Geochemical Prospecting Using Water From Small Streams in Central South Carolina

GEOLOGICAL SURVEY BULLETIN 1378

Geochemical Prospecting Using Water From Small Streams in Central South Carolina

By HENRY BELL, III, *and* GEORGE E. SIPLE

GEOLOGICAL SURVEY BULLETIN 1378

Water from 69 small streams in the Carolina slate belt was sampled and tested for specific conductance, hardness, pH, and iron and chloride content

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1973

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

Library of Congress catalog-card No. 73-600032

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402
Stock No. 2401-00313

CONTENTS

ILLUSTRATIONS

TABLES

GEOCHEMICAL PROSPECTING USING WATER FROM SMALL STREAMS IN CENTRAL SOUTH CAROLINA

By HENRY BELL, III, and GEORGE E. SIPLE

ABSTRACT

The water from 69 small streams draining an average area of 1 square mile in the piedmont of South Carolina was sampled at low flow and tested for unusually high content of inorganic chemical constituents. The tests were made to determine whether the unusual amounts of dissolved constituents that had been found in the water of several shallow domestic wells also occurred in the streams and, thus, whether small streams rather than wells could be used for hydrogeochemical prospecting. The water was tested for specific conductance, hardness, pH, and iron and chloride content. Seven of the streams having the highest specific conductance, hardness, and chloride content were given complete water analysis. The results indicate that water from streams draining crystalline rocks of the Carolina slate belt is different in specific conductance and hardness from water in streams draining areas that have a layer of coastal-plain sedimentary rocks overlying the crystalline rocks. No areas were found in which the water had unusually high dissolved-mineral content.

INTRODUCTION

Rarely, a small stream or well used for domestic water supply is found to have an unusually high content of inorganic chemical constituents. The undesirable properties of such water are frequently attributed to artificial sources or contamination, but they may come from the solution or weathering of some unusually abundant naturally occurring minerals. Many such minerals are of economic importance as ores or are associated with deposits of insoluble ore minerals. Streams or wells with naturally occurring high or exotic mineral contents are, therefore, valuable clues in prospecting for ore deposits. Hydrogeochemical prospecting is a technique based on the analysis of water for traces of ore metals or chemical constituents associated with ore deposits; in this way, areas can be found where ore deposits may be observed directly or found by other methods of exploration.

Hydrogeochemical prospecting has not often been tested in the southeastern piedmont. Price and Ragland (1968) collected samples of water from wells and some streams and springs in the

Kings Mountain district of North Carolina and related the results of their analyses to lithology and areas of sulfide mineralization. LeGrand (1958) found that the quality of ground water in the piedmont of North Carolina reflected the chemical character of the rocks in which the water occurred. He also noted that a well cutting sulfide-bearing rocks had water with unusually high concentrations of iron and sulfate and a very low pH, chemical characteristics which he attributed to solution of the mineralized rock. He (p. 179) suggested that "the chemical character of water may be useful in the exploration for minerals." Several areas containing sulfide-bearing ore deposits occur in the North and South Carolina piedmont along the boundary between crystalline rocks and overlying sedimentary rocks of the coastal plain. Such deposits, even though concealed, might be expected to contribute large amounts of mineral constituents to ground water. Hydrothermally altered areas that commonly have abundant disseminated pyrite are favored places for prospecting and also might be expected to yield ground water with unusually high contents of iron, sulfate, and chloride which are detectable by easily performed analyses. Several wells in central South Carolina have unusual amounts of dissolved constituents in an area that has widely distributed gold-bearing alluvium. This report gives the results of a program to test the possibility (1) that small streams in addition to wells might contain unusual amounts of dissolved constituents detectable by field methods and (2) that small streams rather than wells might be used for hydrogeochemical prospecting in this area. The area tested is the Cedar Creek-Blythewood area in Richland and Fairfield Counties (fig. 1).

ACKNOWLEDGMENTS

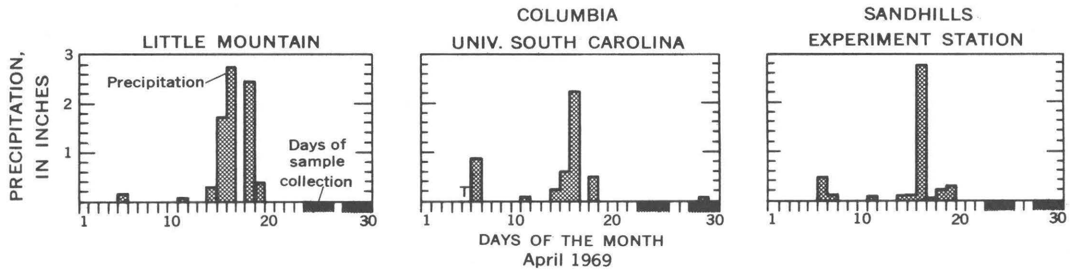
We wish to acknowledge the aid of both Henry S. Johnson, Jr., and Norman K. Olson of the Geologic Division, South Carolina State Development Board. All the complete chemical analyses of water for this study were made in the U.S. Geological Survey Laboratory in Raleigh, N.C.

PHYSIOGRAPHIC SETTING

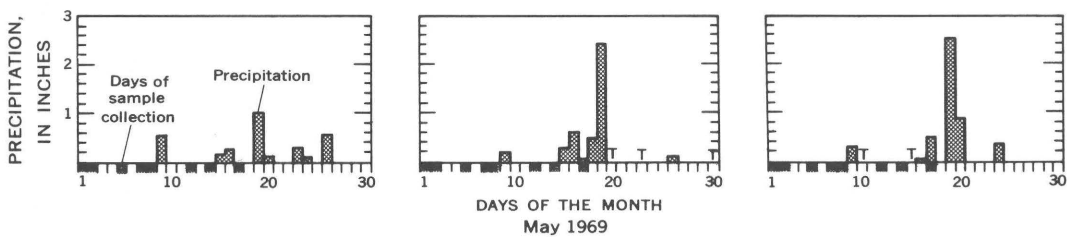
The area investigated has a warm humid climate; average annual rainfall is 48–56 inches, and mean monthly relative humidity is 70–80 percent (U.S. Geol. Survey, 1970a). A large proportion of the area is forested with loblolly and short-leaf pine with an admixture of oak and hickory. A small proportion is cleared and farmed. Although rainfall is fairly evenly distributed over the area, records from individual weather stations (U.S. Weather

FIGURE 1.—Area of stream sampling in South Carolina.

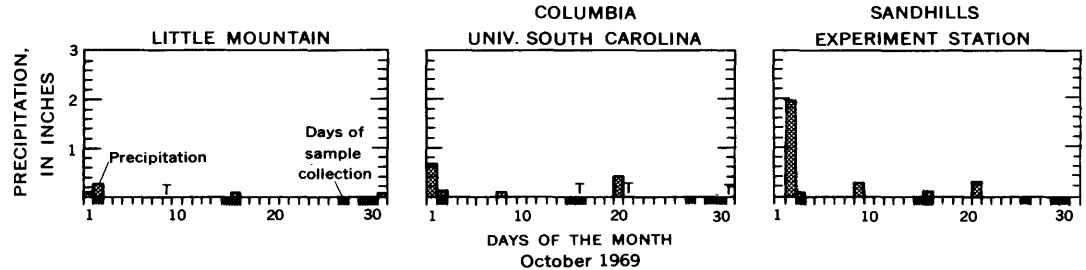
Bureau, 1969) show local variations in amount and duration of precipitation and temperature which influence the amount of discharge from small streams (fig. 2). Streams draining the area of investigation are tributary either to the Broad River or to the Wateree River. The largest stream, Cedar Creek, flows into the Broad River. Figure 3 shows the discharge of Cedar Creek for April and May 1969 measured near Blythewood in the center of the area. Cedar Creek has a drainage area of 48 square miles above the gaging station. Figure 3 shows sharp peaks of discharge for Cedar Creek and a rapid return of discharge to low flow, a characteristic even more pronounced in the smaller streams sampled in this study. Streams are at low flow most commonly in the fall. Figure 4 shows the mean monthly discharge for 1961–65 of the Lynches River, a stream typical of the region (U.S. Geol. Survey, 1970b). The topography in the area studied is characterized by rounded hills, gentle slopes, and relief of 90–320 feet. Table 1 gives some of the characteristics of drainage basins in the area. The dimensions were measured on U.S. Geological Sur-



Location	Temperature (°F)			
	Average max	Average min	Average	Departure from normal
Little Mountain	75.5	51.9	63.7	0.2
Columbia, Univ. of South Carolina	77.4	51.9	63.2	1.5



Location	Temperature (°F)			
	Average max	Average min	Average	Departure from normal
Little Mountain	81.2	58.9	70.1	−1.7
Columbia, Univ. of South Carolina	82.9	61.0	72.0	−0.6



Location	Temperature (°F)			
	Average max	Average min	Average	Departure from normal
Little Mountain	75.2	52.9	64.1	−1.2
Columbia, airport	77.4	53.2	65.3	0.6

FIGURE 2.—Precipitation and temperature distribution at selected stations in central South Carolina (data from U.S. Weather Bureau, 1969). T=trace of precipitation. Dates of water sample collection are patterned on abscissa.

