LEACHING STUDY OF OIL SHALE IN KENTUCKY

with a section on

HYDROLOGIC RECONNAISSANCE OF THE OIL SHALE OUTCROP IN KENTUCKY

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 84-4073

Prepared in cooperation with the
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UNIVERSITY OF KENTUCKY

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"The value of the unmined crude oil and associated by products locked within the oil shales of this state is very great. Thinking men are aware that the dawn of the day of shale development is at hand. That American ingenuity will fashion, if it has not already fashioned, the key which will unlock the treasury of oil close held within the Knobs of Kentucky, there can be no doubt. Less spectacular than crude oil from flowing wells. But more so than coal dug from mines. The coming oil shale industry of Kentucky will call into play alertness, aggressiveness, and trained intelligence. It offers as rewards great wealth and satisfaction in the ultimate solution of a difficult new industrial problem."

Charles Stevens Crouse, 1921

PREFACE

The U.S. Geological Survey, in cooperation with the Kentucky Geological Survey, began a study in 1980 of hydrology in the outcrop area of oil shale in Kentucky. As part of this study Dr. Samuel S. Leung of Eastern Kentucky University conducted a leaching study of selected oil shale samples from several places in the outcrop area. The results of the leaching experiment are in the first section of this report.

The general hydrology of the oil shale outcrop area was studied by personnel of the U.S. Geological Survey and the Kentucky Geological Survey, who made a reconnaissance of the outcrop area and collected quantity and quality data from surface- and ground-water sources. The results of this general hydrology study are in the second section of this report.

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Conversion of inch-pound units to International System of Units (SI)

Data in this report are given in inch-pound units. To convert inch-pound units to SI units, the following conversion factors are used:

Multiply inch-pound units	By	To obtain SI units
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon (gal)	0.003785	cubic meter (m^3)
million gallons (Mgal)	3,785	cubic meters (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
micromho per centimeter at 25° Celcius (umho/cm at 25°C)	1.000	microsiemen per centimeter at 25° Celsius (uS/cm at 25°C)
pound per ton (lb/ton)	0.503	kilogram per metric ton (kg/t)

LEACHING STUDY OF OIL SHALE IN KENTUCKY

by Samuel S. Leung

ABSTRACT

A leaching study was done on six fresh oil shale samples and one retorted oil shale sample. Each sample was crushed to pebble size and placed in nine separate polyvinyl chloride tubes. The first three tubes were leached with distilled water, the second three with a weak sulfuric acid solution (0.0005 N), and the last three with a stronger sulfuric acid solution (0.05 N). These leaching reagents were used because natural water and sulfuric acid are expected to come into contact with retorted or exposed shale if oil shale is mined and processed. The concentration of constituents in the leachates were highly variable and the concentration of sodium, manganese, and zinc in the retorted shale leachate was several orders of magnitude higher than those of the leachates of the fresh shale samples.

INTRODUCTION

Mining and retorting of oil shales could have adverse environmental impacts. These impacts are largely unknown but leaching of retorted shale and freshly exposed shale at mine sites could significantly affect the quality of water in streams and aquifers. Potentially dangerous runoff of acids and toxic metals from the mining areas poses an environmental threat (Dorset and others, 1977).

This investigation examines some of the potential problems, in terms of acids and metals, that may result from chemical weathering and leaching of the oil shale in Kentucky. A controlled leaching experiment using both fresh and spent shale was conducted; and periodically collected leachates were quantitatively analyzed by atomic absorption spectrophotometry to demonstrate the capacity of the oil shale to release abnormally high concentrations of elements to the environment.

ACKNOWLEDGMENTS

This research project was initiated in June 1980 as one aspect of the Oil Shale Hydrology Project jointly funded by the Kentucky Geological Survey and the U.S. Geological Survey. Financial support during the summer of 1980 was granted by the Kentucky Geological Survey. Messrs. Michael Brandy and Terry Wright were hired by the Kentucky Geological Survey to assist in sample collection and sample preparation - crushing and sieving.

The leaching experiment and chemical analyses were carried out at Eastern Kentucky University Department of Geology during 1981. Messrs. Scott Taylor, Paul Wilson and James Furr assisted me in this phase of the research. To these gentlemen I offer my most sincere thanks. Mr. Linden Smith rendered me much help in preparing figures 4 to 11. To him I am equally grateful.

METHODS AND MATERIALS

Sample Location and Description

The oil shale in Kentucky has been known as Chattanooga Shale in the south, New Albany Shale in the northwest, and as Ohio Shale in the northeast. For simplicity it is consistently called oil shale in this report. Figure 1 shows the regional distribution and stratigraphic names of this lithologic unit in eastern United States. Seven samples were collected and used in this leaching experiment. Figure 2 shows the sample locations and table 1 gives the sample description. Sample C, Ohio Shale from Indian Creek, Lewis County, and Sample F, spent Ohio Shale from Ben Willen Hollow, Lewis County, were collected at the Olive Hill plant of the Pyramid Minerals, Inc. The rest of the samples were collected in the field by the author and student assistants. There was a definite shortage of spent materials for this study, and spent shales of known origin were not readily available.

Table 1--Oil shale sample locations

Sample	Collection site	Description
A	Buttonmold Knob Bullitt County	New Albany Shale Top section
B	Buttonmold Knob Bullitt County	New Albany Shale Top Section
C	Indian Creek Lewis County	Ohio Shale
D	Winston Estill County	New Albany Shale Mid section
E	Ben Willen Hollow Lewis County	Ohio Shale Top 10 feet
F	Ben Willen Hollow Lewis County	Ohio Shale Retorted material
G	Ben Willen Hollow Lewis County	Ohio Shale Top 2 feet

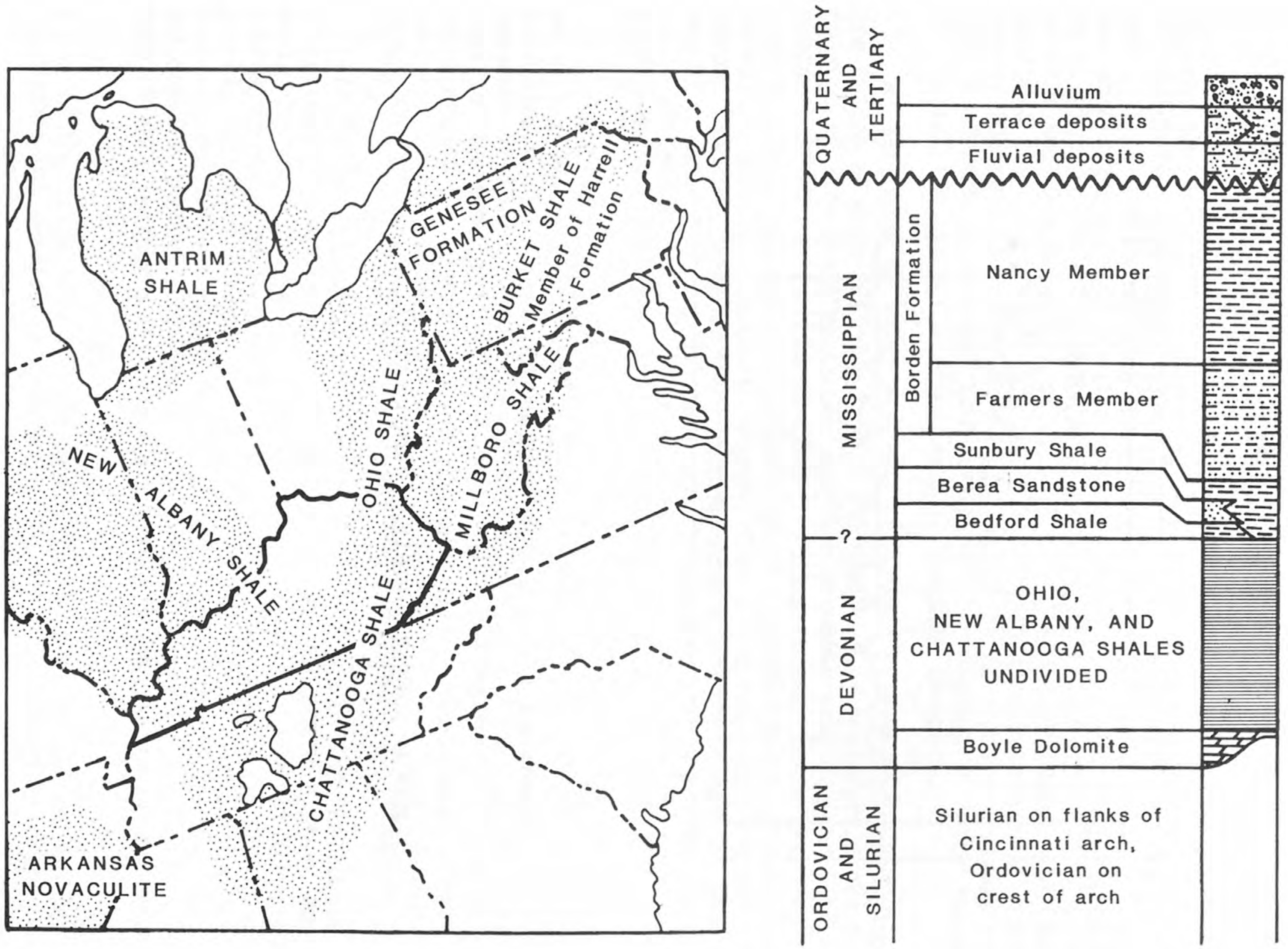

Figure 1.-- Regional distribution of Upper Devonian black shale in Eastern United States with a generalized geologic column for Kentucky.

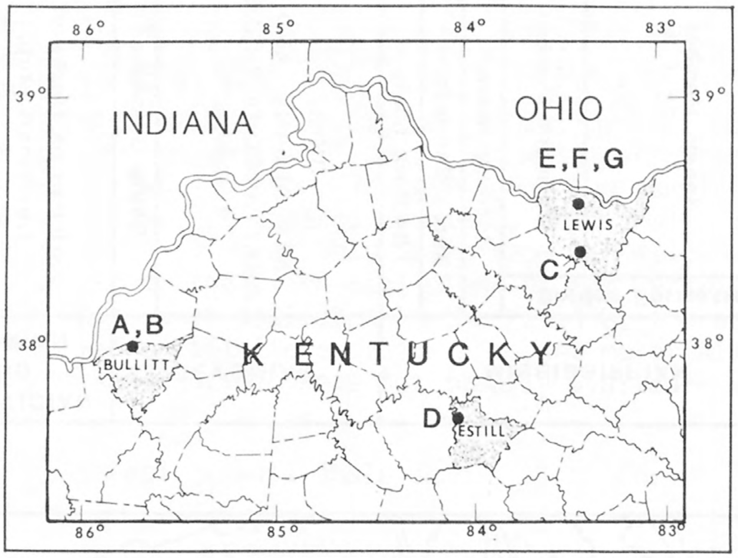

Figure 2.-- Location of sampling sites: samples A and B, Bullitt County; sample C, Lewis County, south central; sample D, Estill County; samples E, F, and G, Lewis County, north central.

Leaching Experiment

Each shale sample used for the leaching study was first crushed in a jaw crusher and sieved through two specially fabricated screens. Shale fragments of medium to large pebble size (13-25 mm diameter) were used for the experiment. This particular size was chosen because most commercial plants would use shale fragments of similar size for retort purposes. Nine subsamples each weighing 900 ± 0.1 grams were prepared from each original sample and put in nine separate polyvinyl chloride (PVC) cylindrical tubes. Each PVC tube designed for this study has a 50-mm inside diameter and measured approximately 700 mm in length. A 70 to 80 mm long drain hose was connected to the bottom of each cylindrical tube and a leak-proof hosecock clamp was applied to control the storage and drainage of leaching reagents.

A small mass of glass wool and a Whatman[1] filter paper were placed at the bottom of each cylinder before the addition of shale fragments to prevent passage of fine shale particles when the reagents were drained. After all subsamples had been packed in the cylindrical tubes, three leaching reagents (900 mL each) were added in triplicates. Consequently the first three tubes contained the first leaching reagent; the next three tubes contained the second leaching reagent; and the last three tubes contained the third leaching reagent. Each cylinder was then capped with a polyethylene lid to avoid contamination by fallout dust and to minimize evaporation during the experiment. Figure 3 is a simple sketch of the experimental setup.

Deionized distilled water (hereafter simply referred to as deionized water), a weak sulfuric-acid solution, 0.0005 $\underline{N}$, and a strong sulfuric-acid solution, 0.05 $\underline{N}$, were used as leaching reagents. The choices of these reagents were well justified because natural water and sulfuric acid are expected to come into contact with the retorted or exposed shale if oil shale is mined and processed. The initial pH values of the three leaching reagents were: deionized water, 5.5 units; 0.0005 $\underline{N}$ H_2SO_4, 3.4 units; and 0.05 $\underline{N}$ H_2SO_4, 1.7 units as measured by a standard laboratory pH meter.

After initially pouring the reagents into the cylindrical tubes containing the shale samples, the reagents were allowed to stand for 24 hours while the shale fragments were totally immersed. On the next day, the leachates produced in the cylinders were drained into 1-liter precleaned plastic bottles and tightly sealed with screw caps. The shale samples were then allowed to remain dry for 24 hours before the same leachates were returned to the cylindrical tubes on the third day. In this manner the samples went through a 24-hour-wet, a 24-hour-dry, and a 24-hour-wet cycle.

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[1] Use of the trade name in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

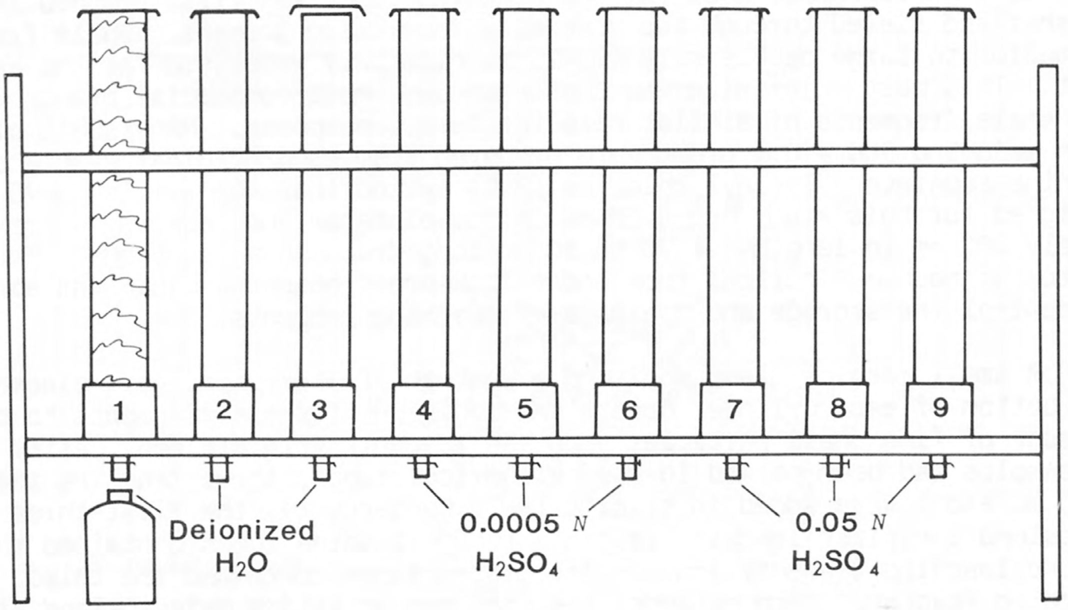

Figure 3.-- Laboratory set-up for the leaching study of Devonian black shale.

Sampling of Leachates

In order to determine the chemical changes and metal ions released from the shale samples as the leaching experiment progressed, 20-mL aliquots were periodically withdrawn from the produced leachates for atomic absorption analysis. Each shale sample was allowed to go through three wet-dry cycles (a total of six days), and the 20-mL leachate sample was taken on the seventh day just prior to returning the leachate to its own leaching tube. The seventh day would then be counted as the beginning of the next six-day cycle. Table 2 records the sampling periods and dates.

The wet-dry cycle and sampling frequency were not followed in two particular occasions. The first irregularity took place during the third sampling period when the shale samples were immersed continuously in the leaching reagents for 14 days before draining on the fifteenth day and sampling on the sixteenth day. The second irregularity happened after the completion of the sixth sampling period when the samples were purposely left immersed in the leaching reagents for a prolonged period of time. The leachates were drained out on the 99th day; and the leachate samples were taken on the 100th day. This completed all seven sets of sampling over an experimental period of 100 days.

Table 2.--Leachate sampling periods and dates

Sampling period	Date	Number of days after experiment started
1	February 23, 1981	6
2	March 1, 1981	12
3	March 16, 1981*	27
4	March 22, 1981	33
5	March 28, 1981	39
6	April 4, 1981	46
7	May 28, 1981*	100

*From March 1 to March 14, again from April 4 to May 27, 1981, the samples were left immersed in leaching reagents continuously.

Analytical Procedures

The leachate samples were analyzed by atomic absorption spectrophotometry for sodium, potassium, calcium, magnesium, iron, zinc, copper, lead, and manganese. Hollow cathode lamps and an air-acetylene flame were used. Most samples could be analyzed directly; but some required a 20-fold dilution with deionized water before determination.

The pH of the first and last sets of leachate samples was measured, using a Fisher Accument pH meter.

The concentrations of cations in the leachate samples were corrected for volume change due to the withdrawal of 20 mL leachate at each sampling period. The corrected cationic concentrations for each group of triplicate samples were then averaged to represent that of the leachate for a single shale sample at that specific sampling period.

RESULTS AND DISCUSSION

Leachate pH values

Two factors controlled the pH of the leachates in this study: the pH of the leaching reagents used in the experiment, and the amount of pyrite and/or calcium carbonate present in the shale samples. The three leaching reagents (deionized water, 0.0005 $\underline{N}$ H_2SO_4, and 0.05 $\underline{N}$ H_2SO_4) used had initial pH values of 5.5, 3.4, and 1.7 units, respectively. As they reacted with the shale samples, these values changed according to the acidic or alkaline nature of the rock.

Table 3 shows the pH values of the leachates sampled at the first and last periods. Each value is the average of three duplicate leachates because it was noted for all sample sets that the triplicate leachates had almost identical pH readings. This indicated a high degree of reproducibility.

Several important observations can be made regarding the pH of the oil shale under investigation. They are summarized below:

(1) All leachates studied had pH values less than 7 units. Samples D, E, F, and G actually generated very acidic leachates with pH around 2.5 units. This situation was very different from the western U.S. oil shales whose leachates have been reported to be alkaline, pH varying between 7.3 and 9.6 units (Stollenwerk and Runnells, 1981).

(2) Samples A and B (from Bullitt County) both appeared to have a slight neutralization potential. The other five samples, including four fresh shale and one retorted, had practically no neutralization potential.

(3) The pH of deionized water changed significantly within the first week of leaching. Values in table 3 demonstrate that most of the oil shale samples acidified the deionized water after only short contact time.

(4) The pH values did not differ much between the first and last period leachate samples indicating that the shale samples reached their equilibrium pH rather rapidly.

