A Brief Overview of the Geochemistry of the Arbuckle-Simpson Aquifer[1]

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Introduction

The Arbuckle-Simpson aquifer outcrops in south-central Oklahoma over an area of about 500 square miles. The aquifer consists of limestone, dolomite, sandstone, and shale of the Arbuckle and Simpson Groups of Late Cambrian to Middle Ordovician age. The aquifer is underlain by Cambrian and Precambrian rhyolite and granite basement rocks. The underlying Timbered Hills Group, which ranges in thickness from 0 to about 700 feet, consists of the Honey Creek Limestone and Reagan Sandstone and probably is part of the same ground-water flow system. The basement rocks are found at the land surface in portions of the study area and as deep as about 8,000 feet in the few wells that penetrate the outcrop of the aquifer (Campbell and Weber, in preparation).

The Arbuckle-Simpson aquifer is highly folded, faulted, and fractured. The rocks were subjected to intensive folding and faulting associated with major uplift of the area during early to late Pennsylvanian time. Small karst features can be seen over much of the outcrop area of the aquifer, but air-filled caves are found in only a few locations.

The Arbuckle-Simpson aquifer study area commonly is divided into three sub-areas, the Hunton, Tishomingo, and Arbuckle Anticlines (fig. 1). These sub-areas are based loosely on geologic and topographic similarities, and the terms are not based strictly on structural geology. The geologic units tend to be thinner within the Hunton Anticline and thicken to the southwest in the Tishomingo and Arbuckle Anticlines. Structural deformation also increases to the southwest, with rocks more flat lying in the Hunton Anticline (dips less than 20 degrees) but increasing to the southwest with vertical and overturned beds to be found within the Arbuckle Anticline.

Hydrology

The primary source of water in the aquifer is diffuse recharge from precipitation, estimated to be about 4.7 inches per year (Fairchild and others, 1990) in the Hunton Anticline. Ground-water flow in the Hunton Anticline generally is to the southeast and ground water discharges to streams and springs, with the largest discharges near the down-gradient portion of the aquifer. Available potentiometric data in the Arbuckle and Tishomingo Anticlines show generally radial flow patterns (Fairchild and others, 1990). As in the Hunton Anticline, ground water in the Arbuckle and Tishomingo Anticlines discharges to streams and springs. The maximum depth of fresh ground water within the outcrop area is not known, but a small number of wells exceed 1,000 feet in depth and did not encounter saline water. A recently drilled test hole produced fresh water from a depth of 1,820 feet.

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The freshwater zone of the aquifer generally coincides with the outcrop area of the aquifer, although a few small confined zones are located in some areas at the edge of the aquifer. The best known confined zone is located near the town of Sulphur and the Travertine District of the Chickasaw National Recreation Area. Ground water flows west from the Hunton Anticline and becomes confined beneath Pennsylvanian-age cemented conglomerates. Ground water discharges to springs, Travertine and Rock Creeks, and wells, some of which are artesian. Another confined zone occurs on the eastern part of the Hunton Anticline, as indicated by a small number of artesian wells where low-permeability geologic units within the Simpson Group appear to act as confining layers.

