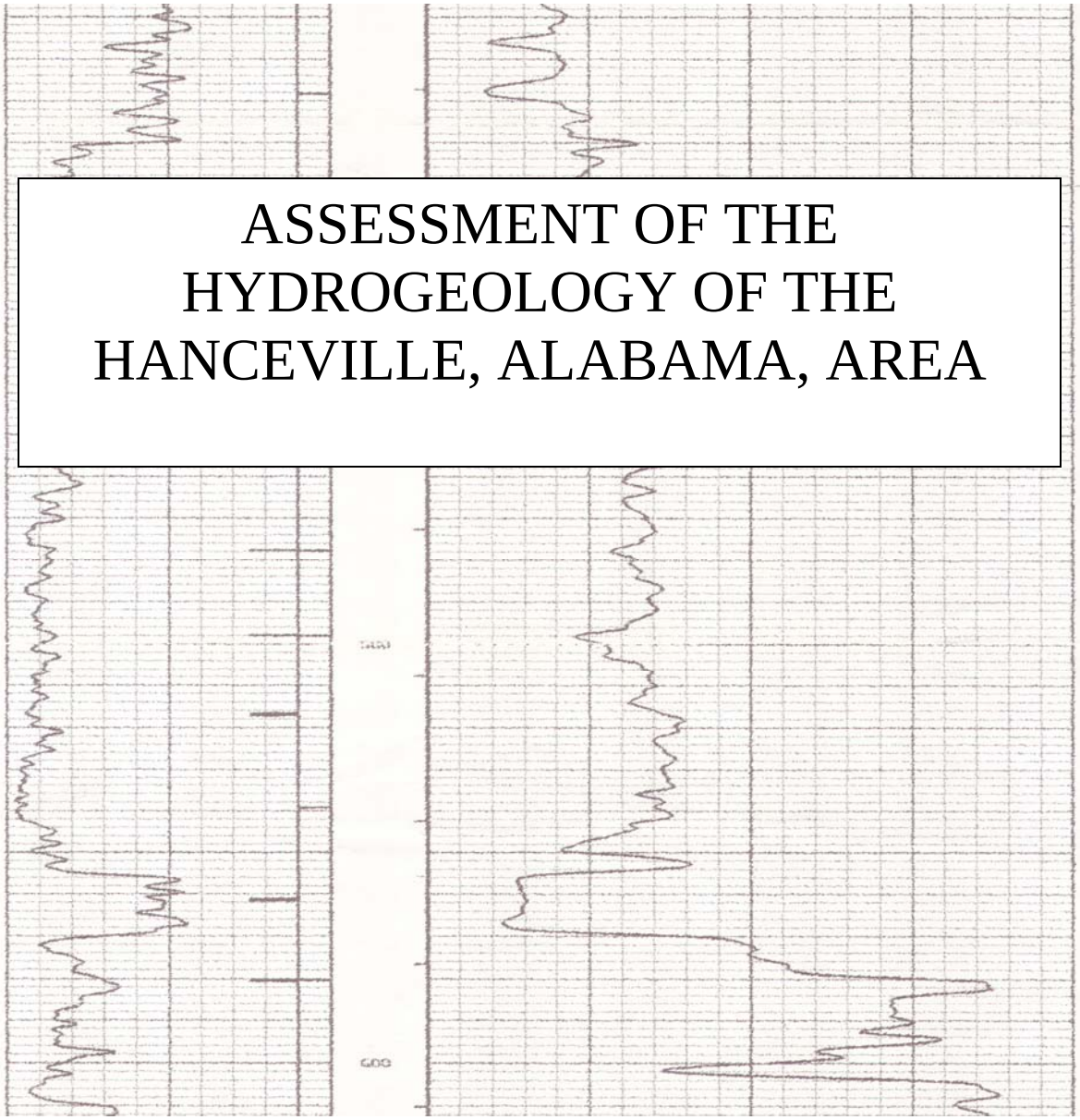
ASSESSMENT OF THE HYDROGEOLOGY OF THE HANCEVILLE, ALABAMA, AREA



GEOLOGICAL SURVEY OF ALABAMA

Berry H. Tew, Jr.
State Geologist

ASSESSMENT OF THE HYDROGEOLOGY OF THE HANCEVILLE, ALABAMA, AREA

A REPORT TO THE

HANCEVILLE WATER WORKS AND SEWER BOARD

OPEN FILE REPORT 1001

By
Stephen P. Jennings
and
Marlon R. Cook

Submitted in partial fulfillment of a contract with the
Hanceville Water Works and Sewer Board

Tuscaloosa, Alabama
2010

CONTENTS

	Page
Introduction	1
Project area	1
Hydrogeology	3
General physiographic and geologic setting	3
Hydrogeologic data from the No. 1 Whaley test well	3
General well history and significance	3
Pump tests	5
Data acquired in 2008 and interpretation of results	7
Interpreted fracture traces in the Pottsville Formation	13
Geochemistry	17
Water samples collected and analyzed	17
Chemical and physical water characteristics	18
Chemical constituents	21
Water age dating	23
Conclusions and recommendations	25
References cited	27

ILLUSTRATIONS

PLATES

(in pocket)

Plate
1. Geologic map of the Hanceville and surrounding area
2. Geologic cross section A-A'
3. Geophysical well logs of the No. 1 Whaley test well
4. Interpreted fracture trace map

FIGURES

Figure	1. Index map showing the Hanceville Water Works and Sewer Board project area	2
	2. Physiographic provinces, geology, and Hanceville Water Works and Sewer Board project area	4
	3. The No. 1 Whaley well, August 21, 2007	6
	4. Temperature gradient, average per 5- foot interval, No. 1 Whaley well	11
	5. Temperature gradient for the interval 240 to 445 feet, No. 1 Whaley well	11
	6. Temperature gradient for the interval 446 to 554 feet, No. 1 Whaley well	12
	7. Temperature gradient for the interval 554 to 1,164 feet, No. 1 Whaley well	12
	8. Fracture azimuth data in the northeast and southeast quadrants	15
	9. Fracture azimuth data in the southwest and northwest quadrants	16

10. Fracture azimuth data for all quadrants 17
11. Piper plot showing water types from samples collected from selected wells in the Hanceville area 20

TABLES

Table 1. Classification of water hardness..... 22
2. Inorganic primary and secondary drinking water constituents and standards and concentrations in water samples collected from selected wells in the Hanceville area 24

ASSESSMENT OF THE HYDROGEOLOGY OF THE HANCEVILLE, ALABAMA, AREA

By

Stephen P. Jennings and Marlon R. Cook

INTRODUCTION

In September 2007, the Geological Survey of Alabama (GSA) was requested by the Hanceville Water Works and Sewer Board to evaluate the potential for development of additional public water supplies to supplement the groundwater currently provided to the city by one well. To that end and by mutual agreement and contract with the Hanceville Water Works and Sewer Board, the staff of the Hydrogeology Section of GSA provided a hydrogeologic assessment of the area comprising the city and surrounding area. In addition, GSA staff were asked to provide assistance in evaluating the feasibility of utilizing as a water supply well an existing oil and gas test hole (No. 1 Whaley well) located about 1.5 miles southwest of town. This test hole was drilled in the 1920s and was subsequently plugged and abandoned, but reportedly flowed fresh water. This report is a summary of the data collected and analyzed and presents interpretations of hydrogeological and geochemical characteristics of the area. Furthermore, it contains a summary of an evaluation of data collected from the No. 1 Whaley test well during the course of this investigation.

PROJECT AREA

The project area includes the service area of the Hanceville Water Works and Sewer Board and surrounding areas (fig. 1). Analysis of data for the project extends beyond the immediate area served by Hanceville in order to adequately evaluate the service area within the context of the geologic, hydrologic, and geochemical setting and to provide a more comprehensive study. Data from surrounding wells and geologic outcrops are significant in the assessment process and important in making recommendations concerning the development of additional groundwater sources.