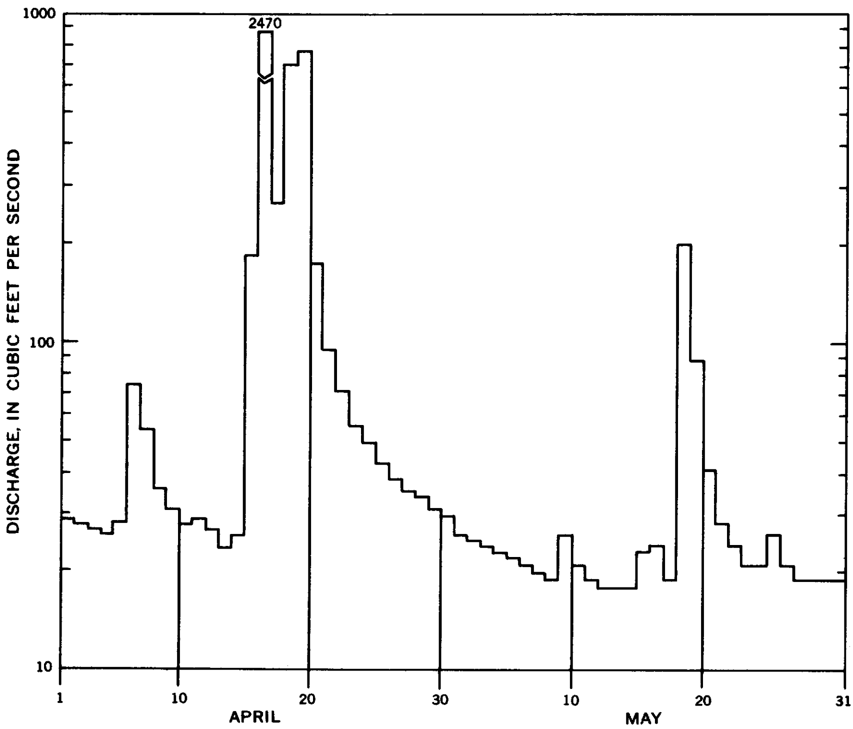


FIGURE 3.—Daily discharge of Cedar Creek, Richland County, S.C., April and May 1969 (from records of U.S. Geol. Survey at Columbia, S.C.)

vey topographic maps of the Richtex, Irmo Northeast, Irmo, Blythewood, and Ridgeway quadrangles at a scale of 1 : 24,000.

TABLE 1.—*Dimensions of small drainage basins sampled in the Cedar Creek-Blythewood area*

	Maximum	*Mean*	*Minimum*
Elevation in area of drainage basins feet above mean sea level	640	----	[1]180
Length of drainage basin ft	14,100	8,000	2,200
Area of drainage basin sq mi	3.33	1.03	0.06
Relief in drainage basin ft	320	185	90

[1] Minimum elevation along the Broad River 160 ft.

GEOLOGIC SETTING

Plate 1 is a geologic map of the Cedar Creek-Blythewood area as mapped by Secor and Wagener (1968). Underlying the western and northern part of the area are rocks of the Carolina slate belt. These upper Precambrian or Paleozoic rocks consist of many

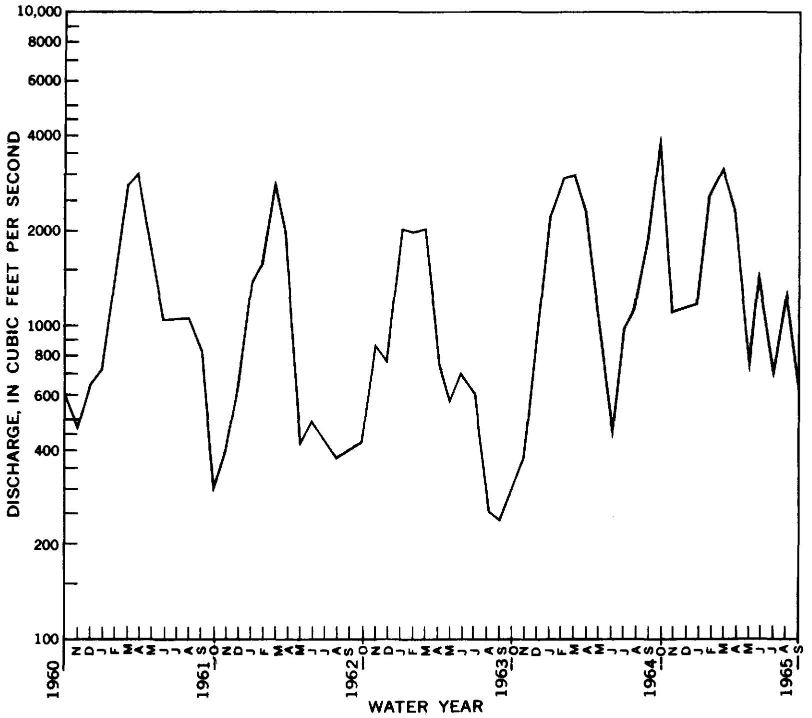


FIGURE 4.—Mean monthly discharge for the Lynches River at Effingham, S.C., water years 1961–65. Data from U.S. Geological Survey (1970b).

thousands of feet of low-grade metasedimentary rocks, fragmental volcanic rocks, and flow rocks. The metasedimentary rocks are slate or argillite, sandstone, and mafic and felsic phyllite and greenstone derived from tuff and mafic amygdaloidal flows. A thick sequence of andesitic and basaltic tuff and amygdaloidal flows was deposited locally. Northward the rocks of the Carolina slate belt pass into gneiss, schist, and amphibolite; the rocks, which are of a higher metamorphic grade, have been intruded by several masses of adamellite, gabbro, and many Triassic diabase dikes. Hydrothermally altered rocks occur in the vicinity of Mount Rehovah. They include sericite schist and light-colored phyllite containing numerous thin gold-bearing quartz veinlets; silicified rocks; disseminated pyrite and pyrite veinlets; and kaolin-rich rocks. The crystalline rocks in much of the southeastern part of the area are overlain unconformably by Cretaceous and younger sedimentary rocks, mostly poorly consolidated sand and clay.

Outcrops are sparse throughout the area and are most common in the beds of small streams. Most rocks are deeply weathered. The residuum of weathering in place, called saprolite, is of varied but unknown thickness; its thickness and extent are different on different rock types. Weathering is most intense and saprolite most thoroughly developed near the surface. The saprolite provides a reservoir for ground water and influences the chemical characteristics of the water. Laboratory tests on saprolite formed from crystalline rocks in the piedmont of Georgia have shown that the porosity of the saprolite there is greatest at depths of 30–40 feet (Stewart, 1962). The tests showed that about 46 percent of the water in storage in the upper 35 feet of the saprolite could be recovered in wells (fig. 5). Saprolite formed on slates and phyllites in the Cedar Creek-Blythewood area probably differs significantly in actual storage capacity from the saprolite formed on gneiss in Georgia because of different grain size, texture, and mineral content. Nevertheless, the water-yielding characteristics of saprolite in the two areas probably are analogous. The water-yielding capacity of unweathered rock is very low. Most ground water in unweathered rock is in joints and fractures. These rock openings apparently are most abundant near the surface, but some may extend to depths greater than the topographic relief. The small amount of water that has circulated deeply and slowly through rock openings is generally thought likely to be high in dissolved-mineral content, for the amount of dissolved solids in ground water is dependent in part on the length of time the water has been in contact with soluble minerals. Because the fractured rocks support little circulation of ground water and because much of the area is crystalline rock, most of the constituents dissolved must come from saprolite.