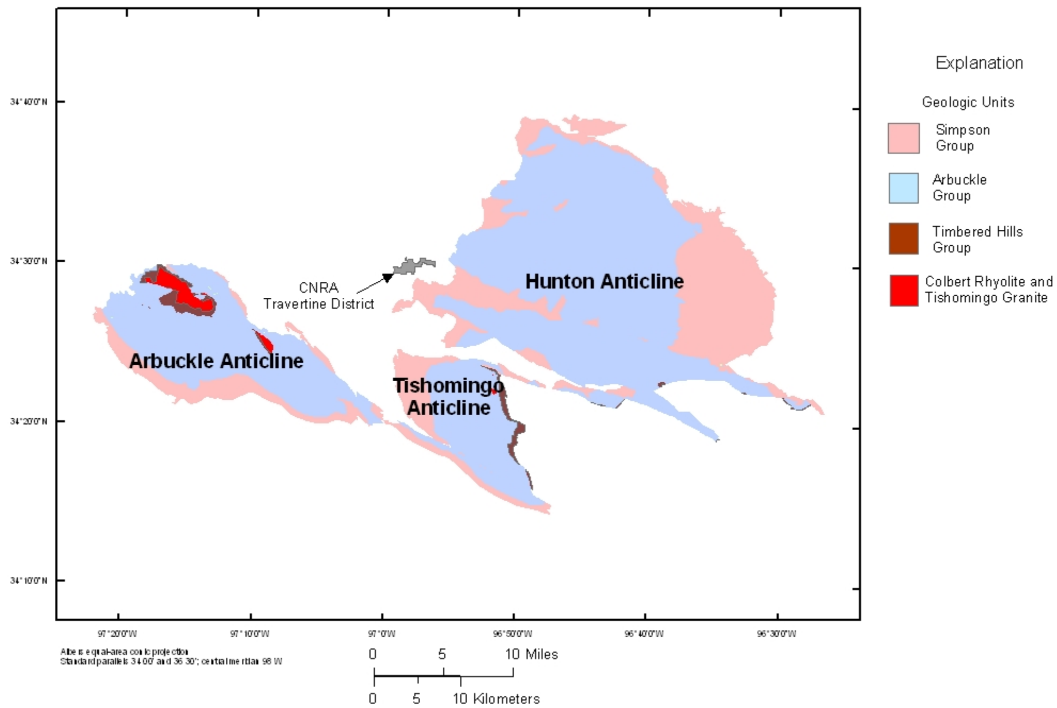

Figure 1. -- Subdivisions of the Arbuckle-Simspon aquifer.

Geochemical Reconnaissance

Ground- and spring-water samples were collected by the U.S. Geological Survey from 24 wells and 5 springs during 2004 as a geochemical reconnaissance for the current investigation of the Arbuckle-Simpson aquifer. The wells and springs included in the reconnaissance were selected in order to obtain broad coverage of the study area, including all three sub-areas. Shallow wells were selected (less than 500 feet deep) because most deep wells in this aquifer are completed with long open intervals and produce water from many zones. The suite of constituents for most samples included major cations and anions, trace metals, nutrients, bacteria, oxygen and hydrogen isotopes, carbon-14, noble gases, and tritium.

The geochemical reconnaissance showed that the quality of ground-water in the Arbuckle-Simpson aquifer is generally good, with most samples suitable for domestic and municipal uses. Two samples had nitrate concentrations that exceeded the U.S. Environmental Protection Agency's 10 mg/L Maximum Contaminant Level (MCL)(U.S. Environmental Protection Agency, 2002). No other MCLs were exceeded.

Water quality was very consistent in water samples from wells and springs in the outcrop areas. For all water samples, dissolved solids concentrations ranged from 222 to 1,250 milligrams per liter (mg/L) with a median concentration of 351 mg/L (table 1). However, for samples from the outcrop area, the inter-quartile range (50 percent of the data centered on the median) of dissolved solids was 332 to 384 mg/L. Most water-quality constituents listed in table 1 have small inter-quartile ranges, indicating relatively uniform water quality.

