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SPECIFIC CATIONS IN GROUND WATERS RELATED TO GEOLOGIC FORMATIONS IN THE BROAD QUADRANGLE, GEORGIA

by

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LETTER OF TRANSMITTAL

Department of Mines, Mining and Geology

June 2, 1967

His Excellency
Governor of Georgia and
Commissioner Ex-Officio
State Division of Conservation
Atlanta, Georgia

Dear Governor Maddox:

I have the honor to submit herewith Bulletin #78 of the Department of Mines, Mining and Geology entitled "Specific Cations in Ground Waters Related to Geologic Formations in the Broad Quadrangle, Georgia" by Charles A. Salotti and James A. Fouts of the Geology Department of the University of Georgia.

This is a technical report which discusses the composition of ground water upon that quadrangle and the known relation of certain elements in the water to underlying rock types of contrasting chemical and mineralogic compositions.

The territory under discussion covers about 60 square miles of Wilkes County in the crystalline area of the State. It is believed that water studies in this geologic environment may prove useful in geochemical exploration for certain minerals and ores; also, certain of the rocks mapped such as granite, syenite and metamorphic rocks may be of possible commerical value.

Very respectfully your,

A. S. Furcron
Director

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A special trace-element laboratory as well as some supplementary equipment was provided with funds obtained from the Office of General Research, The University of Georgia. A Perkin-Elmer model 303 atomic-absorption sqectrophotometer, complete with 13 hollow cathode lamps and a 10 MV recorder, were purchased with funds provided by The Office of Water Resources Research (OWRR), The Department of the Interior. Funds were also provided by OWRR for the execution of this research. It is a pleasure to acknowledge this support.

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ABSTRACT

A suitable "clean" laboratory was built and a favorable field area near Clark Hill Reservoir in the Central Savannah River Area was delineated and mapped geologically in detail. Analytical and collection routines were established that allowed accuracy and reproducibility in these steps.

Twelve wells were analyzed for Ca, Mg, Zn, Cu, Fe, and Mn by atomic-absorption spectrophotometry. Analyses began in December 1965, and continued until July 1966. Well water temperature and regional rainfall were also measured and tabulated.

Results of this investigation show the following: (1) the quantitative dependence of ground-water trace constituents to enclosing rock type; (2) the adjustment of migrating ground water to contrasting lithologies; (3) the quantitative variations in ground-water compositions with seasonal and rainfall variations; and (4) the possible relation between specific trace-element contents and organic activity.

INTRODUCTION

The primary objective of this research was to delineate in detail the behavior of specific trace cations in the subsurface waters that percolate through rocks, saprolite, and soils of contrasting chemical and mineralogic compositions.

A restricted drainage basin was selected in Wilkes County, Georgia, on the southwestern shore of Clark Hill Reservoir. The area was chosen for the following reasons: the diverse bed rock; the proximity to Clark Hill Reservoir, with the principal direction of ground water movement toward the reservoir; the low population and scarcity of farms; the well-known past land-utilization history; and because non-farm dwellings are common enough to provide the properly located wells for sampling. The area includes approximately 60 square miles, all within the United States Geological Survey's 7.5 minute Broad Quadrangle Topographic Map.

The maximum relief in the area is approximately 331 feet. A U.S.G.S. bench mark is located at the topographic high, 631 feet, in the southwestern corner. The height of the water in the Clark Hill Reservoir, the topographic low, is approximately 300 feet. The drainage pattern is dendritic and almost all of the secondary streams are permanent.

The area, once largely farm land, is now mainly pine forested. The present agricultural usage is chiefly as pastures. The soil type is classified by Perkins and Ritchie (1965) as a Cecil-Madison-Lloyd association. These soils are characterized by good drainage and coarse, loamy, surface layers with friable, clayey subsoils. Bed rock outcrops are common (Plate 1).

GEOLOGIC MAPPING

The general area for the study was chosen on the basis of the writer's knowledge of the geology within the state and by using preliminary reconnaissance geologic information of the 13 counties of the Central Savannah River Area prepared by Hurst, V. J. and others (1966). A Wilkes County road map was used in conjunction with a field reconnaissance to select possible well-sampling sites. The final well sites were chosen only after an initial investigation proved their suitability. Detailed geologic mapping was done on U. S. Department of Agriculture aerial photographs, scale 1 inch represents 660 feet. This information was transferred to a U. S. Geological Survey topographic map of the 7.5 minute Broad Quadrangle, scale 1:24,000, with 10 foot contour intervals (Plate 1).

On the basis of the geological field work the following rock types, from youngest to oldest, are mappable:

(1) syenite;

(2) porphyritic granite;

(3) granite gneiss;

(4) chlorite schist;

(5) amphibolite;

(6) fine-grained gneiss;

(7) sericite schist;

(8) metadacite.

These mappable rock units along with their saprolite equivalents and the soils derived therefrom are described in detail in the section on petrology.

SAMPLE COLLECTION

The sample collection was simple and readily reproducible. For wells with a pump, enough water was run to allow a complete exchange of the water in the pump and pipe equal to four or five times its standing volume. For wells that are open, the sample was collected in a polethylene bottle weighted with a special stainless-steel container. The open-well samples were all taken within a few feet of the standing water surface. During the sampling interval, December 1965 to June 1966, this surface showed considerable variation.