GROUND WATER

The studies by LeGrand (1958) and by Price and Ragland (1968) on ground water in the Carolina piedmont were based on wells, either municipal and industrial or shallow domestic. For hydrogeochemical prospecting purposes these are too sparsely and unevenly distributed in the area of study to provide adequate data. The data that are available consist principally of analyses from municipal and industrial wells at Jefferson, Ridgeway, Kershaw, and Heath Springs, towns near but not in the area of investigation. The analyses do not indicate particularly unusual concentrations of chemical constituents. These analyses are shown in table 2. Also available and included in table 2 are analyses of

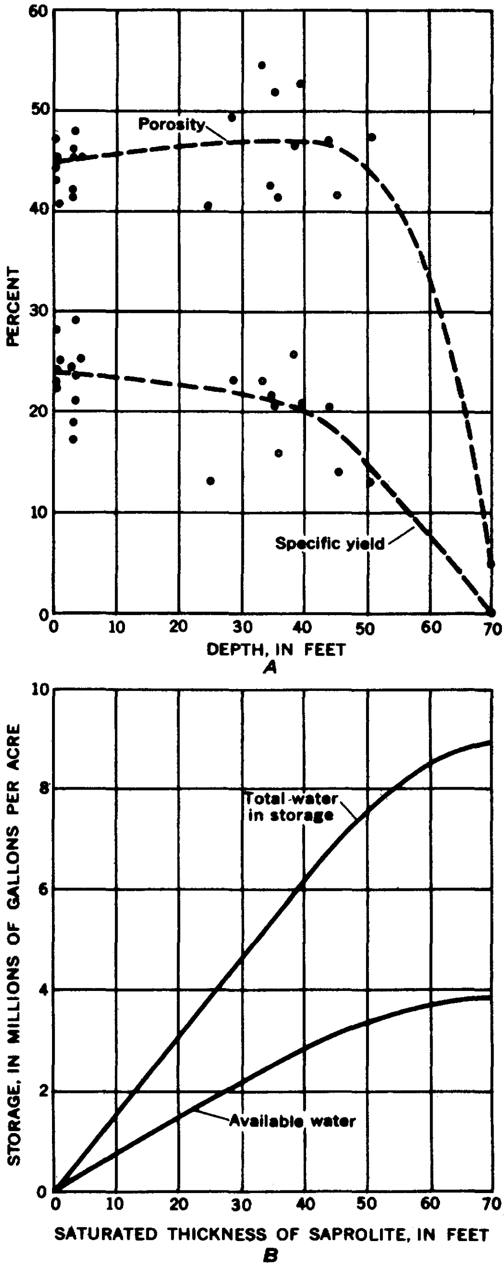


FIGURE 5.—Results of laboratory tests on core samples of saprolite from the Georgia Nuclear Laboratory area. *A*, Porosity and specific yield; *B*, total water in storage and water potentially available to wells. From Stewart (1962).

TABLE 2.—*Chemical analyses of selected samples*

[Concentrations in milligrams per

				Municipal and industrial wells			
	CF-1(a)	CF-1(b)	FA-3	KR-1	KR-2(a)	KR-2(b)	KR-3
Silica (SiO_2)	—	24	—	46	48	—	40
Aluminum (Al)	—	—	—	—	—	—	—
Iron (Fe)[1]	0.31	.00	0.15	.28	.07	0.28	.01
Total iron (Fe)	—	—	—	1.3	.27	—	.19
Manganese (Mn)	—	—	—	—	—	—	—
Calcium (Ca)	—	11	—	11	10	—	25
Magnesium (Mg)	—	4.6	—	3.7	3.1	—	6.7
Sodium (Na)	—	4.6	—	9.6	7.3	—	29
Potassium (K)	—	.5	—	2.4	2.2	—	4.1
Bicarbonate (HCO_3)	20	54	59	49	54	28	62
Sulfate (SO_4)	4	5	1	11	6	13	3.6
Chloride (Cl)	10	8.2	10	14	4.5	6	59
Fluoride (F)	—	.2	.0	.1	.1	.1	.0
Nitrate (NO_3)	6.8	1.5	16	.5	.1	9.2	31
Phosphate (PO_4)	—	—	—	—	—	—	—
Dissolved solids:							
Calculated	—	—	—	—	—	—	—
Residue on evaporation at 180°C	—	87	—	122	107	24	271
Hardness as $CaCO_3$:							
Calcium, magnesium	28	46	64	44	39	—	90
Noncarbonate	—	—	—	—	—	—	—
Specific conductance (micromhos at 25°C)	—	140	—	151	124	—	378
pH	—	6.9	—	6.7	6.9	—	6.6
Color (units)	—	—	—	—	—	—	—

[1] In solution when analyzed.
[2] Turbid when collected; field tests indicate hardness of 570 ppm and Cl of more than 600 mg/l.
[3] South Carolina Health Dept. analysis showed iron concentration as 5.50 mg/l.
[4] Raw-water sample.
CF-1. Town of Jefferson; depth of well 205 ft; collected (a) 12-5-45, (b) 1-5-55.
FA-3. Town of Ridgeway; depth of well 185 ft; collected 10-11-45.
KR-1. Town of Kershaw; depth of well 244 ft; collected 3-11-57.
KR-2. Town of Kershaw; depth of well 152 ft; collected (a) 3-11-57, (b) 11-6-45.
KR-3. Town of Kershaw; depth of well 242 ft; collected 3-11-57.
KR-4. Springs Mill, Kershaw; depth of well 600 ft; collected 3-11-57.

water from seven domestic wells that have anomalous concentrations of chemical constituents or that penetrate hydrothermally altered rocks of the slate belt. Unusually high concentrations of chemical constituents are found in water from a well at Lake Murray, a well on Cody Street in the city of Columbia, and a well near the Cedar Creek community in northern Richland County. The analyses for two of these indicated a specific conductance as high as 1,600 micromhos and a total hardness of about 900 milligrams per liter (mg/l). The range in chloride content was 61–395 mg/l. Possibly urban or industrial contamination is partly responsible for these anomalous analyses, especially in the case of the Cody Street well; however, a field check of the other two wells and their surrounding areas failed to indicate any visible source of contamination. The analyses of these waters resemble the analysis reported by LeGrand (1958, p. 188) for water from a well near Selma, N.C., which cut sulfide-bearing rocks.

SURFACE WATER

Ground water emerges at the surface as springs and seepage in the beds of streams that intersect the water table. LeGrand *of ground water in central South Carolina*

liter except pH and specific conductance]

			Domestic Wells						
KR-4	KR-5	LA-2	LX-16	LX-117[2]	RC-260[3]	RC-291[4]	50425	50426	50427
47	43	—	—	20	3	30	30	29	7.9
—	—	—	—	—	—	—	.2	.5	.2
.18	.03	27	—	—	.02	—	1.4	5.4	1.9
1.6	.04	—	0.25	13	—	.59	—	—	—
—	—	—	—	—	—	—	.04	.75	.08
11	4.2	—	—	41	4.2	140	9.6	9.0	1.9
3.4	2.3	—	—	140	7.5	68	2.5	9.5	6.8
9.2	10	—	—	65	55	46	7.0	6.0	9.9
2.7	2.6	—	—	1.3	6.6	7.6	.6	.4	.5
48	22	38	37	298	35	329	40	66	31
8.4	1.7	8	5	12	.8	136	13	13	2.8
12	8.6	6	5	395	61	228	3.2	4.8	12
.1	.0	—	—	.2	.0	.4	.1	.2	.1
.5	13	.0	.6	.6	67	.2	.2	.1	9.1
—	—	—	—	—	—	—	.15	.01	.00
—	—	—	—	—	—	—	88	111	66
120	97	—	—	836	253	904	80	97	67
40	20	30	34	680	42	630	34	62	33
—	—	—	—	436	14	360	1	8	8
144	115	—	—	1,680	405	1,350	89	126	103
6.7	6.3	—	—	7.3	7.1	7.4	6.3	6.5	6.4
—	—	—	—	—	—	—	0	0	0

KR-5. Springs Mill, Kershaw; depth of well 281 ft; collected 3–11–57.
LA-2. Town of Heaths Springs; depth of well 140 ft; collected 1–17–46.
LX-16. Eight miles NW of West Colombia; depth of well 50 ft; collected 6–1–48.
LX-117. Lake Murray Club; depth of well 60 ft; collected 12–13–65.
RC-260. Cody Street, Colombia; depth of well 65 ft; collected 5–11–64.
RC-291. Cedar Creek Community; depth of well 110 ft.
50425. Near Chapin, Newberry County; collected 10–23–68.
50426. Near Mount Rehovah, Fairfield County; depth of well 160 ft; collected 10–22–68; cuts hydrothermally altered slate belt rocks.
50427. Near Mount Rehovah, Fairfield County; depth of well 100 ft approximately; collected 10–22–68; cuts hydrothermally altered slate belt rocks.