Water type

Most of the water samples from wells and springs producing water from the outcrop area were of a calcium bicarbonate or calcium magnesium bicarbonate water type. Figure 2 shows Stiff diagrams, which graphically represent the dominant major cations and anions dissolved in the water. On figure 2, the Stiff diagram is positioned above the well or spring (shown as a black dot) from which the water sample was collected. Wells or springs such as the Line Camp well produce water in which calcium is the dominant cation (the middle left axis of the Stiff diagram) and bicarbonate (the middle right axis of the Stiff diagram) is the dominant anion. Stiff diagrams of water samples from wells and springs producing water from the Arbuckle Anticline show a distinct diamond shape characteristic of calcium bicarbonate waters. Stiff diagrams of water samples from wells and springs producing water from the Hunton Anticline have a slightly different shape in which the lower left axis, representing magnesium, is longer (see for example the Stiff diagram for Antelope Spring). Water from the Hunton Anticline tends to have higher magnesium concentration than water from the Arbuckle Anticline, which is consistent with the geology. The Arbuckle Anticline tends to have more limestone, which consists mostly of calcium carbonate, and the Hunton Anticline tends to have more dolomite, a form of carbonate rocks similar to limestone but with a substantial amount of magnesium.

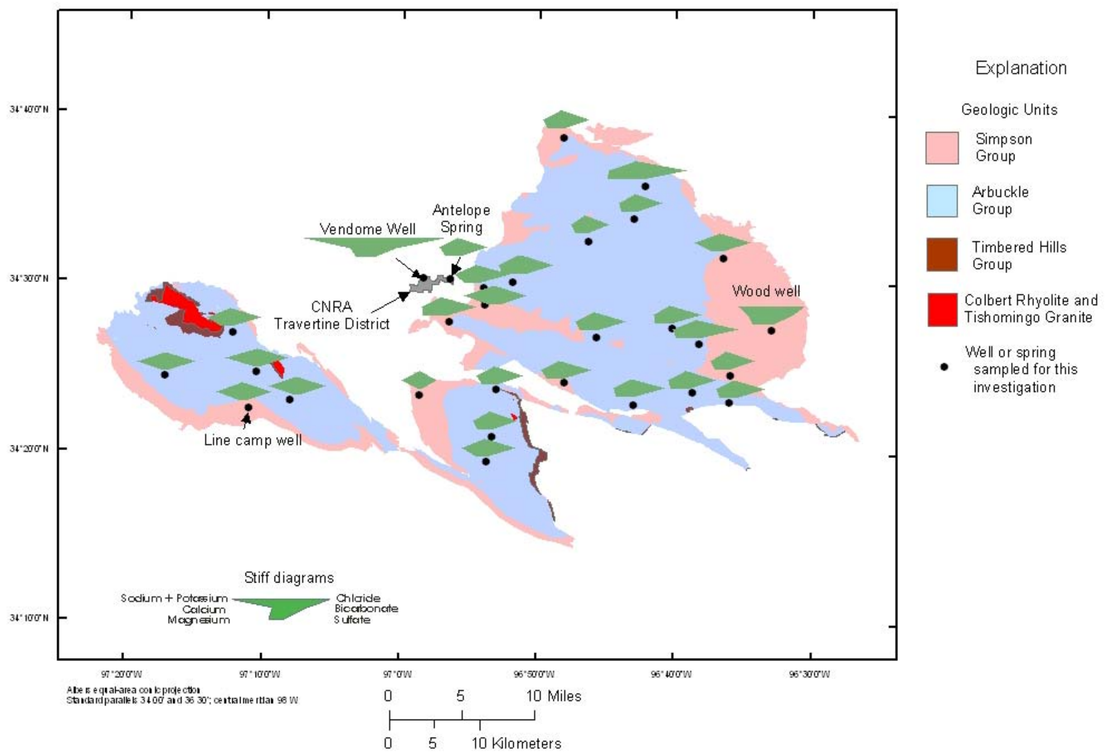

Figure 2. -- Stiff diagrams of the major ion chemistry of the Arbuckle-Simpson aquifer

Age-dating tracers

Chemicals and isotopes that are dissolved in ground water can be used to determine the apparent age of ground water. The apparent age of ground water is considered to be the amount of time determined from an age-dating tracer that has elapsed since the water was last in contact with the atmosphere. These chemicals and isotopes are referred to as “age-dating tracers.” Several different age-dating tracers were used for the geochemical reconnaissance, helium-3/tritium and carbon-14.