Immediately upon collection the samples were frozen by placing them in an insulated container with dry ice. The temperature of the non-collected part of the sample was also taken at this time. The frozen samples were brought back to the laboratory and kept in a freezer until analyzed. As a check, parts of the same sample were left unfrozen and run later along with the frozen fraction. In all cases the unfrozen part recorded lower concentrations of trace elements than did the simultaneously collected frozen samples. Later, a part of a fresh sample was acidified to .1N by adding distilled HCl and a few drops of 30% H_2O_2 and left unfrozen. The trace-element content of the sample so treated was essentially the same as that of the frozen samples. Because the freezing technique was somewhat more convenient this method of collection was used for all of the recorded samples.

A portable pH meter was not available until the final month of sample collection. Natural water is so weakly buffered that the pH of the thawed samples differed significantly from the pH obtained on a counterpart sample measured immediately upon discharge. Consequently, the pH values measured in the laboratory are in error and are not included.

ANALYSIS

Standards of appropriate concentrations (ug/ml) were prepared from standard solutions obtained from Hartmann-Leddon Company and Fisher Scientific Company. The standards were prepared immediately before their use by dispensing the standard solution using an appropriate pipette and adding the correct amount of distilled, de-ionized water to obtain the desired concentration. The walls of the pipette were flushed with standard solution prior to its use. The water used for dilution was first distilled, then passed through a standard type, and then through a mixed-bed resin-exchange column. The distilled water was added to the standard solution by means of a buret, calibrated in accordance with the practices set forth in N.B.S. Circular 602.

A Perkin-Elmer Model 303 atomic-absorption spectrophotometer in line with a Sola voltage regulating transformer was used for the analyses. The analytical lines used are as follows: Ca, 4227; Cu, 3247; Fe, 2483; Mg, 2852; Mn, 2795; and Zn, 2138. Acetylene was the fuel and air the support gas. The samples were allowed to reach room temperature unopened, and then run. The procedures to guard against anionic chemical interferences were taken where necessary. The standards and samples were so dilute that no matrix effects were present and the working curves were linear.

All of the analyses were done in a specially prepared laboratory equipped with an electrostatic air filter, and temperature and humidity control. As a further precaution the masonry walls of the room were "sealed" with a thick penetrating layer of varnish to prevent scaling.

RESULTS

GENERAL GEOLOGY

The area lies entirely within the Piedmont Physiographic Province. The present surface is gently sloping with the rolling topography dissected by a permanent northeast-trending dendritic drainage. The underlying rocks are a thick sequence of intercalated, fine-grained metavolcanic and metasedimentary rocks (The Little River Series) intruded by a succession of felsic plutons. The Little River Series was named by Crickmay (1952) from exposures along the Little River in Wilkes, Lincoln, and McDuffie counties. This series is the southwestern extension into Georgia of what, in South Carolina, is referred to as the Carolina State Belt (Overstreet and Bell, 1964). Most of the series has a well-developed foliation that strikes about N45°E with vertical dips. Early fine-grained granite (now granite gneiss), porphyritic granite (Danburg type) and syenite are intrusive into the Little River rocks. The age of these rocks is uncertain. The Little River Series is likely early Paleozoic (Carolina State Belt equivalent), and the younger felsic intrusions are probably late Paleozoic in age (post-early Paleozoic and pre-Triassic).

All of the rocks show some degree of non-surficial weathering.

Evidence of large-scale folding is present locally and within the surrounding areas (Fouts, 1966, and Hurst and others, 1966); and shear zones, commonly silicified, are present. Both folds and faults undoubtedly exert a control over much subsurface water movement, but without detailed studies their exact influence is indeterminate. The inclusion within the sequence of highly phyllitic schists greatly inhibits intraformation porous shear zones.

The rock-unit boundaries are exactly located where outcrops occur. Where bed rock does not crop out, the underlying rock is identified by the remaining primary and developed secondary structure and mineralogy known to be peculiar to a mappable rock type. Some rock types can be identified by peculiar characteristics of their derived soils. This method must be used with great caution, because for some rock units the interpretation of the bedrock is not possible from a soil examination.

Syenite

No water samples were collected within the syenite; therefore, this rock unit was not studied petrographically. Crawford, and others (1966), p. 13, have described the syenite as follows:

> The syenite is nearly circular in outline and about 4,500 feet in diameter. On the east it is bounded by the Danburg granite; on the west it is bounded by fine-grained hornblende and biotite gneisses of the Little River series. Apophyses of the syenite extend into the bordering chloritic hornblende gneiss. Marginal zones of the syenite are locally siliceous, with thickly disseminated quartz grains.
>
> Thin sections of the syenite show evidences of metamorphism: sutured grain boundaries and the conversion of hornblende to magnetite and fine-grained alteration products. The mineralogical composition varies somewhat from outcrop to outcrop.

Table 1 — Modal Analysis of Syenite

(Crawford, T. J., and others, 1966)

Feldspar (microclinic + albite)	88.8
Hornblende	7.0
Biotite	1.7
Magnetite	1.7
Transparent accessories	0.3
Opaque accessories other than magnetite	0.5
	100.00

Porphyritic Granite

A porphyritic rock called the Danburg granite forms a large well-defined pluton in the western part of the area. The mineralogy of the granite and its texture are extremely uniform. Zoned feldspar phenocrysts occur in a matrix of quartz, feldspar and biotite. Phenocrysts range from 6-12 mm. thick, 12-50 mm. long, and 6-25 mm. wide. Where the contact can be well observed, the granite is clearly intrusive into the Little River Series. The granite lacks the quartz veins that are so typical of the surrounding rocks and petrographically shows less non-surficial alteration than do older units. A distinctive gruss overlies much of this unit.