(1958, p. 179) has stated that "the linear distance between the point where a drop of water first reaches the water table and the point where it is discharged at a spring or seepage area is almost everywhere less than a mile, and commonly less than half a mile." Small streams at low flow in basins of not much more than 1 square mile might be expected, therefore, to give the closest approximation to ground water in mineral content of any surface water. That is, base flow of small streams will reflect the composition of the ground water, but it will not reflect the exact concentration, for some dilution from surface runoff would be expected to result in a smaller concentration of dissolved constituents in stream water. The assembled analyses of surface waters in the area of investigation and vicinity are shown in table 3. These analyses of samples collected at nine stations are mostly on major streams. These streams are probably too large for hydrogeochemical prospecting purposes inasmuch as they represent the drainage from large areas in which mixing and dilution of ground water of different chemical compositions has taken place. A few of these analyses, however, show concentrations of dis-

TABLE 3.—*Chemical analyses of surface water from selected stations in central South Carolina*

[Data for water year October 1964 to September 1965 from U.S. Geol. Survey, 1969, p. 24, 27–30. Concentration in milligrams per liter except for pH and specific conductance]

Station	1314.4	1314.8	1474	1475	1480	1565	1615[1]	1615	1690
Silica (SiO_2)	8.0	8.7	24	18	9.6	5.7	14	15	7.8
Iron (Fe)	0.12	0.12	0.05	0.05	0.05	0.02	0.06	0.08	0.05
Calcium (Ca)	1.7	1.1	8.3	5.8	4.3	2.0	3.5	3.1	3.4
Magnesium (Mg)	1.0	0.7	3.9	3.2	1.8	0.7	2.2	1.8	1.2
Sodium (Na)	15	2.8	14	4.5	8.2	1.1	4.3	7.8	5.2
Potassium (K)	1.6	0.6	1.9	1.2	1.6	2.0	2.0	1.6	1.8
Bicarbonate (HCO_3)	42	7	56	37	27	10	25	31	21
Sulfate (SO_4)	3.6	3.0	4.6	4.2	5.4	3.2	5.1	2.0	3.0
Chloride (Cl)	4.4	2.7	14	3.4	7.3	1.3	4.0	4.5	4.0
Fluoride (F)	0.0	0.1	0.1	0.1	0.2	0.1	0.1	0.0	0.0
Nitrate (NO_3)	0.4	0.3	0.3	0.5	0.4	0.5	0.4	0.4	0.6
Phosphate (PO_4)	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Dissolved solids:									
Calculated	57	23	99	59	52	22	—	51	37
Residue on evaporation at 180°C	62	27	108	62	55	29	44	55	51
Hardness as $CaCO_3$:									
Calcium, magnesium	8	6	37	28	18	8	18	15	14
Noncarbonate	0	0	0	0	0	0	0	0	0
Specific conductance (micromhos at 25°C)	89	31	150	87	76	29	59	71	53
pH	6.4	5.6	7.5	6.7	6.7	6.0	6.7	6.3	6.4
Color (units)	40	30	15	100	30	25	20	10	27

[1] Maximum concentration for water year October 1959 to September 1960. (See U.S. Geol. Survey 1968, p. 299, for additional analyses made during entire period of record.)

1314.4. Lynches River near Bethune; collected 6–3–65.
1314.8. Little Lynches River near Bethune; collected 6–3–65.
1474. Fishing Creek near Fort Lawn; collected 11–18–64.
1475. Rocky Creek at Great Falls; collected 4–21–65.
1480. Wateree River near Camden; collected 2–9–65.
1565. Broad River near Carlisle; collected 10–6–64.
1615. Broad River near Richtex; collected 10–19–59 and 5–17–65.
1690. Saluda River near Columbia; collected 2–10–65.

solved solids, hardness, and chloride that are higher than average or median values for most surface waters. It is uncertain whether the greater concentration is due to greater solution of mineral components from the rock or to the introduction of waste material upstream. The latter is generally more likely in the larger streams. The chemical analyses of surface waters obtained at the gaging stations near the area showed a greater than average specific conductance, hardness, or chloride content at Fishing Creek near Fort Lawn, Rocky Creek at Great Falls, and Lynches River near Bethune. Maximum measurements in each of these categories were: specific conductance, 150 micromhos; hardness, 37 mg/l; and chloride content, 14 mg/l. These analyses do not appear to offer substantive evidence of solution of soluble mineral-rich zones by ground water.

SAMPLING PROCEDURES AND RESULTS OF ANALYSIS

The area of investigation is covered by a drainage network of many small streams. Samples collected from these streams can be expected to represent the chemical composition of ground water that has traveled only a short time through soil and rock openings more closely than do the samples collected from large streams or rivers. Sixty-nine small streams having an average drainage basin of 1 square mile were sampled (pl. 2). A 2-oz sample of water collected at each site was analyzed by field methods for iron, chloride, hardness (as $CaCO_3$), specific conductance, and pH. The analyses for chloride were made by the standard filtration method, using a solution of silver nitrate and a potassium chromate indicator. The pH and hardness were determined using standard analytical procedures with a HACH colorimeter. The specific conductance was obtained with a Beckman RB3 Solu Bridge. The results of these analyses are shown in table 4. Histograms of the distribution of the values for pH, hardness, iron, and specific conductance are illustrated in figure 6. Inasmuch as higher than normal concentrations of chloride, hardness, and specific conductance are generally indicative of highly mineralized waters, the relation between these constituents is plotted in figures 7 and 8. From these graphs, seven streams that contained water that had a specific conductance of 100 micromhos or higher and that, in addition, had a hardness of 25 mg/l or higher or a chloride content of 20 mg/l or higher were selected for resampling. The water from these seven streams and from four streams having lesser amounts of chemical constituents but known to contain detrital gold were submitted to complete water analysis. The results of these analyses are shown in table 5.

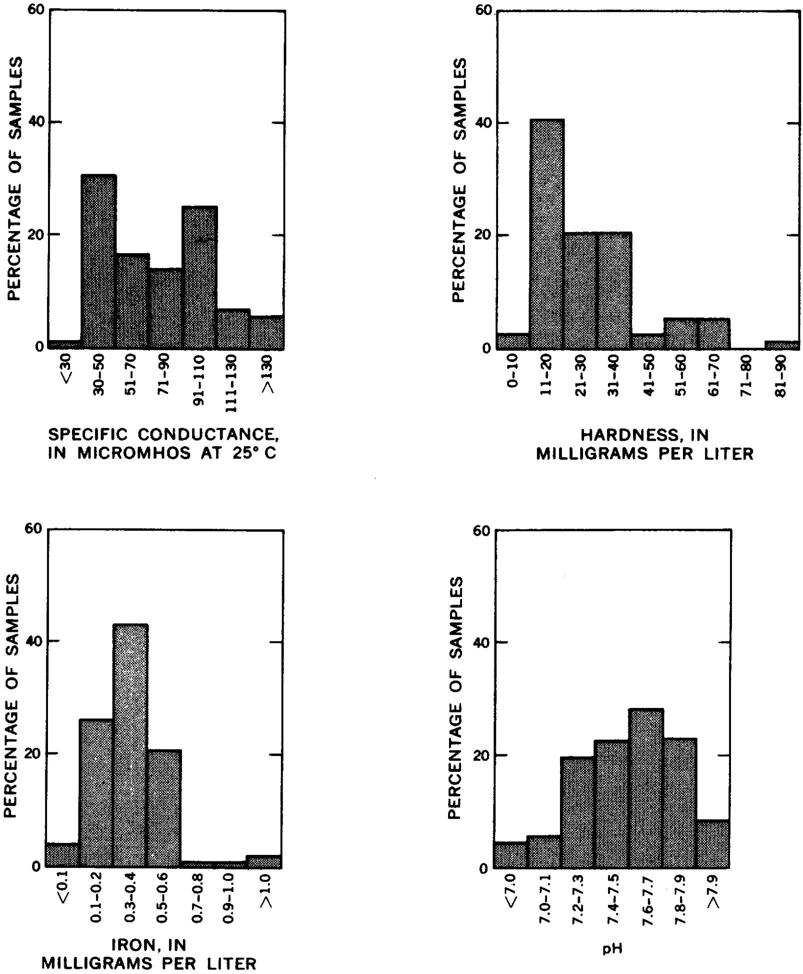


FIGURE 6.—Histograms showing distribution of pH, hardness, iron, and specific conductance in small streams, Cedar Creek-Blythewood area, S.C.