Tritium is a short-lived radioactive isotope of hydrogen with a half-life of 12.32 years. Tritium forms naturally as cosmic radiation interacts with the upper atmosphere, and all precipitation that falls to Earth has small amounts of tritium. During the 1950s and early 1960s, global atmospheric testing of nuclear weapons raised the atmospheric concentrations of tritium hundreds of times above the normal background concentration. After the early 1960s, when the Nuclear Test Ban Treaty was signed and atmospheric testing of nuclear weapons ceased, tritium concentrations in the atmosphere have decreased and are approaching natural levels. By measuring both the helium-3 and tritium content from a ground-water sample, an apparent age can be determined because the rate that tritium decays to helium-3 is known (Lucas and Unterwager, 2000).

Carbon-14 is the radioactive isotope of carbon with a half-life of 5,730 years. Carbon-14 is widely used and is well-known to the public as a tool for dating archeological sites, but carbon-14 also can be used to date ground water. Like tritium, carbon-14 is produced in the upper atmosphere and thus occurs naturally. Atmospheric carbon-14 concentrations were elevated by as much as 50 percent by the testing of nuclear weapons after 1954 (Coplen, 1993).

Figure 3 shows the results of the age-dating tracer samples for the Arbuckle-Simpson geochemical reconnaissance. Most water samples were considered to be modern water. The fact that most water in the aquifer is modern indicates the water is circulating relatively rapidly though the aquifer, in less than about 60 years. Modern ground water generally is more susceptible to contamination than old ground water because of the many man-made contaminants introduced to the environment during the 20th century.

Ground water at the edge of the Arbuckle-Simpson aquifer

Two samples were dissimilar to samples from wells and springs producing water from the outcrop area, the Vendome and Wood artesian wells (fig. 2). The Vendome well is 775 feet deep and completed in the Arbuckle Group west of the Hunton Anticline in the town of Sulphur. The Wood artesian well, on the eastern Hunton Anticline, was logged in 1978 as 950 feet deep but it is not known if it is completed in the Arbuckle or Simpson Groups. These two wells produced the highest dissolved solids concentrations of the wells sampled for this study. Both wells produce water with sodium and chloride as the dominant cation and anion (fig. 2), and the waters from both wells have a distinct hydrogen sulfide odor. Carbon-14 samples from these wells show the waters to be quite old. The uncorrected carbon-14 concentration from the Vendome well water sample indicated an age of about 17,000 years, and water samples from the

Wood well indicated an uncorrected carbon-14 age of over 30,000 years. Noble gas analysis of the water samples from these wells indicate a recharge temperature of about 8 degrees (Vendome) and 9 degrees (Wood) Celsius, which is consistent with cooler temperatures from the Pleistocene Epoch during which the water from these wells probably entered the aquifer. Both the Vendome and Wood wells are considered to be producing water from the edge of the freshwater flow system in the Arbuckle-Simpson aquifer. Connate saline brine surrounds the freshwater portion of the aquifer and the Vendome and Wood wells probably represent a mixture of freshwater and brine at the edge of the freshwater flow system in the aquifer.