Table 2 — Modal Compositions of Danburg Granite

	a	b	c
Quartz	26.6	24.7	25.7
Microcline	36.8	37.4	34.8
Oligoclase	28.6	32.6	32.7
Biotite	5.7	3.9	5.3
Magnetite	1.2	0.4	0.3
Titanite	0.9	----	0.8
Others	0.2	0.2	0.4

a) Crawford, T. J., and others (1966)
b) Vistelius, A. B., and Hurst, V. J. (1964)
c) Sample near well location W-12, 1207 points

Granite Gneiss

Granite Gneiss crops out in the south-central part of the area. Well W-6 is located within granite gneiss. It is a fine-grained, gray to buff rock in hand specimen with a well-defined foliation, but with poor mineralogic banding.

Essential microscopic components are quartz, plagioclase (An_{14}), microcline, biotite, and epidote. Accessory minerals are magnetite and rarely titanite. Plagioclase is unzoned and most is untwinned. Epidote is commonly euhedral and further suggests strong recrystallization of the original rock. The residual textures suggest that the rock may have originally been a fine-grained adamellite, but recrystallization has been so intensive that a positive identification is not possible. The field relations of this unit suggest that it was originally an intrusive igneous rock.

Chlorite Schist

In thin section, the chlorite content of hornblende gneiss varies from traces to 40 percent. In hand specimen, the rock is schistose, greenish gray, medium grained and appears to be composed largely of chlorite. However, in thin section, hornblende is at least as abundant as chlorite. The chlorite is generally penninite. Individual chlorite flakes are as much as 3 mm. across and are usually concentrated in parallel bands as lenses with a maximum width of 1.5 mm. A small amount of biotite is present. The alteration of hornblende and less commonly of biotite appears to be the origin of the chlorite.

Fine-grained plagioclase and quartz are present and some euhedral epidote is rarely included.

Amphibolite

In outcrop, amphibolite is dark greenish gray and mainly fine grained. It varies from well foliated to almost massive with the foliation more obvious in weathered outcrops. The foliation strikes northeast and dips vertically. Epidote is abundant in some areas and, where present in large amounts, imparts a brighter green to the rock. Much epidote is secondary as stringers and veins in quartz. Epidote-rich zones usually parallel the foliation. Chlorite is another common constituent, varying from 0 to 40 percent of the rock. Where chlorite is abundant the rock has a schistose appearance.

In thin section the rock is seen to be composed of hornblende, plagioclase (An_{39}) and quartz. Dark-green prismatic hornblende with an average length of 0.8 mm. is the dominant mineral. The laths of hornblende show a parallel orientation which causes the foliation.

Plagioclase is concentrated in lenticular areas where hornblende is absent, although it occurs throughout the section. Universal stage measurements show it to be andesine (An_{39}).

Fine-grained quartz is the other abundant mineral. Other minerals are epidote, commonly a major component, titanite, magnetite, and scattered apatite.

Table 3 — Modal Analysis of Amphibolite

Hornblende	46.3
Plagioclase (An_{39})	18.2
Quartz	20.1
Chlorite	4.2
Epidote	10.5
Titanite	0.3
Apatite	0.2
Magnetite	0.1
	99.9
1031 Points	

Fine-grained Gneiss

Wells numbered W-10, -11, and -16 are located within fine-grained gneiss. It is a dark-gray rock with a well-developed mineralogic banding. The average grain size is about 1 mm. with little variation except for the presence of scattered large plagioclase porphyroblasts.

In thin section the essential minerals are plagioclase, quartz, biotite, and epidote. Accessory minerals include titanite, magnetite, microcline, and minor apatite.

This rock type is highly variable. The variation is in large part dependent upon the degree of non-surficial alteration. Plagioclase may be only slightly to completely degraded to sericite. Hornblende has altered to epidote and the transformation may be almost complete. Biotite invariably shows some alteration to chlorite. Magnetite and titanite are ubiquitous accessory minerals.

Two types of veinlets are present: early quartz veinlets are transected by later calcite veinlets.

Sericite-Quartz Schist

Fine-grained sericite schist is one of the commonest rock types in the Little River Series. Locally, the schist becomes a metaconglomerate in appearance. Rare lenses of rounded quartz pebbles up to 6 mm. in diameter occur. The rock is deeply weathered, but in outcrop it is unmistakable. Where unstained it is almost snow white and has a silky luster. The identification of individual minerals is difficult because of the fine-grain size.

Microscopically the rock is seen to be mainly quartz and muscovite (table 4).. The rock has an interlocking texture typical of recrystallized quartz-rich rocks. Fine-grained muscovite is concentrated in thin parallel bands.

The soil derived from this rock has a powder like appearance. When rubbed between the fingers the soil has a gritty feel because of the abundant fine-grained quartz. Saprolite derived from sericite-quartz schist is very light colored. Where enough pyrite is present, either in the schist or in the quartz veins that cut the schist, the soil is red. For this reason alone soil color cannot be used to trace this unit in the saprolite.

Table 4—Modal Analysis of Fine-Grained Sericite Schist

Quartz	60.8
Sericite	38.1
Microline	1.0
Biotite	0.1
Pyrite	Tr.
	100.0

1063 points

Metadacite

The rock called metadacite is generally very coarse-grained but shows considerable variation in texture. The fresh rock is blue gray. It becomes light buff when weathered. Blue, opalescent quartz, as spherical grains up to 12 mm. in diameter, is the most obvious mineral. Light-gray, medium-to coarse-grained plagioclase is present in amounts equal to quartz. Isolated patches of biotite and/or chlorite are present and their elongation imparts a distinct foliation. Most outcrops, however, are massive and show no foliation or lineation. The local metadacite is similar to and a part of a much larger unit that locally comprises a significant part of the Little River Series. Overall the unit shows typical volcanic textures including pseudomorphs of high quartz.