AREAL DISTRIBUTION

The areal distribution of the results of field analyses for specific conductance, iron, chloride, and hardness given in table 5 is shown on plate 2. Drainage basins in areas largely underlain by crystalline rocks have water that has a higher specific conductance and hardness than water from basins that are in areas underlain by coastal-plain sedimentary rocks. The stream basins with water high in chloride content are also high in specific conductance and hardness. The chloride content of the water, however, shows no easily discernible distribution pattern into areas containing coastal-plain sedimentary rocks and areas underlain only by crystalline rocks. The results from iron analysis show a distribution which cannot be easily attributed to the distribution of underlying rocks.

SPECIFIC CONDUCTANCE

All but six of the 23 stream drainage basins in which water was found to have a specific conductance of 50 micromhos or less

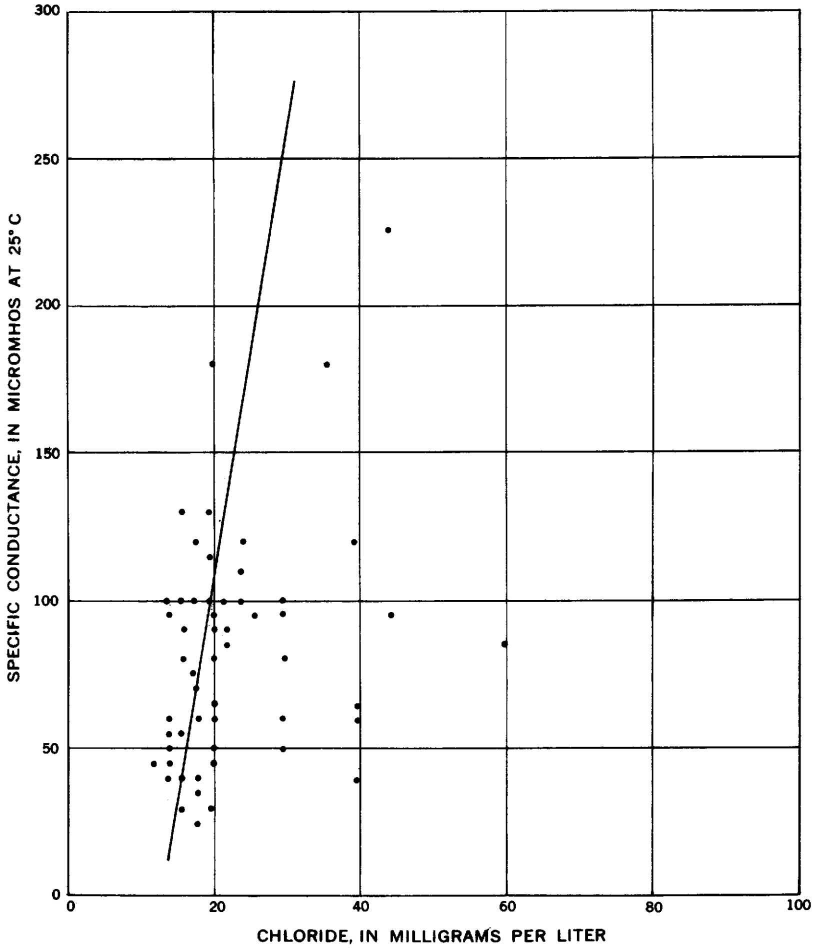


FIGURE 7.—Relation of chloride to specific conductance in small streams, Cedar Creek-Blythewood area, S.C.

TABLE 4.—*Partial chemical analyses of small streams and springs in central South Carolina*

Stream basin and sample No.	Date of collection 1969	Drainage area (sq mi)	Iron (Fe)	Chloride (Cl)	Hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH
			Milligrams per liter				
Streams							
1	4–23	0.14	0.53	14	34	100	7.8
2	4–23	0.33	.20	20	34	115	8.0
3	4–23	0.07	< .10	16	17	50	7.5
4	4–23	0.41	.30	22	28	80	7.4
6	4–23	>1.12	.30	22	28	90	7.4
7	4–23	>0.63	< .10	24	34	100	7.5
9	4–23	1.91	.30	20	28	80	7.7
10	4–23	0.60	.30	26	34	95	7.4
12	4–23	0.56	.20	20	28	95	7.7
13	4–23	0.28	< .10	20	17	80	7.6
14	4–23	0.25	.55	16	34	100	8.0
15	4–23	>1.14	.40	16	28	80	7.5
16R	5–5	1.63	.10	30	68	250	8.0
17	4–24	0.50	.55	34	68	180	7.8
18	4–24	1.46	.10	14	28	95	7.6
19	4–24	0.30	.60	18	17	75	7.6
20	4–24	1.16	.47	24	34	100	7.8
21	4–24	0.62	.30	24	51	120	7.7
22	4–25	2.84	.40	20	17	45	7.2
23	4–25	0.51	1.0	12	17	45	7.7
24	4–25	1.33	.30	26	34	95	7.6
25	4–25	0.69	.40	18	17	60	7.4
26	4–25	0.24	.10	24	34	110	8.0
27	4–25	1.44	.35	20	34	100	7.6
28	4–28	1.19	.30	18	17	35	7.2
29	4–28	0.32	.60	14	17	50	7.3
30	4–28	1.87	.40	14	17	50	7.7
31	4–28	1.08	.30	16	51	100	7.6
32	4–29	0.19	.05	44	85	225	7.9
33	4–29	1.67	.15	18	34	100	7.7
34	4–29	1.12	.32	20	34	65	7.8
35	4–30	1.53	.60	18	34	70	7.4
36	4–30	1.81	.50	16	17	55	7.4
37	5–1	1.04	.50	20	17	30	7.0
38	5–1	1.61	.40	14	17	55	7.2
39	5–1	0.65	.30	22	34	100	7.9
40	5–1	2.12	< .10	16	17	50	7.4
41	5–2	0.40	.05	14	17	45	7.3
42	5–2	1.23	.40	18	17	40	7.2
43	5–2	1.80	.60	18	17	25	7.0
44	5–2	1.74	.30	16	17	30	7.4
45	5–5	0.84	.30	12	17	45	7.3
46	5–5	0.98	.60	20	17	60	7.8
47	5–5	1.15	.40	14	17	40	7.4
48	5–5	0.87	.20	14	17	45	7.3
49	5–5	1.29	.30	16	17	40	7.2
50	5–7	0.96	.60	14	17	60	7.5
51	5–7	0.76	.60	16	17	40	7.4
52	5–7	2.36	.40	30	15	50	7.3
53	5–8	0.91	.70	20	10.8	45	7.1
54	5–8	3.33	.60	40	23.8	60	7.2
55	5–8	0.26	.30	20	16.8	50	7.6
56	5–8	1.80	.30	40	25	65	7.6
57	5–12	1.41	.10	18	51	120	8.3
58	5–12	1.35	.20	30	48	95	7.7

TABLE 4.—*Partial chemical analyses of small streams and springs in central South Carolina*—Continued

Stream basin and sample No.	Date of collection 1969	Drainage area (sq mi)	Iron (Fe)	Chloride (Cl)	Hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH
			Milligrams per liter				
Streams—Continued							
59	5–12	1.08	.60	30	29	80	7.8
60	5–12	1.47	.25	20	68	130	7.6
61	5–12	1.33	.40	20	30.4	90	7.8
62	5–12	1.38	.10	20	13.8	45	7.5
63	5–14	0.32	.20	20	15.6	50	8.6
64	5–14	0.15	.30	30	19	60	7.6
65	5–14	0.37	.30	60	32.2	85	7.2
66	5–14	0.06	2.0	40	8	40	7.4
67	5–17	0.06	2.0	45	27	95	6.2
69	5–17	0.19	.10	30	36.2	100	6.3
70	5–17	0.38	.30	40	46	120	7.3
71	5–17	0.60	.30	20	25.8	95	7.2
72	5–17	1.63	.40	150	21.2	60	7.1
73	5–17	1.66	.50	20	26	65	7.7
Springs							
1	4–22	—	0.20	16	51	90	—
2	4–23	—	.025	16	68	130	7.7
3	—	—	—	—	—	50	—

are those that drain, at least in part, the high ground covered with poorly consolidated coastal-plain deposits. Conversely, the drainage basins having the highest specific conductance are all within the area underlain by crystalline rocks. Specific conductance tends to vary inversely with the discharge of streams, larger discharge commonly showing lower specific conductance (Feltz and Wark, 1962). The discharge from these small drainage basins is not known, but generally where factors influencing discharge other than drainage area are equal, larger basins have a larger discharge. Figure 9 shows the relation of drainage area to specific conductance and indicates that even for these small basins the larger basins tend to have water of lower specific conductance. The larger drainage basins, however, are well distributed throughout the area and are not confined to areas containing coastal-plain sedimentary rocks. The two drainage basins with the highest specific conductance have areas of 1.63 square miles and 0.19 square mile, well above and below the average basin area of 1.03 square miles.

