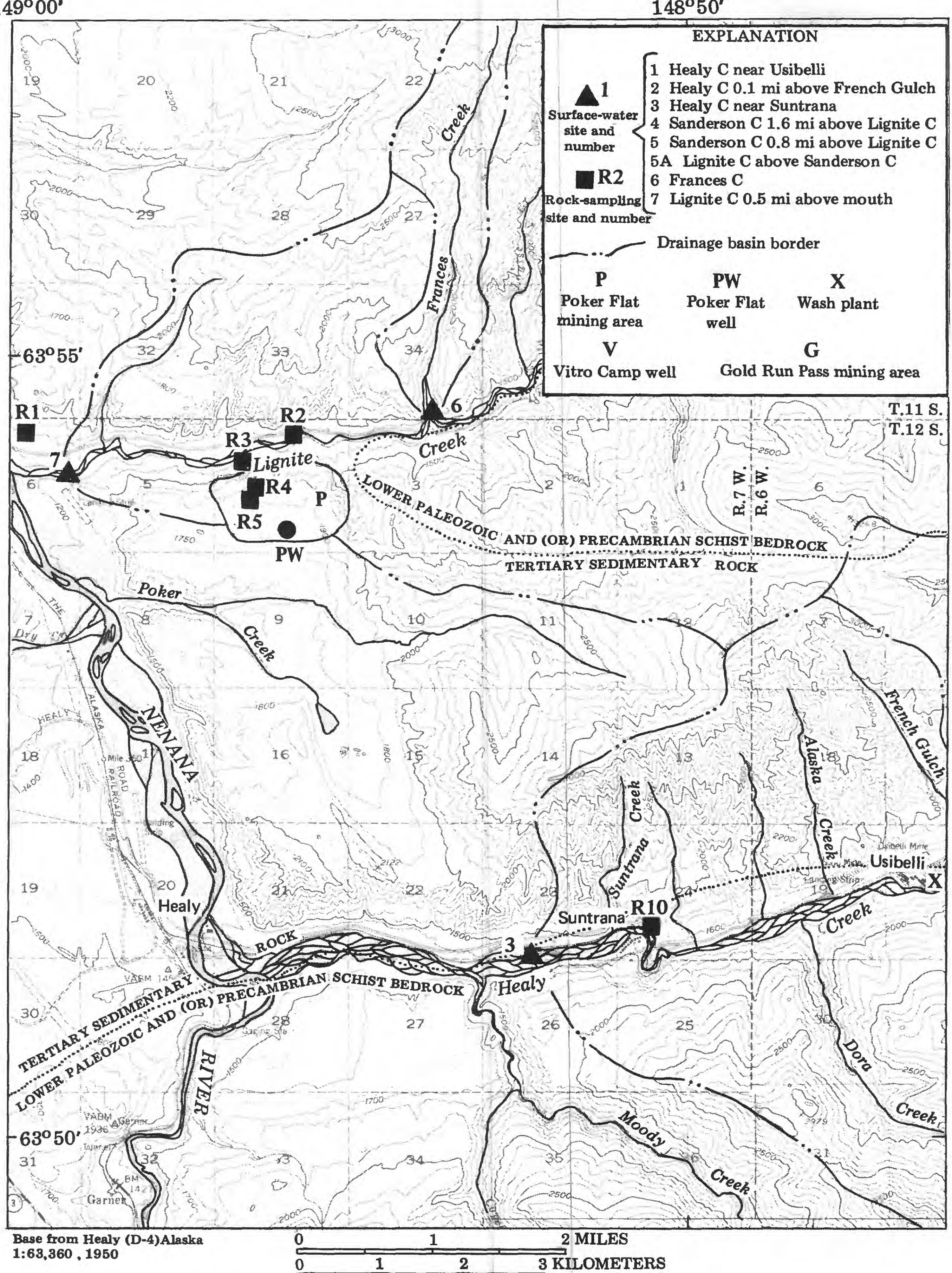


Figure 3.--Location of data-collection sites for this study, generalized bedrock geology, and current mining areas in the Nenana coal field.

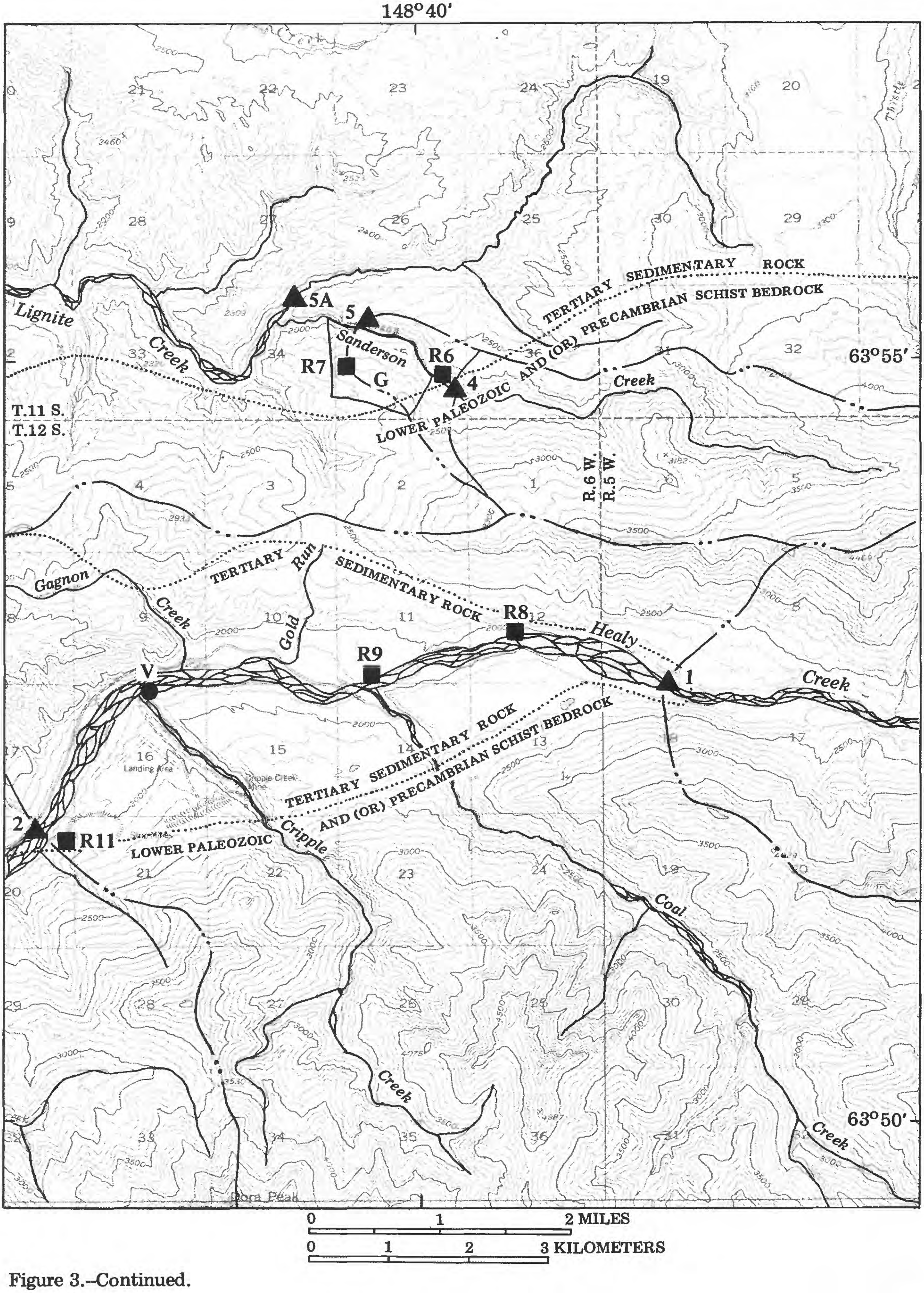


Figure 3.--Continued.

Mining History

Coal mining in the Healy Creek basin began in the 1920's. Early miners used underground methods, but since 1943, when Usibelli Company acquired the mine, strip mining in conjunction with hydraulic mining has been preferred. All underground mining ceased by 1963. Only a small amount of economically strippable coal remains in the Healy Creek coal area.

Mining expanded to the Lignite Creek basin in the 1970's, and two major pits, Gold Run and Poker, were opened (fig. 3). The Gold Run pit on Sanderson Creek is currently inactive but large reserves remain in place. The Poker pit on lower Lignite Creek, the center of mining activity during this study, has a principal coal seam 17 ft thick. The seam lies under 85 ft of overburden, which is removed by dragline and deposited in benches over previously mined areas. Many areas have very steep, unvegetated slopes prior to mining. After mining, the spoil piles are leveled and seeded with grasses and legumes to retard erosion.

A coal washing plant at Usibelli (fig. 3), shut down in 1980 because of environmental restrictions, used settling ponds to reduce the amount of fine coal and sediment that might have otherwise entered Healy Creek. These ponds, however, were located on the flood plain below the plant and fine coal and sediment trapped there are susceptible to erosion during high-water (flood) periods.

Sampling Sites

Samples for analysis of chemical water quality, suspended sediment, and bedload material were collected in 1980 and 1981 at three sites on Healy Creek and four sites on streams in the Lignite Creek basin (fig. 3). The area of the drainage basin above each site and the percentage of the basin covered by rocks of the coal-bearing group or other rocks of Tertiary or Quaternary age are shown in table 1. In the Healy Creek basin, no coal was mined above the upper site (site 1), Healy Creek near Usibelli. Runoff from strip mines east of Usibelli enters Healy Creek above the middle site, Healy Creek 0.1 mi above French Gulch (site 2). Healy Creek near Suntrana (site 3), also called lower site, receives runoff from mined areas in the basin as well as from the wash plant area at Usibelli.