Under the microscope the rock is seen to be essentially quartz and oligoclase (An_{21}). Other minerals are microcline, chlorite, clinozoisite, sericite, titanite, ilmenite, and biotite. Quartz occurs as large spherical grains ranging from 1 to 12 mm. in size. It is typically light blue. Larger grains are commonly fractured, and all grains show undulatory extinction.

Subhedral to euhedral plagioclase (An_{21}) is slightly more abundant than is quartz. Most grains are highly altered to sericite and clinozoisite.

Microcline is much subordinate to quartz and plagioclase. The dominant dark mineral is biotite with ilmenite as a constant associate.

The metadacite is deeply weathered in most places. During weathering, feldspar breaks down into clay minerals and quartz remains unchanged. Soil overlying this unit typically is pale yellow to yellow brown, although the abundance of mafic dikes in some areas results in a darker soil. The quartz-rich residue has been widely used as road metal. Some of the best saprolitic outcrops occur in fields that have been stripped for this purpose.

A commonly observed feature of metadacite weathering is a six-to twelve-inch silicified zone at the base of the A soil horizon. This apparently forms during weathering and can be seen in most large road cuts.

Table 5 — Modal Analysis of Metadacite

Plagioclase (An_{21})	41.6
Quartz	39.9
Microcline	9.5
Clinozoisite*	2.3
Sericite*	4.7
Biotite	0.6
Chlorite	1.1
Titanite	Tr.
Ilmenite	Tr.
	99.7

*Alteration products of Plagioclase; 1327 points.

ANALYTICAL RESULTS

The solution of trace metals from soil, saprolite, and bedrock and their migration within subsurface waters are a function of many interrelated variables. In evaluating these hydrochemical parameters there is no substitute for an "educated sensitivity"; or more pointedly stated, there is no substitute for direct and prolonged experience within the geologic and geographic area investigated. Included among the areal parameters that must be considered are the following:

I. Absolute and seasonal variations in
  - A. Temperature
  - B. Rainfall
  - C. Vegetative activity
  - D. Agricultural activity (liming of soils, etc.)

II. Weathering stability of geologic units
  - A. Mineralogy
    - 1. Bulk mineralogy (chemistry)
    - 2. Presence of pyrite and/or pyrrhotite
  - B. Texture

III. Access to migrating solutions
  - A. Topography
  - B. Permeability
    - 1. Primary permeability
      - a. Fabric
    - 2. Secondary permeability
      - a. Folds

b. Faults
c. Solution channels
d. Precipitation barriers
3. Stratigraphy

IV. Resistance to removal from groundwater
A. Nature of encountered lithologies along migration route
B. Pronounced changes in oxidation or reduction along migration route

V. Dilution effects

Reliable results are likely to be obtained where the area studied has an even topographic surface, the general direction of ground water movement is known, high variations in seasonable rainfall are absent and generally uniform flow rates prevail, and where significant amounts of pyrite and pyrrhotite are present to provide, upon weathering, reasonable amounts of acid to aid in solution.

The area studied is characterized as follows:

1. Humid sub-tropical climate, without a dry season but with two rainfall maxima (February-March and July).
2. Year-round vegetative activity, but with seasonal maximum and minimum.
3. Rolling to gently sloping topography, with permanent dendritic drainage.
4. Bed-rock geology chiefly metamorphic rocks with the foliation parallel to the direction of ground water movement.
5. Variable depth of weathering, but, in general, weathering and erosion appear to be near equilibrium.
6. Pyrite and to a much lesser extent pyrrhotite is a commonly distributed accessory mineral.
7. Unusual seasonal irregularities in the rainfall (December 1965, 1 inch; January 1965, 7.5 inches) resulting in considerable variations in the height of the ground water table.
8. In general, rapid chemical weathering, but weathering of some rock types (sericite schist) also involving considerable mechanical disintegration.
9. Relatively little disturbance by agricultural usage.
10. Bed rock consisting of mineralogically, chemically, and texturally highly contrasting lithologic units.

The analytical results are summarized in figures 1-6. When no water was collected the space is left blank. A dash represents a collected and analyzed sample, but the element was below the detection limit. If the element was detectable, but below the analytical limit of 0.1 PPM it appears as the letter D. All reported values are in parts-per-million (mg/ml).

Numerous relations that lend general credence to the results appear in the data. Water samples from a specific rock type, metadacite [W-2, -8, -11(?)], over widely separated collection sites are all low in zinc. The correspondence of similarly behaving elements is also noticeable; calcium and magnesium, and iron and manganese vary in a generally similar manner in regard to both sample location and seasonal effects. Copper was present in samples from different rock types, and those wells that contained detectable copper in either December, January, or March consistently contained copper, one in measurable amounts (0.39 PPM), during spring and early summer.

Manganese and copper clearly increase in amount in late spring and early summer compared to their concentrations in winter. This increase cannot be attributed to seasonal dilution (see rainfall record, Appendix I). Under the prevailing pH of these subsurface waters, manganese should not be present in ionic form. Rona and others (1962) have demonstrated through dialysis that manganese is present in sea water mainly in the form of large, probably organic, molecular complexes. These molecular complexes can be separated from ionic manganese and MnO_2 by ultrafiltration (10 mu Millipore filter). It may be that manganese, because of its extensive inclusion in biological substances, increases in the spring and early summer as a result of the increased biological production of manganese-bearing organic complexes and/or the release, through an increased decay rate, of manganese-bearing organic materials. The truth of this suggestion can readily be tested.