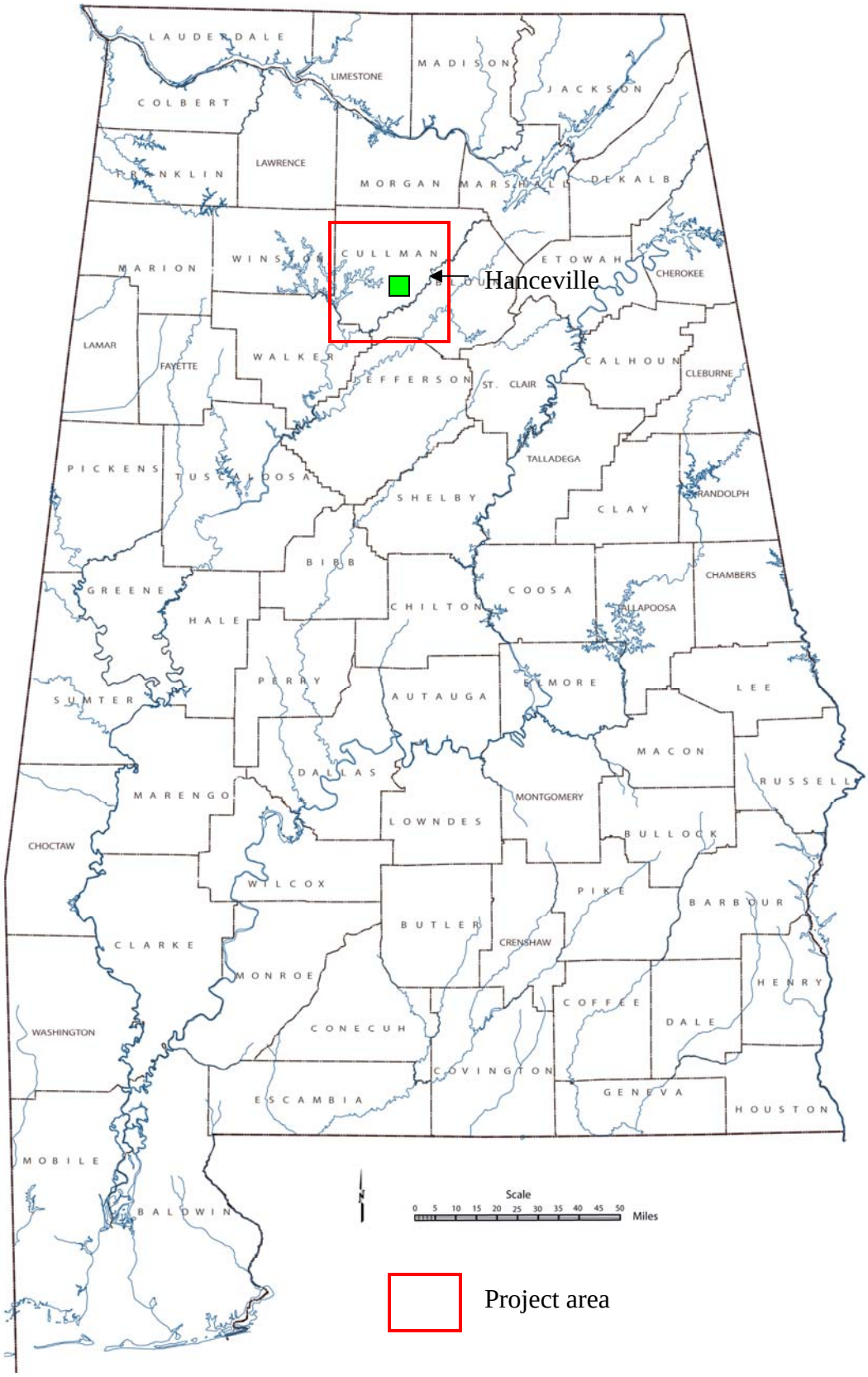


Figure 1.—Index map showing the Hanceville Water Works and Sewer Board project

HYDROGEOLOGY

GENERAL PHYSIOGRAPHIC AND GEOLOGIC SETTING

The project area lies in the Appalachian Plateaus Province (fig. 2), a region of generally low topographical relief and relatively flat-lying rocks. The area is bounded on the southeast by the Sequatchie anticline, a feature marked by greater topographic relief (ridges and valleys) and rocks that are more steeply dipping (bedding inclined from horizontal) due to folding and faulting. Rocks of Pennsylvanian age predominate in the Appalachian Plateau in Cullman County, whereas older rocks are exposed in the Sequatchie anticline area (see plate 1 for a stratigraphic column of rock units underlying the project area). Strata in the Appalachian Plateau dip to the south-southwest at rates of about 40 to 60 feet per mile (plates 1 and 2) (see also Thomas, 1974, plate 8). Rocks of the Pennsylvanian-aged Pottsville Formation outcrop in most of Cullman County (plate 1), and the formation is subdivided into upper and lower parts (Osborne and others, 1988). Sandstone, shale, and coal beds of the lower Pottsville occur to a general depth of about 600 feet in the Hanceville area. The Pottsville Formation contains the major aquifers utilized in Cullman County; one such interval is the aquifer for the municipal water supply well at Hanceville.

HYDROGEOLOGIC DATA FROM THE NO. 1 WHALEY TEST WELL

GENERAL WELL HISTORY AND SIGNIFICANCE

The No. 1 Whaley well (OGB B250, API 01-043-01001-00-00) afforded an opportunity to obtain hydrogeological information about the project area as well as to aid Hanceville in the evaluation of the well's potential as a possible groundwater supply source. The data and discussion presented here are not intended to supplant an engineering analysis of the mechanical aspects or potential production capacity of the well, but are intended to aid the Hanceville Water Works and Sewer Board and others in analyzing existing data concerning the well and to document and interpret hydrogeological characteristics of the potential aquifers penetrated by the well.

The No. 1 Whaley test well was drilled by Manistee Oil and Gas Company in the early 1900s by the cable-tool (percussion) method to a total depth of 2,850 feet below land surface, penetrating the stratigraphic section from the Pottsville Formation to the

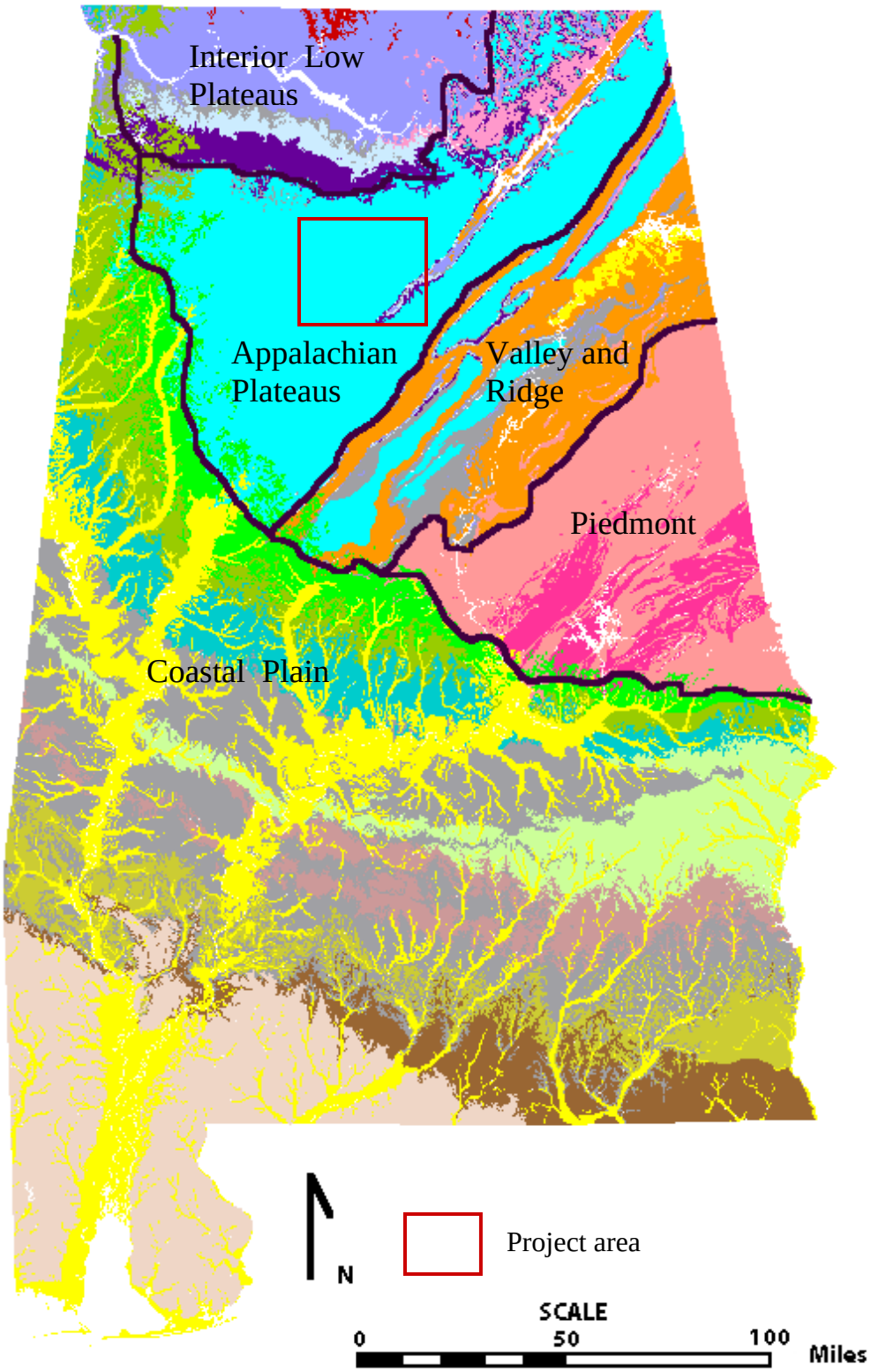


Figure 2.—Physiographic provinces, geology, and Hanceville Water Works and Sewer Board project area. For explanation of geologic units statewide, see GSA (2006). For geologic units in project area, see plate 1.

upper part of the Knox Group (Ordovician) (Semmes, 1929). The well was reportedly cased to a depth of 80 feet with 10-inch diameter steel casing, and 8.25-inch steel casing was set to a depth of 585 feet. The test well was likely plugged and abandoned in 1922 by means of pushing cedar logs into the well bore at several depth intervals. No well cuttings or detailed driller's log is known to exist from the well, and geophysical logging methods had not been introduced until 1927. A brief log of the depths and thicknesses of the geological formations penetrated was presented by Semmes (1929, p.76). Correspondence was sent to Dr. Eugene A. Smith, who was Alabama State Geologist at that time, from drillers and others exploring for petroleum in the region regarding exploration efforts and prospects. Correspondence from the State of Alabama Oil and Gas Board files indicates that at least as long ago as 1901 there were poorly-documented reports of fresh groundwater in central and southern Cullman County at depths ranging from 719 feet to perhaps as deep as 2,400 feet. Despite the lack of information concerning the source of the groundwater, the No.1 Whaley well has been utilized intermittently for years by the owners as a small-scale supply of fresh water for watering livestock (fig. 3). This fact, along with the belief by local citizens that a significant aquifer had been cased off long ago by the petroleum exploration company, indicated to the Hanceville Water Works and Sewer Board that investigation of the No. 1 Whaley well as a possible public water supply source was warranted.

PUMP TESTS

On August 21, 2007, the authors conducted a pump test of the No. 1 Whaley well, using a small capacity pump in order to ascertain basic information about the well and to obtain water samples. The well was sounded and found to be plugged at a depth of approximately 157 feet, but neither the nature of the plugging material nor the integrity of the plug could be determined. From the static water level of 7.23 feet below land surface, the pump test resulted in 21.04 feet of drawdown in 116 minutes of pumping at rates ranging from 5.5 gallons per minute (gpm) to 8.6 gpm. Although these results were not encouraging indications of a significant water source, the low production capacity of the pump coupled with the lack of data concerning the aquifer intervals and the integrity of the casing and plugs prevented an evaluation of the well as a viable water source. For comparison, the amount of water stored in 585 feet of 8.25-inch diameter casing (the

Figure 3.—The No. 1 Whaley well, August 21, 2007.

reported depth of casing in the well) is approximately 1,625 gallons, whereas less than 1,000 gallons of water was pumped from the well during the test. However, holes likely resulting from corrosion were found in the casing, and casing was entirely missing in some intervals, information unknown at the time of the August 21, 2007, pump test.