In the Lignite Creek basin, Sanderson Creek abuts the northern edge of the Gold Run pit. Sanderson Creek 1.6 mi above Lignite Creek (site 4, also referred to as the upper site on Sanderson Creek) is above the pit and thus receives no runoff from mined areas. Sanderson Creek 0.8 mi above Lignite Creek (site 5, also called lower site on Sanderson Creek) is downstream from the pit. This site receives overland and channelized runoff from the pit. Site 6, on Frances Creek, drains only the coal-bearing group and overlying gravels; there has been no mining above this site. The lowermost site in the basin, Lignite Creek 0.5 mi above mouth (site 7), receives runoff from both the Poker and Gold Run pit areas.

Few wells have been drilled in the mining area. Only two wells, both of which penetrate the Tertiary sedimentary rocks, were available for sampling (fig. 3). During this study, a water sample was collected from a well at the shower house at Poker pit in Lignite Creek basin. A well at Vitro Camp in Healy Creek basin was sampled in an earlier study of the area (Scully and others, 1981).

Table 1.--Area of drainage basin and area of basin covered by Tertiary sedimentary rocks for the sites in the Healy Creek and Lignite Creek basins

Site No.	Site name latitude and longtitude	Area of drainage basin above site (mi^2)	Area of basin covered by Tertiary sedimentary rocks (percent)
	Healy Creek Basin		
1	Healy Creek near Usibelli 63°53'08, 148°38'20"	61.7	0
2	Healy Creek 0.1 mi above French Gulch 63°51'58", 148°45'27"	94	8
3	Healy Creek near Suntrana 63°51'04", 148°52'59"	109	12
	Lignite Creek Basin		
4	Sanderson Creek 1.6 mi above Lignite Creek 63°54'49", 148°39'28"	4.66	5
5	Sanderson Creek 0.8 mi above Lignite Creek 63°55'13", 148°40'50"	5.06	20
5A	Lignite Creek above Sanderson Creek 63°55'17", 148°42'10"	8.37	68
6	Frances Creek 100 ft above Lignite Creek 63°54'42", 148°53'40"	1.79	100
7	Lignite Creek 0.5 mi above mouth 63°54'17", 148°59'01"	48.1	76

Sampling Procedures

Standard U.S. Geological Survey methods were followed in sample analysis; however, some nonstandard methods were employed in sample collection. In streams deeper than 0.5 ft, a US DH-48 epoxy-coated trace-metal sampler was used in equal-transit-rate traverses to collect water samples for analysis of dissolved-ion, trace-metal, and suspended-sediment concentrations. In shallower streams, an open-mouth bottle was used for sample collection. The water collected from each site was mixed in a 14-liter churn splitter, from which sample splits were obtained.

Bed-material samples were collected each time water samples were collected, except for the April 1981 trip when the streambed was frozen. Spot samples taken near the shores of flowing channels were considered representative of fine bed material for the streams. Although the size of the bed material ranged from silt to boulder, samples were purposely skewed toward collection of fines because many trace elements typically are concentrated on finer sediments. Only the size fraction less than 2 mm in diameter was analyzed for trace metals and coal.

Eleven samples of fine-grained sedimentary rocks in the coal-bearing group were collected from the study area (fig. 3). The samples were analyzed by a procedure that provides a value for the total amount of trace metal available in the rock (table 2). A summary of these analyses, along with analyses of coals from the area (Affolter and other, 1981) and average trace-metal concentrations of various types of rocks (Hem, 1970) are presented in table 3. Metamorphic rocks in the study area were not sampled but may be a source of trace metals.

CHEMICAL QUALITY OF WATER AND SEDIMENTS

Major Ions

The chemical quality of water is similar at the three sampling sites on Healy Creek. Dominant cations are calcium and magnesium; major anions are bicarbonate and sulfate. Although the percentages of major ions are similar at the three sites (fig. 4), the dissolved-solids concentration increased in a downstream direction (table 4). The most marked change in concentrations of major ions occurred between the upper and middle sites, which is also the reach within which mined-area drainage enters the stream. However, the type of rock traversed by Healy Creek changes just downstream from the upper site, so the cause of the increase in dissolved-solids concentration -- runoff from mined areas or the addition of water draining from Tertiary sediments in the lower part of the basin -- cannot be determined from available data.

Analyses of samples from the Lignite Creek basin indicate that the chemical character of water from different parts of the basin varies dramatically. The percentages of major ions--magnesium, calcium, and sulfate--are similar in samples from the two sites on Sanderson Creek (fig. 5). A slight decrease in pH and in concentration of several ions was detected, however, between the upper and lower sites (table 5). These waters contain the highest concentrations of sulfate determined in this study but are otherwise chemically similar to the water of Healy Creek. The chemical composition of water in Frances Creek is comparable to that in Lignite Creek above Sanderson Creek (site 5A, figs. 3 and 5) sampled in another

Table 2.--Trace metals in fine-grained sedimentary rocks in the coal-bearing group

[See figure 3 for sample locations]

Sample No.	Iron ($\mu g/g \times 10^4$)	Manganese ($\mu g/g$)	Nickel ($\mu g/g$)	Lead ($\mu g/g$)	Zinc ($\mu g/g$)
R1	3.27	412	62	20	107
R2	1.47	123	25	30	33
R3	1.08	78	18	30	35
R4	1.47	127	35	30	93
R5	4.11	1310	54	20	73
R6	0.83	72	21	30	85
R7	6.37	802	47	50	108
R8	5.84	1950	68	30	144
R9	2.80	296	61	20	101
R10	3.93	655	58	20	132
R11	2.00	215	39	40	122
Average	3.02	549	44	29	94

Table 3.--Trace metals in Healy coals, fine-grained rocks from the coal-bearing group and "average" igneous rocks, sandstones, and shales

Rock type	Iron ($\mu g/g \times 10^4$)	Lead ($\mu g/g$)	Manganese ($\mu g/g$)	Nickel ($\mu g/g$)	Zinc ($\mu g/g$)
Average igneous rocks[1]	4.2	16	937	94	80
Average sandstone[1]	1.9	14	392	2.6	16
Average shale[1]	3.9	80	575	29	130
Healy coals:[2]					
Mean	0.38	5.4	88	10	14
Range	0.12-0.84	< 2-15	6.1-220	5-30	2.3-46
Fine-grained sedimentary rocks, Healy area:					
Mean	3.0	29	549	44	94
Range	0.83-6.37	20-50	72-1950	18-68	33-144

[1] Hem (1970, p.7).
[2] Affolter and others (1981).

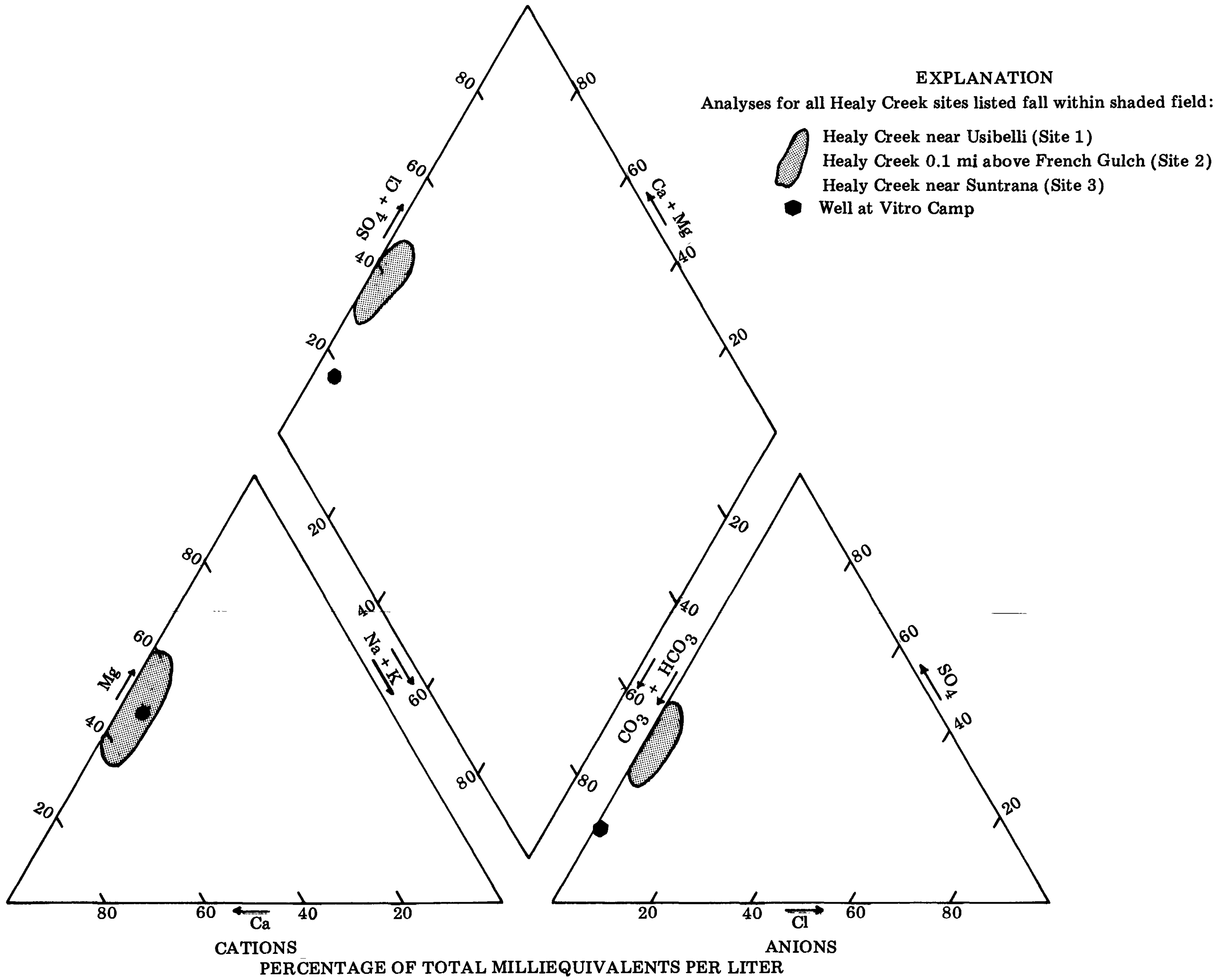


Figure 4.--Trilinear diagram of water-quality analyses in the Healy Creek basin. (See figure 3 for site location.)