If the assumption that the direction of subsurface water migration follows the topographic slope is correct it appears that sericite schist (W-3) may act as a collector for elements released from different rock types.

The well (W-5) located within a silicified shear zone, although an excellent water well, is well below average for all analyzed elements with the possible exception of copper. It appears to be largely barren quartz. This shear is a highly porous zone, and it may act as a sub-surface channel and so reflect more dilution than the other wells.

SUMMARY

This study is only a beginning in the study of the trace-element content of subsurface water in a petrologically complex metamorphic terrain. In general, a correlation exists between the enclosing rock type and the trace-element content of the ground water. The limited data presented indicate that ground water quickly changes character with a change in enclosing rock type.

Seasonal variations have a pronounced effect upon the trace-element content. These changes result from variations in temperature, rainfall amount, and, very likely, the rate of organic activity.

So little is known concerning the detailed relations between rock type and transmitted ground water that little understanding is possible until more basic facts are accumulated. Theory must follow, not lead, this gathering of fundamental relations. This study was exploratory by necessity and has several limitations. The sampling interval is far too short (December 1965 - July 1966) to evaluate properly the various seasonal influences. Well-site selections were dictated by their availability, and almost no choice could be made on the basis of location, well type, or the likelihood of contamination. (However, the regularity of the analysis and the relations between rock type and analysis strongly suggest that the data is reliable.)

The termination of this project has precluded a planned trace-element study of the bed rock, saprolite, and soil within the well-site locations. Such a study would provide much pertinent information. A further aspect worthy of investigation concerns the nature of how the trace elements are present. Hawkes and Webb (1962, p. 229) report "Ground water carries most of its load of metal in one of the ionic phases, with lesser proportions traveling as stabilized colloidal sols." The writer suggests that this depends upon what metals are being discussed, and for some metals it likely is not a valid statement. This clearly is an area that needs further study.

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Fig. 1 Ca in ppm.

WELL	Dec.	Jan.	March	April	May	June 6	June 25
W-2	11.70		8.50	20.88	10.50	13.30	10.28
W-3		10.90	11.30	11.30		13.43	16.42
W-5	3.80	2.80	4.35	7.00	3.05	3.45	
W-6	0.50	0.42	2.20	3.00	0.66	0.40	0.57
W-8	12.00	10.10	12.90	19.86	9.50	11.14	4.22
W-9	0.45		0.50	2.80	0.35	0.53	0.86
W-10	0.95	0.90	1.15	4.55	1.00	1.12	1.25
W-11	0.45		0.72	2.94	0.50	0.60	0.71
W-12	22.30	19.90	22.00	25.50	25.00	26.20	23.84
W-13					30.30	33.42	31.77
W-14	9.60	12.10	12.50	17.40	22.16	22.84	22.82
W-16		1.90	2.20	6.60	1.80	2.43	1.23

Fig. 2 Mg in ppm.

WELL	Dec.	Jan.	March	April	May	June 6	June 25
W-2	0.49		0.49	0.58	0.52	0.54	0.62
W-3		0.15	0.17	0.17		0.18	0.21
W-5	1.37	1.19	1.31	0.84	0.81	0.72	
W-6	D	D	0.20	0.11	0.10	0.10	0.20
W-8	2.77	2.51	3.41	3.33	3.74	3.68	4.62
W-9	0.16		0.17	0.18	0.15	0.18	0.41
W-10	0.62	0.51	0.60	0.41	0.36	0.40	0.74
W-11	0.60		0.69	0.42	0.39	0.43	0.85
W-12	4.02	4.13	3.90	4.38	4.54	4.96	4.94
W-13				9.39	6.30	9.21	9.48
W-14	0.61	0.58	0.98	0.90	1.08	1.03	1.03
W-16		2.70	2.70	2.25	1.70	2.30	2.96

Fig. 3 Zn in ppm.

WELL	Dec.	Jan.	March	April	May	June 6	June 25
W-2	D		D	D	D	D	D
W-3			0.18	0.28		0.71	0.30
W-5	0,25	0.14	0.11	D	D	0.10	
W-6	1.92	2.59	1,22	1.27	2.10	1,76	1.40
W-8	D	D	D	D	D	D	D
W-9	1.04		1.19	1.57	1.04	1.15	1,01
W-10	0.10	1.00	0.98	0.25	0.43	0.27	0.22
W-11	D		D	D	D	D	D
W-12	1.58	2.79	1,79	1.40	2,79	3.00	0.98
W-13				0.30	0.20	0.12	0.71
W-14	0.12	1.06	0.22	0.45	1.14	1,94	0,58
W-16		3.05	2.10	1.34	2.31	2.04	1.14

Fig. 4 Fe in ppm.

WELL	Dec.	Jan.	March	April	May	June 6	June 25
W-2	D		D	D	–	0.14	–
W-3		D	D	–		0.13	D
W-5	D	D	D	–	–	D	
W-6	D	D	D	–	–	D	–
W-8	D	D	D	D	D	D	–
W-9	D		D	–	–	D	–
W-10	D	D	D	–	–	–	–
W-11	D		D	–	D	–	D
W-12	D	D	D	D	–	0.16	0.19
W-13				D	–	D	D
W-14	D	D	–	0.11	0.13	0.40	0.10
W-16		D	D	D	–	D	–

Fig. 5 Mn in ppm.