Table 3.--Leachate pH values
(H_2O, deionized water, pH 5.5; W.A., 0.0005 $\underline{N}$ H_2SO_4, pH 3.4; and S.A., 0.05 $\underline{N}$ H_2SO_4, pH 1.7. Sampling period 1 was six days after experiment started, and sampling period 7 was 100 days after experiment started)

		Sampling period				Sampling period	
		(1)	(7)			(1)	(7)
A -	H_2O	5.5	6.1	E -	H_2O	2.5	2.7
	W.A.	5.9	6.6		W.A.	2.5	2.6
	S.A.	2.5	3.3		S.A.	2.3	2.6
B -	H_2O	5.6	6.5	F -	H_2O	2.4	2.7
	W.A.	5.9	6.3		W.A.	2.4	2.6
	S.A.	2.5	2.8		S.A.	2.2	2.5
C -	H_2O	5.1	3.5	G -	H_2O	2.4	2.8
	W.A.	5.1	3.5		W.A.	2.4	2.7
	S.A.	2.7	3.0		S.A.	2.3	2.7
D -	H_2O	2.4	2.3				
	W.A.	2.3	2.2				
	S.A.	1.9	1.9				

Metals Released From The Oil Shale

A total of 441 (7 samples x 3 reagents x 3 duplicates x 7 periods) leachate samples were analyzed by atomic absorption spectrophotometry for nine dissolved cations; sodium, potassium, calcium, magnesium, iron, manganese, zinc, copper, and lead. The results are presented as averages of the triplicate subsamples in tables 4 to 11. Because of its very low concentration (0 to 8 ug/L) in all leachates, lead is not reported.

Since the deionized distilled water and the diluted ACS reagent-grade sulfuric acid used in this leaching experiment had very little or non-detectable impurities, the dissolved cations found in the leachates can be safely interpreted as being released from the oil shale samples. The variation trends during the seven sampling periods are presented in figures 4 to 11. The following discussion is based primarily on the examination of these figures.

Sodium: Except sample F (a spent Ohio Shale from Lewis County), all shale samples released slightly more sodium into the leachates as leaching progressed (table 4, fig. 4). Sample F, on the contrary, showed a steady and rapid decline with time. Furthermore, it released from 2 to 25 times as much sodium into the leachate than did the other samples.

Throughout the leaching experiment, the strong acid (0.05 $\underline{N}$ H_2So_4), as expected, was more powerful than deionized water and the weak acid (0.0005 $\underline{N}$ H_2SO_4) in leaching sodium from the samples. This is especially true for sample C.

Potassium: The variation trend is quite similar to that of sodium. Samples A, B, C, and D showed an increase of released potassium with time whereas sample E showed a slight decrease (table 5, fig. 5). Sample G released only 0.5 to 3.6 mg/L potassium, much less than the other samples. Sample F (the spent shale) released over 130 mg/L potassium at the beginning and then rapidly decreased, just as in the case of sodium. Again, the strong acid leached more potassium from the shale samples than did the other two leaching reagents.

Table 4.--Sodium concentration of leachates with time (H_2O, deionized water, pH 5.5; W.A., 0.0005 $\underline{N}$ H_2SO_4, pH 3.4; and S.A., 0.05 $\underline{N}$ H_2SO_4, pH 1.7. Results in milligrams per liter.)

Sample	Reagent	Sampling period						
		1	2	3	4	5	6	7
A -	H_2O	12.5	14.2	16.2	16.3	16.3	15.9	30.7
	W.A.	12.0	13.2	15.2	15.8	16.3	15.4	20.8
	S.A.	14.5	15.1	16.7	17.6	18.1	17.6	25.9
B -	H_2O	12.5	13.2	16.2	14.9	16.3	15.4	20.3
	W.A.	10.5	12.7	14.8	14.9	15.4	15.4	19.7
	S.A.	15.5	16.6	18.1	17.6	17.2	17.6	20.6
C -	H_2O	31.0	34.4	37.1	37.5	37.7	37.0	36.1
	W.A.	33.7	36.1	38.1	35.9	37.7	37.9	36.9
	S.A.	52.3	55.3	57.4	54.5	54.9	53.7	51.8
D -	H_2O	3.8	4.1	4.8	4.7	4.6	4.7	5.7
	W.A.	4.0	4.4	4.8	4.9	4.9	4.8	5.7
	S.A.	4.5	5.4	6.2	5.3	5.1	5.0	6.2
E -	H_2O	12.0	13.2	12.9	12.5	13.1	12.3	13.2
	W.A.	11.5	11.2	12.1	12.5	12.2	12.3	12.7
	S.A.	15.5	14.6	14.8	14.4	14.5	13.7	13.8
F -	H_2O	108.7	108.7	100.0	96.3	93.5	88.1	84.5
	W.A.	112.7	109.3	100.0	97.5	93.8	89.9	83.9
	S.A.	113.0	111.6	103.5	96.3	93.8	91.3	86.2
G -	H_2O	3.0	3.3	3.5	3.4	3.4	3.4	4.2
	W.A.	3.5	3.7	4.0	4.0	4.0	3.9	4.5
	S.A.	4.0	4.0	4.6	4.4	4.2	4.0	4.2

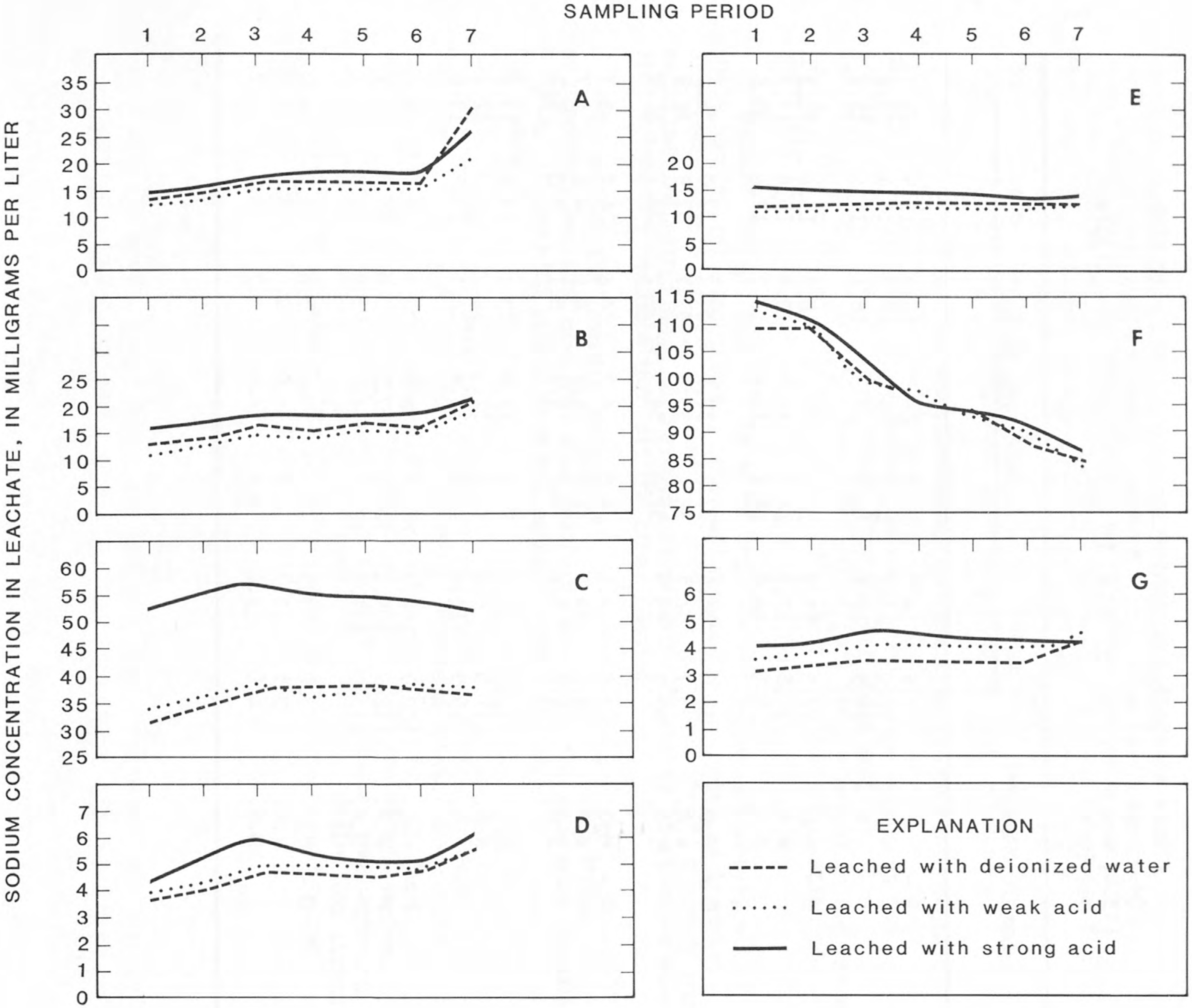

Figure 4.-- Variation of sodium concentration in leachates with time.

Table 5.--Potassium concentration of leachates with time (H_2O, deionized water, pH 5.5; W.A., 0.0005 $\underline{N}$ H_2SO_4, pH 3.4; and S.A., 0.05 $\underline{N}$ H_2SO_4, pH 1.7. Results in milligrams per liter.)

Sample	Reagent	Sampling period						
		1	2	3	4	5	6	7
A -	H_2O	12.0	14.0	15.7	14.2	17.0	17.9	22.0
	W.A.	13.3	15.1	16.8	14.6	17.2	17.4	21.5
	S.A.	20.1	21.0	21.9	20.1	23.1	23.2	24.0
B -	H_2O	11.0	13.7	16.0	15.5	17.5	18.8	22.0
	W.A.	11.6	14.6	17.4	17.2	18.6	19.7	23.6
	S.A.	17.6	19.7	19.8	20.4	22.0	23.2	23.6
C -	H_2O	14.5	18.3	18.9	28.3	24.0	24.9	22.0
	W.A.	15.7	19.5	20.3	18.9	25.3	27.1	23.4
	S.A.	41.5	41.5	38.6	43.2	47.1	48.5	37.2
D -	H_2O	9.0	11.0	18.8	19.3	20.6	21.9	25.4
	W.A.	9.2	11.7	21.7	20.9	23.8	24.7	28.7
	S.A.	16.7	24.2	37.0	37.1	42.5	42.3	45.3
E -	H_2O	16.7	14.5	15.1	13.7	13.6	12.3	16.9
	W.A.	16.3	14.4	15.0	13.7	13.8	11.3	16.1
	S.A.	27.0	28.0	27.0	23.5	23.5	16.6	16.9
F -	H_2O	135.0	115.2	92.4	64.5	61.1	20.3	33.8
	W.A.	130.0	112.3	109.5	80.3	75.6	14.5	32.4
	S.A.	149.0	117.1	85.7	79.4	65.2	4.9	20.8
G -	H_2O	.5	.5	.5	.9	.9	.9	.0
	W.A.	.5	.5	.5	.9	.9	.8	.0
	S.A.	1.5	2.3	2.7	3.7	3.9	3.6	.0

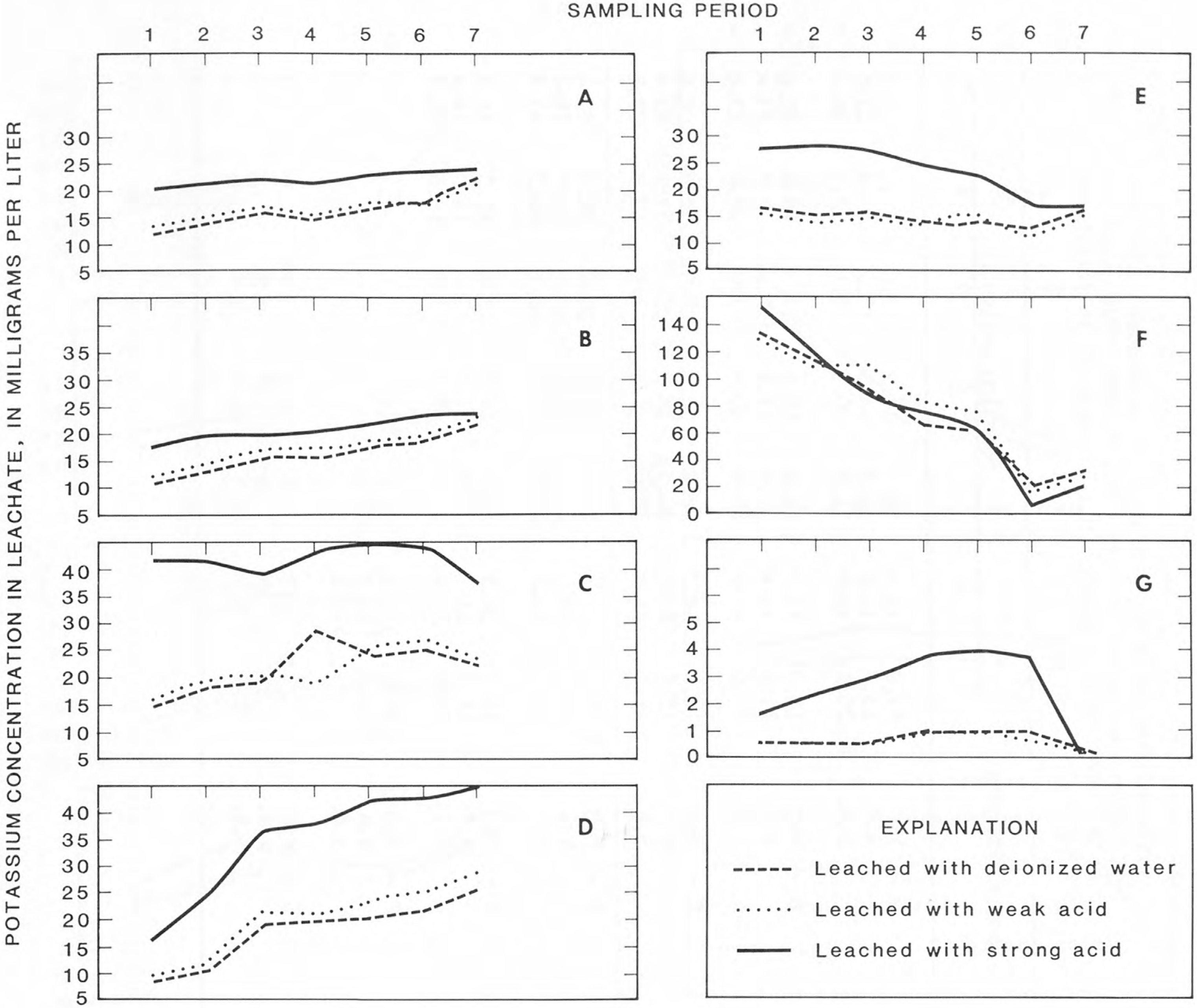

Figure 5.-- Variation of potassium concentration in leachates with time.

Calcium: Samples D and G released less than 0.5 mg/L calcium into the leachates (table 6, fig. 6). All other samples released from 20 to 166 mg/L of calcium during the experiment. Samples A, B, C, and F showed a steady increase of released calcium with time while sample E had a slight decrease. Sample D and sample G did not show any variation trend.

Table 6.--Calcium concentration of leachates with time (H_2O, deionized water, pH 5.5; W.A., 0.0005 N H_2SO_4, pH 3.4; and S.A., 0.05 N H_2SO_4, pH 1.7. Results in milligrams per liter.)

Sample	Reagent	Sampling period						
		1	2	3	4	5	6	7
A -	H_2O	50.0	51.7	66.7	65.9	73.3	79.3	92.4
	W.A.	54.0	57.6	68.6	68.7	78.7	81.9	93.0
	S.A.	122.0	121.1	118.1	125.4	125.8	125.1	118.3
B -	H_2O	66.0	68.3	82.9	80.8	87.8	96.0	109.9
	W.A.	70.0	71.3	82.9	84.5	94.1	96.0	108.7
	S.A.	135.0	122.0	114.3	117.0	125.8	129.5	126.5
C -	H_2O	20.0	34.2	38.1	37.1	49.8	59.0	73.8
	W.A.	26.0	39.1	44.8	42.7	57.0	59.0	76.1
	S.A.	154.0	166.0	142.9	151.4	163.8	159.5	139.7
D -	H_2O	.00	.00	.00	.05	.03	.03	.00
	W.A.	.00	.00	.00	.05	.03	.03	.00
	S.A.	.00	.00	.00	.05	.03	.03	.00
E -	H_2O	60.0	74.2	83.8	78.9	77.8	74.0	63.9
	W.A.	64.0	71.3	82.9	78.0	75.1	69.6	61.1
	S.A.	45.0	39.1	39.1	39.9	39.8	33.5	33.2
F -	H_2O	37.0	49.8	84.8	73.4	86.9	94.3	104.2
	W.A.	39.0	50.8	86.7	80.8	87.8	82.8	99.7
	S.A.	21.0	28.3	57.1	54.8	61.5	69.6	91.8
G -	H_2O	.50	.40	.30	.40	.30	.30	.40
	W.A.	.40	.30	.30	.40	.30	.30	.40
	S.A.	.30	.10	.20	.20	.20	.20	.40

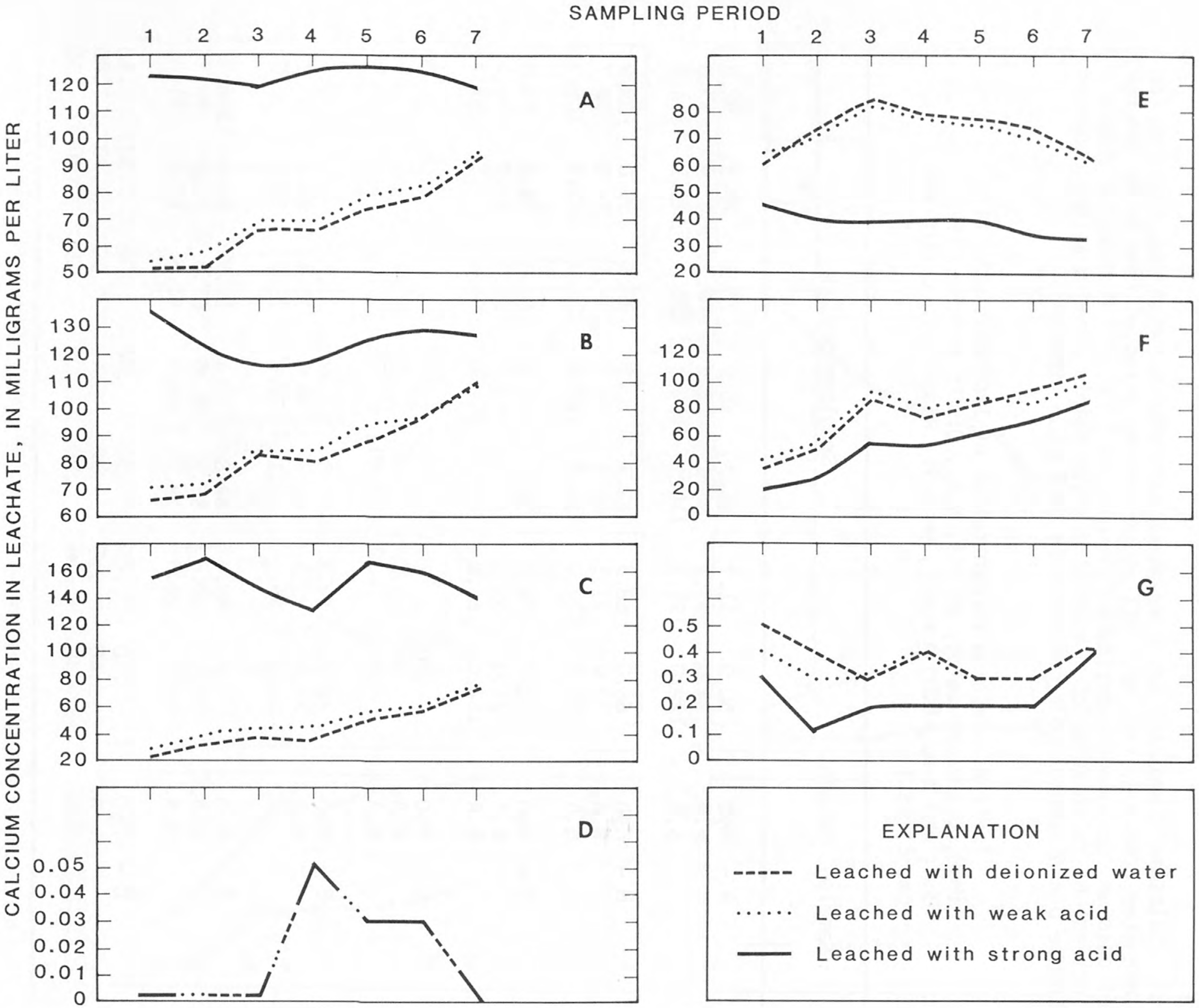

Figure 6.-- Variation of calcium concentration in leachates with time.