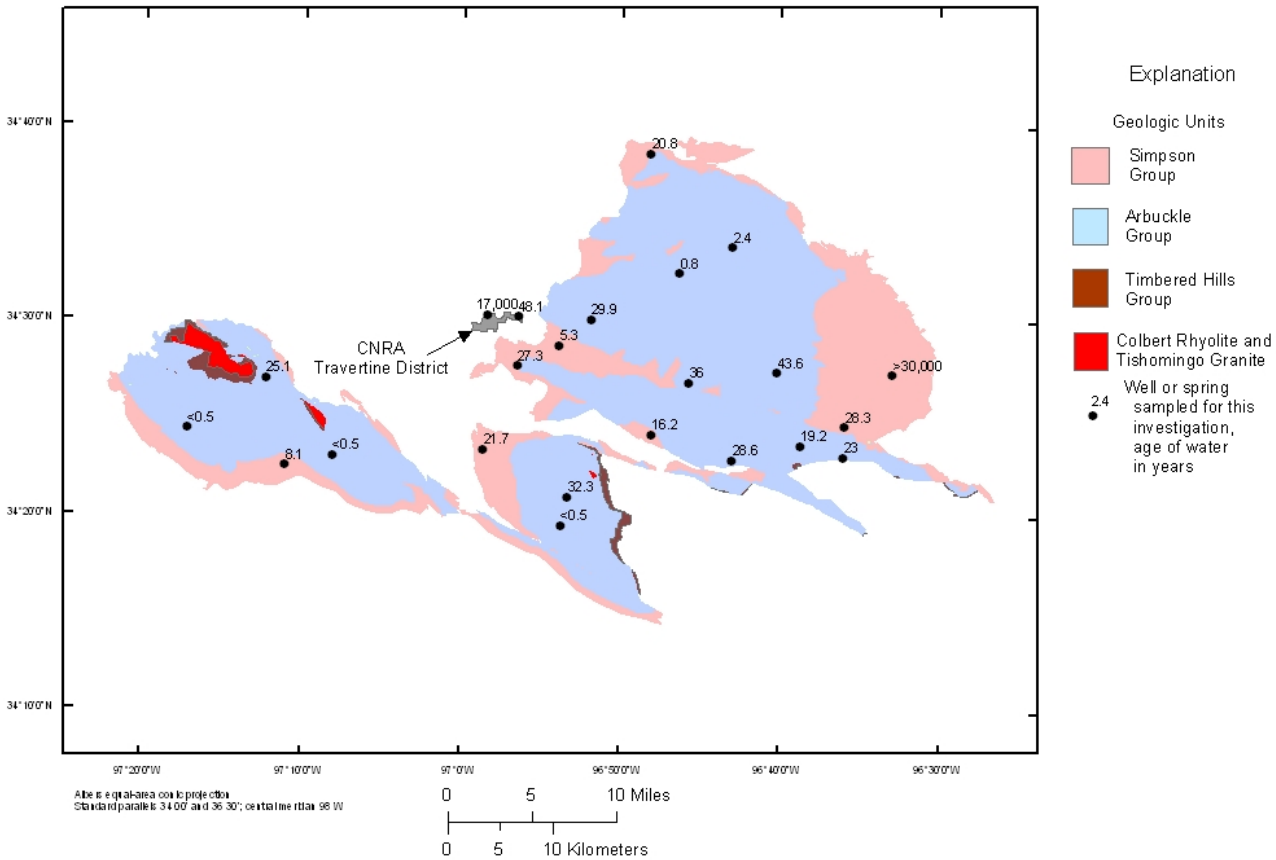

Figure 3. -- Age of water samples from wells and springs.

References

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Table 1. Summary statistics for chemical constituents and physical properties from the Arbuckle-Simpson geochemical reconnaissance
[mg/L, milligrams per liter; µS/cm, microseimens per centimeter; µg/L, micrograms per liter]