WELL	Dec.	Jan.	March	April	May	June 6	June 25
W-2	–		–	–	–	D	D
W-3		D	D	0.10		D	D
W-5	–	–	D	–	–	–	
W-6	–	–	–	–	–	–	–
W-8	–	–	–	–	–	–	–
W-9	D		–	D	D	–	–
W-10	–	–	–	–	D	–	D
W-11	–		–	–	–	–	–
W-12	–	–	–	–	D	–	D
W-13				D	–	D	D
W-14	–	–	–	0.46	D	0.35	0.24
W-16		–	D	–	–	–	–

Fig. 6 Cu in ppm.

WELL	Dec.	Jan.	March	April	May	June 6	June 25
W-2	–		–	–	–	–	–
W-3		–	–	–		D	–
W-5	–	D	–	D	D	D	
W-6	–	–	–	–	–	–	–
W-8	–	–	–	–	–	–	–
W-9	–		–	–	–	–	–
W-10	–	D	–	D	D	D	D
W-11	D		–	D	D	D	D
W-12	–	–	–	–	–	–	–
W-13				–	D	–	D
W-14	–	–	–	–	D	D	D
W-16		–	D	D	D	0.39	D

APPENDIX I

AREAL RAINFALL

Dec.	Lincolnton Ga.	Washington Ga.	Elberton Ga.	Calhoun Falls S.C.
4				0.02
13	0.29	0.26	0.36	0.31
14	T	T		
15	0.34	T	0.05	0.02
16	0.10	0.33	0.13	0.17
17		0.14	0.12	0.16
19	0.13	0.14	0.03	0.05
20		T		
25	0.08	0.14	0.30	0.18
Total	0.94	1.01	0.99	0.91

(continued)

Appendix I (continued)

Jan.	Lincolnton Ga.	Washington Ga.	Elberton Ga.	Calhoun Falls S.C
2	0.05			
3	T	0.07	0.07	0.05
4	T	0.22	0.16	0.23
5	0.94	0.65	0.38	0.34
6	1.10	1.49	1.45	1.26
7				0.05
14	0.27	0.22	0.35	0.23
15	1.58	2.00	0.70	0.80
16	1.21	0.67	1.54	1.52
17		T		0.03
22	0.94	0.72	0.64	0.62
23	0.12	0.14	0.22	0.32
26	0.65	0.83	0.53	0.52
27	0.34	0.23	0.19	0.22
30	0.49	0.25	0.35	0.36
Total	7.69	7.49	6.58	6.55

Feb	Lincolnton Ga.	Washington Ga.	Elberton Ga.	Calhoun Fall S.C.
2	0.32	0.33	0.32	0.22
8				T
10		T	0.20	T
11	0.18	0.20	0.20	0.04
12	0.28	0.29	0.10	0.34
13	1.20	1.40	2.55	1.75
14			0.24	0.04
15		T		
16	0.16	0.14	0.73	0.35
17	0.57	0.70	0.74	0.62
19	T	0.08		
23			T	
24	1.30	0.94	0.83	0.68
25		0.06		0.05
28	0.58	0.25	0.42	0.29
Total	4.59	4.39	6.33	4.38

(continued)

Appendix I (continued)

March	Lincolnton Ga.	Washington Ga.	Elberton Ga.	Calhoun Falls S.C.
1	0.62	0.75	0.59	0.62
3	0.03	0.02	0.05	0.06
4	2.68	3.10	2.70	2.71
5	0.30	0.24	0.13	0.22
14		T		
15		0.03	0.03	0.03
16	0.18	0.34	0.07	0.15
17	0.03	T		T
19	0.09	0.14		T
20				T
24		0.13	0.23	0.06
27				T
Total	3.93	4.75	3.80	3.85

April	Lincolnton Ga.	Washington Ga.	Elberton Ga.	Calhoun Falls S.C.
4	0.96	1.02	0.62	0.66
5				T
14	T	0.25		T
15		0.08	0.04	0.04
20		0.01	0.06	0.06
21	0.25	0.21	0.10	0.08
22		T		T
23	0.52	1.27	1 04	1.45
24				T
26	0.35	0.11	0.07	1.03
27	1.34	1.62	0.72	0.72
28	0.31	0.52	0.65	0.98
29	T	0.03	0.10	0.47
30	0.10	0.20	0.23	0.12
Total	3.83	5.32	3.63	4.61

(continued)

Appendix I (continued)

May	Lincolnton Ga.	Washington Ga.	Elberton Ga.	Calhoun Falls SC
1	0.15	0.22	0.86	0.76
2	0.08	0.01	0.43	0.36
3			0.07	0.03
9		T		
13		0.21	0.50	0.35
14	0.12	0.08	0.53	0.22
17	0.08	0.11	0.25	0.14
18		0.03		T
19	0.55	0.72	0.20	0.24
20		0.01		T
21		T		T
22	1.26	2.25	0.17	0.23
23		T		
24	0.07	0.04		0.03
25		0.11	0.13	0.08
26	0.09	0.06	0.88	0.15
27	0.31	0.02	0.96	0.16
28	0.19	0.18	0.20	2.02
30				0.03
Total	2.90	4.05	5.18	4.80

June	Lincolnton Ga.	Washington Ga.	Elberton Ga.	Calhoun Falls S.C.
8			1.18	0.23
9				0.19
10	2.15	1.53	0.90	1.26
11	0.08	0.07	0.25	0.18
15	0.21	0.50	0.19	0.16
16	0.07	1.07		T
17	0.68	0.63	0.28	0.12
18		0.02		0.04
19	3.35	2.13	0.05	T
Total	6.54	5.95	2.85	2.18