Another pump test was conducted and water sample collected on July 29, 2008, following drilling out of the plugs and opening the hole to a total depth of 1,164 feet. The purposes of this test were to compare the results to those of the pump test conducted August 2007 and to collect another water sample. The well was drawn down a total of 42.4 feet in 100 minutes of pumping in two steps of 2.29 gpm and 5.6 gpm from a static water level of 4.82 feet below land surface. During the second pump test a small amount of water was observed entering through an opening in the casing about 18 feet below land surface, indicating a lack of integrity in the surface casing and the likelihood of groundwater contribution to the wellbore from more than one interval.

DATA ACQUIRED IN 2008 AND INTERPRETATION OF RESULTS

In 2008, the Hanceville Water Works and Sewer Board contracted with Layne Christensen Company, Pensacola, Florida, to drill out the plug(s) in the No. 1 Whaley well and examine the casing with a down-hole video camera. The video run by Layne on April 22, 2008, prior to the commencement of drilling operations, revealed a plug at approximately 159 feet below land surface and other debris (pieces of steel reinforcing bar and garden hose). More importantly, steel casing, though showing evidence of corrosion, was seen to be in place to a depth of approximately 83.5 feet, but from 83.5 feet to 159 feet was open hole (uncased), with visible rock and bedding planes. It is likely that the casing in that interval had dislodged from its original position and had fallen into the borehole, probably in a piecemeal manner, during the 86-year time interval from being set in 1922 until 2008. The rock in the open-hole interval appears to be sandstone, consistent with the interpretation of the occurrence of the Pottsville Formation at that depth (Thomas, 1974). Layne Christensen Company drilled and milled out the plugs and debris in April and May 2008, reaching a depth of about 2,000 feet before ceasing operations. Layne then re-entered the hole with a downhole video camera on June 5, 2008, but the camera could only reach a total depth of approximately 1,172.8 feet due to an undetermined obstruction. The base of surface casing was approximately 83.5 feet as seen in the video taken April 22, 2008, and from that depth to approximately 180 feet was open hole. Partially cased hole was seen in the interval 172.8 to 173.8 feet, supporting the earlier hypothesis that the interval from 83.5 to 180 feet was once cased but the casing had collapsed and fallen deeper into the well. From 180 feet to 581.1 feet

the borehole was cased, but the casing appeared to be significantly corroded and pitted in numerous intervals. The borehole was uncased from 581.1 feet to 1,172.8 feet as recorded in the video. Because the primary purpose of the camera was to obtain a visual record of obstructions and the structural integrity of the casing and borehole, the portions of the well in which geological features were visible is very limited (the camera was aimed downward rather than at the borehole wall for most of the interval below 581.1 feet).

Wireline geophysical logs were run on June 30, 2008, by Enviro-Log, Inc., Piedmont, Oklahoma, with the logger reaching a total depth of 1,164 feet. The geophysical logs included both open-hole logging tools and devices capable of making both open-hole measurements and measurements through steel casing, using natural gamma radiation and neutron devices as well as a casing collar locator (G-N-CCL log) (plate 3). The purposes of acquiring the geophysical logs were to obtain petrophysical data to assist in evaluation of possible aquifer intervals and to obtain data about the location and mechanical integrity of the casing. Missing casing collars shown by the CCL log are generally consistent with the intervals of corroded and pitted casing seen in the video record, indicating that the casing may be very thin so as not to have been recorded by the magnetic CCL device. There is an approximate 1-foot depth discrepancy between the log depths of the G-N-CCL log and the depths of casing threads visible on the video record, likely due to a difference in datum zero depth setting by the operators and/or possible cable stretch differences. Open-hole logs included the spontaneous potential, resistivity (16-inch “short” and 64-inch “long” normals), and induction. A borehole temperature log was also run from ground surface to total depth, showing a general increase in temperature below about 200 feet. Geological formations (stratigraphy) in the No. 1 Whaley well, determined by lithologic interpretation of the logs and correlation with logs from other wells in the area (plates 1 and 2) and using depths below ground level shown on the G-N-CCL log, are as follows: lower Pottsville Formation, near ground surface to 554 feet; Parkwood-Pennington formations or equivalent, 554 feet to 580 feet; Bangor Limestone, 580 feet to 996 feet; Hartselle Sandstone, 996 feet to 1,132 feet; Pride Mountain Formation, 1,132 feet to 1,164 feet (base of Pride Mountain not reached) (plate 3).

The neutron log is largely a measure of hydrogen content, with higher hydrogen contents shown as lower API neutron counts, commonly interpreted as indicating intervals containing hydrocarbons (petroleum) or water. Thus, by inference, the neutron log is a measure of the volume of fluid-filled pore space (porosity) and is especially useful if the neutron counts can be calibrated with measured porosity from rock core samples from the well or other means. Though a more precise and accurate calibration of the neutron log was unavailable for rock porosity determination due to the lack of core porosity data and/or other geophysical logs used to estimate porosity, an accepted method (Frank, 1988) of making generalized porosity estimates was utilized by the authors. The method assumes an overall maximum porosity of 50%, a maximum shale porosity value of 40%, and an overall minimum porosity value of 1%. It should be noted that none of the geophysical logs run in the well are capable of measuring permeability or accurately evaluating related features such as fractures, joints, bedding plane solution channels, cavities, or faults.

High resistivity measurements coupled with low natural gamma measurements in limestone intervals of the Bangor Limestone and in sandstone intervals in the Hartselle Sandstone formations are likely the result of low porosity as shown by the neutron log. However, there are several relatively thin intervals in the Bangor Limestone that exhibit somewhat increased indications of water. These depth intervals (in feet) are 644 to 647; 702 to 704; 727 to 729; 734 to 740; 759 to 763; 780 to 787 feet; 803 to 813; and 818 to 820 (plate 3). Porosity determinations from the neutron log for these intervals are below 7%, except for the interval 644 to 647 feet which indicates porosity of about 20%. Resistivity measurements from the logs are greater than or equal to 50 ohm-meters in each of the above-listed zones, suggesting the possible presence of relatively fresh groundwater, but these relatively high measurements may also result from the generally low porosities exhibited. In the interval from 923 to 928 feet, porosity of up to 35% is shown, but the very low resistivity measurements indicate that formation water probably contains excessive chloride.

The temperature log is a record of geological formation temperatures and their contained fluids as well as the fluid in the well bore. Temperature anomalies in well bores have been associated with intervals of groundwater flow. Effects of the casing on the

temperature measurements in the No. 1 Whaley are not known due to the casing's degraded condition; temperature data from intervals cased with continuous, structurally sound casing ordinarily would be disregarded for anomaly detection. Although the temperatures shown on the log are lower than might be expected from the depths measured, some interesting, though not altogether well understood, trends can be observed. Not unexpected is an overall decrease in temperature from ground level to about 200 feet and an overall increase downward below that depth (plate 3). The rate of increase in temperature is not constant, however, with a subtle "flattening" of the trend in the interval from about 450 feet to approximately 530 feet. Below about 530 feet the temperature increases at a greater rate. These visual observations of the log can be better quantified through analysis of the rates of change of the temperature with depth, i.e. plotting the temperature gradients versus depth. The gradients, or first derivatives, calculated for 5-foot increments for the entire temperature log, are shown in figure 4, with negative gradients (temperature decreases) at the shallower depths and generally positive gradients (temperature increases) below about 200 feet. Disregarding the shallow depth data and analysis, data from the portion of the hole below 240 feet were analyzed and related to the stratigraphy. The average temperature gradient in the interval from 240 feet to 445 feet of the Pottsville Formation is approximately 0.0054 degrees per 5 feet (deg/5ft) (fig. 5). The interval from 446 to 554 feet, the lowermost Pottsville Formation, has an average gradient of 0.0039 deg/5ft (fig. 6). The temperature data from 554 to 1160 feet, the interval that includes the Parkwood-Pennington Formations, the Bangor Limestone, the Hartselle Sandstone, and the upper part of Pride Mountain Formation, shows an average gradient of 0.0077 deg/5ft (fig. 7), a rate of change nearly twice that in the interval from 446 to 554 feet. The temperature trends shown in the log are not unequivocal indications of groundwater flow from a particular interval or zone, but they do suggest, along with the other data and the video record, that groundwater may be entering the well bore from numerous, possibly small conduits of flow, such as bedding planes, and through various leaks in the casing. Moreover, because the casing was likely originally set without modern cementing methods designed to seal off and protect fresh-water aquifers, groundwater may move vertically within the annular space (between casing and rock).