Table 4.--Concentration of major ions in and physical properties of water, Healy Creek basin

[Constituents measured in milligrams per liter, except as noted]

Station name and USGS identification number	Date	Streamflow, instantaneous (ft³/s)	Specific conductance (μmho/cm at 25°C)	Temperature (°C)	pH	Solids, residue 180 °C dissolved	Silica, dissolved (SiO_2)	Hardness ($CaCO_3$)	Hardness, noncarbonate ($CaCO_3$)	Calcium, dissolved	Magnesium, dissolved	Sodium, dissolved	Potassium, dissolved	Alkalinity, field ($CaCO_3$)	Sulfate, dissolved	Chloride, dissolved	Fluoride, dissolved	Nitrogen NO_2+NO_3 dissolved (N)
Healy Creek	1980																	
near Usibelli	May 22	64	445	7.5	8.4	---	---	---	---	---	---	---	---	140	---	---	---	---
(635308148382000)	July 09	65	475	12.0	8.2	272	---	---	---	---	---	---	---	140	---	---	---	---
	Aug. 29	93	530	6.5	8.6	328	2.7	270	86	59	30	3.7	0.8	180	120	3.6	0.1	0.22
	Sept. 22	127	553	2.5	8.4	292	3.8	260	120	58	28	3.5	1.0	140	110	4.0	.1	.37
	1981																	
	Apr. 03	54	422	2.0	8.0	281	4.2	230	100	58	21	5.2	.9	160	92	5.4	.0	---
	June 11	61	438	9.5	8.4	258a	---	230	58	55	22	4.9	---	170	93	5.6	---	---
	July 29	105	455	9.0	8.4	268a	---	250	81	56	27	3.8	---	170	100	3.2	---	---
	Sept. 11	101	441	7.0	8.2	260a	---	310	140	58	40	4.1	---	170	110	11	---	---
Healy Creek	1980																	
0.1 mi above	May 23	108	500	8.0	8.4	---	---	---	---	---	---	---	---	160	---	---	---	---
French Gulch	July 09	95	530	12.5	8.3	292	---	---	---	---	---	---	---	160	---	---	---	---
near Usibelli	Aug. 29	177	580	6.5	8.6	338	2.6	340	140	58	47	4.0	1.2	200	140	3.4	.1	.23
(635158148452700)	Sept. 23	203	675	1.5	8.6	375	3.8	330	120	57	45	3.9	1.2	210	120	3.2	.1	.85
	1981																	
	Apr. 03	61	487	.5	7.8	299	4.7	250	110	58	25	6.9	1.0	170	100	6.8	.0	---
	June 12	98	485	8.5	8.3	276a	---	260	68	52	31	5.2	---	190	100	4.8	---	---
	July 29	193	510	9.0	8.4	290a	---	290	75	52	40	4.0	---	220	100	2.8	---	---
	Sept. 11	142	529	9.0	8.2	301a	---	310	100	59	40	4.7	---	210	110	3.8	---	---
Healy Creek	1980																	
near Suntrana	May 23	118	500	9.5	8.2	---	---	---	---	---	---	---	---	160	---	---	---	---
(635104148525900)	July 08	117	530	14.0	8.2	310	---	---	---	---	---	---	---	160	---	---	---	---
	Aug. 28	179	625	9.0	8.4	373	2.7	340	140	58	47	4.0	1.2	200	130	3.0	.1	.23
	Sept. 23	226	675	2.0	8.6	364	3.8	330	120	57	46	3.5	1.2	210	130	3.0	.1	.48
	1981																	
	Apr. 02	70	501	.0	7.8	314	4.7	250	100	58	26	6.7	1.0	180	100	6.8	.1	---
	June 12	93	508	12.0	8.4	300a	---	270	73	55	33	5.2	---	200	110	4.7	---	---
	July 29	215	497	9.5	8.4	293a	---	300	87	53	40	4.0	---	210	100	2.5	---	---
	Sept. 11	147	547	9.0	8.2	323a	---	310	95	60	40	4.3	---	220	120	3.2	---	---
Vitro Camp near	1975																	
Usibelli (Well)	Sept. 17	---	255	1.0	7.2	165	15	140	18	30	16	2.2	1.2	120	25	0.6	0.1	.02
(635305148440001)																		

a Calculated using specific conductance value

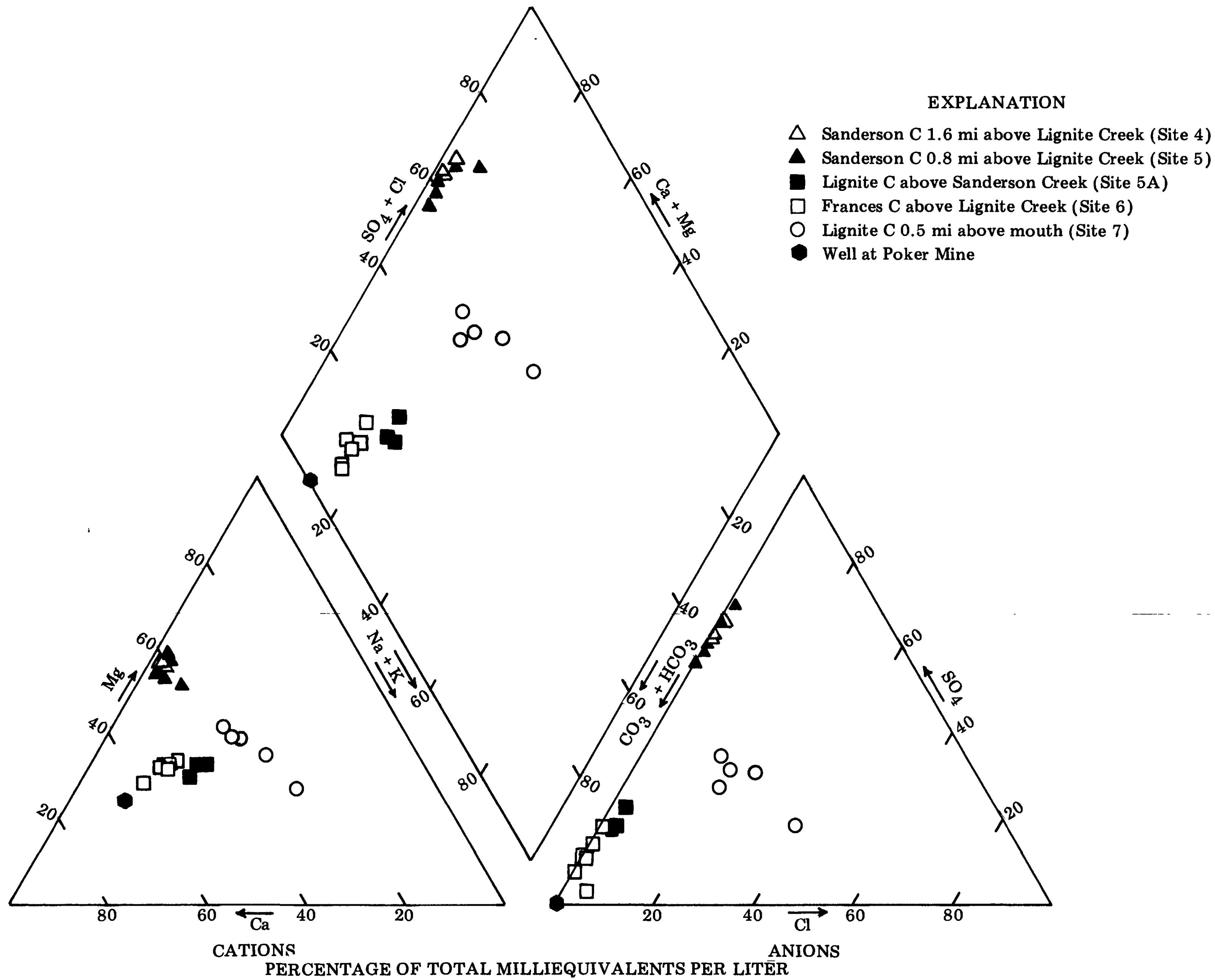


Figure 5.--Trilinear diagram of water-quality analyses in the Lignite Creek basin. (See figure 3 for site location.)