The strong acid released more calcium from Samples A, B, and C, but less from samples E, F, and G when compared with deionized water and the weak acid. It was obviously an anomaly; but no good explanation can be offered at this time.

Magnesium: Sample D released less than 4 mg/L of magnesium into solution, while the other samples released from 18 to 425 mg/L (table 7, fig. 7). In samples A, B, and C, the strong acid released from 2 to 9 times as much magnesium as the weak acid or deionized water. In samples E and F, more was released from the strong acid, but the difference was not as pronounced. In sample G, the strong acid released about the same amount as the other solutions. Samples A through F show an increasing trend of magnesium release with time, while sample G decreases with time.

Iron: Iron concentrations released from the samples fluctuated widely (table 8, fig. 8). However, the quantity of iron released from various samples deserves attention. Samples A, B, and C released from 0 to 143 mg/L of iron into the leachates, samples E, F, and G released from 75 to 1,076 mg/L, while Sample D released the most, from 1,140 to 1,450 mg/L. Even deionized water leached an extraordinarily large quantity of iron from this sample.

Manganese: The strong acid solution released from 1 to 15 times more manganese from the shale samples than did deionized water, except from sample D, which released only 1.5 mg/L (table 9, fig. 9). Samples B and F, particularly the latter, released more manganese than the other samples, and ranged from 5.2 to 45.7 mg/L. A very slight increase of manganese was released with time for most samples. Sample F, being the only exception, released more manganese during the first week of leaching.

Zinc: The strong acid was again more powerful than deionized water and the weak acid in releasing zinc from the samples (table 10, fig. 10). Sample A released less zinc with time whereas samples C and E showed a generally increasing trend. For the other samples, there was no consistent variation. Samples D, E, and G released from 43 to 131 mg/L of zinc into the leachates, but sample F (the spent shale) released about twice as much. Samples A and B released only 0.01 to 1.17 mg/L of zinc throughout the entire leaching experiment.

Copper: Samples A, B, C, and F released from 0 to 2.4 mg/L of copper into the leachates; samples E and G released from about 1 to 9 mg/L; sample D released the most, from 9.2 to 23 mg/L (table 11, fig. 11). There was a generally decreasing trend of copper released as leaching progressed with samples C, D, E, and G, while with samples A, B, and F, the copper released fluctuated up and down.

Table 7.--Magnesium concentration of leachates with time (H_2O, deionized water, pH 5.5; W.A., 0.0005 $\underline{N}$ H_2SO_4, pH 3.4; and S.A., 0.05 $\underline{N}$ H_2SO_4, pH 1.7. Results in milligrams per liter.)

Sample	Reagent	Sampling period 1	2	3	4	5	6	7
A -	H_2O	50	63	86	84	97	106	141
	W.A.	53	68	92	84	106	112	156
	S.A.	237	261	270	263	286	285	361
B -	H_2O	117	140	173	170	175	188	262
	W.A.	120	143	171	166	179	188	234
	S.A.	243	276	311	307	326	344	425
C -	H_2O	18	36	43	44	61	65	74
	W.A.	26	44	50	51	65	69	82
	S.A.	167	173	178	174	181	188	220
D -	H_2O	2.8	2.3	2.2	2.2	2.1	2.1	2.8
	W.A.	2.2	2.3	2.4	2.0	2.1	2.1	3.1
	S.A.	2.0	2.1	2.6	2.2	2.4	2.5	3.7
E -	H_2O	237	226	241	236	226	244	312
	W.A.	245	245	254	246	252	248	332
	S.A.	275	278	320	307	317	308	420
F -	H_2O	225	236	251	260	255	250	287
	W.A.	233	234	268	262	255	254	338
	S.A.	280	276	306	319	321	330	357
G -	H_2O	73	75	71	67	59	53	52
	W.A.	76	72	70	66	58	52	52
	S.A.	61	58	53	51	51	50	62

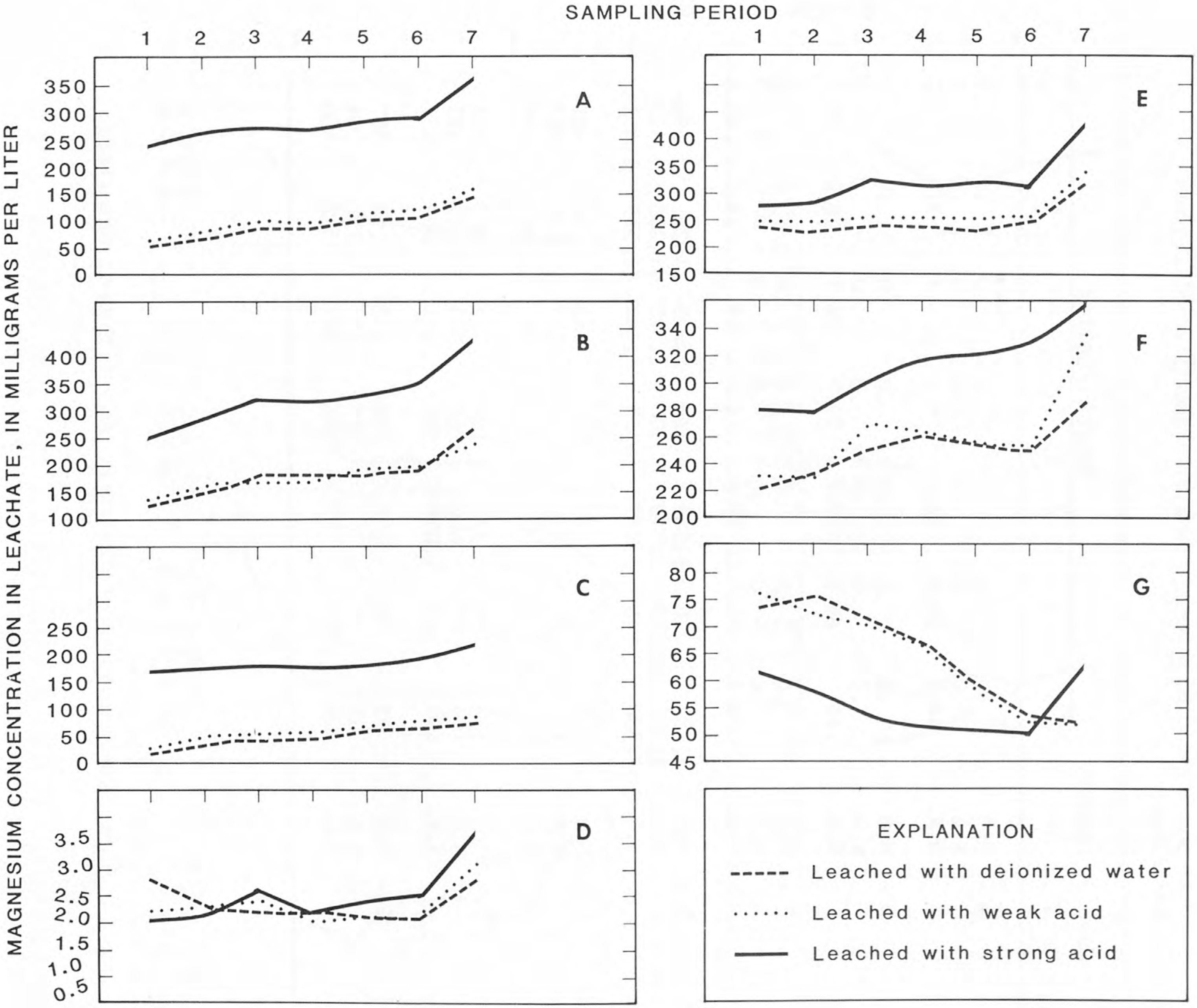

Figure 7.-- Variation of magnesium concentration in leachates with time.

Table 8.--Iron concentration of leachates with time. (H_2O, deionized water, pH 5.5; W.A., 0.0005 N H_2SO_4, pH 3.4; and S.A., 0.05 N H_2SO_4, pH 1.7. Results in milligrams per liter.)

Sample	Reagent	Sampling period						
		1	2	3	4	5	6	7
A -	H_2O	.0	.0	.0	.0	.0	.0	.0
	W.A.	.0	.0	.0	.0	.0	.0	.0
	S.A.	44.0	20.0	12.4	6.5	6.3	3.1	1.2
B -	H_2O	.0	.0	.0	.0	.0	.0	.0
	W.A.	.0	.0	.0	.0	.0	.0	.0
	S.A.	143	63.5	25.7	29.7	26.7	28.2	39.3
C -	H_2O	.0	.0	.0	.0	.0	.0	.0
	W.A.	.0	.0	.0	.0	.0	.0	.0
	S.A.	68.0	21.5	13.8	16.7	13.1	18.1	42.8
D -	H_2O	1,280	1,220	1,143	1,263	1,285	1,251	1,296
	W.A.	1,310	1,279	1,248	1,300	1,321	1,286	1,411
	S.A.	1,360	1,298	1,267	1,337	1,348	1,313	1,451
E -	H_2O	118	117	159	123	145	154	485
	W.A.	140	129	438	135	167	174	527
	S.A.	530	371	300	399	443	467	704
F -	H_2O	210	180	336	179	217	112	423
	W.A.	203	183	405	269	204	101	423
	S.A.	490	542	1,076	585	651	366	637
G -	H_2O	93	75	159	130	138	154	307
	W.A.	103	75	167	135	143	152	284
	S.A.	405	247	329	293	357	352	530

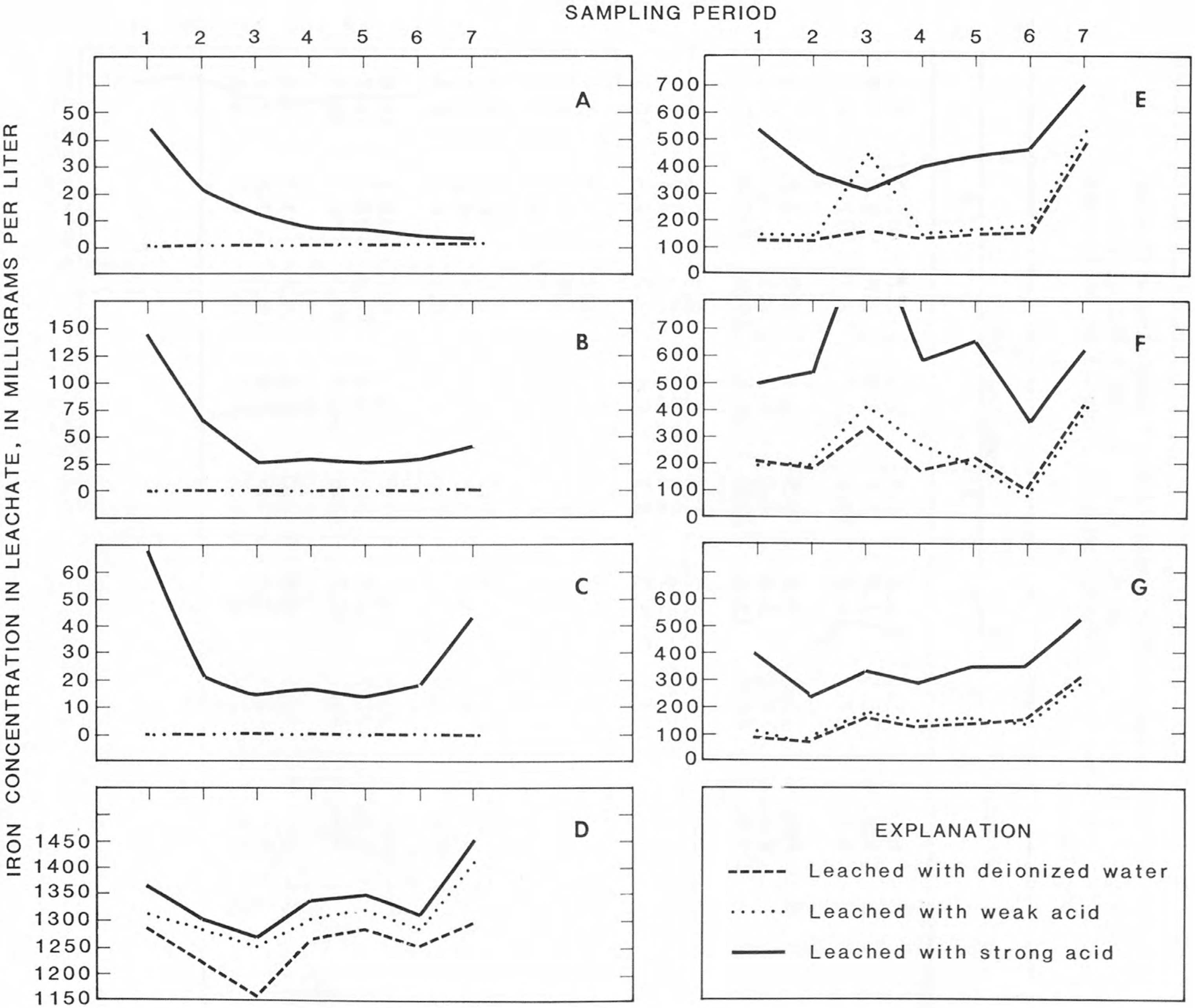

Figure 8.-- Variation of iron concentration in leachates with time.

Table 9.--Manganese concentration of leachates with time (H_2O, deionized water, pH 5.5; W.A., 0.0005 N H_2SO_4, pH 3.4; and S.A., 0.05 N H_2SO_4, pH 1.7. Results in milligrams per liter.)

Sample	Reagent	Sampling period						
		1	2	3	4	5	6	7
A -	H_2O	1.1	1.6	1.7	2.0	2.1	2.3	2.2
	W.A.	1.5	1.8	1.9	2.0	2.6	2.4	3.4
	S.A.	13.7	14.2	12.6	12.3	12.7	12.7	14.0
B -	H_2O	5.3	5.8	5.9	6.2	6.9	6.8	7.6
	W.A.	5.2	5.6	6.0	6.2	6.5	6.5	7.2
	S.A.	16.6	15.1	19.2	18.8	19.8	20.8	22.6
C -	H_2O	.6	1.2	1.6	1.8	2.3	2.6	4.1
	W.A.	.9	1.7	1.9	2.0	2.7	3.1	4.3
	S.A.	9.2	9.3	9.2	9.6	9.7	9.8	10.1
D -	H_2O	1.2	1.2	1.1	1.2	1.2	1.3	1.4
	W.A.	1.2	1.2	1.1	1.5	1.4	1.4	1.5
	S.A.	1.2	1.2	1.1	1.4	1.4	1.3	1.4
E -	H_2O	5.2	5.2	5.2	5.7	6.0	6.2	6.3
	W.A.	5.4	5.2	5.5	5.8	6.2	6.5	6.8
	S.A.	6.6	7.0	7.6	8.0	8.2	8.1	8.5
F -	H_2O	20.5	18.4	17.8	18.3	18.1	18.1	15.8
	W.A.	21.7	18.8	18.9	19.1	19.8	18.2	16.7
	S.A.	45.7	39.0	42.8	42.5	42.3	41.0	38.0
G -	H_2O	3.5	3.8	4.0	4.0	3.8	3.8	3.8
	W.A.	3.3	3.6	3.9	3.8	3.8	3.8	3.7
	S.A.	3.8	4.0	4.3	4.2	4.3	4.2	4.5

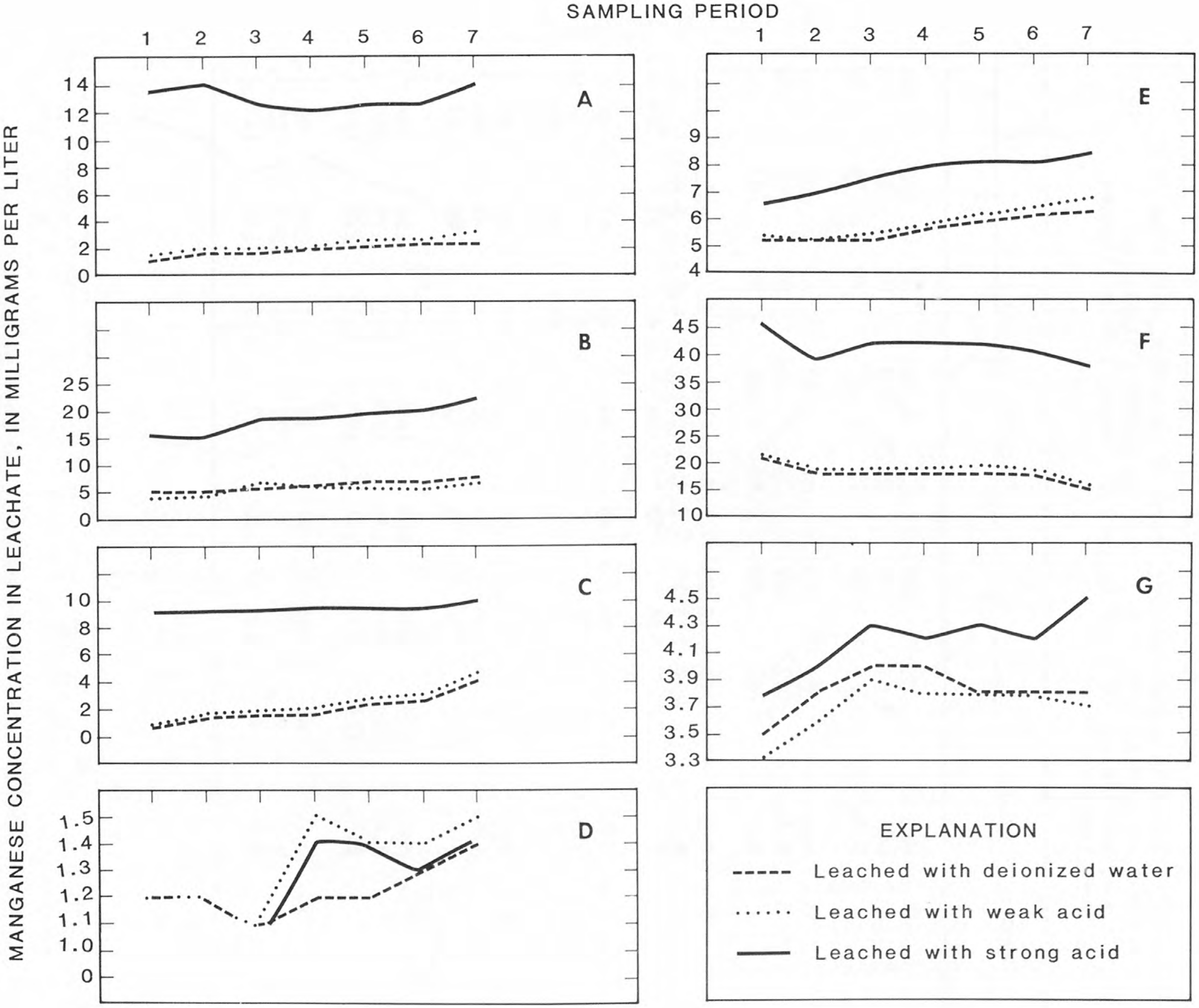

Figure 9.-- Variation of manganese concentration in leachates with time.