The rocks of the coastal plain are largely poorly consolidated sands, clayey sands, and sandy clays. These rocks probably have much higher infiltration rates than the more clay-rich saprolite that rests on fractured crystalline rocks. Coastal-plain rocks

TABLE 5.—*Chemical analyses of water from*

[Concentrations in milligrams per liter

Stream basin and sample No.	Date of collection (Oct. 1969)	Silica (SiO_2)	Aluminum (Al)	Iron (Fe)[1]	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
										Small streams with
16R	15	2.4	0.2	0.14	0.06	19	8.9	13	2.0	116
20	29	20	.3	1.0	2.0	33	11	17	5.3	169
21	29	14	.4	.59	.47	28	13	9.0	2.0	143
32	16	8.9	.4	.89	.52	29	11	10	1.2	114
39	29	18	.1	.16	.05	12	5.8	8.0	1.1	61
60	15	28	.6	.50	.05	7.8	10	12	2.7	82
70	2	8.1	.9	.41	.06	21	7.4	11	1.8	86
										Gold-bearing
50	27	11	0.2	1.0	0.13	6.6	5.2	5.0	1.3	47
52	15	10	.7	7.5	.06	5.0	2.3	3.5	.8	24
56	29	13	.2	.89	.06	6.9	5.8	3.9	1.4	50
72	30	18	.3	1.3	.90	6.2	6.6	5.0	.7	51

[1] In solution when collected.

may contribute a disproportionately large share of water with low specific conductance to the discharge of streams which drain small areas of these rocks. Springs are not uncommon at the unconformity separating Cretaceous and younger rocks from the weathered upper Precambrian or Paleozoic rocks beneath. Three samples of water from springs are included in table 4, but none of these issue from the base of the coastal plain sedimentary rocks. The discharge from streams in the area is commonly smaller in October than in April and May, as illustrated by Lynches River (fig. 4). Figure 10 shows the specific conductance and hardness of all 11 streams sampled in April and May plotted against the specific conductance and hardness of the same streams sampled in October. All except four values showed an increase in these properties during the time of lower discharge. Slack (1964) and Cleaves, Godfrey, and Bricker (1970) have pointed out that decaying of leaves shed by trees in the fall contributes a large amount of dissolved-mineral matter to the water of small streams in the fall months. The increase of specific conductance and hardness in the small streams of this area may be due, at least in part, to this phenomenon.

The time during which ground water is in contact with easily soluble minerals also may influence the concentration of dissolved-mineral constituents and the specific conductance. In areas of high relief, ground water probably moves more rapidly to areas of discharge than it does in areas of low relief. In areas of high relief, therefore, specific conductance will probably be lower than *small streams in the Carolina slate belt*

except for pH and specific conductance]

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180°C	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Color (units)
high specific conductance											
2.4	15	0.2	1.4	0.18	123	155	85	0	177	7.0	15
.8	25	.4	.4	.10	199	197	126	0	315	7.1	35
1.2	19	.1	.7	.02	158	165	123	6	205	6.9	5
5.2	32	.0	.0	.00	155	168	118	25	211	7.1	0
3.4	12	.0	.0	.04	91	127	54	4	115	6.9	5
3.4	8.2	.2	.9	2.1	116	112	62	0	134	7.1	10
1.8	28	.2	.6	.03	124	126	83	12	176	6.9	10
streams											
3.0	6.6	0.0	0.0	0.01	64	64	38	1	82	6.7	10
2.0	6.4	.0	.7	.02	51	41	20	1	50	6.5	10
2.4	6.7	.0	.1	.01	64	66	40	0	84	6.8	20
2.0	6.3	.0	.0	.01	84	62	42	0	84	6.8	10

in otherwise comparable drainage basins in areas of low relief. The relief in the Cedar Creek-Blythewood area, however, is fairly uniform and does not appear to have influenced the distribution of water with low specific conductance. Figure 11 suggests that specific conductance and relief are largely independent in this area.

The crystalline rocks have been grouped into several formations, as shown on plate 1. The various drainage basins having greater than 100 micromhos specific conductance are not confined to any specific formation. A swarm of northwest-trending Triassic diabase dikes, however, cut all the formations. The dikes are most abundant in the vicinity of Cedar Creek, where six of the nine streams with more than 100 micromhos specific conductance, including the streams with the two highest specific conductances are found. Sulfide-bearing ore deposits in the piedmont of the Carolinas are not known to be related to Triassic diabase dikes, although the dikes are known to cut at least one important sulfide ore body. The dikes dip nearly vertically and may provide fractures for deep circulation of ground water, which could then be expected to be more highly charged with dissolved-mineral constituents. Or, the dike swarm may have been intruded into zones of weakness, that is, into areas of shearing and hydrothermal alteration containing sulfide minerals, and ground water could become highly mineralized for this reason. Additional samples of water collected from domestic wells or springs might locate more closely the source of the water with high specific conduct-

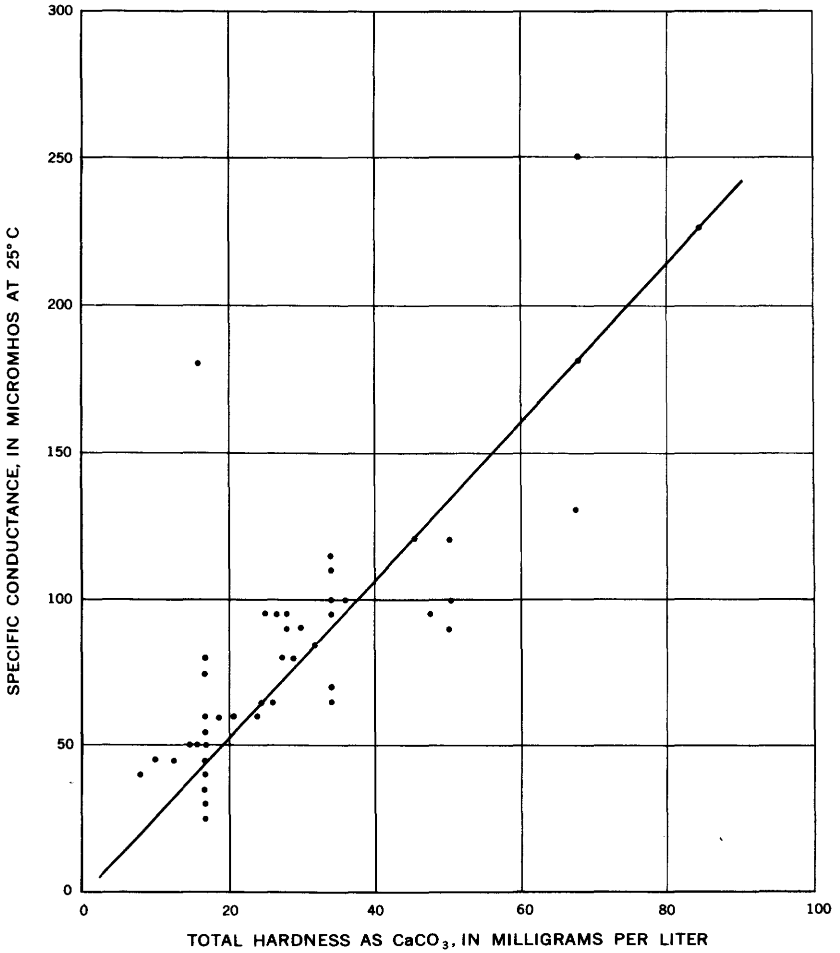


FIGURE 8.—Relation of hardness to specific conductance in small streams, Cedar Creek-Blythewood area, S.C.

ance in the drainage basin for which the stream specific conductance is high.