Table 5.--Concentration of major ions in and physical properties of water, Lignite Creek basin

[Constituents measured in milligrams per liter, except as noted]

Station name and USGS identification number	Date	Streamflow, instantaneous (ft³/s)	Specific conductance (μmho/cm at 25°C)	Temperature (°C)	pH	Solids, residue 180 °C dissolved	Silica, dissolved (SiO_2)	Hardness ($CaCO_3$)	Hardness, noncarbonate ($CaCO_3$)	Calcium, dissolved	Magnesium, dissolved	Sodium, dissolved	Potassium, dissolved	Alkalinity, field ($CaCO_3$)	Sulfate, dissolved	Chloride, dissolved	Fluoride, dissolved	Nitrogen NO_2+NO_3 dissolved (N)
Lignite Creek	1977																	
above Sanderson	Aug. 04	5.4	180	17.0	7.6	125	19	81	6	20	7.5	9.3	1.4	75	22	2.2	0.1	---
Creek near	Nov. 01	5.4	205	0.0	6.7	141	21	90	0	21	9.1	10	1.3	107	23	2.1	.1	---
Usibelli	1978																	
(635517148421000)	Sept. 07	6.5	160	7.0	7.5	111	16	70	1	16	7.4	8.9	1.2	69	15	1.7	.1	---
Lignite Creek	1980																	
0.5 mi above	May 22	45	470	4.0	7.8	---	---	---	---	---	---	---	---	90	---	---	---	---
mouth near	July 08	20	585	15.0	8.2	331	---	---	---	---	---	---	---	130	---	---	---	---
Healy	Aug. 28	34	575	8.0	8.2	324	7.1	200	---	38	26	31	4.0	---	83	39	.3	0.22
(635417148590100)	Sept. 22	61	539	1.5	8.0	284	8.8	190	59	35	24	22	3.4	130	81	27	.3	1.5
	1981																	
	Aug. 02	9.0	825	.0	6.6	451	18	220	50	45	26	72	6.5	200	70	110	.2	---
	June 10	27	568	15.5	8.2	312a	---	200	54	39	26	48	---	150	100	58	---	---
	July 29	31	625	14.0	7.8	344a	---	200	---	39	26	51	---	---	83	65	---	---
	Sept. 11	35	510	9.0	7.8	280a	---	200	38	38	25	30	---	160	79	40	---	---
Frances Creek	1980																	
100 ft above	July 08	.06	260	18.0	8.2	148	---	---	---	---	---	---	---	104	---	---	---	---
Lignite Creek	Aug. 28	.29	230	10.0	8.2	144	13	100	0	24	9.7	8.4	1.1	110	15	.2	.1	.18
near Suntrana	Sept. 22	.09	244	2.0	8.0	141	18	97	0	23	9.6	8.1	1.3	105	17	.5	.1	.71
(635442148534000)	1981																	
	Apr. 02	.03	420	.5	7.8	284	32	200	1	54	16	13	2.3	240	26	.6	.2	---
	June 10	.21	170	17.5	7.8	105a	---	81	0	20	7.6	7.2	---	100	22	.3	---	---
	July 29	.11	220	12.5	7.9	136a	---	110	0	26	10	9.0	---	120	12	.1	---	---
	Sept. 11	.16	210	9.0	7.8	130a	---	100	0	26	9.7	8.1	---	120	5.0	5.2	---	---
Sanderson Creek	1980																	
0.8 mi above	May 23	4.4	630	4.0	7.9	---	---	---	---	---	---	---	---	110	---	---	---	---
Lignite Creek	July 09	3.3	680	10.0	7.5	485	---	---	---	---	---	---	---	140	---	---	---	---
near Usibelli	Aug. 28	12	720	8.5	8.3	464	2.1	380	210	62	54	4.9	1.9	170	210	.1	.5	.10
(635513148405000)	Sept. 22	13	723	2.5	8.0	442	3.5	350	200	62	48	4.3	1.6	150	210	.7	.6	.26
	1981																	
	Apr. 03	.24	1486	.0	7.5	1130	9.0	800	550	140	110	34	5.6	310	560	6.5	.7	---
	June 11	3.7	734	7.5	8.0	499a	---	410	260	72	56	8.3	---	150	280	1.4	---	---
	July 30	4.5	802	9.0	7.5	545a	---	430	---	76	59	8.0	---	---	270	.7	---	---
	Sept. 12	5.1	784	5.5	7.5	533a	---	450	250	76	62	7.0	---	200	280	.7	---	---
Sanderson Creek	1981																	
1.6 mi above	June 11	3.1	755	9.0	8.1	513a	---	420	260	71	58	6.7	---	160	300	1.5	---	---
Lignite Creek	July 30	4.2	840	8.5	7.8	571a	---	480	---	78	70	5.9	---	---	300	.8	---	---
near Usibelli	Sept. 12	4.2	822	5.0	7.8	559a	---	480	290	81	68	4.7	---	190	300	1.1	---	---
(635449148392800)																		
Poker Mine	1981																	
shower house	June 10	---	423	14.0	7.7	---	---	210	0	62	14	12	---	290	.7	.5	---	---
(well)																		
(635327148542201)																		

a Calculated using specific conductance value study (Scully and others, 1981); streamflow at both these stations is derived from runoff from unmined areas of the coal-bearing group. Major cations are calcium and magnesium and the major anion is bicarbonate. The water also contains a significant amount of sodium (about 20 percent of the cations). The major-ion composition of Lignite Creek 0.5 mi above the mouth appears to be a mixture of the two types of water found in the mined and unmined parts of the basin, but it has higher concentrations of sodium and chloride than any of the contributing water sampled. No specific sources for the sodium and chloride have been identified.

Water from the two wells sampled--at Vitro Camp (fig. 4) and at Poker Mine (fig. 5)--is a calcium bicarbonate type. The well water at Poker Mine has less magnesium than any other water sampled in this study and contains virtually no sulfate or chloride. Its chemical composition is similar to the sample collected from Frances Creek (unmined area) at low flow (April 2, 1981), when ground water was the primary contributor to streamflow. The well water at Vitro Camp has cation percentages similar to those of Healy Creek but the well has a high percentage of bicarbonate and only half the percentage of sulfate. These data indicate that locally, mining has affected ground-water quality only slightly, if at all.

Suspended Sediment

Fine-grained sediment has a large surface area that can adsorb ions from solution. Changes in pH, Eh, or water temperature can cause ions to move from the dissolved state to the adsorbed state and back to the dissolved state. Adsorption by sediment plays an important role in the transport of trace elements. Concentrations of suspended sediment for sites in the Healy Creek and Lignite Creek basins are shown in table 6. Graphs of suspended-sediment concentrations versus discharge show little or no relation, with the exception of data from the Frances Creek site (figs. 6, 7, and 8).

Suspended-sediment concentration is plotted against discharge for the sites on Healy Creek in figure 6. Although considerable overlap exists in the ranges of suspended sediment and discharge for the three sites, the concentration of suspended sediment generally increased in a downstream direction on each sampling trip. It commonly nearly doubled between the middle and lower sites. This increase may be attributed largely to the lithologic change to Tertiary sediments below the upper site, but it may be affected to some extent by runoff from areas disturbed by mining activities.

Suspended sediment is plotted against discharge for the Sanderson Creek sites in figure 7. The data show a seven- to ten-fold increase in the suspended-sediment concentration from above to below the Gold Run pit each time sites 4 and 5 were sampled concurrently. The suspended-sediment versus discharge plots for Frances Creek and Lignite Creek are shown in figure 8.

Coal in Bed Material

Concentrations of coal in samples of bed material ranged from 1 to 41 μg/g (table 7). The highest values determined were for the Sanderson Creek site directly below the Gold Run pit. The presence of silt and clay in bed material can interfere with the analysis for coal and can cause an anomalously high concentration of coal to be

Table 6.--Trace metals and suspended-sediment concentrations in water, Healy and Lignite Creek basins

[Constituents in micrograms per liter, except as noted]

Station name and USGS identification number	Date	Iron, dis-solved	Iron, sus-pended	Lead, dis-solved	Lead, sus-pended	Manga-nese, dis-solved	Manga-nese, sus-pended	Nickel, dis-solved	Nickel, sus-pended	Zinc, dis-solved	Zinc, sus-pended	Sus-pended sed-iment (mg/L)
Healy Creek	1980											
near Usibelli	May 22	20	130	45	22	10	10	0	3	10	10	2
(635308148382000)	July 09	10	1800	5	10	10	40	0	4	0	40	93
	Aug. 29	40	490	0	0	10	10	3	0	10	0	17
	Sept. 22	50	1050	0	4	20	0	0	5	20	60	87
	1981											
	Apr. 03	10	370	0	4	4	16	0	3	30	0	2
	June 11	10	90	1	4	3	7	2	0	7	0	2
	July 29	10	1300	0	5	1	29	0	3	6	4	67
	Sept. 11	10	170	0	9	1	10	0	1	20	0	6
Healy Creek	1980											
0.1 mi above	May 23	20	2180	42	14	10	50	0	95	10	10	126
French Gulch	July 09	20	1580	0	16	10	30	1	4	10	10	51
near Usibelli	Aug. 29	80	800	0	1	20	10	3	0	10	20	20
(635158148452700)	Sept. 23	30	3570	3	7	10	60	0	12	130	210	132
	1981											
	Apr. 03	10	3100	0	1	5	55	3	2	10	30	53
	June 12	10	210	1	3	3	7	2	0	4	0	7
	July 29	10	3000	2	4	3	67	0	6	8	2	112
	Sept. 11	10	780	0	18	1	20	1	0	3	20	19
Healy Creek	1980											
near Suntrana	May 23	10	3490	34	9	30	130	0	13	0	30	368
(635104148525900)	July 08	10	6590	6	5	20	140	1	7	10	20	354
	Aug. 28	50	2750	0	4	20	70	5	1	50	0	101
	Sept. 23	30	4570	0	8	20	80	0	13	0	110	232
	1981											
	Apr. 02	10	3290	0	3	10	10	0	7	5	45	86
	June 12	10	450	2	2	20	10	2	0	10	0	19
	July 29	10	9300	0	6	12	248	0	10	8	42	439
	Sept. 11	10	730	0	12	15	15	3	0	3	17	19
Vitro Camp near	1975											
Usibelli (well)	Sept. 17	6500	0	---	100a	910	90	---	50a	---	360a	---
(635305148440001)												
Lignite Creek	1980											
0.5 mi above	May 22	50	56000	46	26	190	1100	7	87	10	340	2580
mouth near Healy	July 08	50	15000	17	13	210	240	7	23	20	120	1220
(635417148590100)	Aug. 28	110	16000	0	12	270	240	12	31	10	140	485
	Sept. 22	80	16000	0	14	190	310	8	33	10	230	804
	1981											
	Apr. 02	90	460	0	2	300	0	16	3	70	0	2
	June 10	40	12000	1	14	250	240	14	18	10	90	308
	July 29	56	11000	0	9	290	220	9	20	9	91	443
	Sept. 11	48	5800	1	14	250	100	16	11	15	95	110
Frances Creek	1980											
100 ft above	July 08	50	950	5	7	120	20	0	4	10	10	77
Lignite Creek	Aug. 28	70	1400	0	5	130	30	4	2	20	50	---
near Suntrana	Sept. 22	100	410	2	4	120	0	0	9	110	0	---
(635442148534000)	1981											
	Apr. 02	40	120	0	1	60	0	2	1	20	10	6
	June 10	90	48000	1	21	80	850	2	77	4	186	2250
	July 29	84	6100	0	4	120	120	1	10	11	19	390
	Sept. 11	38	3200	0	10	110	70	2	3	18	12	224
Sanderson Creek	1980											
0.8 mi above	May 23	20	32000	51	8	500	500	27	73	30	310	1270
Lignite Creek	July 09	40	5100	4	9	580	30	33	9	40	150	136
near Usibelli	Aug. 28	70	13000	0	13	310	190	22	38	170	210	343
(635513148405000)	Sept. 22	40	8500	3	6	410	80	38	16	130	300	215
	1981											
	Apr. 03	260	330	2	2	2200	100	65	1	190	10	3
	June 11	20	4500	1	8	510	40	42	7	60	110	119
	July 30	28	7000	2	13	540	60	34	24	82	260	132
	Sept. 12	10	8200	0	1	680	50	52	27	68	330	108
Sanderson Creek	1981											
1.6 mi above	June 11	10	1900	1	7	300	20	48	2	50	140	9
Lignite Creek	July 30	10	4600	0	2	380	0	42	15	58	300	15
near Usibelli	Sept. 12	10	6300	0	9	550	20	70	24	72	420	11
(635449148392800)												
Poker Mine shower	1981											
house (well)	June 10	170	1500	1	7	550	0	1	0	340	80	---
(635327148542201)												