Table 10.--Zinc concentration of leachates with time (H_2O, deionized water, pH 5.5; W.A., 0.0005 $\underline{N}$ H_2SO_4, pH 3.4; and S.A., 0.05 $\underline{N}$ H_2SO_4, pH 1.7. Results in milligrams per liter.)

Sample	Reagent	Sampling period						
		1	2	3	4	5	6	7
A -	H_2O	.03	.03	.01	.02	.02	.02	.08
	W.A.	.03	.02	.01	.03	.02	.03	.36
	S.A.	1.17	1.04	.72	.89	.70	.59	.30
B -	H_2O	.02	.03	.01	.02	.02	.02	.02
	W.A.	.02	.02	.01	.02	.03	.01	.01
	S.A.	.63	.53	.46	.81	.85	.83	.61
C -	H_2O	.41	1.27	1.7	1.5	3.6	4.1	7.4
	W.A.	.92	1.95	2.1	2.1	4.3	5.4	.8
	S.A.	31	36	39	34	47	44	57
D -	H_2O	53	55	64	59	65	43	68
	W.A.	53	56	67	59	65	59	64
	S.A.	56	58	70	66	69	67	69
E -	H_2O	44	45	56	47	59	56	65
	W.A.	47	48	58	51	62	65	68
	S.A.	65	63	74	62	78	88	83
F -	H_2O	159	191	183	144	191	181	139
	W.A.	159	194	175	128	191	175	138
	S.A.	217	237	231	185	231	222	121
G -	H_2O	81	95	91	78	91	100	90
	W.A.	78	95	90	79	91	105	95
	S.A.	95	114	110	97	112	131	117

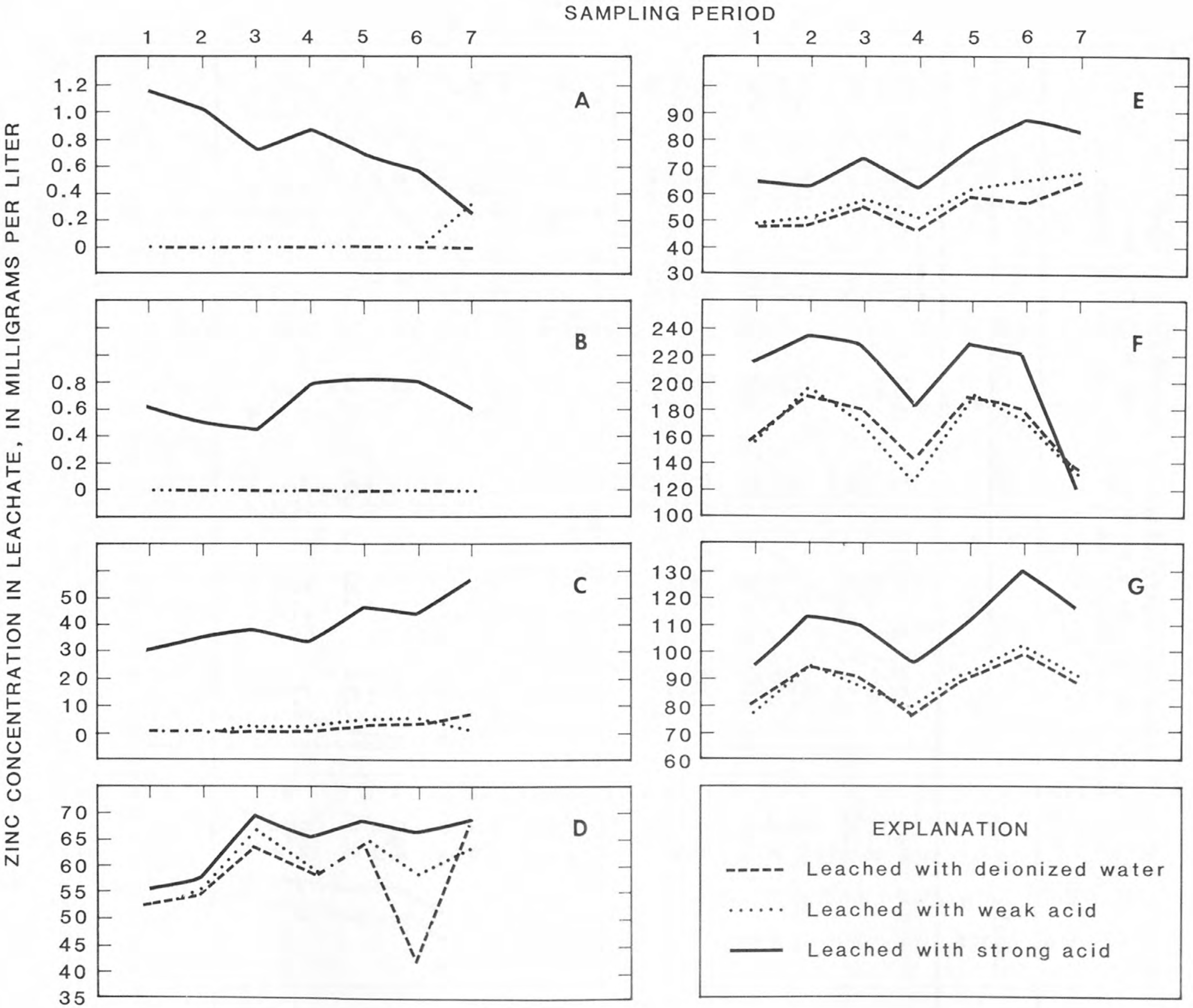

Figure 10.-- Variation of zinc concentration in leachates with time.

Table 11.--Copper concentration of leachates with time (H_2O, deionized water, pH 5.5; W.A., 0.0005 *N* H_2SO_4, pH 3.4; and S.A., 0.05 *N* H_2SO_4, pH 1.7. Results in milligrams per liter.)

Sample	Reagent	Sampling period						
		1	2	3	4	5	6	7
A -	H_2O	.04	.00	.12	.04	.07	.51	.02
	W.A.	.04	.04	.15	.04	.52	.51	.07
	S.A.	.58	.16	.18	.15	.52	.14	.00
B -	H_2O	.00	.02	.02	.02	.00	.04	.04
	W.A.	.00	.05	.00	.08	.06	.00	.04
	S.A.	.19	.13	.09	.12	.05	.09	.06
C -	H_2O	.10	.02	.07	.09	.05	.02	.00
	W.A.	.02	.02	.05	.09	.06	.06	.04
	S.A.	2.4	1.6	.40	.68	.32	.14	.04
D -	H_2O	20	18	16	16	13	14	8.5
	W.A.	18	20	16	14	14	13	9.2
	S.A.	23	23	20	20	18	19	13
E -	H_2O	8.3	7.7	3.0	3.8	4.2	4.1	.90
	W.A.	8.1	7.9	3.9	3.4	4.3	4.0	.90
	S.A.	9.3	8.5	7.3	6.7	7.8	7.2	2.1
F -	H_2O	.20	.20	.19	.21	.18	.18	.06
	W.A.	.23	.13	.13	.18	.18	.06	.11
	S.A.	.23	.20	.00	.18	.18	.20	.14
G -	H_2O	6.3	5.2	3.2	3.3	3.9	3.5	1.0
	W.A.	6.2	5.0	3.8	3.1	3.8	3.3	1.0
	S.A.	7.7	6.8	4.8	4.2	4.9	4.8	1.7

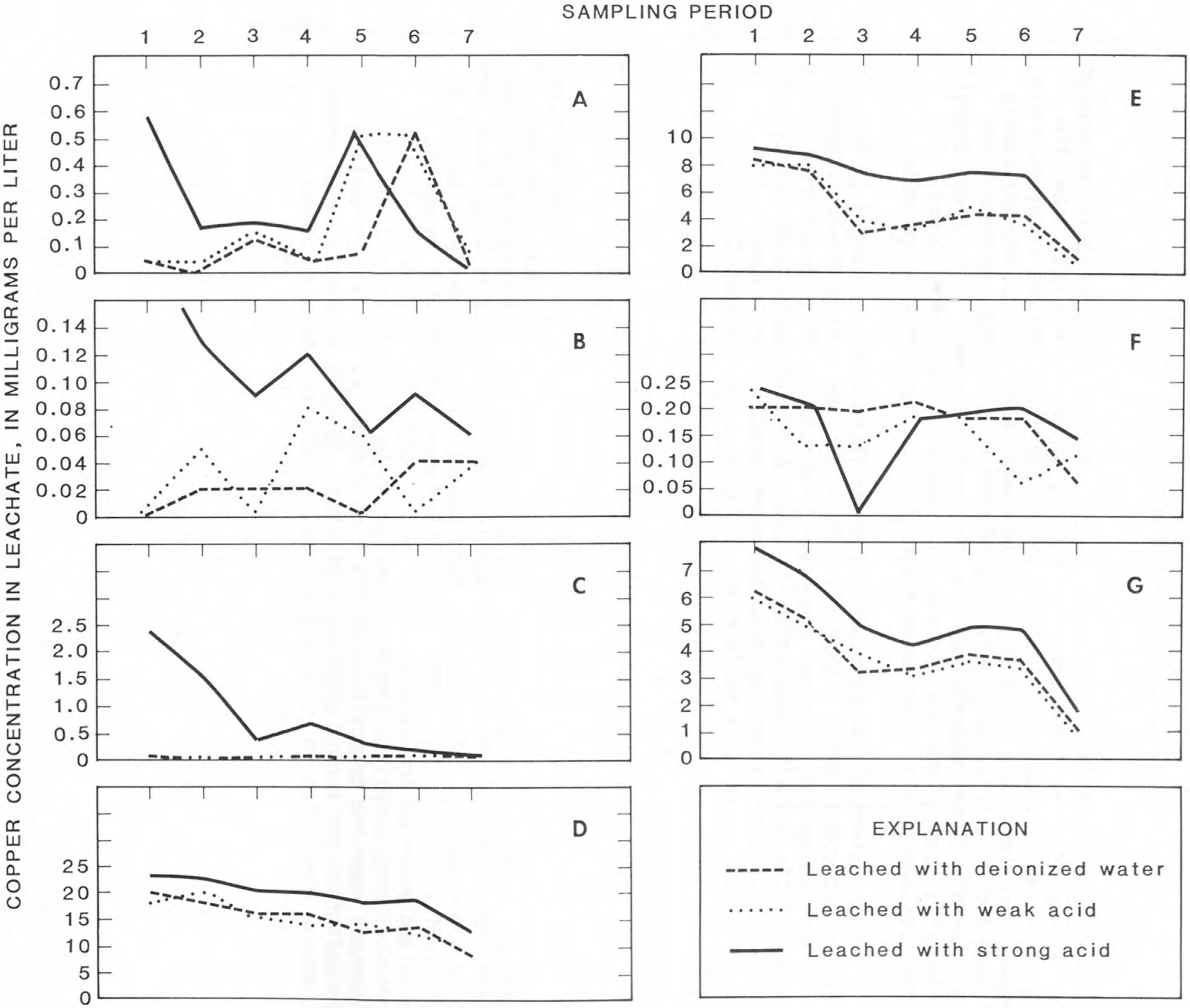

Figure 11.-- Variation of copper concentration in leachates with time.

SUMMARY

Table 12 presents a summary of the leachate data collected at the end of the first week after three series of wet-dry cycles. This data shows the highly variable reaction to leaching of the six fresh and one retorted shale sample leachates. The retorted shale leachate (sample F) is several orders of magnitude higher in concentrations of sodium, potassium, manganese and zinc than the other leachate samples, but does not appear to be significantly different in concentrations of calcium, magnesium, iron, and copper. The concentrations in all fresh shale leachate samples are highly variable.

Investigators of the Colorado oil shale found similar changes in the retorted (or spent) shale (table 13). These include a significant increase in sodium, potassium, calcium, magnesium, and sulfate after retorting. Several of the elements studied in the present investigation were not tested for by the Colorado investigators, and some constituents tested by the Colorado studies, notably sulfate and chloride, were not tested in this study.

CONCLUSION

This investigation has generated previously unavailable analytical data on the oil shale with respect to leaching by water and sulfuric acid, both of which are common in mining areas. The analytical data indicate that the six fresh shale and one retorted shale samples behaved very differently from each other upon leaching. In addition, each sample released chemical elements at different rates and at different quantities when leached with solutions of deionized water as compared to 0.0005 N and 0.05 N sulfuric acid. This indicates that materials leached from oil shale mining sites will be dependent upon the composition of shale at that site, and on the quality of precipitation and runoff reaching that site. Similar studies will be needed at actual mine sites to predict the local effects on the environment.

Table 12.--Comparison of first-week leachates
(Results in milligrams per liter)

Sample	Na	K	Ca	Mg	Fe	Mn	Zn	Cu	pH(units)
(A) Leaching reagent: Deionized water									
A	12.5	12.0	50	50	0	1.1	0.03	.04	5.5
B	12.5	11.0	66	117	0	5.3	.02	0	5.6
C	31.0	14.5	20	18	8	.6	.41	.10	5.1
D	3.8	9.0	0	2.8	1,280	1.2	53.0	20.0	2.4
E	12.0	16.7	60	237	118	5.2	44.0	8.3	2.5
F	108.7	135.0	37	225	210	20.5	159.0	.2	2.4
G	3.0	.5	.5	73	93	3.5	81.0	6.3	2.4
(B) Leaching reagent: 0.0005 N H_2SO_4									
A	12.0	13.3	54.0	53	0	1.5	.03	.04	5.9
B	10.5	11.6	70.0	120	0	5.2	.02	0	5.9
C	33.7	15.7	26.0	26	0	.9	.92	.02	5.1
D	4.0	9.2	.0	2.2	1,310	1.2	53	18	2.3
E	11.5	16.3	64.0	245	140	5.4	47	8.1	2.5
F	112.7	130.0	39.0	233	203	21.7	159	.23	2.4
G	3.5	.5	.4	76	103	3.3	78	6.2	2.4
(C) Leaching reagent: 0.05 N H_2SO_4									
A	14.5	20.1	122	237	44	13.7	1.17	.58	2.5
B	15.5	17.6	135	243	143	16.6	.63	.19	2.5
C	52.3	41.5	154	167	68	9.2	31.0	2.4	2.7
D	4.5	16.7	0	2	1,360	1.2	56.0	23.0	1.9
E	15.5	27.0	45	275	530	6.6	65.0	9.3	2.3
F	113.0	149.0	21	280	490	45.7	217.0	.23	2.2
G	4.0	1.5	.3	61	405	3.8	95.0	7.7	2.3

Table 13.--Data on leachates from fresh and retorted Colorado oil shale

Constituent	POS-1 (fresh)		PSS-1 (retorted)	
	First leachate	Last leachate	First leachate	Last leachate
Study A[1]. (Data in milligrams per liter)				
SO_4	1,800	700	16,800	3,700
Cl	24	5.3	475	74
Ca	8.6	3.3	540	470
Mg	12	3.3	39	26
Na	2,400	930	8,400	1,200
K	15	7.0	1,100	310
Mo	31	7.4	2.5	.7
pH	8.4	8.5	9.6	9.4
Dissolved solids	8,700	3,600	27,700	5,900

Ion	Raw Shale (fresh)	TOSCO II (retorted)	USBM (retorted)	Union-A (retorted)
Study B[2]. (Data in pounds per ton)				
K	.48	.64	1.44	12.5
Na	.96	3.30	4.50	42.0
Ca	.2	2.30	.84	6.54
Mg	.02	.54	.08	1.82
Cl	.44	.16	.26	.66
SO_4	1.58	14.6	12.0	124

[1] Modified from Stollenwerk and Runnells, 1981, p. 1344, table IV.

[2] Ward and others, 1971; cited in University of Oklahoma Science and Public Policy Program, 1979, p. 227.

HYDROLOGIC RECONNAISSANCE OF THE OIL SHALE OUTCROP IN KENTUCKY

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ABSTRACT

The major oil shale outcrop belt in Kentucky covers approximately 1,000 square miles in a horseshoe pattern from Vanceburg, Lewis County, in the east, to Louisville, Jefferson County, in the west. The belt is within, and adjacent to, the Knobs physiographic region. The Knobs are characterized by rolling to steep hills and low, flat-topped ridges.

Oil shales are predominantly of Devonian age and have been given various names for rocks that are laterally correlative. The most prominent names are the Ohio, Chattanooga, and New Albany Shales. These units consist of black to dark gray to greenish-gray clay shale with minor amounts of pyrite, siltstone, sandstone, limestone, and dolomite. The Devonian oil shale is overlain by less organic-rich shale of Mississippian age. Older limestones, dolomites, and shales uncomformably underlie the oil shale.

The Kentucky, Red, and Licking Rivers cross the oil shale outcrop belt. The Rolling Fork River flows along the strike of the shale in the southwest part of the outcrop. The Ohio River flows past the outcrop at the ends of the "horseshoe," near Vanceburg and Louisville. The shale does not appear to significantly alter water quality of these rivers or their tributaries, but more samples are needed to clarify minor differences in constituent concentrations between upstream and downstream samples.

The oil shale is not an aquifer, but seeps and small springs flow from fractures in the shale and indicate that water moves through it. This water occurs within a system of joint sets which are found throughout the shale belt, but usually do not extend more than 50 feet into the shale. Oil shale does not yield adequate supplies of ground water for domestic purposes. Ground-water quality is highly variable; for example, specific conductance ranges from 106 to 8,000 micromhos per centimeter and pH from 2.8 to 7.8 units.

INTRODUCTION

Energy use in the United States is heavily dependent on foreign petroleum. In an effort to reduce this dependency, the nation is studying alternative energy sources. In Kentucky, alternative sources of energy are coal, tar sands, and organic rich shales, the latter source having a potential of producing 20 billion barrels of oil (Hower, 1981, p. 3).

The mining and retorting of the oil shale may require large quantities of water, and can alter surface and ground water hydrology. There is need, therefore, for hydrologic data in the shale outcrop area to aid in the development of the resource and to provide a base line to assess the hydrologic effects of shale mining and retorting processes.

Purpose and Scope

The purpose of this report is to provide baseline data on the quality and quantity of water available from the oil shale outcrop area in the Knobs physiographic region in Kentucky. This study was made by the U.S. Geological Survey in cooperation with the Kentucky Geological Survey in 1981-82.

The scope of this study was a general hydrologic reconnaissance of the oil shale outcrop area in the Knobs. This included compiling previously published water-quality data, collecting additional water samples for analysis, analyzing surface-water flow data, and discussions with people in the area.