HARDNESS

All the streams with water having a specific conductance above 100 micromhos have water that is harder than average; the stream with the hardest water is in this group. Secor and Wagener (1968) described the Richtex, Persimmon Fork, and Wildhorse Branch Formations in this area (pl. 1) as composite in nature. The formations include layers of metamorphic rock derived from intermediate or mafic volcanic rocks; these metamorphic rocks probably contain some carbonate minerals that would contribute to the high specific conductance and hardness in streams draining the crystalline rocks. None of the water has a hardness that would suggest the presence of abundant carbonate minerals associated with hydrothermal ore deposits. In general terms, the ground water in Richland and Fairfield Counties is moderately hard, according to the classification of Durfor and Becker (1964, p. 27).

IRON

The areal distribution of iron values shown in table 4 does not coincide with stream basins in or outside areas underlain by coastal-plain sedimentary rocks. There is an indication, however, that water with high specific conductance and hardness is low in iron content. Although the results of field analysis given in table 4 show no exceptionally high values for iron, laboratory analyses (table 5) show some fairly high values for surface water from a few streams. The average iron content of water from streams containing gold-bearing alluvium is higher than the average iron content of all streams tested by the field method. The water from all the gold-bearing streams analyzed in the laboratory has fairly high values for iron, lower-than-average dissolved solids, and lower pH than the analyses for the other streams given in table 5.

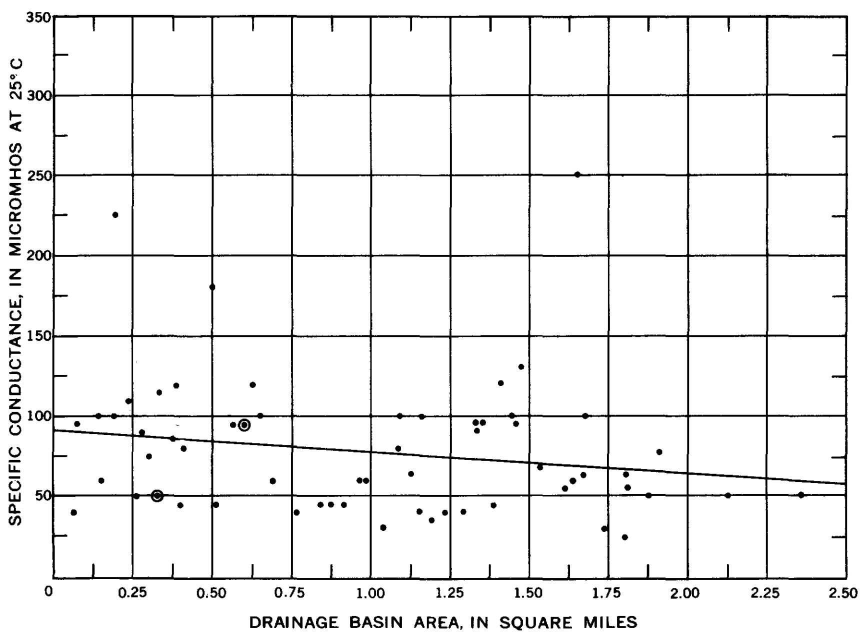


FIGURE 9.—Relation of drainage area to specific conductance.

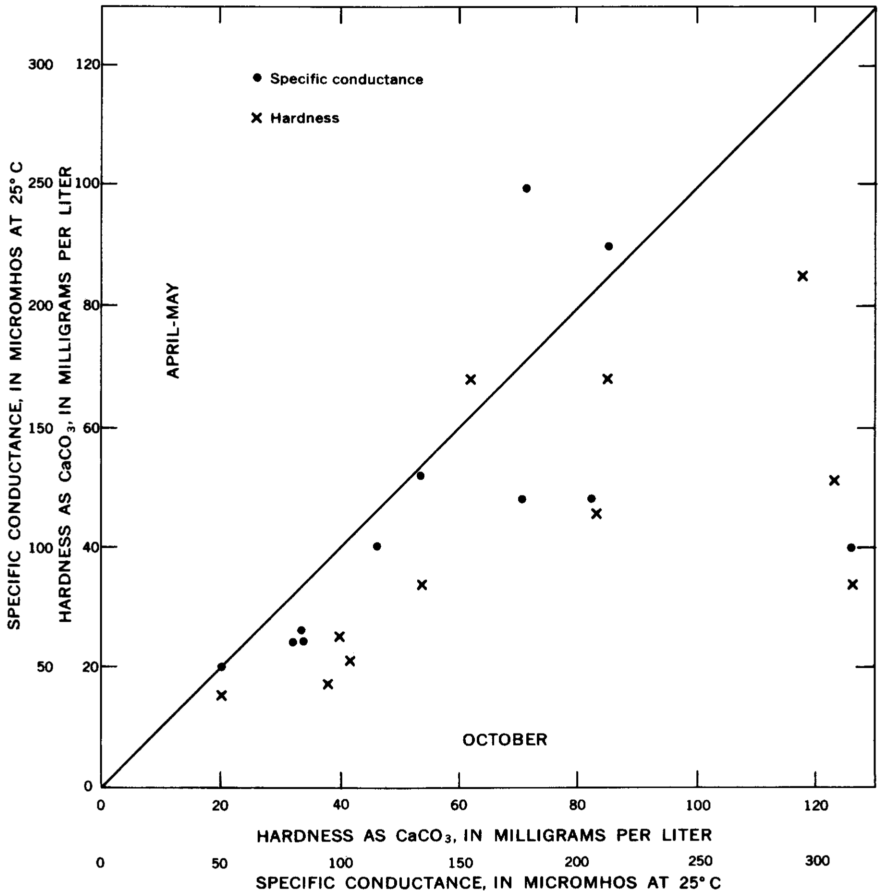


FIGURE 10.—Specific conductance and hardness of 11 small streams in April–May 1969 compared with October 1969.

These values may reflect hydrothermally altered gold-bearing rocks containing some pyrite and silicified or silicated rocks low in carbonates.

CONCLUSIONS

Water samples from seven streams having high specific conductance, hardness, and chloride content were submitted to complete chemical analysis. In addition, water samples from four streams which contain detrital gold but which have low specific conductance and hardness were submitted to complete chemical analysis. These analyses (table 5), together with analyses of the four domestic wells from the area, nearby surface water, and the unusual water analysis reported by LeGrand from Selma,

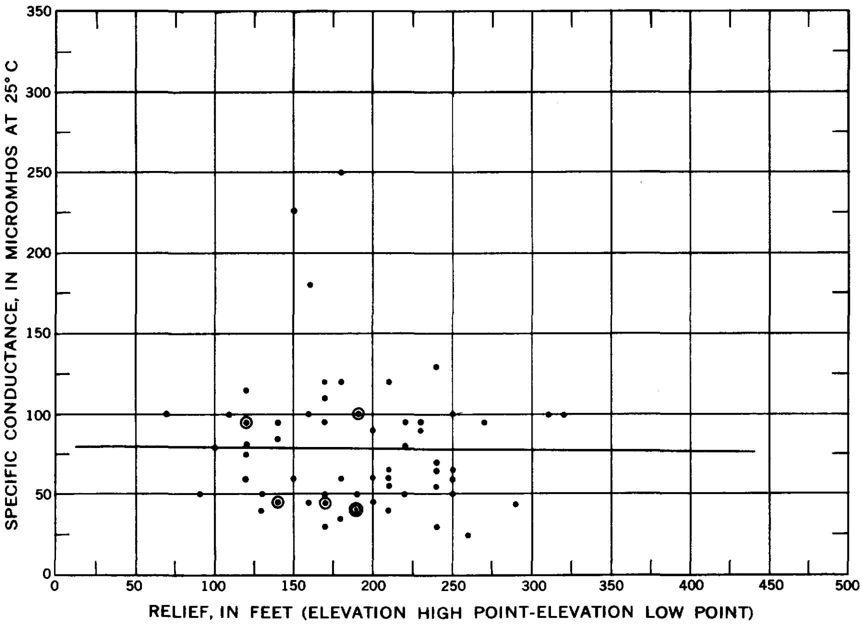


FIGURE 11.—Relation of relief to specific conductance.

N.C., are shown in table 6, all expressed as mole ratios of the various dissolved constituents to HCO_3^- for comparison. Bar graphs show graphically the variation in six of these analyses (fig. 12). None of the water is as high in dissolved constituents as the water from the well near Selma. The small-stream samples are lower in dissolved-mineral constituents than the ground water from wells. In comparison with the surface water from Fishing Creek and Broad River, the small streams show similar concentrations of silica, sulfate, and chloride; higher concentrations of iron, magnesium, and calcium; and lower concentrations of sodium and potassium.