a Total-recoverable concentration

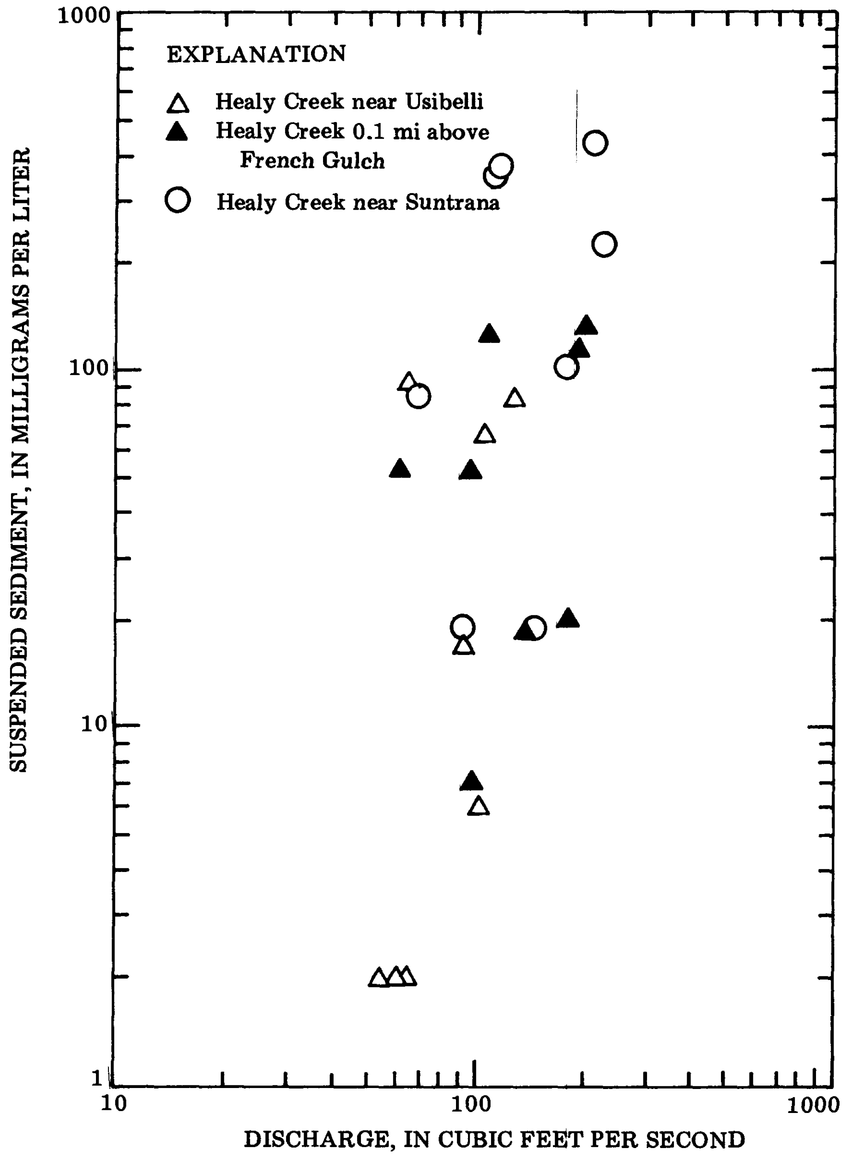


Figure 6.--Suspended sediment plotted against discharge for the Healy Creek sites.

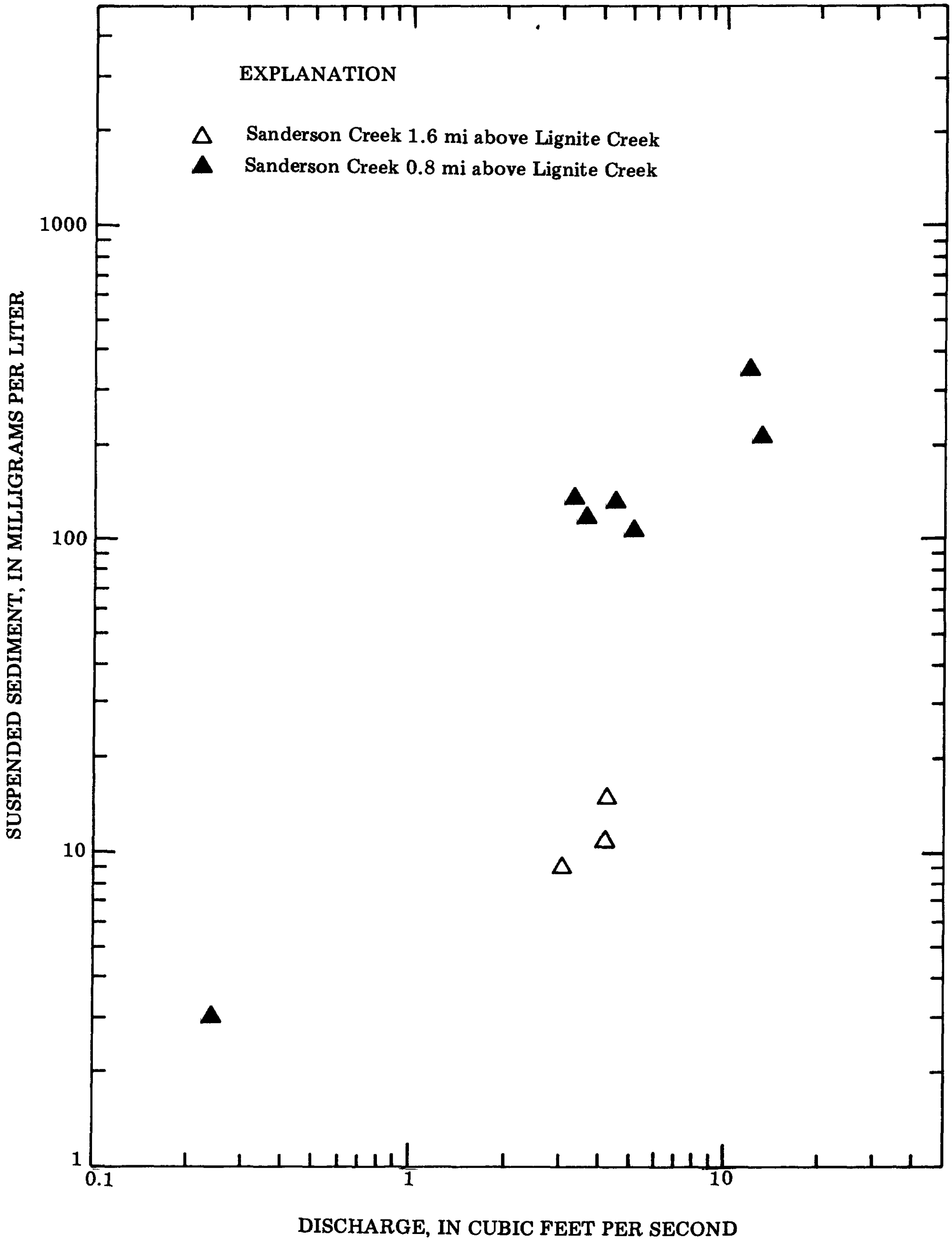


Figure 7.--Suspended sediment plotted against discharge for sites above and below Gold Run mine pit on Sanderson Creek.