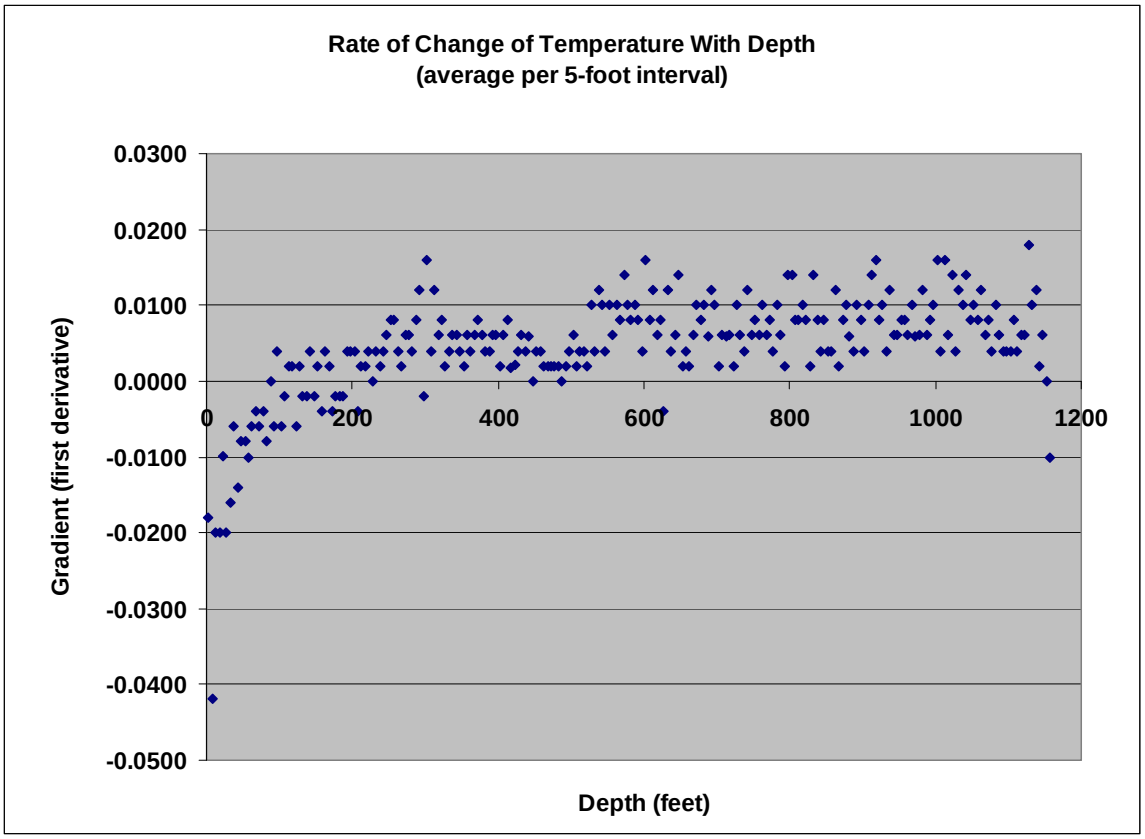


Figure 4.—Temperature gradient, average per 5-foot interval, No. 1 Whaley well.

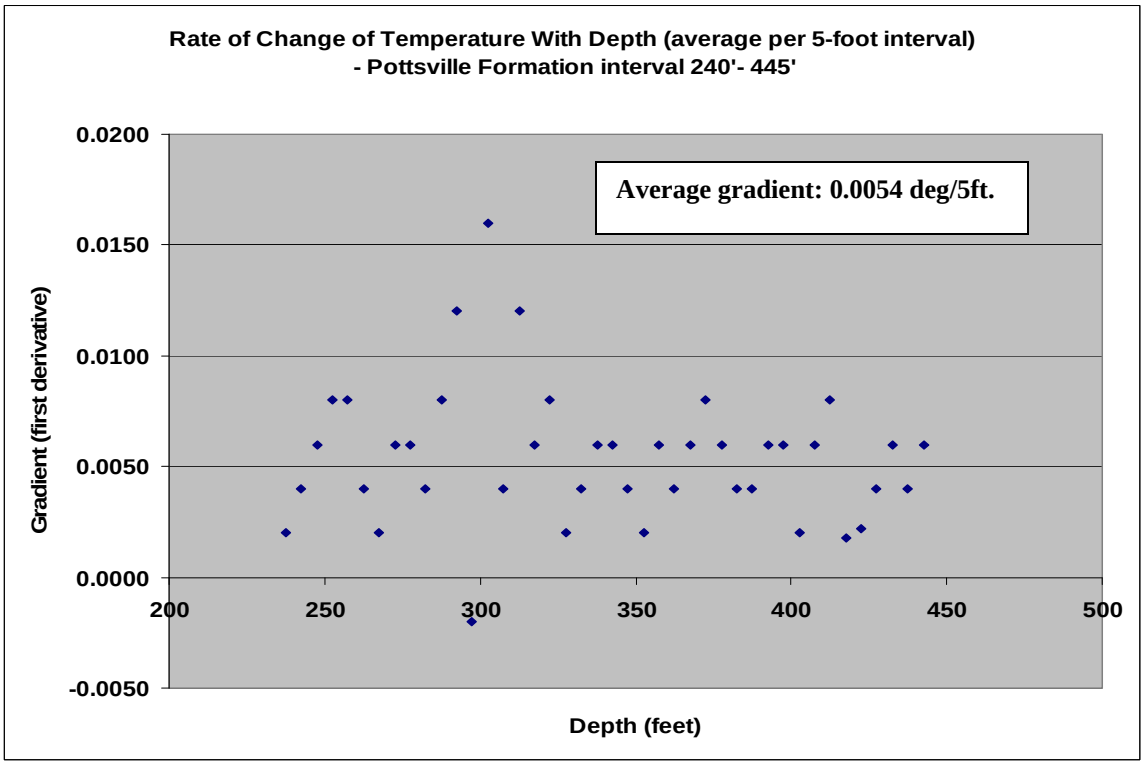


Figure 5.—Temperature gradient for the interval 240 to 445 feet, No. 1 Whaley well.

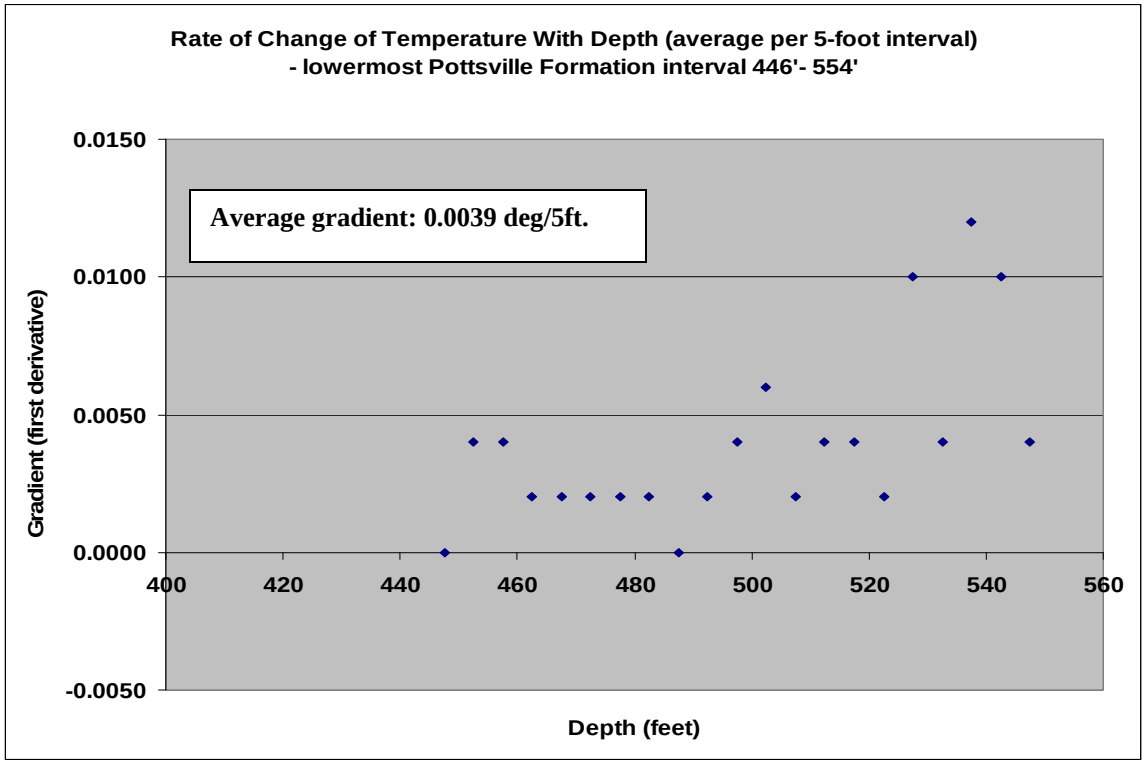


Figure 6.—Temperature gradient for the interval 446 to 554 feet, No. 1 Whaley well.

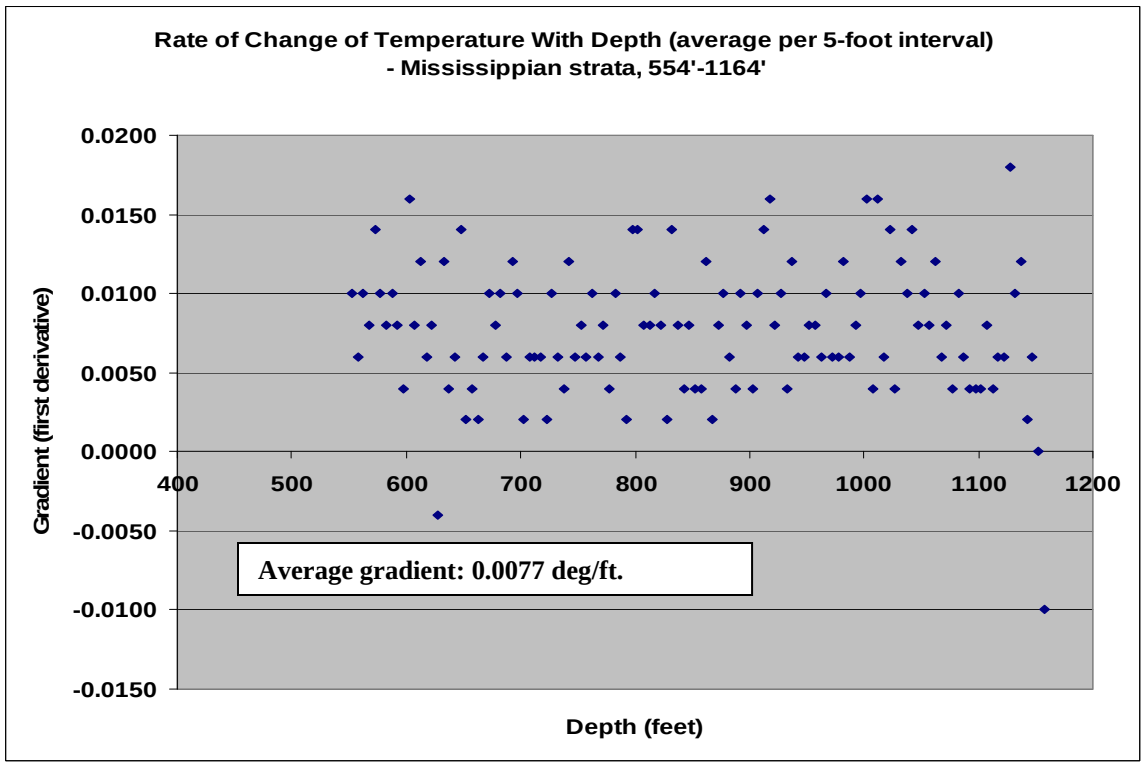


Figure 7.—Temperature gradient for the interval 554 to 1,164 feet, No. 1 Whaley well.