APPENDIX II
H_2O TEMPERATURE IN °C

WELL	Dec.	Jan.	March	April	May	June 6	June 25
W-2	17.5		15.8	16.4	16.5	16.5	18.1
W-3			11.8	18.6		21.9	23.4
W-5	17.0	13.8	15.2	17.5	18.3	19.6	
W-6	17.9	16.3	16.6	17.7	17.5	17.9	19.5
W-8	16.7	16.4	16.7	17.3	17.3	17.4	18.4
W-9	15.8		12.1	20.9	21.4	25.6	27.0
W-10	17.8	11.7	15.5	19.4	19.6	23.8	23.2
W-11	14.2		11.8	17.8	21.3	23.0	26.5
W-12	16.9	16.3	16.4	17.4	17.6	17.4	19.0
W-13				17.9	17.9	19.9	26.0
W-14	16.7	14.7	15.5	16.9	16.9	16.6	18.0
W-16			12.8	19.2	19.4	24.5	18.9

APPENDIX III

ELEMENTS DETECTABLE BUT LESS THAN 0.1 P.P.M.

COPPER

December W-11 January W-5 W-10 March W-16	April W-5 W-11 W-10 W-16 May W-5 W-13 W-10 W-14 W-11 W-16	June 6 W-3 W-11 W-5 W-14 W-10 W-16(.398) June 25 W-10 W-14 W-11 W-16 W-13

IRON

December All Samples Collected January All Samples Collected March All Samples Collected Except W-14	April W-2 W-13 W-8 W-16 W-12 May W-8 W-11	June 6 W-5 W-9 W-6 W-13 W-8 W-16 June 25 W-3 W-13 W-11

MANGANESE

December W-9 January W-3 March W-3 W-16 W-5	April W-9 W-13 May W-9 W-12 W-10 W-14	June 6 W-2 W-13 W-3 June 25 W-2 W-12 W-3 W-13 W-10

Appendix IV

WELL DESCRIPTIONS

W-1—Open well in "Danburg granite." Well about 50 feet deep and 4 feet in diameter. No outcrops are in the immediate vicinity of the well but the soil is distinctly that of the "Danburg granite." No recent farming nearby and no other visible source of contamination.

W-2—Open well located well within a body of a light-gray quartz-feldspar rock (metadacite). The rock is generally coarse grained. Quartz is commonly in the form of medium to coarse, spherical grains. The well is approximately 30 feet from the house.

W-3—Well with pump recently drilled to a depth of 54 feet. The rock type is a fine-grained quartz-sericite schist. A well-developed foliation strikes N46°E and has a nearly vertical dip. Three sets of joints are present in outcrop 20 feet from the well. These have trends of N24°E, N20°W, and N80°W. Rock sample collected 30 feet from well; soil sample from well.

W-4—Open well at abandoned house. No rock crops out near well, but surrounding rocks are mostly fine-grained quartz-feldspar-mica rocks. Some of these rocks contain enough mica to be schistose and similar to the rock described at W-3. Interbedded with these are some relatively thin, basic units. These are fine-grained amphibolitic rocks. The rocks have a northeastern trend, and typical samples were collected 800 feet northeast of the well. The soil at the well is red and micaceous.

W-5—Well with pump located in center of a fairly large silicified zone. The silicified zone is 80 to 100 feet wide and can be traced for several hundred feet. The quartz commonly has a drusy appearance and masses of poorly-formed, intergrown crystals are common. The nature of the rock on either side of the silicified zone is difficult to determine. Some fragments of a gray, fine-grained, hornblende-feldspar rock were found nearby. Rock and soil samples were collected 25 feet from well.

W-6—Open well on the farm of Mr. Heard. The well is about 15 feet from the house. It has a pump, but it is open also. Several outcrops of a gray, fine-grained granite occur on all sides of the well although none are present in the immediate vicinity.

Soil near the well contains abundant quartz and appears identical to that of the fine-grained granites. Two samples of float were collected nearby and Mr. Heard stated that the small sample came from the well. Soil sample was collected 200 feet from well in fresh road cut. The well is 60 feet deep.

W-7—Open well near abandoned house. Large pasture nearby but no apparent recent farming. The well is well within the "Danburg granite".

W-8—Open well in a sericite-quartz schist near contact with unit described in W-2. Well has been recently dug and soil sample was taken from dirt from the well. No rock crops out in vicinity, but some small fragments of sericite schist were in soil from well.

W-9—Well of unknown depth in "Danburg granite" on Mr. Shoemaker's farm. No farming in the last two years. Rock sample collected 600 feet north of well.

W-10—Drilled well at Buford's store. Well is 132 feet deep and lower 70 feet are in "solid rock". A section of the drill core was collected. It is a dark-gray, fine-to medium-grained rock that appears to be composed of quartz, feldspar, epidote, and biotite. The biotite is concentrated in bands and lenses which give a distinct foliation. No outcrops of this rock were seen. Soil near the well is rich in mica and fine-grained quartz. Approximately 200 feet from the well some float of a medium-grained granitic rock were found. Sample of granitic float was taken in addition to core. Well is five years old.