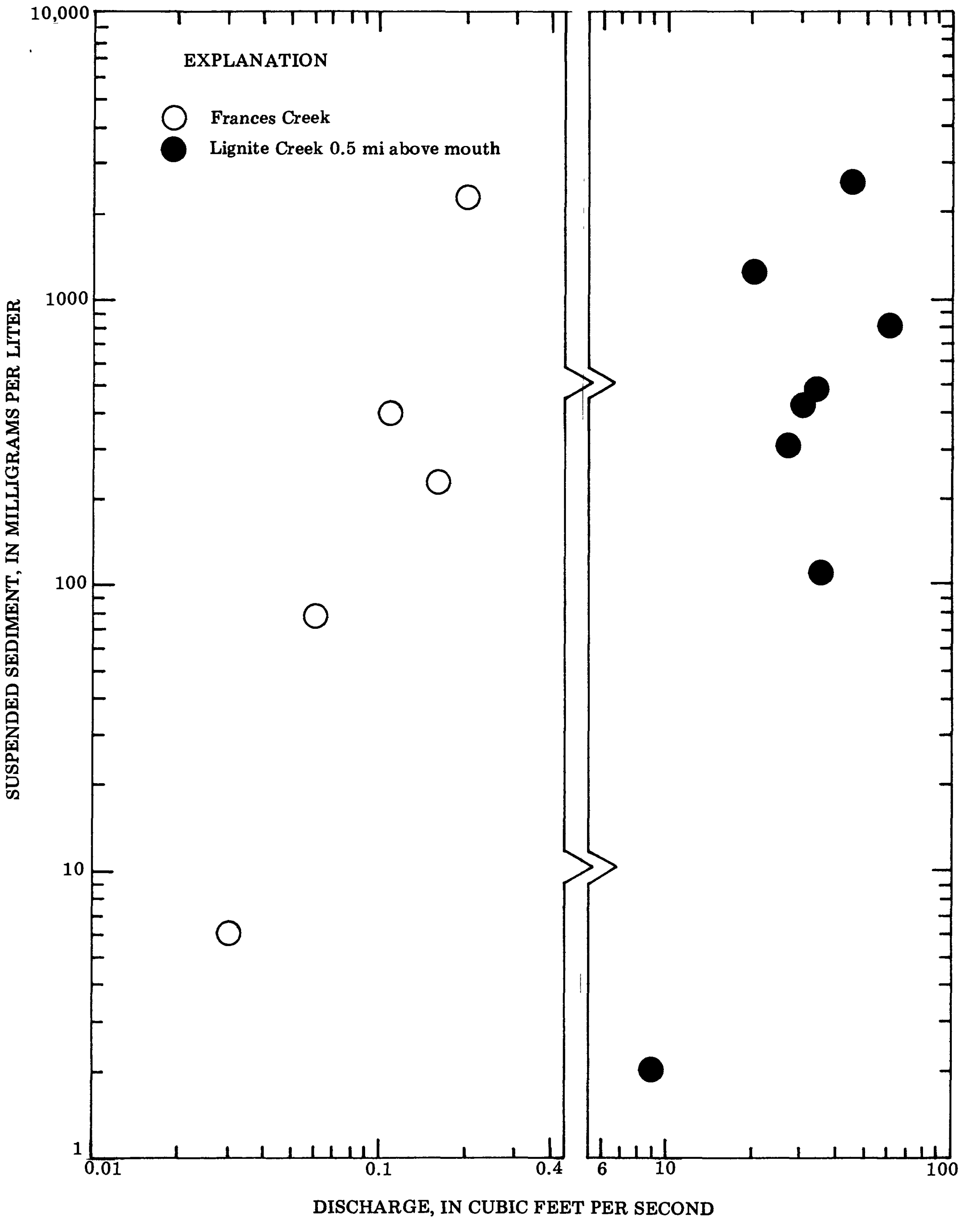


Figure 8.--Suspended sediment plotted against discharge for Frances Creek and Lignite Creek 0.5 mile above mouth.

Table 7.--Trace metals and coal in bed material, Healy and Lignite Creek basins

[Constituents in micrograms per gram]

Station name and USGS identification number	Date	Trace metals recoverable from bed material: Iron	Lead	Manganese	Nickel	Zinc	Coal, in bed material
Healy Creek near Usibelli (635308148382000)	1980						
	May 22	18000	10	340	30	40	9
	July 09	4600	10	160	10	18	6
	Aug. 29	11000	20	330	20	36	3
	Sept. 22	5500	10	200	10	24	5
	1981						
	June 11	6000	10	150	10	26	8
	July 29	7000	10	210	15	44	8
	Sept. 11	10000	10	370	15	28	7
Healy Creek 0.1 mi above French Gulch near Usibelli (635158148452700)	1980						
	May 23	16000	10	350	30	40	1
	July 09	7400	20	300	13	31	4
	Aug. 29	12000	10	220	20	31	5
	Sept. 23	7500	10	300	10	22	7
	1981						
	June 12	12000	10	320	20	43	9
	July 29	8000	10	340	15	26	15
	Sept. 11	9000	10	290	12	32	7
Healy Creek near Suntrana (635104148525900)	1980						
	May 23	14000	10	330	40	55	9
	July 08	8300	20	280	13	28	4
	Aug. 28	8700	10	290	20	26	2
	Sept. 23	7000	20	290	10	23	11
	1981						
	June 12	6000	10	230	10	33	10
	July 29	8000	10	360	15	32	19
	Sept. 11	5000	10	270	10	17	8
Sanderson Creek 0.8 mi above Lignite Creek near Usibelli (635513148405000)	1980						
	May 23	25000	10	350	40	95	20
	July 09	9100	20	330	20	68	5
	Aug. 28	9700	10	320	20	69	25
	Sept. 22	9500	20	300	20	50	14
	1981						
	June 11	15000	20	140	30	110	35
	July 30	11000	10	340	20	80	32
	Sept. 12	10000	10	280	25	95	41
Sanderson Creek 1.6 mi above Lignite Creek near Usibelli (635449148392800)	1981						
	June 11	14000	10	440	30	130	7
	July 30	13000	10	490	23	85	5
	Sept. 12	12000	20	550	22	90	5
Lignite Creek 0.5 mi above mouth near Healy (635417148590100)	1980						
	May 22	5500	10	120	10	25	12
	July 08	4600	10	140	10	26	11
	Aug. 28	9200	10	220	20	86	11
	Sept. 22	6000	10	200	20	37	17
	1981						
	June 10	6500	10	320	10	35	9
	July 29	6500	10	140	11	35	12
	Sept. 11	6500	10	190	15	46	17
Frances Creek 100 ft above Lignite Creek near Suntrana (635442148534000)	1980						
	July 08	2000	10	72	3	11	2
	Aug. 28	4300	10	160	10	25	2
	Sept. 22	3600	10	140	10	18	5
	1981						
	June 10	7000	10	170	20	40	6
	July 29	6500	10	230	15	33	5
	Sept. 11	7000	10	220	15	33	8

reported. Thus reported concentrations of coal in bed material should be regarded only as estimates.

Trace Metals

At the outset of this study samples were analyzed for 12 trace metals. These early analytical results showed that arsenic, barium, chromium, cobalt, copper, and uranium were present in very low concentrations in the surface waters and stream sediments in the Lignite and Healy Creek basins. Aluminum concentrations were determined to be misleading because the suspended or total recoverable aluminum largely reflects the amount of clay in the sample. Analytical results for the above trace metals are not included in this report, but are published in Water Resources Data for Alaska (U.S. Geological Survey, 1981 and 1982).

Concentrations of five other trace metals (iron, lead, manganese, nickel, and zinc) in water samples from the Healy Creek and Lignite Creek basin sites are listed in table 6. Both dissolved and suspended (recoverable by a partial digestion from the suspended load) concentrations are shown. Concentrations of these trace metals in bed material are reported as total-recoverable values, the concentration extracted during a partial digestion of the bed material (table 7).

The U.S. Environmental Protection Agency (EPA) (1977) has recommended maximum concentrations for iron, lead, and manganese in public drinking water. For aesthetic reasons, dissolved iron is recommended to be less than 300 µg/L. The concentration should be less than 1,000 µg/L in fresh water to avoid damage to aquatic life. Dissolved lead is recommended not to exceed 50 µg/L for health reasons, and for aesthetic reasons dissolved manganese should not exceed 50 µg/L. No limits have been recommended for concentrations of nickel and zinc. In small concentrations, nickel is nontoxic to man. Zinc is essential and beneficial to human metabolism, but, in concentrations greater than 5 mg/L, it imparts a taste to water.

Dissolved trace-metal concentrations in Healy Creek did not exceed EPA recommended limits for drinking water at any site. Suspended sediment, dissolved solids, and several trace-metal concentrations increased as Healy Creek flowed past mined areas, but any effects of coal mining cannot be separated from effects due to the change in lithology.

Trace-metal concentrations are generally higher in Lignite Creek than in Healy Creek. Dissolved manganese consistently exceeded 50 µg/L at each site. Frances Creek, which drains an unmined basin, has lower trace-metal concentrations than the three other sites, two of which drain mined areas. Sanderson Creek shows a slight decrease in dissolved solids but a marked increase in suspended sediment and several dissolved and suspended trace metals as it flows past the Gold Run mine pit.

SOURCE AND TRANSPORT OF TRACE METALS

Several investigators have shown that the concentration and type of minor elements in natural stream systems can be related to suspended-sediment transport and to rock types in a basin. Most of the minor elements are transported either as crystalline particles or as metal hydroxide coatings on the sediments (Gibbs, 1977). Considerably less than 20 percent is usually transported in the dissolved phase. Consequently, under natural conditions the amount of metals transported in the suspended phase should be related to the amount of sediment transported and the average concentration of metals in the rocks of the basin.

Strip mining of coal exposes large volumes of earth materials to weathering and the accelerated physical or chemical breakdown of materials. One of the reactions that commonly occurs, as water and oxygen act upon the exposed iron sulfides, is the production of ferrous sulfate and hydrogen and sulfate ions. The resulting acidic water can bring many other constituents, especially metals, into solution. These metals are then subject to other reactions, such as the formation of precipitates or sorption on sediments (Toler, 1982, p. 6-7). Where significant quantities of acid mine drainage occur, both the dissolved- and suspended-metals concentrations in the receiving waters may be greater than the average for the natural materials. In some cases streambed sediments will become a sink for the metals.