The interval of greatest interest to the authors in the No. 1 Whaley well as a possible groundwater source is in the lowermost Pottsville Formation from 446 feet to 554 feet. The overall slight increase in natural gamma response from the lowest response at 540 feet upward to 446 feet is likely indicative of a fining-upward stratigraphic sequence of sandstone as can be seen elsewhere in outcrops of lower Pottsville Formation conglomeratic sandstones that fine upward to fine-grained sandstones. This interval is behind casing and therefore not visible in the video record in the No. 1 Whaley well. In addition, the neutron log porosity calibration is likely altered somewhat from the open-hole portion of the well, as discussed above for the Bangor Limestone and underlying formations. Porosity in the interval from 446 to 554 feet ranges from about 10% to about 21%, with an average of about 12%. The temperature log data for this interval, as discussed previously, suggests a subtle, but measurable temperature anomaly at the approximate depths of the sandstone. This approximately 100-foot-thick interval of largely continuous sandstone may have significant storage capacity for water compared to other sandstone intervals in the Pottsville Formation and, if bedding plane conduits or fractures exist, may be capable of transmitting significant quantities of water to a properly constructed well.

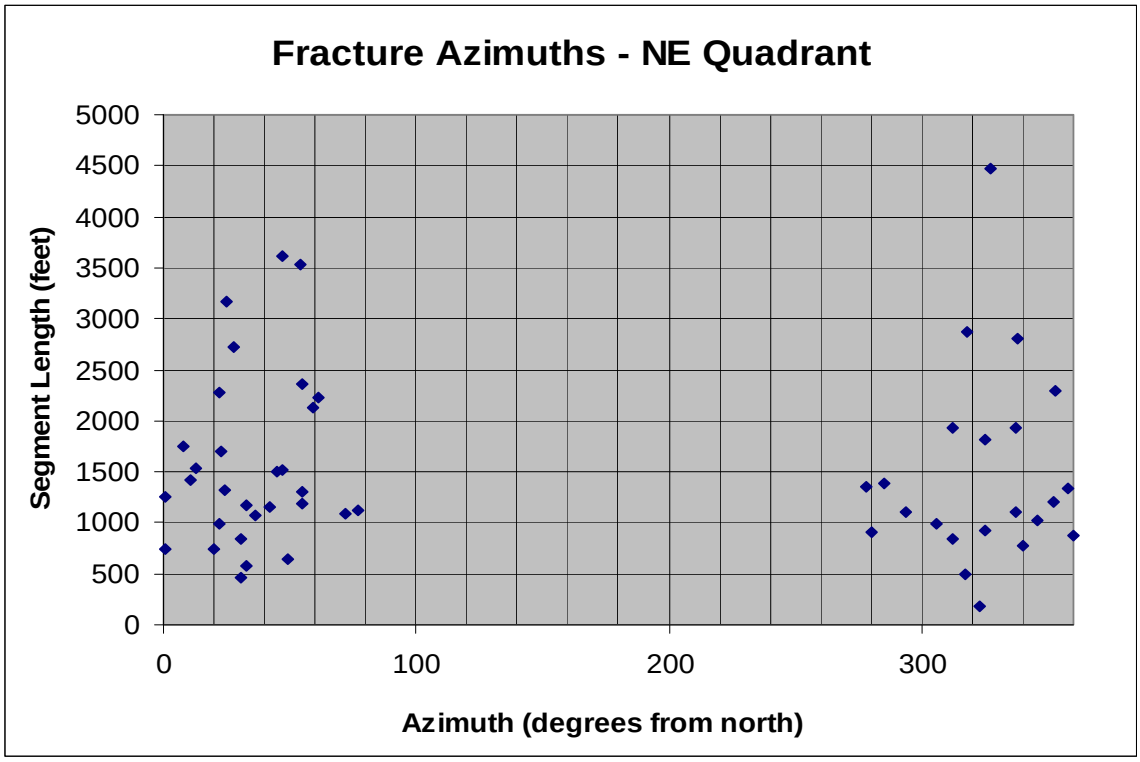
Correlation of the basal Pottsville Formation sandstone with other available well logs in Cullman County indicates the interval in the No. 1 Whaley well is a thicker, more contiguous unit than elsewhere. Plate 2 illustrates the correlation with the Geomet, Inc., Montgomery 6-7-4 (OGB 15481) petroleum test well drilled in 2007 to a depth of 1,998 feet. A suite of geophysical logs was run in the open-hole portion of the Montgomery 6-7-4 well that includes the lower Pottsville Formation. The correlative basal Pottsville interval in the Montgomery well also exhibits a generally fining-upward sequence, but it contains several shale intervals. It is not a continuous sandstone interval as in the No. 1 Whaley well and therefore, not as prospective as a potential aquifer.

INTERPRETED FRACTURE TRACES IN THE POTTSVILLE FORMATION

The Hanceville area was also examined for evidence of fractures and joints in the Pottsville Formation as seen or interpreted from outcrops and geomorphic data. Discontinuities such as joints, fractures, and faults are indicators of stress applied to rocks and can be useful in delineating possible groundwater flow pathways. The geologic

history of the region includes the major compressive tectonic event which formed the Sequatchie anticline, and it is likely that some of the energy expended during this major continental-scale event was transmitted to the rocks in the project area. Joints and fractures can be seen in outcrops of the lower Pottsville Formation along Mulberry Fork east of Hanceville. The drainage patterns of the channels of Mulberry Fork, Broglen River, Duck River, and several smaller incised streams strongly suggest considerable control by fractures and joints in the Pottsville Formation through which they flow. In addition, linearity of ridges and other geomorphic features in the area may also be fracture-controlled. The general lack of well control or other geological or geophysical data precludes interpretation of faults in the area, but fractures and joints are likely important contributors to groundwater flow through the Pottsville Formation and possibly in underlying formations as well.

Fracture (and/or joint) traces examined and interpreted from outcrops along a portion of Mulberry Fork, topographic maps, and high altitude aerial photography are shown in plate 4. To better quantify the fracture trace interpretations, the area was subdivided into four quadrants (plate 4) in order to examine possible geographic variation. Fracture azimuth (bearing from north) and length for each trace were measured, tabulated, and plotted graphically (figs. 8-10). Fracture trace length was used as a means of weighting the significance of each possible fracture, with longer traces considered more important. The data indicate two general azimuths, about 25-30 degrees from north (a northeasterly direction) and about 315-330 degrees from north (a northwesterly direction). The southwest and southeast quadrants appear to show less variation in azimuths, especially in the northwesterly azimuths. The northeast quadrant exhibits the greatest variation in azimuths, possibly the result of the greater number of fracture traces plotted there. However, the larger number of traces in the northeast quadrant may also indicate a positive relationship with the proximity to the Sequatchie anticline or some other yet unknown aspect of that structure. Fracture trace length variation is about equal in all quadrants, except for more uniform northwesterly-bearing fracture traces of the southeast quadrant. Based upon these data and interpretations, there is an increased likelihood of encountering fractures or joints in the Pottsville Formation in wells drilled