Location

The study area is the major outcrop area of oil shale in Kentucky (fig. 12). This area, bordered on the north by the Ohio River, extends in a horseshoe pattern from Vanceburg, Lewis County, in the east to Louisville, Jefferson County, in the west. This outcrop area of the oil shale covers approximately 1,000 square miles (Burroughs, 1926, p. 76). Less extensive outcrops of oil shale occur in south central Kentucky, but are not included in this report because of the limited time and scope of this study.

Previous Investigations

Reconnaissance reports on the geology and availability of ground water in the Blue Grass region, including the Knobs region, have been made by Palmquist and Hall (1960a,b,c), and Hall and Palmquist (1960a,b,c). Studies of ground-water hydrology restricted to the Knobs region have not been made.

McFarland (1943) and Burroughs (1926) described the geology and geography of the Knobs region. Detailed descriptions of the occurrence and composition of the oil shale are presented in the geological quadrangle maps that cover the area. (Index to maps is available from the Kentucky Geological Survey).

The chemical quality of ground water throughout Kentucky, including the Knobs region, has been compiled by Faust and others (1980). Streamflow data and some chemical analyses of surface water in the Knobs are published in the annual Water-Data report (U.S. Geological Survey).

Method of Investigation

Field work for this report was done in the fall of 1981 and spring of 1982. It consisted of collecting surface and ground water samples, making discharge measurements, and performing a visual reconnaissance of the oil shale outcrop area in the Knobs region. Water samples were analyzed for inorganic, metal, and radiochemical constituents.

Previously collected data included in this report were compiled from the sources listed in the previous section and from data filed in the National Water Data Storage and Retrieval System of the U.S. Geological Survey's computer system.

PHYSIOGRAPHY

Figure 13 shows the physiographic regions of Kentucky. The study area of this report is commonly referred to as the Knobs region (Burroughs, 1926, Fenneman, 1938). However, the total area of conical hills (known as knobs) is relatively small compared to the overall oil shale outcrop area.

The oil shale outcrop area is characterized by rolling to steep-sided hills, low flat-topped ridges, and the steep-sided faces of the Pottsville and Muldraugh's Hill escarpments (fig. 13). Knobs are usually present where more resistant overlying rocks have preserved the shale as outlying conical hills left as remnants of the retreating escarpments. The low, flat topped ridges are usually near streams and are frequently mantled by alluvial deposits.

Drainage in the Knobs region is characterized by broad, flat valleys along main stems of streams and by steep, narrow valleys in the headwaters.

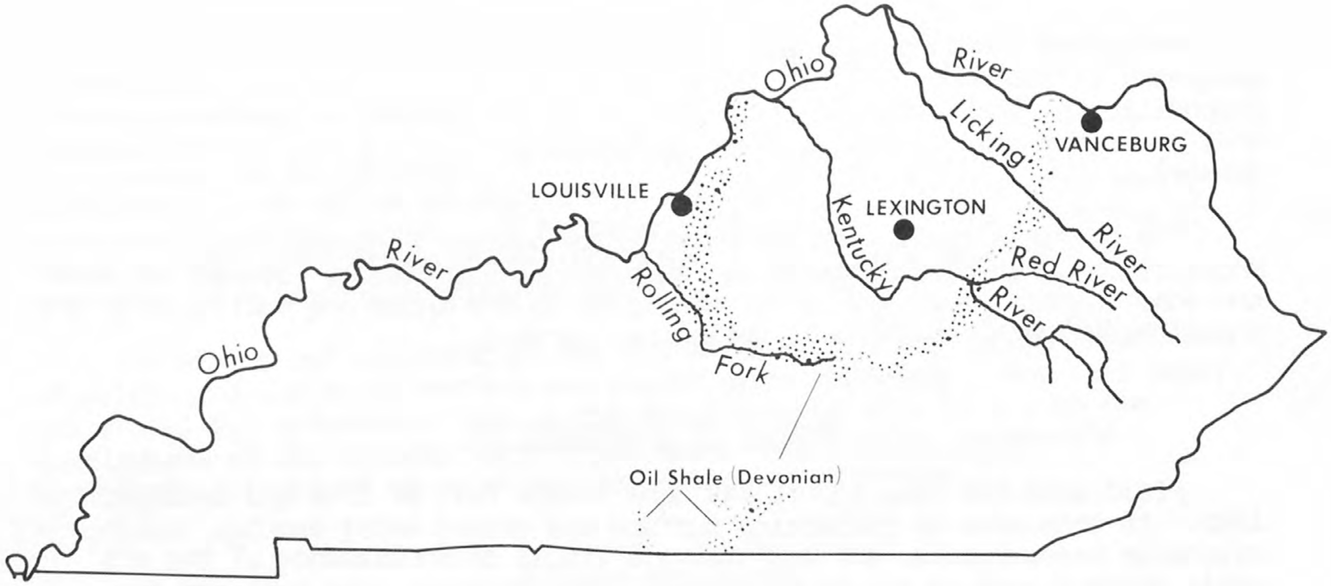

Figure 12.-- Location of oil shale outcrop areas in Kentucky.

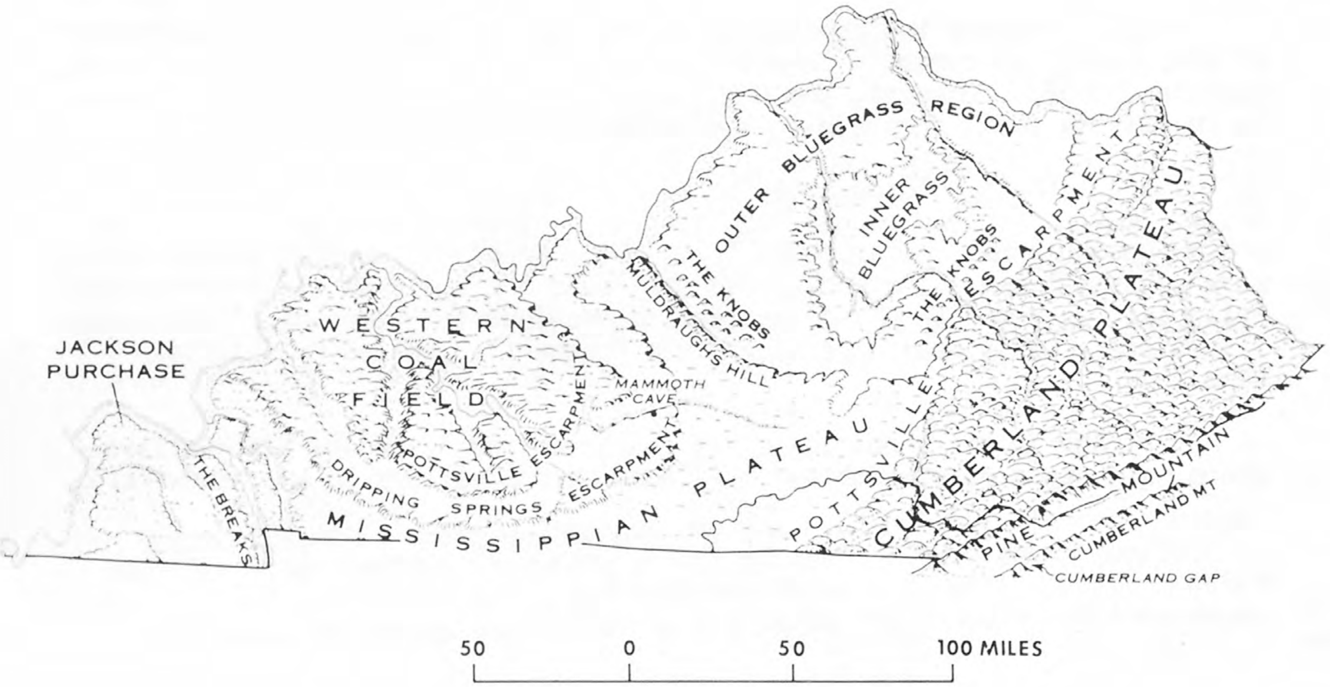

Figure 13.-- Physiographic regions of Kentucky.

Vegetation cover in the shale outcrop area ranges from farm land on the flat-topped ridges and river bottoms, to pasture land on the rolling hills, to heavily wooded slopes and hilltops on the Knobs and escarpments. Natural forest growth consists of several species of oaks, hickory, chestnut, and pine. Sycamores are also present, but mostly along the river bottoms (Burroughs, 1926, p. 93). Most of the original forest was cut during the late 1800's and early 1900's. Forest areas now consist principally of secondary growth which support lumbering activities throughout the area.

GEOLOGY

Rocks of Devonian age, which includes most of the oil shales, are presented in a generalized geologic map of Kentucky (fig. 14). Various names have been given to the units since the earliest geologic investigations of oil shales in Kentucky. David Dale Owen (1856) described them as "Black Lingula Shale" and over the years various workers mapping in the State applied names to the black shales which were in use elsewhere in the eastern half of the United States. The various names for these shales, especially Ohio, Chattanooga, and New Albany Shales, are found throughout the literature. The distribution of the black organic rich or oil shales of major interest and names applied to the Devonian age rocks in the Eastern United States and a generalized geologic column for Kentucky were shown in figure 1.

The Devonian oil shale is overlain by less organic-rich shale of Mississippian age. Older limestones, dolomites, and shales uncomformably underlie the oil shale. Other geologic units present in this area are the Quaternary and recent unconsolidated gravels, sand, clay, and silts in alluviated river bottoms and on high level terraces.

The Chattanooga, New Albany, and Ohio sequence of organic-rich shales range in age from Middle and Late Devonian to, in some places, as late as Early Mississippian (Kinderhookian). For practical purposes, they are often considered as Devonian black shale, but, in this report, will hereafter be referred to as "oil shale." The oil shale is generally 20 to 40 feet thick along the crest of the Cincinnati Arch. The rocks consists of black to dark gray to greenish-gray clay shale with minor amounts of pyrite, siltstone, sandstone, limestone and dolomite. Fossil material is present, but not abundant.

Downdip from the outcrop area, the shale thickens to more than 1,700 feet in extreme eastern Kentucky and to 460 feet in Crittenden and Union Counties in western Kentucky (Schwalb and Potter, 1978; Potter, 1978; and Fulton, 1979). Detailed stratigraphic and lithologic descriptions can be found on the geologic quadrangle maps. In addition, Pollock and others (1981) provide a good summary of the lithology of the shale in east-central Kentucky.

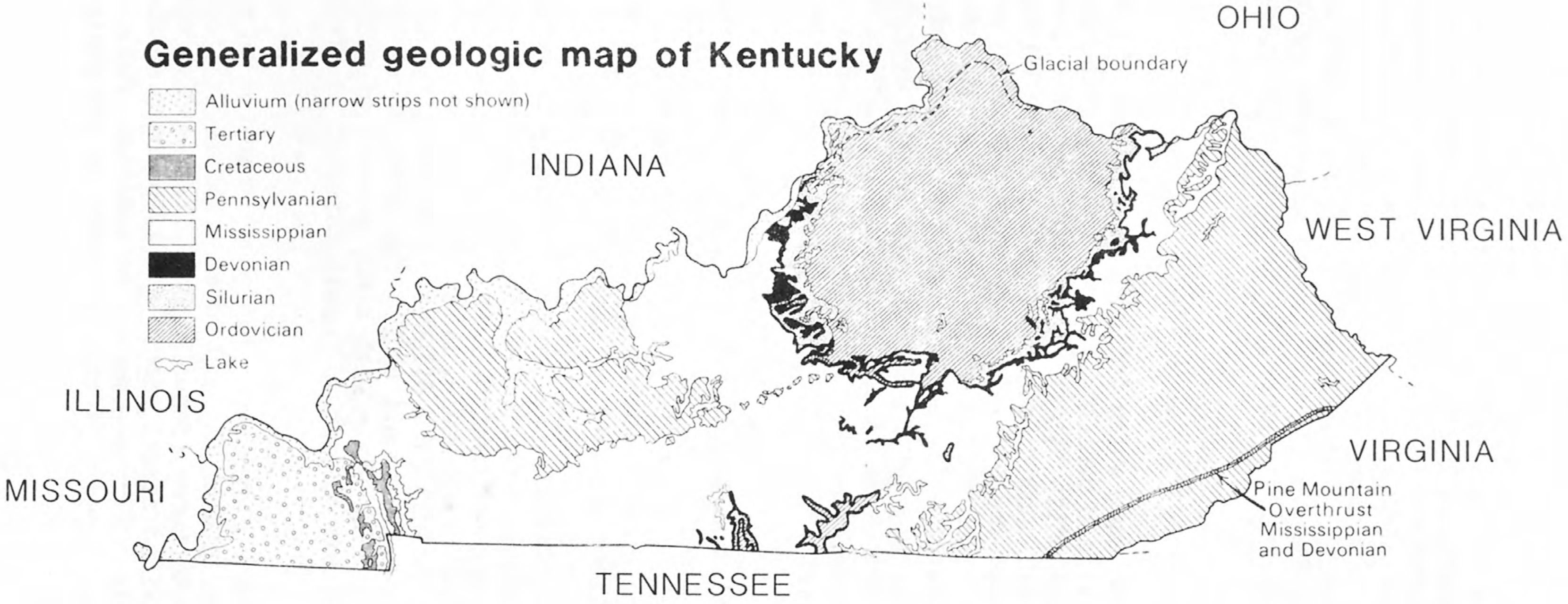

Figure 14.-- General geology of Kentucky.

Major structural features which have the most direct influence on the outcrop area of the oil shale are the Cincinnati Arch and Kentucky River Fault System (fig. 15). The Cincinnati Arch is a dominant structural feature and is essentially a broad and elongated dome extending in a northeast-southwest direction through Kentucky. The regional dips on the flanks of the dome range from 20 to 60 feet per mile. The Kentucky River Fault System consists of a series of en echelon normal faults which form grabens (Black and Haney, 1975). The general movement was down to the southeast and the throw of the faults can be as much as 600 feet. In addition to this system, a set of northeast and east-northeast trending faults and hundreds of northwest trending normal faults and grabens occur in central Kentucky. All of these systems affect the outcrop pattern and subsurface structure of the oil shale.

In addition to the major structural features, there are many smaller synclines and anticlines (fig. 16) throughout the study area (Dillman, 1980). Joints and fractures, which are related to the structural features, can be found throughout the outcrop area. At least two major sets of joints can be mapped and a third set may be present. The joint sets are especially visible along stream beds and fresh outcrops (fig. 17). The joints are generally small and usually do not extend more than 50 feet into the shale (Hall and Palmquist, 1960a,b,c).

HYDROLOGIC CONDITIONS

Ground-water occurrence

A general reconnaissance of the oil shale area showed the principal sources of domestic water in rural areas are cisterns, springs, and hauled water. The oil shale does not usually yield adequate supplies of ground water for domestic purposes (minimum of 100 gallons per day), and wells which do obtain water from the shale may go dry during summer months.

Water in oil shale occurs along the system of intersecting joint sets previously described (Hall and Palmquist, 1960a-c; Burroughs, 1926, p. 85). In some areas, weathered zones of shale between unweathered shale have been observed in freshly cut core samples from test holes (R. C. Kepferle, oral commun., 1982). These weathered zones and the wide-spread occurrence of joints suggest that ground water may circulate in the oil shale along the joints and also along bedding planes or through more permeable units within the shale.

Additional evidence to support the concept of ground water circulation in joints was reported by residents in the eastern part of the outcrop area. They reported that some dug wells and springs went dry after an earthquake in 1980. Earth movement or slumping may have sealed some of the joints, impeding the flow of ground water.

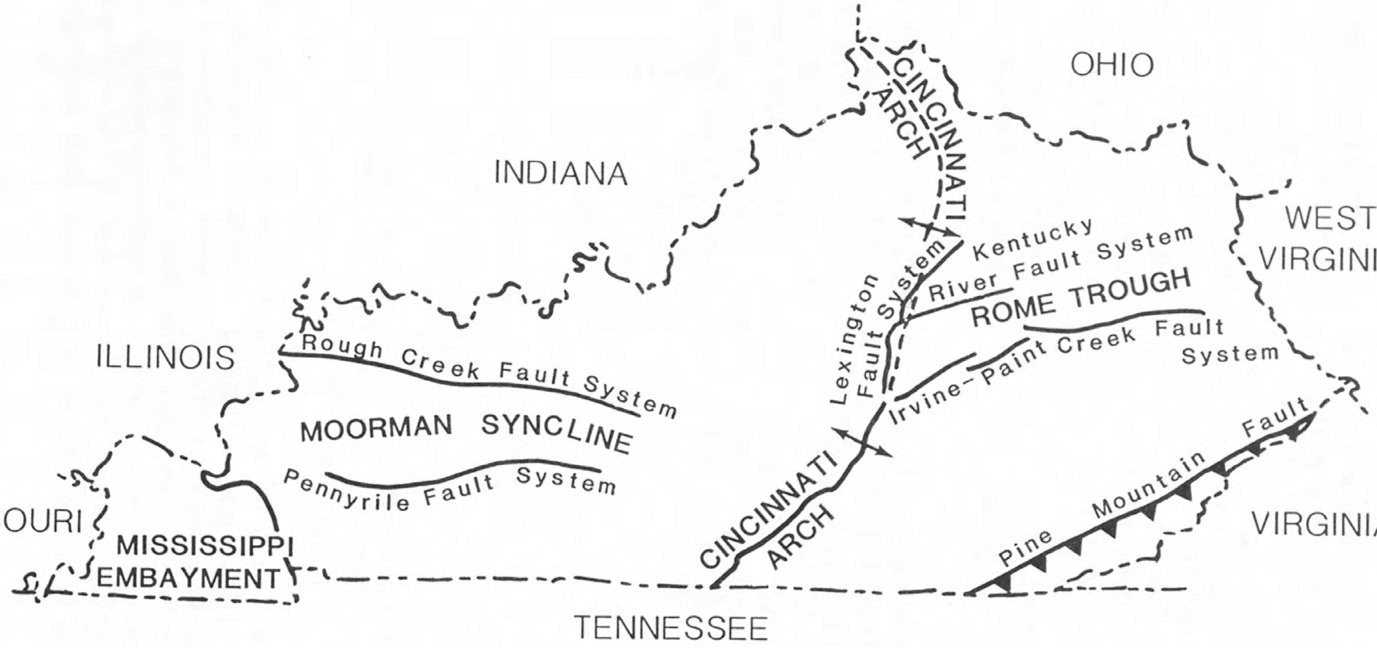

Figure 15.-- Major structural features of Kentucky.

Figure 16.--Small anticline in oil shale along Slate Creek, Montgomery County, Kentucky.