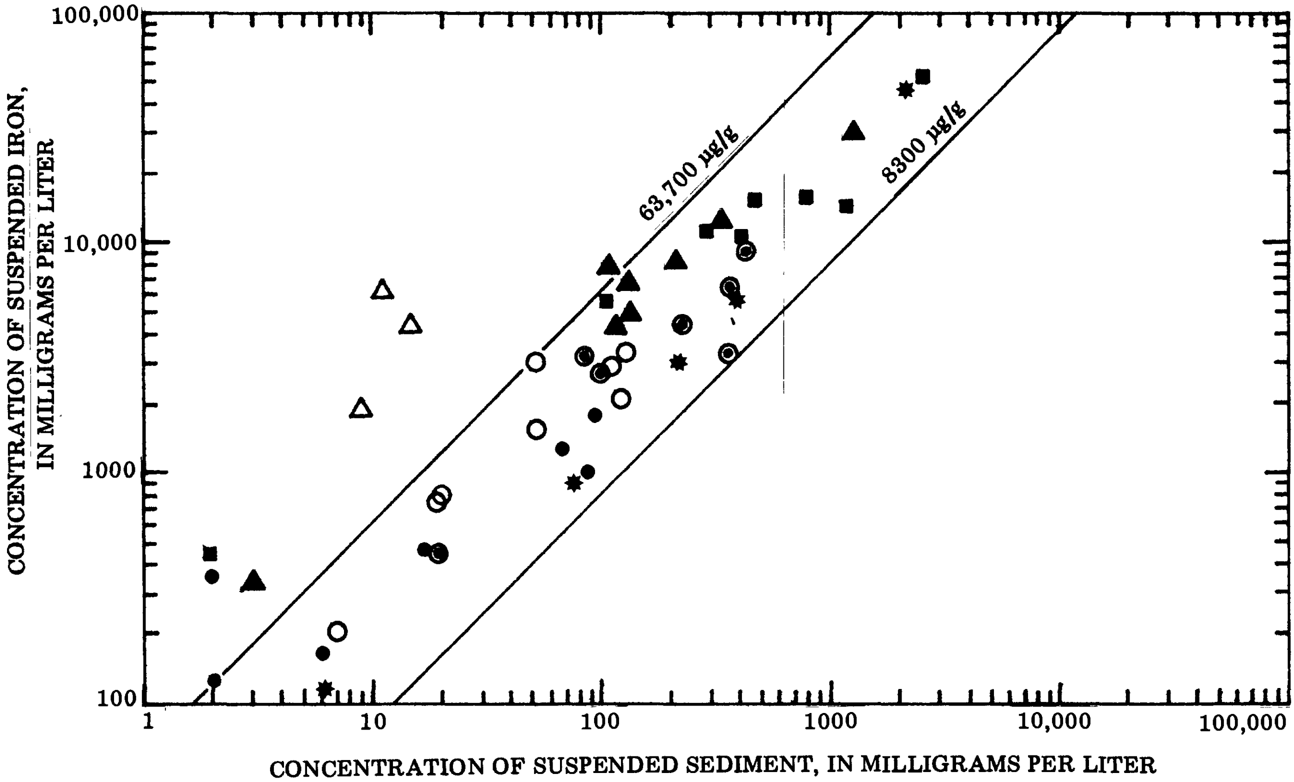
When the acidic drainage enters a stream system, it may be wholly or in part neutralized in a short distance, depending on the amount of carbonate alkalinity present in the stream water. Although the acid is neutralized, the sulfate ion will remain in solution, so that large increases in the percentage of sulfate in a stream can be an indication of acid mine drainage.

The relationship of suspended metals to suspended sediment in the streams sampled in the Healy and Lignite Creek basins is shown in figures 9-13. The solid lines on the graphs are lines of equal concentration and represent the range of concentration of metals found in the rock samples, expressed as micrograms per gram (ug/g). With the exception of Sanderson Creek, the concentration of metals in the suspended sediments agrees quite closely with that determined from the rock samples (table 2).

Sanderson Creek drains an area in which extensive coal burns have occurred (Barnes and others, 1951, p. 162). The burning of the coal outcrops was probably the result of natural causes: lightning, forest fires, or spontaneous combustion (Wahrhaftig and Birman, 1954, p. 6-8). Accelerated erosion and the residue from these burned areas may be the source of the relatively high trace-metal concentrations at the upper Sanderson Creek site. Fairbridge (1972, p. 1204) showed the trace-metal content of the ashes of coals to be, in some cases, orders of magnitude higher than that found in the earth's crust.

At sites where concurrent data are available (table 8) there is no significant increase in the yield of sulfate (in tons per day per square mile) below the mined areas. The concentration of dissolved metals is generally low and the concentration of metals in the bed material was not found to be elevated above that found in the samples of the sedimentary rocks. These data indicate that acid mine drainage is not produced in significant quantities as the result of mining operations.

Because the suspended sediments are the primary transport vehicles for trace metals, and because the percentage of trace elements in the sediments from mined and unmined areas is roughly equivalent (except for Sanderson Creek), the total amount of trace metals added to the system from mining operation should be a func-



EXPLANATION

Site 1 ● Healy Creek near Usibelli
Site 2 ○ Healy Creek 0.1 mi above French Gulch
Site 3 ◉ Healy Creek near Suntrana
Site 4 △ Sanderson Creek 1.6 mi above Lignite Creek
Site 5 ▲ Sanderson Creek 0.8 mi above Lignite Creek
Site 6 ✸ Frances Creek
Site 7 ■ Lignite Creek 0.5 mi above mouth

Solid lines are lines of equal concentration (µg of minor element per g of material), and they represent the range of concentrations found in the rock samples.

Figure 9.--Relationship of suspended iron to suspended sediment.

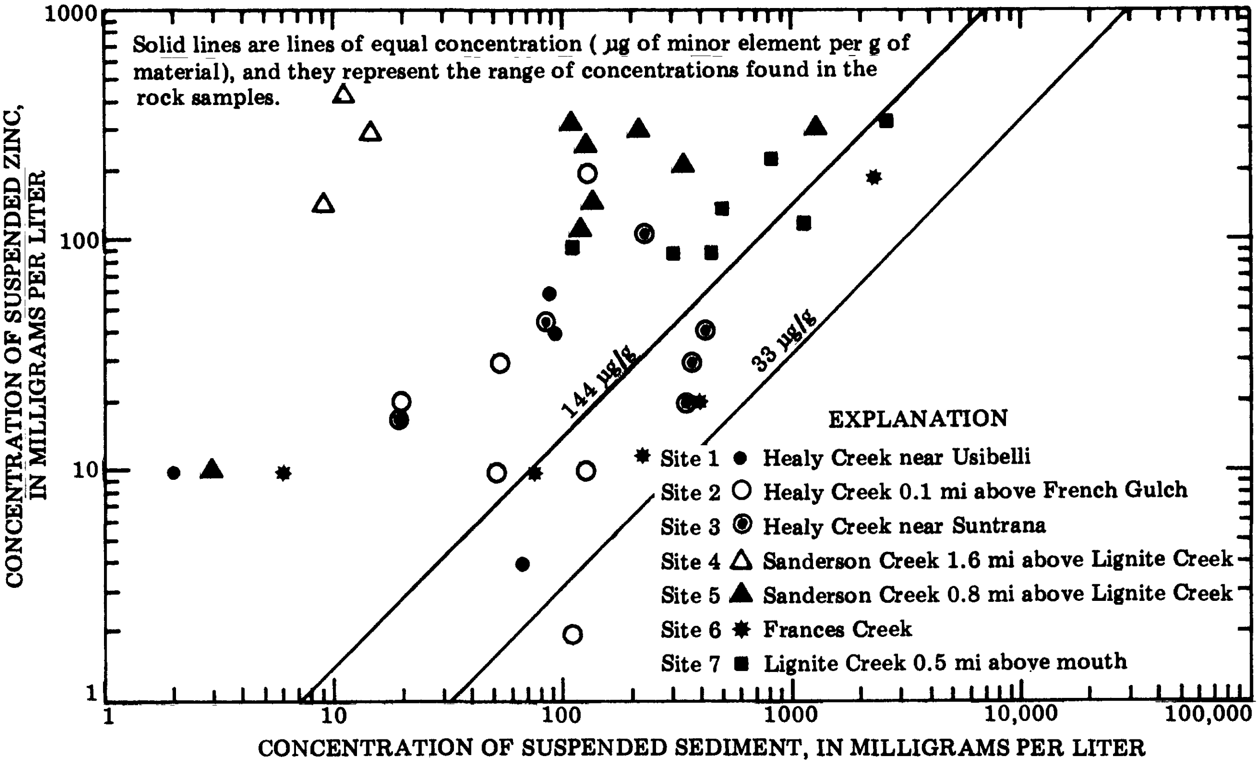


Figure 10.--Relationship of suspended zinc to suspended sediment.