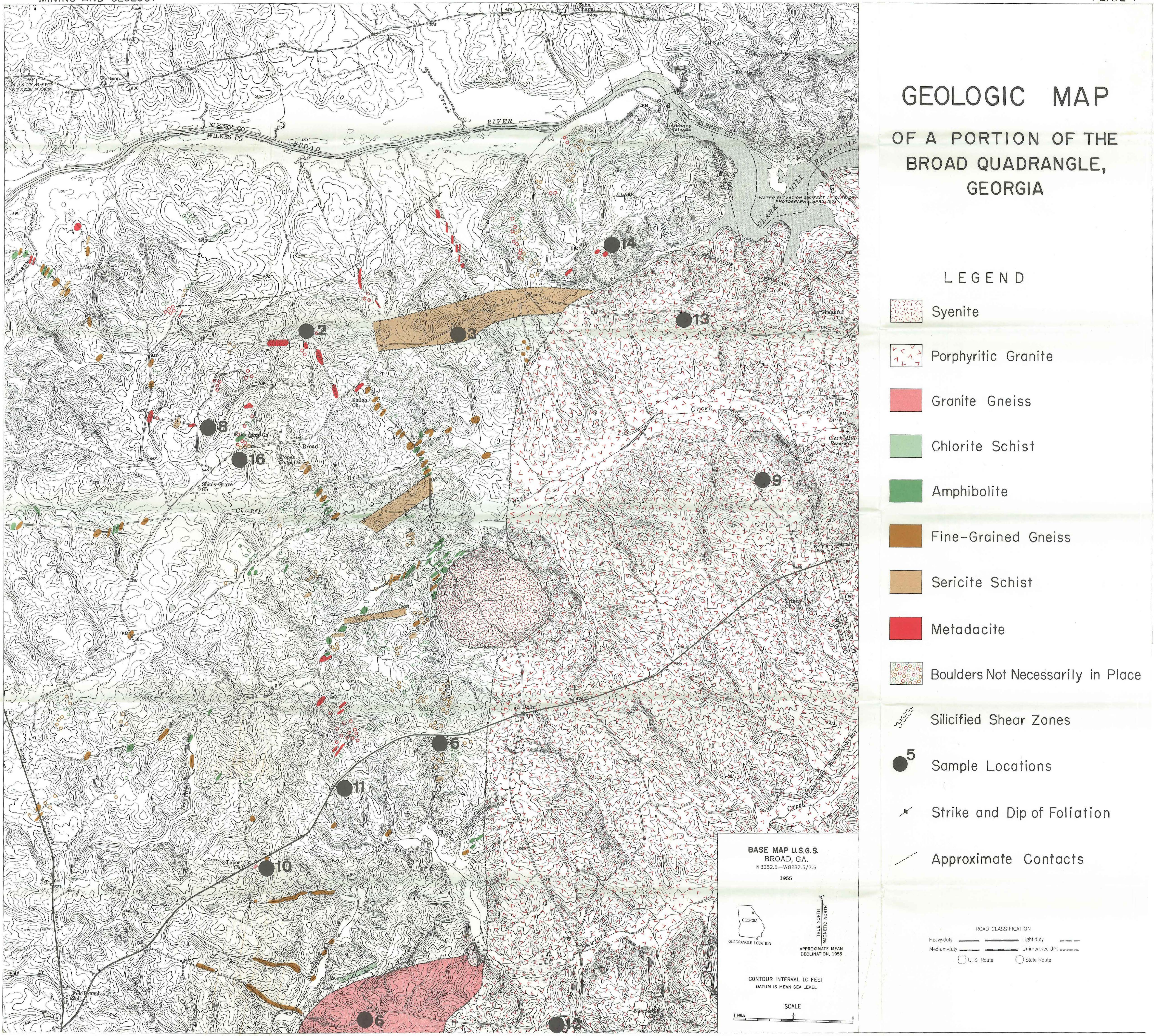
W-11—Well with pump. No outcrops nearby but float and saprolite indicate that fine-to medium-grained quartz-feldspar rock is most abundant. A small amount of fine-grained amphibolite is also present. Float samples of basic rock and quartz-feldspar rock with coarse quartz taken 85-100 feet east of well.

W-12—Open well in "Danburg granite" said to be 60 feet deep. Nearby land was formerly farm land but hasn't been farmed for at least two years. Soil sample collected 50 feet from well in fresh road cut.

W-13—Well with pump in "Danburg granite." Well is 4 feet in diameter and 72 feet deep. Property owned by Mr. Cox. Soil sample collected 8 feet from well. No outcrops nearby. Well has cement casing.

W-14—Open well on property of Columbus Johnson. Well is approximately 35 feet deep. A short distance south of the well the rock type is a fine-grained quartz-feldspar rock with a small amount of mica. Float of a schistose rock with fairly coarse grains of quartz is found about 20 feet from the well. Also float of a non-schistose rock with coarse grains of quartz are found near well. Soil sample from well. Well has cement casing.

W-16—Drilled well 132 feet deep at Mr. Andrew's store. A section of core from the well is a dark-gray, quartz-feldspar-epidote-biotite rock somewhat similar to that from W-10. Some course, blue quartz is present and biotite is fairly abundant. The float is similar to the core sample, and the quartz in the soil suggests that all rock in the vicinity of the well is the same as the core sample. Float samples were collected 120 feet east of the well and soil samples are from a nearby road cut.


GEOLOGIC MAP
OF A PORTION OF THE
BROAD QUADRANGLE,
GEORGIA
LEGEND
Syenite
Porphyritic Granite
Granite Gneiss
Chlorite Schist
Amphibolite
Fine-Grained Gneiss
Sericite Schist
Metadacite
Boulders Not Necessarily in Place
Silicified Shear Zones
Sample Locations
Strike and Dip of Foliation
Approximate Contacts
BASE MAP U.S.G.S.
BROAD, GA.
N3352.5—W8237.5/7.5
1955
GEORGIA
QUADRANGLE LOCATION
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1955
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL
SCALE
1 MILE
ROAD CLASSIFICATION
Heavy-duty
Light-duty
Medium-duty
Unimproved dirt
U.S. Route
State Route
BROAD RIVER
ELBERT CO
WILKES CO
CLARK HILL RESERVOIR
Broad
Chapel
Creek