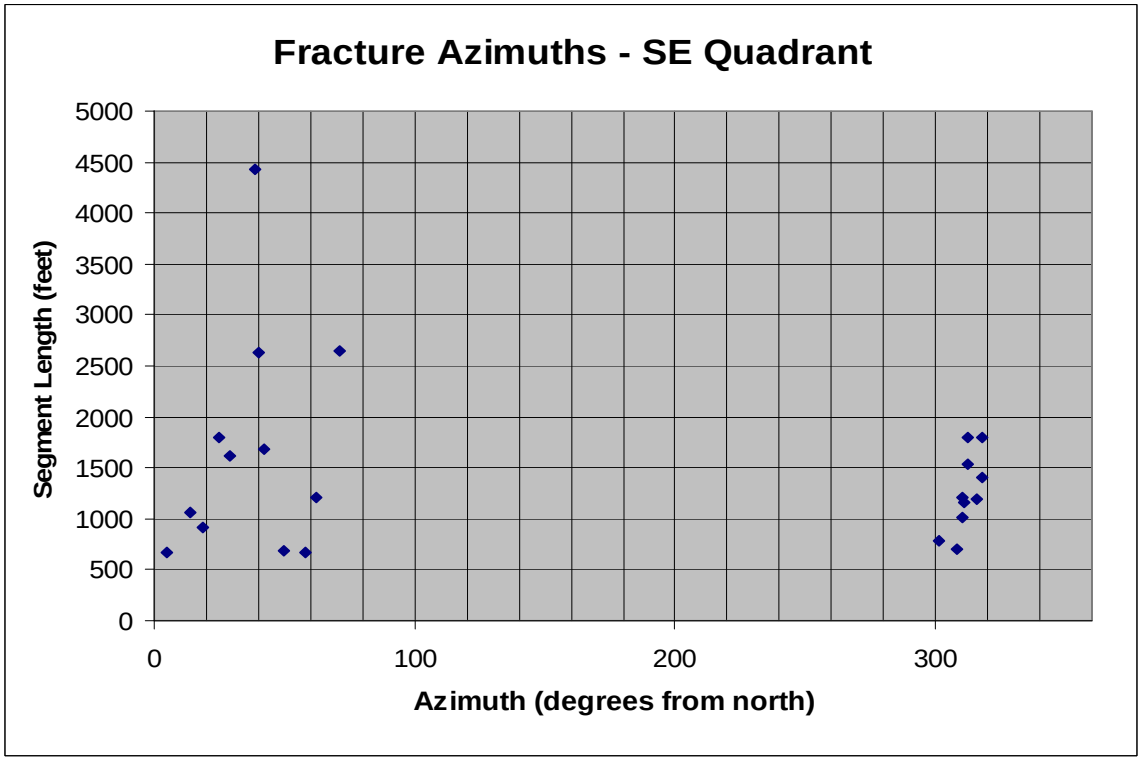
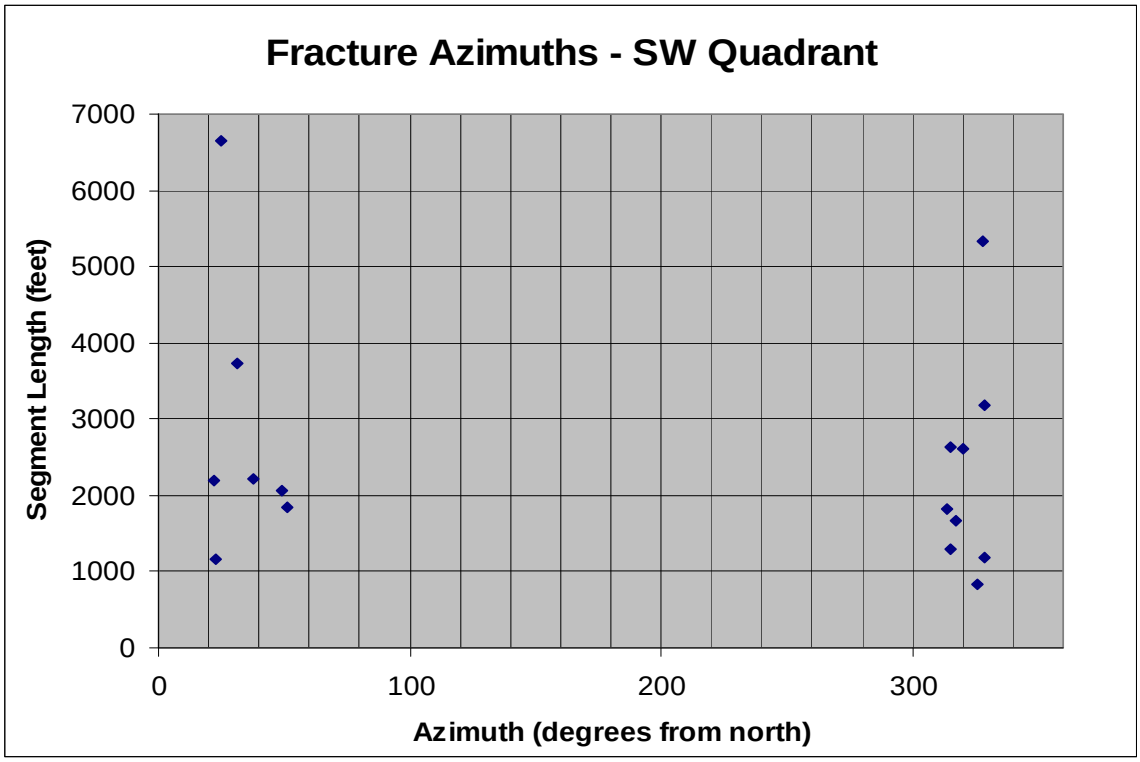


Figure 8.—Fracture azimuth data in the northeast and southeast quadrants (see plate 4).



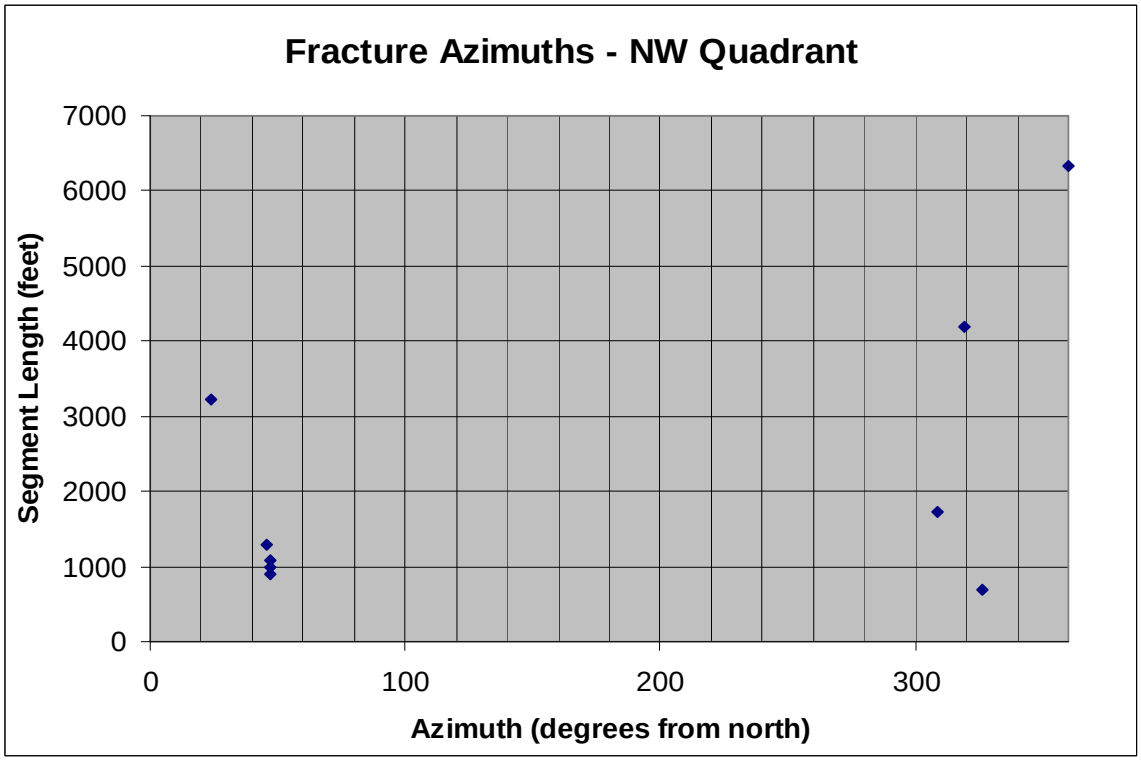


Figure 9.—Fracture azimuth data in the southwest and northwest quadrants (see plate 4).

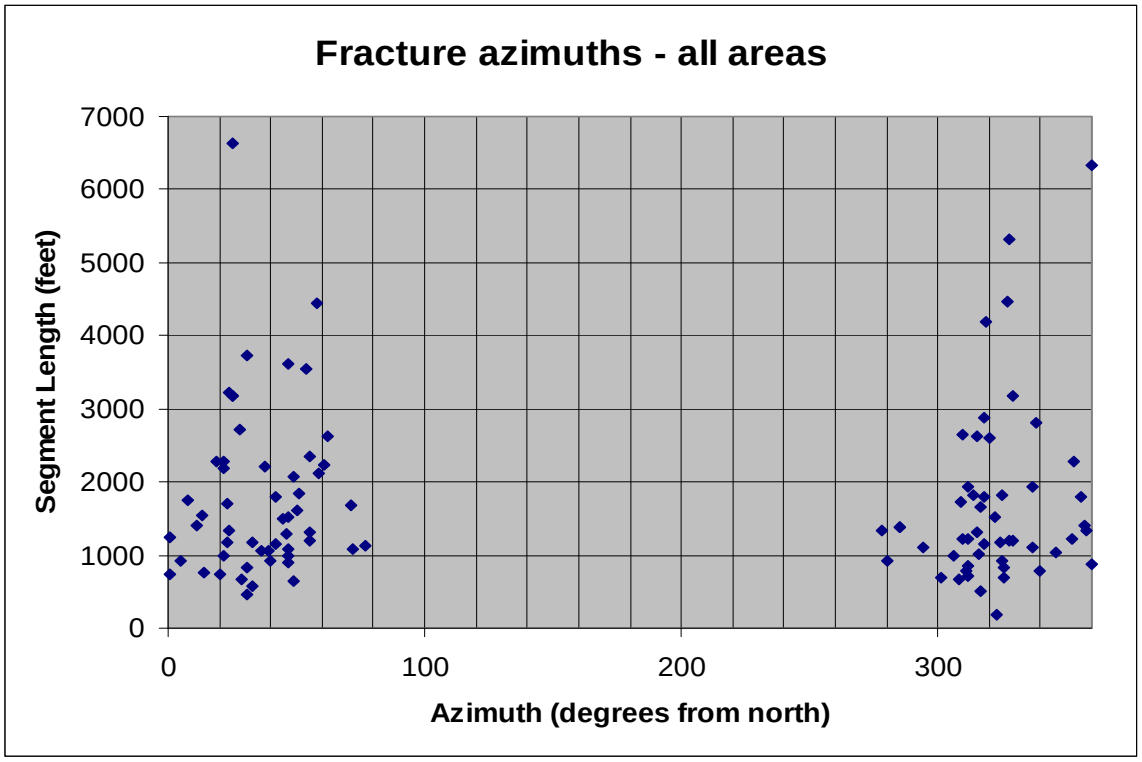


Figure 10.—Fracture azimuth data for all quadrants (see plate 4).

in the northeast quadrant or the northern part of the southeast quadrant in close proximity to fracture traces (plate 4).

GEOCHEMISTRY

WATER SAMPLES COLLECTED AND ANALYZED

In order to evaluate groundwater quality in the Hanceville area, water samples were collected from three wells constructed at varying depths. Two water samples (designated HW-1) were collected from the No. 1 Whaley well (plate 4), one on March 11, 2008, prior to removal of plugs and obstructions in the well (well open to a depth of 157 feet) and one on August 21, 2008, after plugs and obstructions were removed (well open to a depth of 1,164 feet). The Pennington and Parkwood Formations, Bangor Limestone, Hartselle Sandstone, and the uppermost part of the Pride Mountain Formation are exposed in the well and much of the Pottsville Formation is behind casing. However, as discussed previously, the casing is not intact and allows water from the Pottsville Formation to enter the well.

A water sample (designated HW-2) was collected from the Hanceville Water Works

and Sewer Board well (plate 4) at the water treatment plant near downtown Hanceville. This well was constructed to a depth of 170 feet in the Pottsville Sandstone and serves as the primary source of public water supply for the town of Hanceville.

A sample was collected from the Geomet, Inc., Montgomery 6-7-4 well (OGB 15481) near Dodge City (plate 4), about 10 miles southwest from Hanceville. This well was drilled as a gas test well to a total depth of 1,998 feet and completed in the Chattanooga Shale.