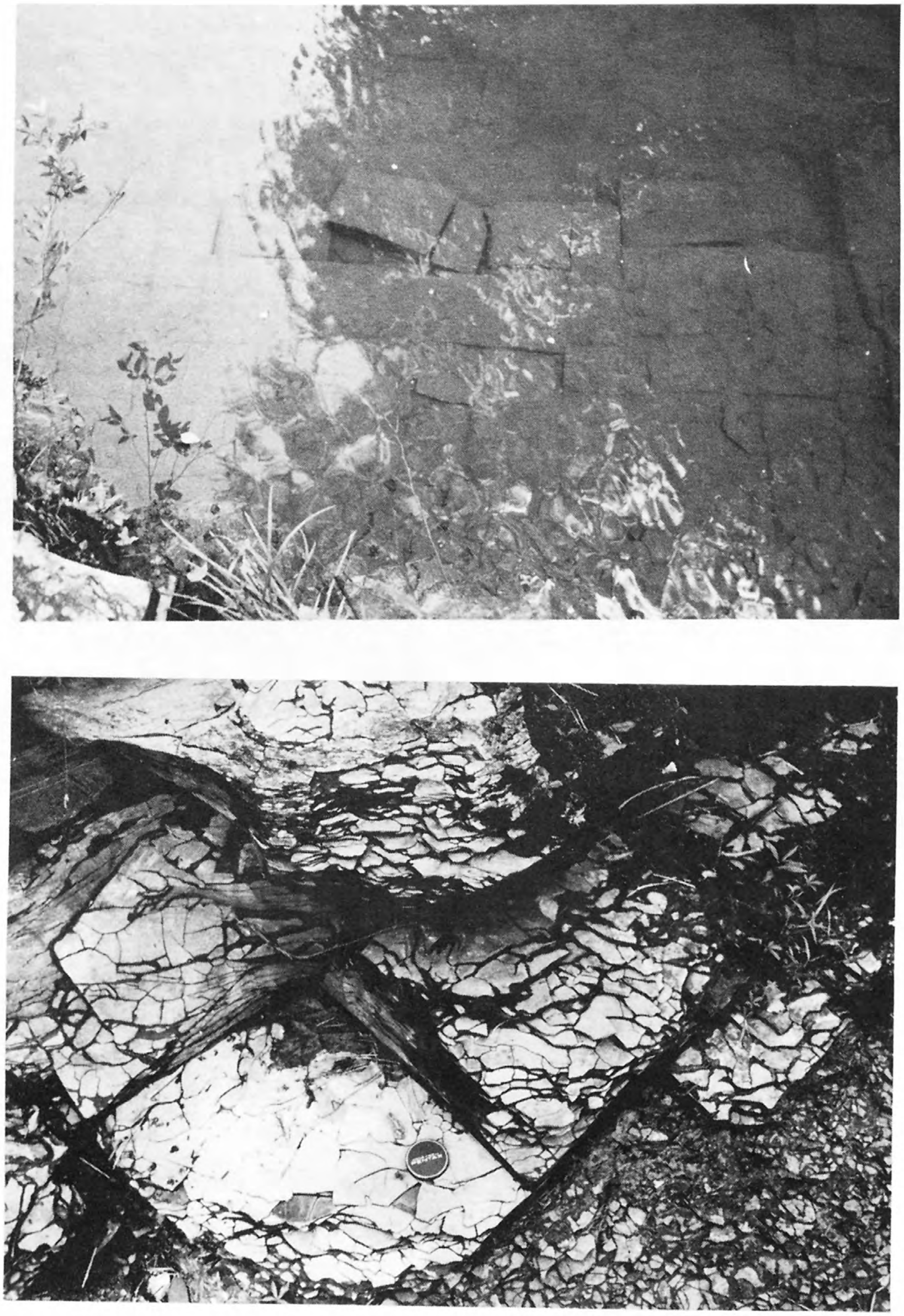

Figure 17.--Joint pattern and weathering of oil shale along Little Slate Creek, Montgomery County, Kentucky.

The success of wells drilled in the oil shales may depend on the location of the wells with respect to valleys. Wayrick and Borchers (1981), from a study at Twin Falls State Park in West Virginia, postulated that stress release caused by unloading of overburden by stream erosion causes horizontal bedding-plane compression-release fractures under valley floors and nearly vertical and horizontal slump fractures along valley walls. The fractures tend to pinch out under the valley walls. Therefore, wells drilled in the valley flats or close to valley walls may yield more water than wells drilled in higher areas away from the valleys. Well yields in the study area of this report tend to support this hypothesis.

Many springs and seeps are found throughout the study area. In general, springs that occur within the oil shale and at the basal contact with the underlying formations produce small quantities of water that are unfit for most domestic uses. Another spring horizon, yielding water usually of better quantity and quality, is commonly found a short distance below the oil shale in non-shale formations.

Some springs in the oil shale outcrop belt were of commercial value in the early 1900's. The better known of these "mineral" springs are Sulphur Springs in Marion County, Alum Springs in Boyle County, Dripping Springs in Garrard County, Estill Springs in Estill County, and Olympian Springs in Bath County (Burroughs, 1926) (plate 1). Spout Springs in Estill County is currently used as a water supply for several families (plate 1).

Surface Water Occurrence

Three major streams, the Kentucky, Red, and Licking Rivers, flow across the outcrop in the eastern part of the area, and the Rolling Fork River flows along the strike of the oil shale in the southwest. The Ohio River flows across the outcrop in Lewis County (north-eastern Kentucky) and again in Jefferson County (north-central Kentucky, plate 1). Numerous small tributary streams originate in the oil shale outcrop, but very few cross it. In places, small streams disappear underground in fractures in dolomite or limestone after flowing on the shale outcrop. The interaction between stream flow and ground water is not well documented, but it is probable that water is intermixed between the ground water system and the streams along the outcrop belt.

Streamflow in the outcrop area is highly variable. During low rainfall periods, stream flow is poorly sustained by ground water, and many streams go dry. Streams with a drainage area of less than about 60 mi^2 have a 7 day-10 year low flow of zero (table 14). In contrast, flooding in the area can be severe. The floods of December 1978 exceeded the 50-year recurrence

Table 14.--Flow data for the Licking, Red, Kentucky, and Rolling Fork River basins

Site number	Station	Station number	Period of record	Drainage area (mi^2)	Flow, in cubic feet per second				Type of station
					Average flow	Maximum flow	Minimum flow	7-day 10-year low flow	
	Licking River basin								
1	Licking River at Farmers[1]	03249500	1938-82	826	1,070	24,000	0.70	50	Daily discharge, water quality.
2	Triplett Creek at Morehead	03250000	1941-80	47.5	73	18,600	.0	.1	Daily discharge, water quality.
3	North Fork Triplett Creek near Morehead	03250100	1967-82	84.7	134	8,200	.0	.1	Daily discharge, water quality.
4	Licking River near Moores Ferry[1]	03250125	1981-82	1,102	-------	-------	---	-----	Water quality.
5	Slate Creek near Jeffersonville	03250185	1973-82	56.7	-------	-------	.0	.0	Low flow.
6	Slate Creek near Owingsville	03250240	1970-71	185	-------	-------	---	-----	Water quality.
7	Rose Run Tributary near Olympia	03250243	1975-82	0.7	-------	[470	---	-----	Peak flow.
8	Rock Lick Creek near Sharkey	03250320	1973-82	4	8.04	1,990	.0	-----	Daily discharge.
	Red River basin								
9	Red River at Clay City	03283500	1938-82	362	487	28,800	1.2	3.7	Daily discharge, water quality.
10	Lulbegrud Creek Tributary at Westbend	03283610	1975-82	.33	-------	90	---	-----	Peak flow.
11	Lulbegrud Creek at Log Lick	03283630	1973-82	49	-------	-------	---	.1	Low flow.
12	Red River near Trapp	03283700	1981-82	487	-------	-------	---	-----	Water quality.
	Kentucky River basin								
13	Kentucky River at Lock 14, near Heidleberg[2]	03282000	1925-82	2,657	3,667	120,000	4.0	114 (since 1960)	Daily discharge.
14	Kentucky River at Irvine	03282250	1981-82	3,138	--------	-------	---	-----	Water quality.
15	Kentucky River near Trapp	03282300	1981-82	3,236	--------	-------	---	-----	Water quality.
16	Kentucky River at Lock 10, near Winchester[2]	03284000	1907-82	3,955	5,307	101,000	[10.0	154 (since 1960)	Daily discharge.
	Rolling Fork River basin								
17	North Rolling Fork near Gravel Switch	03298710	1974-82	66.2	--------	-------	---	.0	Low flow.
18	North Rolling Fork at Bradfordville	03298760	1973-75	95.7	--------	-------	---	-----	Water quality.
19	Big South Fork at Bradfordville	03298865	1974-82	59.6	--------	-------	---	.0	Low flow.

Table 14.--Flow data for the Licking, Red, Kentucky, and Rolling Fork River basins--Continued

Site number	Station	Station number	Period of record	Drainage area (mi^2)	Flow, in cubic feet per second: Average flow	Maximum flow	Minimum flow	7-day 10-year low flow	Type of station
				Rolling Fork River basin					
20	Rolling Fork near Lebanon	03299000	1938-82	239	344	54,800	.0	.1	Daily discharge, water quality.
21	Pottinger Creek near New Hope	03299445	1974-82	43.5	--------	-------	---	.0	Low flow.
22	Beech Fork at Maud	03300400	1972-82	436	740	33,300	.74	1.0	Daily discharge, water quality.
23	Hardins Creek near Holy Cross	03300780	1975-78 1980-82	57.8	--------	-------	---	.0	Low flow.
24	Town Creek Tributary at Bardstown	03300990	1975-82	.32	--------	120	---	-----	Peak flow.
25	Beech Fork at Bardstown	03301000	1939-74 1975-78 1980-82	669	906	39,900	.0	.2	Daily discharge to 1974, water Water quality.
26	Rolling Fork near Boston	03301500	1938-82	1,299	1,819	65,000	.4	2.2	Daily discharge, water quality.
27	Rolling Fork near Lebanon Junction	03301630	1975-82	1,375	--------	-------	---	-----	Water quality.

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[1] Flow regulated by Cave Run Lake since 1973, minimum designed flow of 50 ft^3/s.
[2] Flow regulated by Buckhorn Lake since 1960.

interval at the North Fork Triplett Creek near Morehead (site number 3), Red River near Clay City (site number 9), and Rolling Fork near Boston (site number 26). The 100-year recurrence interval was exceeded during the same flood at the Kentucky River at Lock 10, near Winchester (site number 16) (Sullavan and Quinones, 1979, p. 15). More detailed surface-water data are presented in the following sections.

Licking River

The Licking River drains about 3,700 mi^2, or about 10 percent of the State. Flow data for this basin are listed in table 14. The Licking originates in Magoffin County, flows across the Eastern Kentucky coal field, the Cumberland Plateau, the Knobs, and the outer Bluegrass physiographic regions, and empties into the Ohio River at Covington. The main stem is about 320 miles long.

The Licking River flows about eight miles on the oil shale outcrop (plate 1). The principal tributaries in this area are Slate Creek (draining 230 mi^2), Fox Creek (117 mi^2), and Triplett Creek (187 mi^2). Much of the drainage in Slate and Fox Creeks is from the oil shale outcrop area, whereas much of the drainage from Triplett Creek is from outside this area. Cave Run Reservoir (8,270 acres during normal pool) is just upstream from the oil shale outcrop.

Red River

The Red River drains 487 mi^2 of Kentucky. Flow data for this basin are listed in table 14. The Red River originates in Wolfe County, flows across the Eastern Kentucky coal field, Cumberland Plateau, and Knobs physiographic regions, and empties into the Kentucky River between Estill and Clark Counties. The main stem is about 85 miles long.

The Red River flows about 10 miles through the oil shale outcrop (plate 1). The principal tributaries in this area are Lulbegrud Creek (53 mi^2), Twin Creek (drainage area not determined), and Hardwick Creek (drainage area not determined). Much of the drainage from these streams is from within the oil shale outcrop area.

Kentucky River

The Kentucky River drains about 7,000 mi^2 of Kentucky, or about 17 percent of the State. Flow data are listed in table 14. The Kentucky River is formed by the confluence of the North Fork and South Fork Kentucky Rivers, flows across the Eastern Kentucky Coal Field, Cumberland Plateau, Knobs, Inner Bluegrass, and Outer Bluegrass physiographic regions, and empties into the Ohio River at Carrolton. The main stem is about 260 miles long.

The Kentucky River flows about 11 miles through the oil shale outcrop area (plate 1). The principal tributaries in this area are Drowning Creek (37 mi^2) and Station Camp Creek (217 mi^2). Most of the drainage from Drowning Creek and Red Lick Creek tributary of Station Camp Creek is from the oil shale outcrop area.

Rolling Fork River

The Rolling Fork River drains about 1,450 mi^2 of Kentucky and much of this is in the oil shale outcrop area. Flow data for this basin are listed in table 14. The Rolling Fork originates in Marion County, flows along the strike of the Knobs physiographic region, and empties into the Salt River. The Salt River empties into the Ohio River at Westpoint. The main stem of the Rolling Fork River is about 110 miles long.

The principal tributaries of the Rolling Fork are Wilson Creek (38 mi^2), Beech Fork (752 mi^2), North Rolling Fork (99 mi^2), and Big South Fork (65 mi^2). With the exception of Beech Fork, the headwaters of these streams are in the oil shale outcrop belt.

Water Quality

As water moves in the hydrologic system, its chemical character changes. Water entering the system as precipitation contains dust, smoke, gases, and chemicals dissolved from the atmosphere. As water moves through the system, it dissolves or deposits additional constituents from the earth materials. The character of the material and the length of time that the water is in contact with this material determines the water's chemical quality. The source and significance of chemical constituents commonly found in water are given in table 15.

Ground Water

Water-quality data have been collected by the U.S. Geological Survey intermittently at wells and springs in the oil shale outcrop area for many years. In addition, seven water samples were collected from wells and springs for this study. Table 16 is a summary of these analyses and table 17 provides the detailed results. These data show the high variability of the quality of ground water in the oil shale. For example, specific conductance values ranged from 106 to 8,000 micromhos per centimeter, and pH ranged from 2.8 to 7.8 units. This variability may be the result of the length of contact time with the oil shale, depth of the well, type of overlying material, or impurities within the oil shale.

Table 15.--Source and significance of dissolved mineral constituents and physical properties of natural waters

Constituent or physical property	Source or cause	Significance
Bicarbonate (HCO_3) and Carbonate (CO_3)	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbon dioxide gas. In combination with calcium and magnesium cause carbonate hardness.
Calcium (Ca) and Magnesium (Mg)	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Causes most of the hardness and scale-forming properties of water; soap consuming (see hardness). Waters low in calcium and magnesium desired in electroplating, tanning, dyeing, and in textile manufacturing.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brines, sea water, and industrial brines.	In large amounts in combination with sodium gives salty taste to drinking water. In large quantities increases the corrosiveness of water. Drinking water standards recommend that the chloride content should not exceed 250 mg/L on the basis of taste preferences.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth depending on the concentration of fluoride, the age of the child, amount of drinking water consumed, and susceptibility of the individual. (Maier, F. J., 1950, Fluoridation of public water supplies: Journal American Water Works Association, v. 42, pt. 1, p. 1120-1132.)
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment. More than 1 or 2 mg/L of dissolved iron in surface waters usually indicates acid wastes from mine drainage or other sources.	On exposure to air, iron in ground water oxidizes to reddish-brown sediment. More than about 0.3 mg/L stains laundry and utensils. Objectionable for food processing, beverages, dyeing, bleaching, ice manufacture, brewing, and other processes. Federal drinking water standards recommend that dissolved iron and manganese together should not exceed 0.3 mg/L. Larger quantities cause unpleasant taste and favor growth of iron bacteria.

Table 15.--Source and significance of dissolved mineral constituents and physical properties of natural waters--Continued

Constituent or physical property	Source or cause	Significance
Manganese (Mn)	Dissolved from some rocks and soils. Not so common as iron. Large quantities often associated with high iron content and with acid waters.	Same objectionable features as iron. Causes dark brown or black stain. Federal drinking water standards recommend that dissolved iron and manganese together should not exceed 0.3 mg/L.
Silica (SiO_2)	Dissolved from practically all rocks and soils, usually in small amounts from 1 to 50 mg/L. High concentrations, as much as 100 mg/L, generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high-pressure boilers to form deposits on blades of steam turbines. Inhibits deterioration of zeolite-type water softeners.
Sodium (Na) and Potassium (K)	Dissolved from practically all rocks and soils. Found also in ancient brines, sea water, some industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers and a high sodium ration may limit the use of water for irrigation.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfide, and other sulfur compounds. Usually present in mine waters and in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. More than 250 mg/L of sulfate in drinking water acts as a laxative.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils. Includes any organic matter and some water of crystallization.	Waters containing more than 1,000 mg/L of dissolved solids are unsuitable for many purposes.
Hardness as $CaCO_3$	In most waters nearly all the hardness is due to calcium and magnesium. All of the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called noncarbonate hardness. Waters of hardness up to 60 mg/L are considered soft; 61-120 mg/L, moderately hard; 121-180 mg/L, hard; more than 180 mg/L, very hard.

Table 15.--Source and significance of dissolved mineral constituents and physical properties of natural waters--Continued

Constituent or physical property	Source or cause	Significance
Hydrogen-ion concentration (pH)	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides and phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also be corrosive.
Specific conductance (micromhos per centimeter at 25°C)	Ionic content of the water.	Specific conductance is a measure of the capacity of the water to conduct an electric current. Varies with concentration and degree of ionization of the constituents. Varies with temperature; reported at 25°C. Multiplied by 0.6 approximately equals the dissolved solids.
Temperature		Affects usefulness of water for many purposes. For most users, a water of uniformly low temperature is desired. Shallow wells show some seasonal fluctuations in water temperature. Ground waters from moderate depths usually are nearly constant in temperature, which is near the mean annual air temperature of the area. In very deep wells the water temperature generally increases on the average about 1°F with each 60-foot increment of depth. Seasonal fluctuations in temperatures of surface waters are comparatively large depending on the depth of water but do not reach the extremes of air temperatures.