None of the water from the small streams sampled was found to be sufficiently unusual in amount of dissolved mineral constituents to indicate the presence of abundant soluble ore or gangue minerals.

Water sampling, nevertheless, may have some use in prospecting for mineral deposits in the southeastern piedmont. Partial chemical analysis of water is a rapid inexpensive method of water testing which, applied to small streams, might be used to appraise large areas systematically for anomalous ground water conditions. In areas where water showed anomalously high mineral content or unexpected changes in chemistry, other more expensive

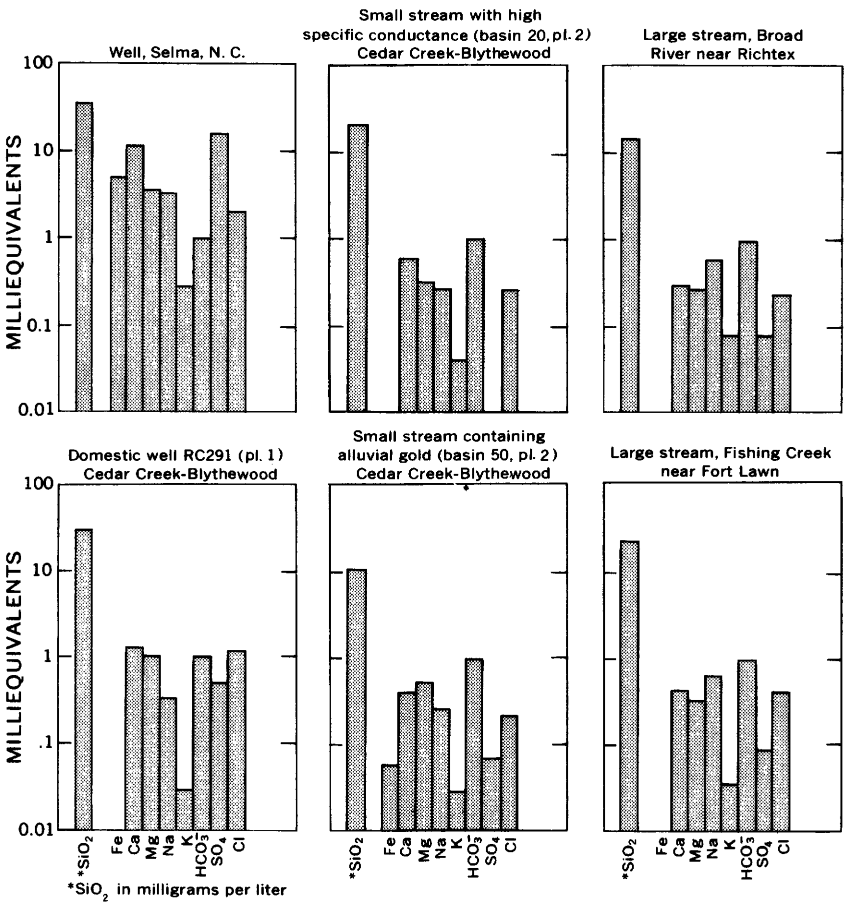


FIGURE 12.—Mole ratios of dissolved constituents (milliequivalents adjusted to 1.0 meq HCO_3^-) in water from various sources in the Carolina piedmont.

or time-consuming prospecting techniques might be indicated. The ground water in drainage basins of small streams found to have anomalously high mineral content might be further investigated by testing water from springs or, in well-populated areas, water from shallow domestic wells. Even domestic wells penetrating through thin coastal-plain sedimentary rocks could be expected to yield information about ground-water chemistry in the underlying crystalline rocks. Shallow boreholes might be drilled to sample ground water in selected areas where coastal-plain sedimentary rocks, thick saprolite, or heavy vegetation hinder other methods of surface sampling.

TABLE 6.—*Mole ratios of dissolved constituents to* HCO_3^- *in water from small streams and other selected sources in the piedmont*

	Silica (SiO_2)	Iron (Fe)[1]	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3-)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)
Well (Selma, N.C.)										
	35	4.09	11.13	3.57	3.28	0.28	1	15.3	1.99	0.00
Domestic wells, Cedar Creek-Blythewood area and vicinity										
RC–291	30	0.00	1.29	1.03	0.37	0.03	—	0.52	1.19	—
50425	30	.10	.73	.32	.45	.03	—	.41	.13	0.01
50426	29	.27	.42	.72	.27	.00	—	.25	.13	.00
50427	7.9	.20	.18	1.12	.86	.02	—	.12	.68	.02
Average	24	.14	.65	.80	.49	.02	—	.32	.53	—
Small streams with high specific conductance										
16R	2.4	0.00	0.49	0.38	0.29	0.02	—	0.02	0.22	0.00
20	20	.01	.59	.32	.26	.04	—	.00	.25	.00
21	14	.01	.59	.45	.16	.02	—	.00	.22	.00
32	8.9	.02	.77	.48	.23	.01	—	.05	.48	—
39	18	.00	.59	.47	.34	.02	—	.07	.33	—
60	28	.01	.28	.61	.39	.04	—	.05	.17	.00
70	8.1	.01	.74	.42	.33	.02	—	.02	.55	.00
Average	14.2	.01	.58	.45	.28	.02	—	.03	.32	—
Small streams containing alluvial gold										
50	11	0.06	0.41	0.55	0.27	0.03	—	0.07	0.23	—
52	10	1.02	.61	.46	.38	.05	—	.10	.46	—
56	13	.05	.41	.57	.19	.03	—	.04	.22	—
72	18	.08	.36	.64	.25	.01	—	.04	.20	—
Average	13	.30	.45	.56	.27	.03	—	.06	.28	—
Nearby surface water										
Fishing Creek near Fort Lawn	24	0.00	0.44	0.34	0.65	0.04	—	0.09	0.42	0
Broad River near Richtex	15	.00	.30	.28	.66	.08	—	.08	.24	0

[1] Total iron calculated as Fe^{+3}.

REFERENCES CITED

Cleaves, E. T. Godfrey, A. E., and Bricker, O. P., 1970, Geochemical balance of a small watershed and its geomorphic implications: Geol. Soc. America Bull., v. 81, no. 10, p. 3015–3032.

Durfor, C. N., and Becker, Edith, 1964, Public water supplies of the 100 largest cities in the United States, 1962: U.S. Geol. Survey Water-Supply Paper 1812, 364 p.

Feltz, H. R., and Wark, J. W., 1962, Solute degradation in the Potomac River basin: U.S. Geol. Survey Prof. Paper 450–D, p. D186–D187.

LeGrand, H. E., 1958, Chemical character of water in the igneous and metamorphic rocks of North Carolina: Econ. Geology, v. 53, no. 2, p. 178–189.

Price, Van, and Ragland, P. C., 1968, Ground water chemistry as a tool for geologic investigations in the southeastern Piedmont: Southeastern Geology, v. 9, no. 1, p. 21–38.

Secor, D. T., and Wagener, H. D., 1968, Stratigraphy, structure, and petrology of the Piedmont in central South Carolina: South Carolina Div. Geology, Geol. Notes, v. 12, no. 4, p. 67–84.

Slack, K. V., 1964, Effect of tree leaves on water quality in the Cacapon River, West Virginia: U.S. Geol Survey Prof. Paper 475–D, p. D181–D185.

Stewart, J. W., 1962, Water-yielding potential of weathered crystalline rocks at the Georgia Nuclear Laboratory: U.S. Geol. Survey Prof. Paper 450–B, p. B106–B107.

U.S. Geological Survey, 1968, Quality of surface waters of the United States, 1960—Parts 1 and 2, North Atlantic slope basins and South Atlantic slope and eastern Gulf of Mexico basins: U.S. Geol. Survey Water-Supply Paper 1741, 418 p.

——— 1969, Quality of surface waters of the United States, 1964—Parts 1 and 2, North Atlantic slope basins and South Atlantic slope and eastern Gulf of Mexico basins: U.S. Geol. Survey Water-Supply Paper 1954, 606 p.

——— 1970a, National atlas of the United States of America: Washington, D.C., 417 p.

——— 1970b, Surface water supply of the United States, 1961–1965—Part 2, South Atlantic slope and eastern Gulf of Mexico basins—Volume 1, Basins from James River to Savannah River: U.S. Geol. Survey Water-Supply Paper 1904, 942 p.

U.S. Weather Bureau, 1969, Climatological data, South Carolina: v. 72, nos. 4, 5, 10.