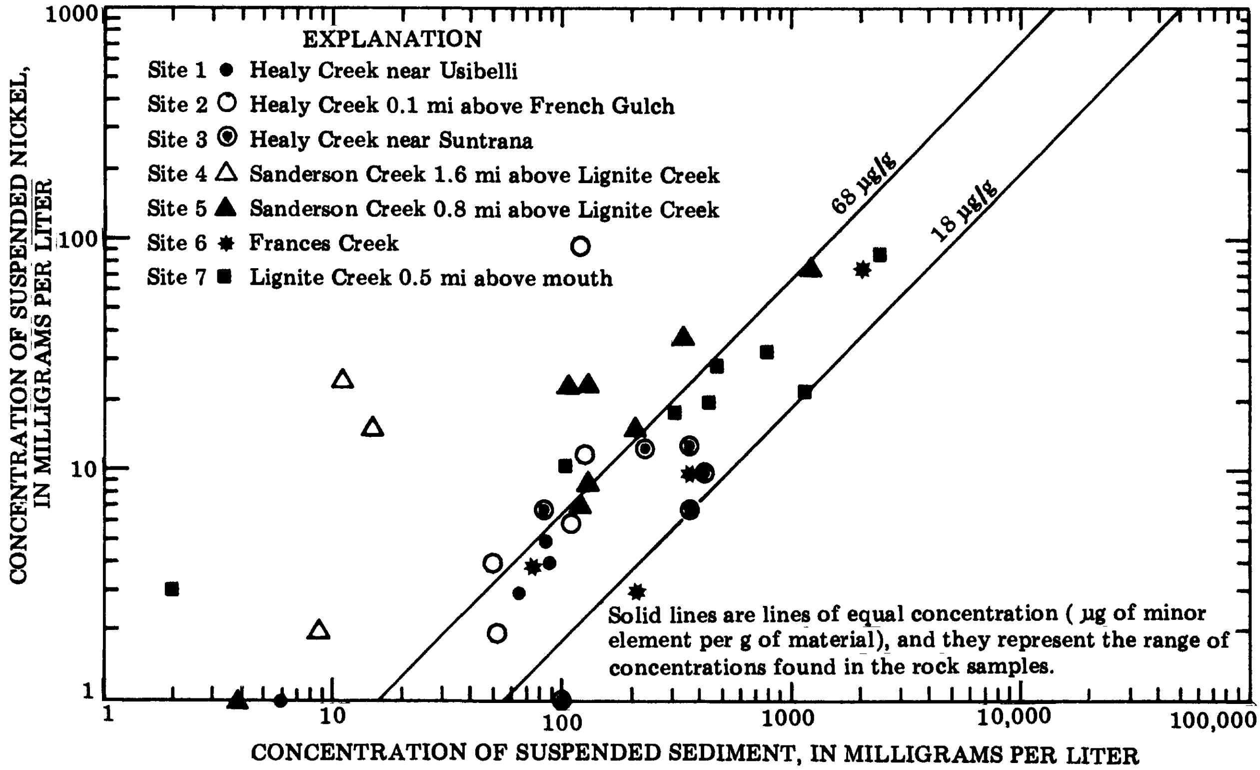


Figure 11.--Relationship of suspended nickel to suspended sediment.

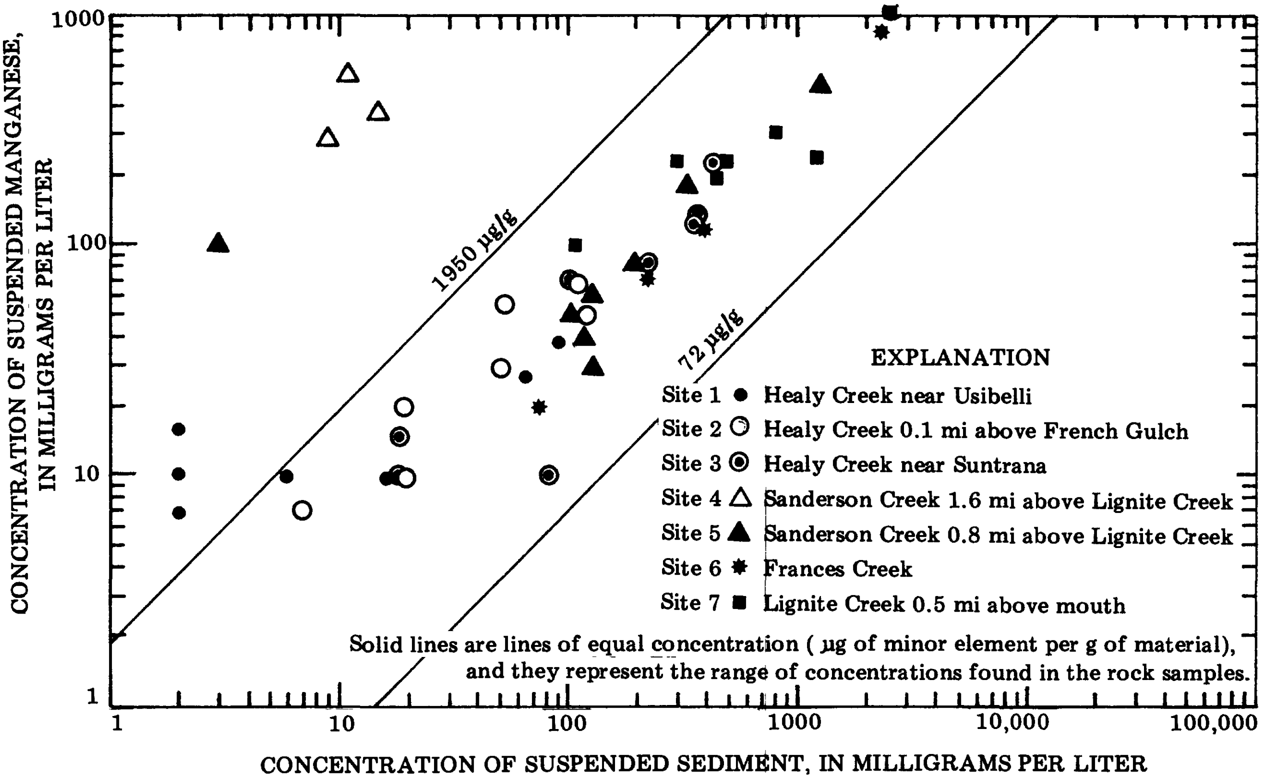


Figure 12.--Relationship of suspended manganese to suspended sediment.

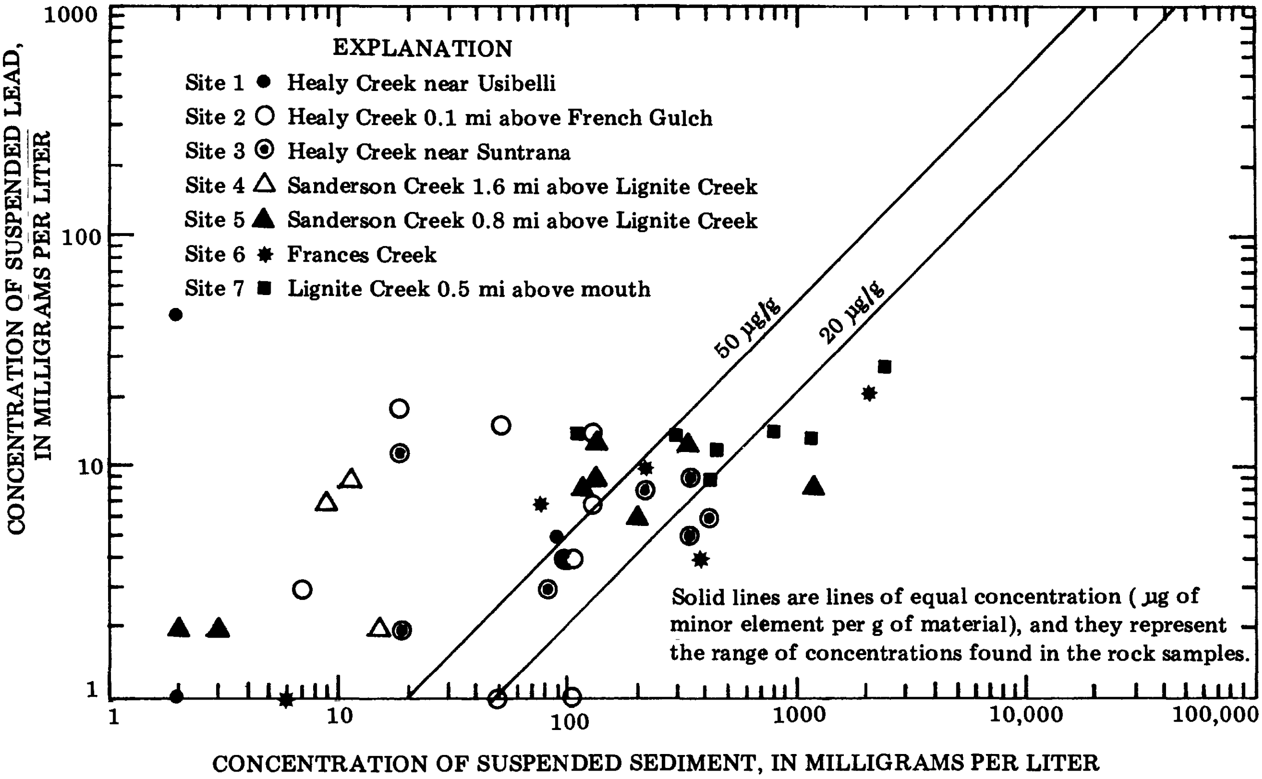


Figure 13.--Relationship of suspended lead to suspended sediment.

Table 8.--Sulfate yields for Healy and Sanderson Creek sampling sites

[Data in tons per day per square mile]

Date	Healy Creek near Usibelli	Healy Creek 0.1 mi above French Gulch	Healy Creek near Suntrana
1980			
Aug. 28-29	0.49	0.71	0.57
Sept. 22-23	.61	.70	.73
1981			
Apr. 2-3	.22	.18	.17
June 11-12	.25	.28	.25
July 29	.46	.55	.53
Sept. 11	.49	.45	.44

	Sanderson Creek 1.6 mi above Lignite Creek	Sanderson Creek 0.8 mi above Lignite Creek
1981		
June 11	0.54	0.55
July 30	.73	.65
Sept. 12	.73	.76

tion of the additional suspended sediment added. If mining activities add more suspended sediment to the stream system than would be available under natural conditions, the percentage of trace metals in the sediments may not change but the total amount of metals transported will be increased.

CONCLUSIONS

The chemical characteristics of water and stream sediments in the Lignite and Healy Creek basins indicate that coal mining in the Nenana coal field has not had a large effect on the water quality. Streams draining mined areas in the Lignite Creek basin have somewhat higher concentrations of major ions, trace metals, and suspended sediments than those draining unmined areas of the basin. The largest changes occurred on Sanderson Creek below the Gold Run pit. The cause of the increased concentration is not readily apparent from the available data. It may be due in part to mining activities, the change in basin lithology as the streams enter the mined areas, or from drainage through burned coal beds in the upper reaches of the basin. The few ground-water data collected also indicate no effect from the mining.

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