Table 16.--Mean, median, maximum, and minimum values for selected water-quality parameters of ground water from the oil shale, 1953 to 1983

Parameter	Number of samples	Parameter values			
		Mean	Median	Maximum	Minimum
Specific conductance (umho/cm)	34	1,708	697	8,000	106
pH	16	--	6.9	7.5	2.8
Temperature (°C)	20	15.0	13.5	29.0	9.5
Hardness (mg/L as $CaCO_3$)	33	348	209	1,470	35
Non-carbonate hardness (mg/L as $CaCO_3$)	20	262	53	1,350	.0
Calcium (mg/L as Ca)	16	60	44	168	10
Magnesium (mg/L as Mg)	16	25	19	91	2.5
Sodium (mg/L as Na)	16	309	34	1,800	6.2
Potassium (mg/L as K)	16	6.3	4.8	18	1.2
Bicarbonate (mg/L as HCO_3)	25	263	234	830	.0
Alkalinity (mg/L as $CaCO_3$)	5	368	545	690	.0
Sulfate (mg/L as SO_4)	33	286	58	1,670	1.4
Chloride (mg/L as Cl)	33	234	17	2,400	1.3
Fluoride (mg/L as F)	33	.4	.3	1.2	.0
Silica (mg/L as SiO_2)	16	28	22	72	7
Solids (total dissolved mg/L)	15	1,190	320	4,630	250
Nitrogen NO_2+NO_3 dissolved (mg/L as N)	2	--	--	.05	.04
Aluminum dissolved (ug/L as Al)	3	7,800	5900	16,000	1,500
Iron dissolved (ug/L as Fe)	2	--	--	80	20
Manganese dissolved (ug/L as Mn)	2	--	--	120	60

Table 17.--Analyses of ground-water samples from the oil shale outcrop area

STATION NUMBER	STATION NAME	COUNTY	MAP NUMBER	LATI- TUDE	LONGI- TUDE	SEQUENCE NUMBER	SITE	DATE OF SAMPLE
		BOYLE						
373557084565101	OLLIE ENGLE		1	37 35 57	084 56 51	01	GW	53-08-07
		BULLITT						
375737085421901	COPPER RIDGE CHURCH		2	37 57 37	085 42 19	01	GW	64-05-22
		CLARK						
375450084003701	ROSCOE SNOWDEN		3	37 54 50	084 00 37	01	GW	54-03-17
	ROSCOE SNOWDEN						GW	55-10-18
		ESTILL						
373701084010301	LLOYD RHODES		4	37 37 01	084 01 03	01	GW	53-07-24
374242083574801	FOX, LINDA		5	37 42 42	083 57 48	01	GW	82-07-22
		FLEMING						
381510083413701	PARRISH JACKSON		6	38 15 10	083 41 37	01	GW	62-08-01
	PARRISH JACKSON						GW	63-03-27
	PARRISH JACKSON						GW	63-10-02
381527083340901	MF5E		7	38 15 27	083 34 09	01	GW	75-06-25
	MF5E						GW	75-09-23
	MF5E						GW	79-10-24
382422083331701	J. EARL MC BRAYER		8	38 24 22	083 33 17	01	GW	53-09-10
382433083332101	PARK LAKE ASSOC.		9	38 24 33	083 33 21	01	GW	55-01-05
		JEFFERSON						
380529085415301	E. MC CAWLEY		10	38 05 29	085 41 53	01	GW	53-04-07
	E. MC CAWLEY						GW	56-01-14
	E. MC CAWLEY						GW	56-04-17
	E. MC CAWLEY						GW	56-08-06
380757085423401	J. PENDLETON		11	38 07 57	085 42 34	01	GW	53-04-13
		LEWIS						
382640083292401	A. KIDWELL		12	38 26 40	083 29 24	01	GW	54-05-12
383655083214901	CLARK,DWIGHT		13	38 36 55	083 21 49	01	GW	82-07-21
		LINCOLN						
372631084314901	C. ADAMS		14	37 26 31	084 31 49	01	GW	53-09-04
		MADISON						
374554084080401	E. QUILLEN		15	37 45 54	084 08 04	01	GW	54-03-10
		MARION						
373735085142901	TOM MATTINGLY		16	37 37 35	085 14 29	01	GW	53-11-19
		MONTGOMERY						
380009083484801	MCGUIRE HOME, TOWN BRANCH RD		17	38 00 09	083 48 48	01	GW	82-07-08
380107083473501	MR. COREY		18	38 01 07	083 47 35	01	GW	65-05-11
		NELSON						
373512085302001	MILLERS SPRING		19	37 35 12	085 30 20	01	SP	82-05-18
374512085385801	BLACK SHALE SEEP ON BLUEGRASS PARKWAY		20	37 45 12	085 38 58	01	SP	82-05-18
		POWELL						
374816083545001	GROVER BARNETT		21	37 48 16	083 54 50	01	GW	53-06-03
374913083570401	MORTON, JAMES		22	37 49 13	083 57 04	01	GW	82-07-22
		ROWAN						
380910083331301	D.C. CAUDILL		23	38 09 10	083 33 13	01	GW	53-04-30
380958083353401	BLACK SHALE SEEP ON I-64		24	38 09 58	083 35 34	01	GW	82-04-14
381133083362201	BURL MOORE		25	38 11 33	083 36 22	01	SP	53-04-30
	BURL MOORE						SP	55-10-19

Table 17.-- Analyses of ground-water samples from the oil shale outcrop area--Continued

STATION NUMBER	DATE OF SAMPLE	SAMPLING DEPTH (FEET)	DEPTH OF WELL, TOTAL (FEET)	SPECIFIC CONDUCTANCE (UMHO)	PH (UNITS)	TEMPERATURE (DEG C)	HARDNESS (MG/L AS $CACO_3$)	HARDNESS, NONCARBONATE (MG/L $CACO_3$)	CALCIUM DISSOLVED (MG/L AS CA)	MAGNESIUM, DISSOLVED (MG/L AS MG)	SODIUM, DISSOLVED (MG/L AS NA)
BOYLE											
373557084565101	53-08-07	--	81	4490	--	--	302	--	--	--	--
BULLITT											
375737085421901	64-05-22	--	90	2730	7.4	14.4	95	0	--	--	--
CLARK											
375450084003701	54-03-17	--	42	698	--	11.6	202	--	--	--	--
	55-10-18	--	42	536	4.2	--	227	227	43	29	6.2
ESTILL											
373701084010301	53-07-24	--	31	588	--	--	283	--	--	--	--
374242083574801	82-07-22	--	--	495	--	29.0	180	--	54	10	31
FLEMING											
381510083413701	62-08-01	--	65	2580	7.0	--	1290	1060	--	--	--
	63-03-27	--	65	2860	7.6	--	1470	1190	--	--	--
	63-10-02	--	65	2910	7.3	13.8	1400	1350	--	--	--
381527083340901	75-06-25	--	310	8000	7.2	12.0	230	0	64	18	1800
	75-09-23	--	311	6220	--	--	--	--	--	--	--
	79-10-24	--	--	6330	7.7	--	240	0	64	19	1700
382422083331701	53-09-10	--	66	479	--	14.4	193	--	--	--	--
382433083332101	55-01-05	--	--	373	4.9	10.0	78	75	15	7.5	36
JEFFERSON											
380529085415301	53-04-07	--	--	409	--	--	196	--	--	--	--
	56-01-14	--	--	411	7.2	12.2	172	47	36	20	14
	56-04-17	--	--	393	6.7	10.5	172	34	36	20	13
	56-08-06	--	--	422	6.8	9.4	180	29	41	19	14
380757085423401	53-04-13	--	--	1910	--	13.3	552	--	--	--	--
LEWIS											
382640083292401	54-05-12	--	--	106	--	--	234	--	--	--	--
383655083214901	82-07-21	--	50	516	--	19.0	35	--	10	2.5	97
LINCOLN											
372631084314901	53-09-04	--	--	452	--	14.4	209	--	--	--	--
MADISON											
374554084080401	54-03-10	--	--	697	--	11.6	376	--	--	--	--
MARION											
373735085142901	53-11-19	--	--	787	--	15.5	327	--	--	--	--
MONTGOMERY											
380009083484801	82-07-08	35.0	35	465	--	22.0	150	--	45	10	37
380107083473501	65-05-11	--	--	792	7.5	--	400	60	86	45	28
NELSON											
373512085302001	82-05-18	--	--	3300	--	12.5	770	--	160	91	460
374512085385801	82-05-18	--	--	1380	6.9	21.0	630	--	168	50	43
POWELL											
374816083545001	53-06-03	--	--	1070	--	--	118	--	--	--	--
374913083570401	82-07-22	65.0	120	3080	--	23.0	140	--	34	13	650
ROWAN											
380910083331301	53-04-30	--	37	252	--	--	66	--	--	--	--
380958083353401	82-04-14	--	--	1530	2.8	10.5	300	--	71	29	8.9
381133083362201	53-04-30	--	--	379	3.8	--	126	130	--	--	--
	55-10-19	--	--	443	4.3	--	159	159	26	23	6.6

Table 17.-- Analyses of ground-water samples from the oil shale outcrop area--Continued

STATION NUMBER	DATE OF SAMPLE	POTASSIUM, DISSOLVED (MG/L AS K)	BICARBONATE FET-FLD (MG/L AS HCO_3)	ALKALINITY FIELD (MG/L AS $CACO_3$)	SULFATE DISSOLVED (MG/L AS SO_4)	CHLORIDE, DISSOLVED (MG/L AS CL)	FLUORIDE, DISSOLVED (MG/L AS F)	SILICA, DISSOLVED (MG/L AS SIO_2)	SOLIDS, RESIDUE AT 180 DEG. C DISSOLVED (MG/L)	NITROGEN, NO_2+NO_3 DISSOLVED (MG/L AS N)
BOYLE										
373557084565101	53-08-07	--	664	545	109	1087	1.1	--	--	--
BULLITT										
375737085421901	64-05-22	--	830	--	11	490	.8	--	--	--
CLARK										
375450084003701	54-03-17	--	2	--	293	9.5	.3	--	--	--
	55-10-18	7.4	0	--	263	10	.3	54	463	--
ESTILL										
373701084010301	53-07-24	--	286	--	46	16	.0	--	--	--
374242083574801	82-07-22	3.2	--	--	58	11	.3	20	318	--
FLEMING										
381510083413701	62-08-01	--	280	--	1390	10	.0	--	--	--
	63-03-27	--	340	--	1540	10	.0	--	--	--
	63-10-02	--	56	--	1670	20	.1	--	--	--
381527083340901	75-06-25	18	734	602	9.6	2400	.6	8.3	4450	.04
	75-09-23	--	--	--	--	--	--	--	--	--
	79-10-24	14	--	690	11	2300	.6	8.6	4630	.05
382422083331701	53-09-10	--	234	--	54	12	.2	--	--	--
382433083332101	55-01-05	3.5	3	3	128	21	.2	22	250	--
JEFFERSON										
380529085415301	53-04-07	--	196	--	46	12	.2	--	--	--
	56-01-14	2.5	153	--	43	28	.4	37	259	--
	56-04-17	2.5	168	--	41	18	.2	37	252	--
	56-08-06	2.7	185	--	41	17	.2	46	267	--
380757085423401	53-04-13	--	588	--	7.8	350	.4	--	--	--
LEWIS										
382640083292401	54-05-12	--	28	--	33	2.0	.1	--	--	--
383655083214901	82-07-21	6.5	--	--	31	14	.5	15	317	--
LINCOLN										
372631084314901	53-09-04	--	244	--	34	6.4	.2	--	--	--
MADISON										
374554084080401	54-03-10	--	376	--	80	19	.0	--	--	--
MARION										
373735085142901	53-11-19	--	352	--	84	32	.1	--	--	--
MONTGOMERY										
380009083484801	82-07-08	4.3	--	--	37	6.0	.2	29	310	--
380107083473501	65-05-11	2.9	415	--	88	16	.4	12	452	--
NELSON										
373512085302001	82-05-18	14	--	--	980	350	1.1	22	2430	--
374512085385801	82-05-18	5.6	--	--	550	41	.8	17	--	--
POWELL										
374816083545001	53-06-03	--	442	--	1.4	134	.3	--	--	--
374913083570401	82-07-22	5.4	--	--	700	250	1.2	7.0	2020	--
ROWAN										
380910083331301	53-04-30	--	7	--	48	20	.1	--	--	--
380958083353401	82-04-14	1.2	--	--	630	1.3	.5	72	1110	--
381133083362201	53-04-30	--	0	0	180	5.0	.2	--	--	--
	55-10-19	6.8	0	--	186	5.0	.4	48	320	--

Table 17.-- Analyses of ground-water samples from the oil shale outcrop area--Continued

STATION NUMBER	DATE OF SAMPLE	ALUM- INUM, DIS- SOLVED (UG/L AS AL)	IRON, DIS- SOLVED (UG/L AS FE)	MANGA- NESE, DIS- SOLVED (UG/L AS MN)
	BOYLE			
373557084565101	53-08-07	--	--	--
	BULLITT			
375737085421901	64-05-22	--	--	--
	CLARK			
375450084003701	54-03-17	--	--	--
	55-10-18	16000	--	--
	ESTILL			
373701084010301	53-07-24	--	--	--
	FLEMING			
381510083413701	62-08-01	--	--	--
	63-03-27	--	--	--
	63-10-02	--	--	--
381527083340901	75-06-25	--	80	120
	75-09-23	--	--	--
	79-10-24	--	20	60
382422083331701	53-09-10	--	--	--
382433083332101	55-01-05	1500	--	--
	JEFFERSON			
380529085415301	53-04-07	--	--	--
	56-01-14	--	--	--
	56-04-17	--	--	--
	56-08-06	--	--	--
380757085423401	53-04-13	--	--	--
	LEWIS			
374242083574801	82-07-22	--	--	--
382640083292401	54-05-12	--	--	--
383655083214901	82-07-21	--	--	--
	LINCOLN			
372631084314901	53-09-04	--	--	--
	MADISON			
374554084080401	54-03-10	--	--	--
	MARION			
373735085142901	53-11-19	--	--	--
	MONTGOMERY			
380009083484801	82-07-08	--	--	--
380107083473501	65-05-11	--	--	--
	NELSON			
373512085302001	82-05-18	--	--	--
374512085385801	82-05-18	--	--	--
	POWELL			
374816083545001	53-06-03	--	--	--
374913083570401	82-07-22	--	--	--
	ROWAN			
380910083331301	53-04-30	--	--	--
380958083353401	82-04-14	--	--	--
381133083362201	53-04-30	--	--	--
	55-10-19	5900	--	--

Conner (1981) reported on the non-carbon mineral matter in Kentucky oil shale. Table 18 is a summary of his results and indicates that silica and aluminum oxides are the predominant minerals in the oil shale. Water is the next most abundent constituent, followed by magnesium and calcium oxides. Leung (this report), indicates that various types and amounts of minerals in oil shale may be the dominant factor in accounting for the differences in water quality. Water-quality data collected by Zehner (1979) included data for samples from several formations, including the Ohio Shale. These data are also variable, with water from the oil shale having higher specific conductance, sodium, and chloride values and lower values for calcium, magnesium, and sulfate than water from other formations (Zehner, 1979, p. 42).

Surface Water

Surface-water quality data has also been collected intermittently by the U.S. Geological Survey in the oil shale outcrop area. Although somewhat sparse, these data (table 19) indicate that water quality of streams throughout the area is adequate for most uses with proper treatment. Water-quality data is also collected by the Kentucky Natural Resources and Environmental Protection Cabinet, Division of Water Quality, as part of their ambient monitoring program. In each sampled river basin, water quality is rated as good, fair, or poor, based on nine categories: temperature, dissolved oxygen, pH, bacteria, trophic nutrients, aesthetics, solids, and organic and inorganic toxicants. "Good," "fair," and "poor," are defined as follows:

Good: Water quality standards for selected parameters were exceeded in less than 10 percent of samples, with the violations occurring in less than 25 percent of the basin.

Fair: Water quality standards for selected parameters were exceeded in 10 percent to 33 percent of the samples, with violations occurring in 25 to 75 percent of the basin.

Poor: Water quality standards for selected parameters exceeded in 33 percent or more of the samples, with violations occurring in 75 percent or more of the basin.

Ratings of the river basins in the oil shale outcrop area are presented with the discussion of each river on the following pages.

Table 18.--Percentage values of chemical constituents determined in 88 oil shale samples in Kentucky (Source: Modified from Conner, 1981)

Constituent	Percentage values		
	High	Low	Mean
SiO_2	67.7	42.4	55.2
Al_2O_3	19.6	10.6	13.4
H_2O	9.8	1.8	5.1
K_2O	5.4	2.2	3.7
MgO	4.7	.6	1.2
TiO_2	1.0	.55	.76
CaO	8.5	.0	.6
Na_2O	.9	.1	.4
P_2O_5	.31	.02	.10
MnO	.13	.01	.05

Table 19.--Summary of selected parameters from surface water in the oil shale outcrop area from 1951 to 1982

Site number	Station number	Station name	County	Drainage basin	Drainage area (mi^2)	Sample size	Discharge (ft^3/s) Maximum	Minimum	Mean	Median
1	03249500	Licking River at Farmers	Bath	Licking River	827	38	4,910	13	1,150	258
2	03250000	Triplett Creek at Morehead	Rowan	do	47.5	12	328	3.3	69	28
3	03250100	North Fork Triplett Creek near Morehead	do	do	4.7	43	9,190	0.1	526	33
6	03250240	Slate Creek near Owingsville	Bath	do	185	2	11	7.4	-	-
8	03250320	Rock Lick Creek near Sharkey	Fleming	do	4.01	31	54	0.02	6.2	1.8
14	03282250	Kentucky River at Irvine	Estill	Kentucky River	3,138	2	3,090	1)142	-	-
15	03282300	Kentucky River near Trapp	do	do	3,955	2	3,500	1)151	-	-
9	03283500	Red River at Clay City	Powell	Red River	362	40	4,600	11	557	257
12	03283700	Red River near Trapp	do	do	487	2	5,880	1)21	-	-
18	03298760	North Rolling Fork near Bradfordville	Marion	Rolling Fork River	96	2	2.4	0.5	-	-
20	03299000	Rolling Fork near Lebanon	do	do	239	26	6,600	0.02	474	107
22	03300400	Beech Fork at Maud	Nelson	do	436	39	32,800	1.24	1,340	210
25	03301000	Beech Fork at Bardstown	do	do	669	3	71	3.8	36	34
26	03301500	Rolling Fork near Boston	do	do	1,299	20	8,720	38	1,588	806
27	03301630	Rolling Fork near Lebanon Junction	Bullitt	do	1,375	87	40,200	26	3,040	844

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[1] Estimated

Table 19.--Summary of selected parameters from surface water in the oil shale outcrop area from 1951 to 1982--Continued

Station number	Specific conductance (umho/cm)					pH				Sulfate (mg/L)				
	Sample size	Maximum	Minimum	Mean	Median	Sample size	Maximum	Minimum	Median	Sample size	Maximum	Minimum	Mean	Median
03249500	41	350	90	159	140	6	7.9	6.9	7.2	6	28	14	18	16
03250000	12	410	100	195	185	-	-	-	-	-	-	-	-	-
03250100	31	520	54	157	120	5	7.1	6.8	6.9	5	20	11	16	19
03250240	2	315	270	-	-	2	7.6	7.2	-	2	32	20	-	-
03250320	29	460	90	203	180	-	-	-	-	-	-	-	-	-
03282250	2	400	220	-	-	2	7.5	6.0	-	2	83	54	-	-
03282300	2	470	210	-	-	2	7.9	6.6	-	2	83	39	-	-
03283500	36	686	85	250	212	5	7.7	6.4	7.6	5	15	10	13	13
03283700	2	560	140	-	-	2	8.0	7.4	-	2	16	16	-	-
03298760	3	323	306	311	307	1	-	-	8.5	2	32	28	-	-
03299000	25	420	160	298	295	2	7.7	7.5	-	2	32	25	-	-
03300400	32	540	58	355	335	1	-	-	7.9	3	26	23	25	25
03301000	4	488	293	368	347	4	8.2	7.2	7.4	4	35	20	27	26
03301500	23	420	149	290	294	13	8.5	6.9	7.4	13	33	13	22	22
03301630	88	488	135	347	350	88	8.2	6.1	7.4	87	54	9.0	30	31

Table 19.--Summary of selected parameters from surface water in the oil shale outcrop area from 1951 to 1982--Continued

Station number	Alkalinity (mg/L)				
	Sample size	Maximum	Minimum	Mean	Median
03249500	5	64	22	44	52
03250000	-	-	-	-	-
03250100	5	39	10	24	21
03250240	2	131	112	-	-
03250320	-	-	-	-	-
03282250	2	68	33	-	-
03282300	2	64	40	-	-
03283500	2	62	56	-	-
03283700	2	77	46	-	-
03298760	2	136	126	-	-
03299000	2	172	147	-	-
03300400	3	153	113	128	120
03301000	4	190	120	148	141
03301500	3	192	130	162	163
03301630	71	200	48	141	150

Water samples were collected upstream and downstream of the oil shale outcrop on the Licking, Red, and Kentucky Rivers for this study (plate 1). The sites were the Licking River at Farmers (site number 1), Licking River near Moores Ferry (site number 4), Red River at Clay City (site number 9), Red River near Trapp (site number 12), Kentucky River at Irvine (site number 14), and Kentucky River near Trapp (site number 15). Samples were collected twice at these sites, once in late summer representing low flow conditions and once in early spring representing medium to high flow conditions.