CHEMICAL AND PHYSICAL WATER CHARACTERISTICS

Water samples described above were analyzed for a comprehensive group of physical properties, inorganic metallic and nonmetallic constituents, and a limited group of organic constituents (table 2). Samples were also age dated using the Carbon-14 age dating method.

More than 90 percent of the dissolved solids in groundwater can be attributed to eight ions: sodium, calcium, potassium, magnesium, sulfate, chloride, bicarbonate, and carbonate (Fetter, 2001). These ions are divided into cations (ions with a positive electrical charge) and anions (ions with a negative electrical charge). The quantity of major cations and anions determines water types, which are used to characterize groundwater quality in specified areas. The primary cations in the water from the Paleozoic aquifers in Cullman County are sodium and calcium. Sodium primarily originates from downgradient movement of water through sedimentary rocks that compose the aquifers. Dissolution of calcareous material (primarily calcite, $CaCO_3$) by movement of fresh water through the aquifer causes increased concentrations of carbonate and calcium in the groundwater. Ionic exchange between sodium and calcium ions results in release of sodium ions into the water resulting in increased concentrations of sodium ions and decreased concentrations of soluble calcium ions. Reduction of calcium ions causes continued dissolution of calcite, resulting in releases of additional sodium ions in the groundwater so that large concentrations of sodium generally are present in the deep aquifers, where optimum conditions for ionic exchange exist. This was evident in the Piper Plot (fig. 11) of samples collected during this investigation, where calcium is the dominant cation in sample HW-2 from the relatively shallow

Hanceville Water and Sewer Board well, and sodium is the dominant cation in samples HW-1 and HW-3 collected from the relatively deep No. 1 Whaley and Montgomery wells, respectively.

The primary anions that compose the chemical facies of water samples collected from Paleozoic aquifers in this study are bicarbonate, sulfate, and chloride. Bicarbonate facies generally are distributed along the upgradient portion of coastal plain aquifers or shallow Paleozoic aquifers. High concentrations of bicarbonate are caused primarily by dissolution of calcareous material, which releases carbonate and calcium into the ground-water. Ionic exchange between the sodium and calcium ions prevents these ions from reaching equilibrium, which promotes the process of dissolution and increases concentrations of bicarbonate (Back, 1966).

Sulfate is commonly found in waters from the Pottsville Formation and probably originates from organics, including coal, that are in contact with water moving through the formation.

Chloride is the most abundant of all halogen elements; however, concentrations in precipitation and shallow groundwater generally are low due to the nonreactive chemical characteristics of chloride ions relative to other major ions. The circulation of chloride ions in the hydrologic cycle is primarily accomplished by physical processes. These processes include leaching, transport, and concentration of soluble salts by movement of water in the deep subsurface over long periods of time; retention of selected ions by filtering effects of fine-grained sediments on connate waters; and transfer of water with high concentrations of soluble salts from deep, water-bearing zones into shallow aquifers along open fracture and fault zones (Hem, 1985).

Results of chemical analyses of samples collected during this investigation indicate that chloride concentrations generally increase with depth. As water moves through the subsurface over long periods of time, soluble salts, including chlorides, are leached from adjacent sediments and are transported to greater depth. Sample HW-2 collected from the shallowest well had a chloride concentration of 6.4 milligrams per liter (mg/L) and sample HW-3 collected from the deepest well had a chloride concentration of

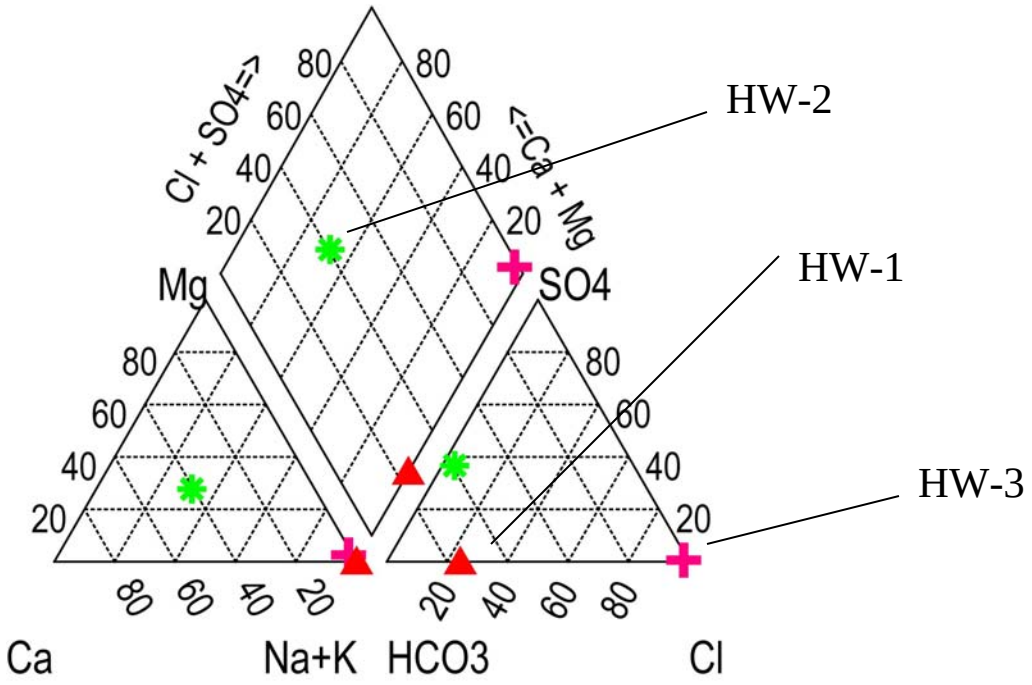


Figure 11. —Piper plot showing water types from samples collected from selected wells in the Hanceville area.

12,700 mg/L. Sample HW-1 (sample 2, well open to 1,164 feet) collected from the No. 1 Whaley well had a chloride concentration of 131 mg/L. However, this relatively low chloride concentration is probably due to a combination of shallow water entering the well from the Pottsville Formation through openings in the steel casing and an anomalously small amount of mineralization in waters contributed to the well from the deeper formations.

Analytical data indicate that each sampled well has its own unique chemical classification. Water types include calcium-magnesium-bicarbonate (Ca-Mg-HCO_3) for the Hanceville Water and Sewer Board well (H-2), sodium-bicarbonate-sulfate (Na-HCO_3-SO_4) for the No. 1 Whaley well (H-1), and sodium-chloride (Na-C1) for the Montgomery well (H-3) (fig. 11).

Calcium-bicarbonate type waters are prevalent in shallow aquifers in Cullman

County. Sample HW-2 from the relatively shallow Hanceville Water and Sewer Board well (Ca-Mg-HCO_3 type water) consists of 43.8 mg/L calcium, 17.3 mg/L magnesium, and 194 mg/L bicarbonate. Calcium-magnesium-bicarbonate waters generally contain low concentrations (less than 200 mg/L) of dissolved solids, chloride, sodium, and fluoride. However, sample HW-1 had 329 mg/L dissolved solids. Sample HW-1 from the No. 1 Whaley well (Na-HCO_3-SO_4 type water) had 334 mg/L sodium, 727 mg/L bicarbonate, and 1.06 mg/L sulfate. Sample HW-3 (Na-C1 type water) had 7,260 mg/L sodium and 12,700 mg/L chloride.

Hardness of water is defined as its content of metallic ions that react with sodium soaps to produce solid soaps or produce mineral scales when evaporated. Hardness is expressed as the total concentration of calcium (Ca^2+) and magnesium (Mg^2+) as milligrams per liter equivalent of calcium carbonate ($CaCO_3$) (table 1) (Freeze and Cherry, 1979). The hardness of the water in sample HW-2 was classified as very hard (181 mg/L as $CaCO_3$). The hardness of water in sample HW-1 was soft (5 mg/L as CaCO3) and probably indicates the influence of water from deep carbonate formations in the well. Hardness classification and corresponding concentrations of equivalent $CaCO_3$ are shown in table 1.

CHEMICAL CONSTITUENTS

Localized areas of poor water quality exist throughout north-central Alabama where the Pottsville Formation is the major aquifer due to naturally occurring chemical constituents including iron, manganese, sulfate, and other metals in concentrations large enough to be objectionable for drinking water. Potential deep aquifers underlying the Pottsville aquifer may have concentrations of chloride that exceed state and federal drinking water standards as was observed in the Montgomery well where the water at a depth of less than 2,000 feet was mineralized with high concentrations of chloride and metals. Although a large volume of water was not pumped from the No. 1 Whaley well, most constituents were relatively low including iron and chloride.

Table 1.—Classification of water hardness (Durfor and Becker, 1964).

Concentration (mg/L as $CaCO_3$)	Classification
0-60	Soft
61-120	Moderately Hard
121-180	Hard
More than 180	Very Hard

Iron naturally occurs in waters throughout Alabama, although concentrations generally are low due to the characteristic insolubility of iron under natural aquifer conditions. The drinking water standard for iron (0.3 mg/L) is commonly exceeded, especially in coastal plain aquifers and some Paleozoic aquifers. Iron is one of the most objectionable drinking water constituents of groundwater and generally, when iron is encountered at concentrations near or above drinking water standards in a test well, the well is abandoned.

Iron primarily occurs in two forms, which are determined by the presence of iron-bearing minerals and reactions of these minerals with water under specific subsurface conditions of pH and Eh (oxidation-reduction potential). However, consideration of Eh and pH alone in explaining iron concentrations is simplistic and may not be adequate in every situation.

Most of the iron released from sediments near the surface is oxidized to form slightly soluble to insoluble ferric iron Fe^{3+} ($Eh > 0.20$ and $pH > 5$) (Hem, 1985). With increasing depth, oxygen is consumed, and as the environment becomes reducing (Eh 0.20 to –0.10), ferric iron is reduced and ferrous iron (Fe^{2+}) becomes the dominant form within the normal pH range of natural water (pH 5-9) (Hem, 1985). Iron concentrations in a relatively reducing environment may exceed 10 mg/L. Sample HW-2 had a pH of 7.5 and an iron concentration of 1.6 mg/L and was probably collected from this environment, although Eh was not measured in any samples.