Water-quality data between the upstream and downstream sites from the Licking River is similar during both low and high flow conditions (table 20). Specific conductance values changed from 95 to 105 umho/cm at low flow, and from 159 to 150 umho/cm at high flow. Most of the other parameters increased or decreased slightly. These data indicate that the water quality of the Licking River is not significantly changed after crossing the outcrop area of the oil shale. The overall water quality of the entire Licking River Basin is considered fair (Kentucky Department for Natural Resources and Environmental Protection, 1981).

Differences between data at the Kentucky River sites are evident, but these are not considered significant. Most parameters increased somewhat at low flow and decreased at high flow between the upstream and downstream sites (table 21). These data indicate that the oil shale outcrop may affect the water quality in this reach of the river. Discharges from the city of Irvine, which is located between the sites, may also contribute to the differences noted in the data. The overall water quality of the entire Kentucky River Basin is considered poor, with higher counts of bacteria, and increased concentrations of nutrients, iron, lead, and mercury (Kentucky Department for Natural Resources and Environmental Protection, 1981). Sources for these constituents are mining, agricultural practices, and sewage treatment operations (Kentucky Department for Natural Resources and Environmental Protection, 1981).

Water-quality data from the Red River sites (table 22) show more variability than the data for the other two rivers. The Clay City station, during low flow, has higher concentrations for most parameters and a lower pH than the downstream site. The drainage for the headwaters of the Red River is an area of extensive coal mining and oil drilling, which may be the source of the higher concentrations at Clay City. As this water travels downstream, it is diluted by the various small streams which enter the Red River, which may explain the lower values and higher pH near Trapp. At high flow, most constituent concentrations increased from the upstream to downstream site. Samples were collected at Clay City on March 16, 1982, at 12:00 p.m. (discharge of 4,600 ft^3/s), and near Trapp on March 17 at 3:00 p.m. (discharge of 5,880 ft^3/s). The discharge at Clay City on March 17, at

Table 20.--Results of chemical analyses of samples from the Licking River (mg/L, milligrams per liter; ug/L, micrograms per liter; pCi/L, picocuries per liter; NTU, nephelometric turbidity units; [, less than)

	Medium to high flow		Low flow	
Parameters	Licking River at Farmers (site 1) 03/17/82	Licking River near Moores Ferry (site 4) 03/16/82	Licking River at Farmers (Site 1) 08/31/81	Licking River near Moores Ferry (Site 4) 08/31/81
Stream flow (ft^3/s)	2,170	1)2,950	74	84
Specific conductance (umho/cm)	159	150	95	105
pH	7.9	7.1	7.3	7.3
Temperature (°C)	9.0	11.0	26.0	26.5
Turbidity (NTU)	15	25	6.6	1.8
Hardness (mg/L as $CaCO_3$)	52	47	43	48
Non carbonate hardness (mg/L as $CaCO_3$)	30	27	19	17
Calcium (mg/L as Ca)	13	12	12	13
Magnesium (mg/L as Mg)	4.7	4.2	3.2	3.7
Sodium (mg/L as Na)	7.9	6.7	4.1	5.3
Potassium (mg/L as K)	2.1	2.0	1.9	2.0
Alkalinity (mg/L as $CaCO_3$)	22	20	24	31
Sulfate (mg/L as SO_4)	28	27	21	20
Chloride (mg/L as Cl)	16	12	6.8	7.8
Fluoride (mg/L as F)	[.1	[.1	[.1	[.1
Silica (mg/L as SiO_2)	5.3	5.8	5.1	4.7
Solids (total dissolved mg/L)	103	92	81	88
Nitrogen NO_2+NO_3 total (mg/L as N)	------	------	----	.38
Nitrogen ammonia total (mg/L as N)	------	------	.08	.06
Nitrogen organic total (mg/L as N)	------	------	.31	.75
Phosphorous total (mg/L as P)	.02	.03	.03	.05
Arsenic total (ug/L as As)	1	9	2	1
Arsenic dissolved (ug/L as As)	1	1	2	1
Barium total (ug/L as Ba)	100	100	100	100
Barium dissolved (ug/L as Ba)	49	40	100	100
Cadmium total (ug/L as Cd)	[1	[1	[1	[1
Cadmium dissolved (ug/L as Cd)	[1	[1	[1	[1
Chromium total (ug/L as Cr)	10	10	20	20
Chromium dissolved (ug/L as Cr)	10	10	10	[10
Copper total (ug/L as Cu)	6	17	6	6
Copper dissolved (ug/L as Cu)	1	4	2	2
Iron total (ug/L as Fe)	910	1,300	510	690
Iron dissolved (ug/L as Fe)	47	45	30	20
Lead total (ug/L as Pb)	2	3	2	2
Lead dissolved (ug/L as Pb)	[1	[1	1	1
Manganese total (ug/L as Mn)	210	160	150	280
Manganese dissolved (ug/L as Mn)	180	130	120	190
Mercury total (ug/L as Hg)	.2	.2	.5	.6
Mercury dissolved (ug/L as Hg)	.2	.2	.5	.4
Nickel total (ug/L as Ni)	5	6	2	3
Nickel dissolved (ug/L as Ni)	[1	1	1	1
Zinc total (ug/L as Zn)	20	30	20	20
Zinc dissolved (ug/L as Zn)	[10	[10	20	20
Gross alpha dissolved (ug/L as U-NAT)	4.2	5.0	[1.3	[1.5
Gross beta dissolved (pCi/L as Cs-137)	4.0	4.4	2.6	3.4
Phenols (ug/L)	2	2	1	[1
Total organic carbon (mg/L as C)	2.4	2.6	2.6	2.6
Suspended sediment (mg/L)	26	30	22	14

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[1] Estimated value.

Table 21.--Results of chemical analyses of samples from the Kentucky River
(mg/L, milligrams per liter; ug/L, micrograms per liter; pCi/L,
picocuries per liter; NTU, nephelometric turbidity units; [, less than)

	Medium to high flow		Low flow	
Parameters	Kentucky River at Irvine (site 14) 04/07/82	Kentucky River near Trapp (site 15) 04/07/82	Kentucky River at Irvine (site 14) 09/02/81	Kentucky River near Trapp (site 15) 09/01/81
Stream flow (ft^3/s)	3,090	3,500	1)142	1)151
Specific conductance (umho/cm)	220	210	400	470
pH	7.5	7.9	6.0	6.6
Temperature (^{o}C)	11.0	11.5	26.5	26.0
Turbidity (NTU)	17	17	3.5	3.3
Hardness (mg/L as $CaCO_3$)	83	85	150	160
Non carbonate hardness (mg/L as $CaCO_3$)	50	45	81	96
Calcium (mg/L as Ca)	20	21	38	41
Magnesium (mg/L as Mg)	8.1	7.8	13	14
Sodium (mg/L as Na)	10	8.6	20	34
Potassium (mg/L as K)	1.7	1.5	3.1	3.2
Alkalinity (mg/L as $CaCO_3$)	33	40	68	64
Sulfate (mg/L as SO_4)	54	39	83	83
Chloride (mg/L as Cl)	11	9.2	24	61
Fluoride (mg/L as F)	[.1	.2	.1	.1
Silica (mg/L as SiO_2)	6.4	6.5	4.7	4.7
Solids (total dissolved mg/L)	137	129	245	299
Nitrogen NO_2+NO_3 total (mg/L as N)	.26	.25	.17	.28
Nitrogen ammonia total (mg/L as N)	.04	.06	.06	.06
Nitrogen organic total (mg/L as N)	------	------	----	----
Phosphorous total (mg/L as P)	.03	.06	----	----
Arsenic total (ug/L as As)	1	1	3	10
Arsenic dissolved (ug/L as As)	1	1	1	1
Barium total (ug/L as Ba)	100	100	200	300
Barium dissolved (ug/L as Ba)	87	61	200	300
Cadmium total (ug/L as Cd)	3	3	[1	4
Cadmium dissolved (ug/L as Cd)	[1	[1	[1	[1
Chromium total (ug/L as Cr)	30	20	10	[10
Chromium dissolved (ug/L as Cr)	20	10	10	[10
Copper total (ug/L as Cu)	2	8	3	3
Copper dissolved (ug/L as Cu)	[1	[1	2	2
Iron total (ug/L as Fe)	1,000	770	530	290
Iron dissolved (ug/L as Fe)	31	14	10	20
Lead total (ug/L as Pb)	10	9	7	8
Lead dissolved (ug/L as Pb)	3	6	[1	1
Manganese total (ug/L as Mn)	150	100	140	60
Manganese dissolved (ug/L as Mn)	88	80	90	30
Mercury total (ug/L as Hg)	.2	.4	[.1	[.1
Mercury dissolved (ug/L as Hg)	.2	.2	[.1	[.1
Nickel total (ug/L as Ni)	3	2	3	4
Nickel dissolved (ug/L as Ni)	3	2	2	2
Zinc total (ug/L as Zn)	50	40	20	20
Zinc dissolved (ug/L as Zn)	[10	[10	[10	[10
Gross alpha dissolved (ug/L as U-NAT)	[2.7	4.1	[4.8	[5.2
Gross beta dissolved (pCi/L as Cs-137)	2.1	2.3	5.2	[3.5
Phenols (ug/L)	2	2	[1	-
Total organic carbon (mg/L as C)	1.2	1.5	3.3	2.9
Suspended sediment (mg/L)	19	34	-	-

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[1] Estimated value.

Table 22.--Results of chemical analyses of samples from the Red River (mg/L, milligrams per liter; ug/L, micrograms per liter; pCi/L, picocuries per liter; NTU, nephelometric turbidity units; [, less than)

Parameters	Medium to high flow		Low flow	
	Red River at Clay City (site 9) 03/16/82	Red River near Trapp (site 12) 03/17/82	Red River at Clay City (site 9) 09/01/81	Red River near Trapp (site 12) 09/01/81
Stream flow (ft^3/s)	4,600	5,880	16	1)21
Specific conductance (umho/cm)	85	140	686	560
pH	7.6	8.0	6.4	7.4
Temperature (°C)	15.0	11.5	25.0	23.0
Turbidity (NTU)	100	290	1.2	4.0
Hardness (mg/L as $CaCO_3$)	34	57	160	140
Non-carbonate hardness (mg/L as $CaCO_3$)	10	11	94	67
Calcium (mg/L as Ca)	10	18	49	44
Magnesium (mg/L as Mg)	2.3	3.0	9.4	8.3
Sodium (mg/L as Na)	3.8	3.5	75	50
Potassium (mg/L as K)	1.4	1.8	2.8	2.8
Alkalinity (mg/L as $CaCO_3$)	24	46	68	77
Sulfate (mg/L as SO_4)	14	16	11	16
Chloride (mg/L as Cl)	6.8	5.6	180	120
Fluoride (mg/L as F)	[.1	[.1	[.1	[.1
Silica (mg/L as SiO_2)	5.2	5.6	3.8	3.5
Solids (total dissolved mg/L)	68	90	460	331
Nitrogen NO_2+NO_3 total (mg/L as N)	------	------	.26	.17
Nitrogen ammonia total (mg/L as N)	------	------	.08	.06
Nitrogen organic total (mg/L as N)	------	------	-	.05
Phosphorous total (mg/L as P)	.15	.27	.03	.05
Arsenic total (ug/L as As)	2	3	2	2
Arsenic dissolved (ug/L as As)	1	1	1	1
Barium total (ug/L as Ba)	100	100	800	500
Barium dissolved (ug/L as Ba)	41	33	800	500
Cadmium total (ug/L as Cd)	[1	1	[1	[1
Cadmium dissolved (ug/L as Cd)	[1	[1	[1	[1
Chromium total (ug/L as Cr)	10	30	10	[10
Chromium dissolved (ug/L as Cr)	10	10	[10	[10
Copper total (ug/L as Cu)	10	15	3	3
Copper dissolved (ug/L as Cu)	2	2	2	1
Iron total (ug/L as Fe)	7,500	22,000	450	420
Iron dissolved (ug/L as Fe)	26	150	10	10
Lead total (ug/L as Pb)	87	24	8	10
Lead dissolved (ug/L as Pb)	4	2	1	[1
Manganese total (ug/L as Mn)	280	500	140	90
Manganese dissolved (ug/L as Mn)	30	12	140	80
Mercury total (ug/L as Hg)	.3	.3	.1	[.1
Mercury dissolved (ug/L as Hg)	.3	.1	[.1	[.1
Nickel total (ug/L as Ni)	11	41	6	4
Nickel dissolved (ug/L as Ni)	1	1	1	1
Zinc total (ug/L as Zn)	40	120	20	10
Zinc dissolved (ug/L as Zn)	[10	[10	[10	[10
Gross alpha dissolved (ug/L as U-NAT)	[0.9	[1.6	[8.3	[7.9
Gross beta dissolved (PCi/L as Cs-137)	1.7	2.1	4.4	[4.6
Phenols (ug/L)	[1	4	[1	[1
Total organic carbon (mg/L as C)	4.5	8.4	2.5	3.2
Suspended sediment (mg/L)	271	494	11	12

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[1] Estimated value

3:00 p.m., was 4,800 ft^3/s. These data indicate that there was an inflow of about 1,000 ft^3/s between the upstream and downstream stations on March 17. Precipitation data collected on March 17 indicate that storm activity in the area probably accounts for the increase in streamflow from the upstream to downstream site, and for related increases in water-quality constituents. More samples need to be collected during high flow conditions to clarify these differences. The overall water quality of the Red River is considered fair (Kentucky Department for Natural Resources and Environmental Protection, 1981). However, improper oil and gas drilling operations have recently caused a serious water-quality problem, (Kentucky Department for Natural Resources and Environmental Protection, 1981) which is evidenced by the increased concentrations of sodium and chloride noted in the low-flow analysis.

Water samples have been collected on a monthly basis since 1975 from the Rolling Fork near Lebanon Junction (site number 27) as part of the National Surface Water Quality Accounting Network (NASQAN). Most of the drainage of the Rolling Fork is from the oil shale outcrop area (plate 1). Water quality of the Rolling Fork (table 23) is considered poor overall (Kentucky Department for Natural Resources and Environmental Protection, 1981) with bacteria, nutrients, suspended solids, and iron being the major water quality problems (Kentucky Department for Natural Resources and Environmental Protection, 1981). The major sources contributing to these problems are agricultural runoff, (including fertilizer and pesticides), and domestic sewage (Kentucky Department for Natural Resources and Environmental Protection, 1981).

Table 23.--Summary of analyses of samples from the Rolling Fork River
(mg/L, milligrams per liter; ug/L, micrograms per liter; pCi/L,
picocuries per liter; NTU, nephelometric turbidity units)

Parameters	Number of samples	Mean	Median	Minimum Value	Maximum Value
Stream flow (ft^3/s)	87	3,040	844	26.0	40,200
Specific conductance (umho/cm)	88	347	350	135	488
pH	88	------	7.4	6.1	8.2
Temperature (oC)	87	14.6	14.5	0.0	29.5
Turbidity (NTU)	43	43.7	32	0.4	250
Dissolved oxygen (mg/L)	12	9.3	10.3	5.8	11.8
Fecal Coliform (colonies per 100 mLs)	60	1,380	370	6.0	25,000
Fecal Streptococci (colonies per 100 mLs)	59	3,650	268	9.0	76,000
Hardness (mg/L as CaCO$_3$)	86	172	179	58	240
Non-carbonate hardness (mg/L as CaCO$_3$)	86	32	32	7.0	58
Calcium (mg/L as Ca)	86	50	51	18	71
Magnesium (mg/L as Mg)	86	11.5	12.0	3.1	18
Sodium (mg/L as Na)	86	4.8	4.4	1.0	16
Potassium (mg/L as K)	86	2.9	2.7	1.2	5.2
Alkalinity (mg/L as CaCO$_3$)	71	141	150	48	200
Sulfate (mg/L as SO$_4$)	87	30.5	31	9.0	54.0
Chloride (mg/L as Cl)	87	5.9	5.4	0.6	19
Fluoride (mg/L as F)	87	.2	.1	.1	.5
Silica (mg/L as SiO$_2$)	86	5.4	5.6	1.2	8.3
Solids (total dissolved mg/L)	87	212	223	89	300
Nitrogen NO$_2$+NO$_3$ total (mg/L as N)	82	.64	.63	.09	1.5
Nitrogen ammonia total (mg/L as N)	42	.09	.07	.03	.28
Nitrogen,ammonia + organic total (mg/L as N)	84	.70	.59	.01	2.10
Phosphorous total (mg/L as P)	86	.24	.18	.04	.87
Phosphorous dissolved (mg/L as P)	45	.08	.07	.03	.39
Arsenic total (ug/L as As)	30	1.6	1.0	0	4
Arsenic dissolved (ug/L as As)	30	1.3	1.0	0	4
Cadmium total (ug/L as Cd)	29	2.4	2.0	0	10
Cadmium dissolved (ug/L as Cd)	29	1.8	2.0	0	7
Chromium total (ug/L as Cr)	30	18.9	20	10	30
Cnromium dissolved (ug/L as Cr)	30	5.7	2.5	0	20
Cobalt total (ug/L as Co)	30	2.1	1.5	0	11
Cobalt dissolved (ug/L as Co)	30	0.5	0	0	3
Copper total (ug/L as Cu)	30	19.0	15	3.0	67
Copper dissolved (ug/L as Cu)	29	6.1	6.0	0	15
Iron total (ug/L as Fe)	30	3,880	2700	590	25,000
Iron dissolved (ug/L as Fe)	30	59	27	10	720
Lead total (ug/L as Pb)	29	16	12	0	70
Lead dissolved (ug/L as Pb)	28	4.7	3	0	24
Manganese total (ug/L as Mn)	30	185	150	60	810
Manganese dissolved (ug/L as Mn)	30	57	40	4.0	320
Mercury total (ug/L as Hg)	30	.4	.5	.1	1.0
Mercury dissolved (ug/L as Hg)	30	.4	.5	.1	.9
Zinc total (ug/L as Zn)	29	40	30	10	130
Zinc dissolved (ug/L as Zn)	30	16	7.5	0	100
Gross alpha dissolved (ug/L as U-NAT)	3	6.9	5.9	11	4.0
Gross beta dissolved (pCi/L as Cs-137)	3	6.2	6.5	5.4	6.6
Total Organic Carbon (mg/L as C)	41	6.7	6.1	2.0	16
Suspended sediment (mg/L)	74	140	85	4.0	857

SUMMARY

In evaluating the historical data and data collected from the reconnaissance, the following observations can be made:

1) Very few wells drilled into the oil shale yield enough water for domestic supplies.

2) Joints and fractures are the predominant source of water storage in the shale.

3) The quality of ground water is highly variable. Various types and amounts of minerals in the oil shale may be the dominant factor in this variability.

4) Surface-water flow is highly variable. Many of the smaller streams and tributaries go dry in summer months, yet flooding can be severe throughout the outcrop area during spring, fall, or winter.

5) Surface-water quality of the major rivers crossing the outcrop is considered fair to poor by the Kentucky Department for Natural Resources and Environmental Protection, with the major problems being caused by runoff from coal mines and oil drilling operations, faulty agricultural practices, and effluent from sewage treatment plants.

6) Except for the Red River basin, the data suggest that the oil shales do not significantly affect the surface-water quality. Additional data will be necessary to verify this.

7) Further studies are needed to determine the relation of jointing in the shale to the occurrence of springs in underlying formations, to ground-water occurrence and movement, and to ground-water quality. More detailed surface-water quality data are also needed to better determine the influence of the oil shale outcrop on surface-water quality over the total range of flow conditions for the streams flowing on and across the outcrop area.

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