At greater depth, the environment becomes more reducing and pH increases. In this zone, calcite is dissolved and sodium is the dominant cation. Dissolved iron in waters at these depths is limited by dissolution of sulfate, which is reduced to form

disulfide (HS^-), which leads to the formation of pyrite (FeS_2) and other iron rich minerals. Sample HW-1 had a pH of 8.6 and an iron concentration of 0.07 mg/L and probably contained water from the shallow oxidized zone as well as from the deeper more reducing environment.

As hydrogen ions are consumed at even greater depth, farther downgradient, the environment becomes more strongly reducing and pH values decrease. Sample HW-3 had a pH of 7.5 and an iron concentration of 1.04 mg/L. However, water quality in this well is not of great concern since the water is mineralized to the point that it is unusable for most purposes. Table 2 shows primary and secondary drinking water standards and concentrations in the No. 1 Whaley well and in the Hanceville Water and Sewer Board well.

WATER AGE DATING

Knowledge concerning the residence time of groundwater is essential in determining the geochemical evolution of water from the time it enters the recharge area until it becomes mineralized to the point that it is unusable. Recent advances in analytical techniques make it possible to accurately measure extremely small concentrations of isotopes of key elements that enable the relatively accurate age dating of water. This project employed an age dating technique involving the radioactive isotope, carbon 14 (^{14}C) to determine the age of water collected from 3 wells in Cullman County. Isotopic data, when combined with other geochemical and hydrogeologic information, can be used to determine the history of movement and evolution of geochemical character of water in the aquifer and to determine areas of possible future development of water resources.

Carbon 14 (^{14}C) is a radioactive isotope formed when a neutron is ejected from an atom after being struck by a cosmic ray, releasing a free neutron. This free neutron then is captured by a nitrogen atom (7 protons, 7 neutrons) and becomes carbon 14 (6 protons, 8 neutrons) and a proton (hydrogen atom - 1 proton, 0 neutrons). This most often happens in the upper atmosphere at which point the carbon 14 atom is oxidized to become carbon dioxide. Carbon 14 has a half-life of 5,568 years and is useful for dating groundwater that originated between the year 1950 and about 50,000 years

before the present (BP). Since carbon 12 and carbon 13 are stable isotopes, to date a material, the amount of ^{14}C is compared to ^{12}C or ^{13}C and then is compared to a known modern standard.

Table 2.—Inorganic primary and secondary drinking water constituents and standards and concentrations in water samples collected from selected wells in the Hanceville area. (Concentrations exceeding primary or secondary drinking water standards are noted in red font.)

Constituent	USEPA primary/secondary drinking water standards (mg/L)	No. 1 Whaley sample HW-1 (mg/L)	Hanceville Water and Sewer Board well sample HW-2 (mg/L)
Aluminum	0.05-.2	*BDL <0.06	BDL <0.06
Antimony	0.006	BDL <0.003	BDL <0.003
Arsenic	0.010	BDL <0.003	BDL <0.002
Barium	0.06	0.33	0.28
Beryllium	0.004	BDL <0.0001	BDL <0.001
Cadmium	0.005	BDL <0.003	BDL <0.004
Chloride	250	131	6.4
Chromium	0.1	BDL <0.008	BDL <0.008
Copper	1.3/1.0	BDL <0.006	BDL <0.008
Fluoride	2.0	2.3	0.08
Iron	0.3	BDL <0.007	1.69
Lead	0.015	BDL <0.002	0.005
Manganese	0.05	0.002	0.214
Mercury	0.002	BDL <0.00006	BDL <0.001
Nitrate (as Nitrogen)	10	BDL <0.01	BDL <0.02
Nitrite (as Nitrogen)	1	BDL <0.01	BDL <0.01
pH	6.5-8.5	8.6	7.5
Selenium	0.05	BDL <0.003	BDL <0.003
Silver	0.1	BDL <0.015	BDL <0.010
Sulfate	250	1.06	91.4
Thallium	0.002	BDL <0.002	BDL <0.002
Total dissolved solids	500	856	329
Zinc	5.0	BDL <0.0048	BDL <0.004

*BDL—Below detection limit.

Water samples HW-1, HW-2, and HW-3 were analyzed for ^{14}C concentrations and age dates were calculated. The age of sample HW-1 (a mixture of waters from the Pottsville, Pennington, and Parkwood Formations, Bangor Limestone, and Hartselle Sandstone) is 36,630 years before present (years bp) +/- 30 years. The age of sample HW-2 (Pottsville Sandstone) is 10,300 years bp +/- 40 years and the age of sample HW-3 (Chattanooga Shale) is 33,460 years bp +/- 40 years. Age dates indicate that waters in all of three sampled wells have significant residence times. Although ages are similar in samples HW-1 and HW-3, mineralization of the water in these wells is vastly different and indicates that water below the Pottsville Sandstone in the area of the No.1 Whaley well may be suitable for public water supply if adequate quantities are located.

Groundwater quality is a major concern for public water supplies in Cullman County. Most groundwater is produced from the Pottsville Formation and is locally characterized by high concentrations of sulfate, iron, and other trace metals. Water in the basal zone of the Pottsville Formation (discussed earlier) has not been extensively tested and may provide a sustainable source of good quality groundwater. Deeper units are virtually untested, although limited data collected from the No. 1 Whaley well indicate that potable water may exist in these deeper zones. However, finding adequate quantities of water in these deeper zones may be difficult.

CONCLUSIONS AND RECOMMENDATIONS

The Hanceville Water and Sewer Board service area is in the Appalachian Plateau area with geologic strata dipping in a general south-southwest direction at about 40 to 60 feet per mile. The lower part of the Pottsville Formation occurs at the surface across most of the area and is present to depths of about 600 feet. Fractures and joints in the Pottsville Formation as well as bedding plane conduits are geologic features that likely provide groundwater flow pathways. Analysis of fracture trace azimuths indicates predominant 25-30 degrees and 315-330 degrees azimuths. A greater number of interpreted fracture traces in northeastern to southeastern directions from Hanceville indicate a greater likelihood of encountering fractures and joints in possible test wells.

Data collected during this investigation from the No. 1 Whaley petroleum test well

indicate a possible aquifer in the interval 446 to 554 feet below land surface. This interval is currently behind casing set in the 1920s. The casing integrity is likely severely compromised in some intervals and completely missing in others as evidenced from borehole video and geophysical well logs. The source for the groundwater in the well is currently unknown and is likely from several geologic units.

Groundwater samples collected for geochemical analysis and age dating from three wells in the project area, the Hanceville water supply well, the No. 1 Whaley well, and the Geomet, Inc., Montgomery 6-7-4 well reveal significant differences in concentrations, water types, and ages. Water from the Hanceville public supply well is a calcium-magnesium-bicarbonate type water, whereas the water sample collected from the No. 1 Whaley well is a sodium-bicarbonate-sulfate type, and water from the Montgomery 6-7-4 well is a sodium-chloride type water, with chloride concentrations of 12,700 mg/L. Chloride concentration in the Hanceville public supply well was 6.4 mg/L, and the No. 1 Whaley well sample had a chloride concentration of 131 mg/L. Hardness in the public supply well at Hanceville was much higher (181 mg/L) than that of the No. 1 Whaley well, which had a hardness of only 5 mg/L. Iron and pH were measured at 1.6 mg/L and 7.5, respectively, for the Hanceville well, indicating dominant ferrous iron concentrations at the depth of 170 feet. The No. 1 Whaley well iron concentration and pH were found to be 0.07 mg/L and 8.6, respectively, while the Montgomery 6-7-4 well water sample measured 1.04 mg/L iron with a pH of 7.5. Groundwater from the No. 1 Whaley well exhibits concentrations and physical characteristics that suggest it may be a mixture of water from shallow zones as well as deeper intervals, a finding consistent with other physical characteristics of the formations penetrated and exposed to open bore hole, depth, and conditions of the casing. All of the water samples tested by carbon-14 age dating technique in this investigation indicate significant residence times, with the Hanceville water well sample dated at 10,300 years before present, and the No. 1 Whaley well and Montgomery 6-7-4 well water samples indicating dates of 36,630 and 33,460 years before present, respectively.

Although total dissolved solids in the No. 1 Whaley water sample was somewhat high (856 mg/L), chloride concentration was relatively low (131 mg/L), especially considering the depth of the borehole at 1,164 feet (assuming some water may have been

contributed from that depth). This may indicate the possibility of finding suitable quality water at considerably greater depth than the 170-foot-deep Hanceville water well, including possibly below the Pottsville. The presence of a relatively thick, untested lower Pottsville Formation sandstone interval (446-554 feet) in the No. 1 Whaley well and the evidence of fractures in the area, especially in the eastern part of the project area are indications of possible success in developing additional groundwater supplies in the Pottsville aquifer within the service area of the Hanceville Water Works and Sewer Board.

REFERENCES CITED

Back, W. B., 1966, Hydrochemical facies and ground-water flow patterns in the northern part of Atlantic Coastal Plain: U.S. Geological Survey Professional Paper 498-A, 42 p.

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

Fetter, C.W., 2001, Applied hydrogeology, Fourth Edition, Upper Saddle River, New Jersey, Prentice-Hall, Inc., 598 p.

Frank, R.W., 1988, Prospecting with old E-logs: Schlumberger Educational Services, 161 p.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 604 p.

Geological Survey of Alabama, 2006, Geologic map of Alabama Special Map 220A.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural waters (3rd ed.): U.S. Geological Survey Water Supply Paper 2254, 264 p.

Osborne, W.E., Szabo, M.W., Neathery, T.L., and Copeland, C.W., Jr., 1988, Geologic map of Alabama, northeast sheet and southeast sheet: Tuscaloosa, Geological Survey of Alabama Special Map 220.

Semmes, D.R., 1929, Oil and Gas in Alabama: Tuscaloosa, Geological Survey of Alabama Special Report 15, 408 p.

Thomas, W.A., 1974, Mississippian stratigraphy of Alabama: Tuscaloosa, Geological Survey of Alabama Monograph 12, 121 p.