Constituents and properties	Sample size	Minimum	Percentiles 5	10	25	50	75	90	95	Maximum
Properties and major ions										
Specific conductance (µS/cm)	29	377	492	517	597	635	719	874	1350	2100
pH (standard units)	29	6.7	6.7	6.7	6.8	6.9	7.0	7.1	7.2	7.2
Temperature (ºC)	29	16.1	16.7	17.4	18.0	18.4	18.9	19.6	19.8	20.6
Oxygen, dissolved (mg/L)	29	0.1	0.5	0.7	3.3	4.9	6.7	7.6	7.7	8.2
Alkalinity (mg/L as CaCO3)	29	179	256	258	297	325	338	365	443	546
Dissolved solids (mg/L)	29	222	291	301	332	351	384	628	768	1250
Calcium (mg/L)	29	63.2	67.6	70.4	76.9	84.8	104	121	133	134
Magnesium (mg/L)	29	3.13	4.97	6.96	23.0	34.5	38.9	49.6	55.1	77.5
Sodium (mg/L)	29	1.18	1.50	1.61	2.15	3.82	8.33	20.4	141	316
Potassium (mg/L)	29	0.37	0.38	0.46	0.79	1.10	2.11	9.60	11.40	12.80
Bicarbonate (mg/L)	29	218	313	314	362	397	412	445	540	666
Carbonate (mg/L)	29	0	0	0	0	0	0	0	0	0
Sulfate (mg/L)	29	4.9	5.5	5.5	7.5	11.5	17.1	39.9	49.2	50.6
Chloride (mg/L)	29	1.22	1.42	1.60	2.28	3.35	9.82	28.3	279	558
Fluoride (mg/L)	29	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.7	0.7
Bromide (mg/L)	28	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	0.28	0.96	2.08
Iodide (mg/L)	29	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.007	0.034	0.062
Silica (mg/L)	29	7.86	8.82	9.01	9.51	10.4	12.4	13.2	13.3	14.0
Nutrients										
Nitrite (mg/L as N)	29	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Nitrite plus nitrate (mg/L as N)	29	<0.06	<0.06	<0.06	0.42	1.14	2.61	7.60	14.4	14.4
Ammonia (mg/L)	29	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.3	0.43
Orthophosphate (mg/L)	29	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Trace elements										
Aluminum (µg/L)	28	<2	<2	<2	<2	<2	<2	<2	<2	6
Antimony (µg/L)	29	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

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Arsenic (µg/L)	29	<0.2	<0.2	<0.2	<0.2	<0.2	0.2	0.4	0.5	0.5
Barium (µg/L)	29	35	36	38	47	62	88	202	213	240
Beryllium (µg/L)	29	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06
Boron (µg/L)	29	11	11	11	13	17	21	52	321	496
Trace elements--continued										
Cadmium (µg/L)	29	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.04	0.88
Chromium (µg/L)	29	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	2.4
Cobalt (µg/L)	29	0.152	0.16	0.177	0.194	0.262	0.305	0.347	0.373	0.389
Copper (µg/L)	29	0.3	0.4	0.4	1	2.2	3.8	6.1	9.5	22.2
Iron (µg/L)	29	<6	<6	<6	<6	<6	<6	14	18	19
Lead (µg/L)	29	<0.08	<0.08	<0.08	<0.08	0.14	0.28	0.76	0.91	0.93
Lithium (µg/L)	29	<0.6	<0.6	<0.6	0.9	1.1	2.2	5.2	37.9	66.2
Manganese (µg/L)	29	<0.2	<0.2	<0.2	<0.2	0.2	1.1	2.2	3.3	7.3
Molybdenum (µg/L)	29	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	1.2	2.9	4.0
Nickel (µg/L)	29	<0.06	0.45	0.45	0.60	0.87	1.57	1.86	2.08	2.26
Selenium (µg/L)	29	<0.4	<0.4	<0.4	<0.4	<0.4	0.5	1.1	1.7	2.5
Silver (µg/L)	28	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Strontium (µg/L)	29	22.6	42.3	42.7	67.2	83.2	163	1350	2480	6860
Thallium (µg/L)	29	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.09
Vanadium (µg/L)	29	<0.3	<0.3	<0.3	0.4	0.7	1.0	1.3	1.3	2.8
Zinc (µg/L)	29	<0.6	<0.6	<0.6	1.1	3.9	10.5	21.1	30.9	196
Isotopes and radionuclides										
Deuterium/protium ratio (per mil)	29	-35.6	-35.2	-33.6	-31.2	-29.9	-28.7	-27.6	-25.5	-24
Oxygen-18/oxygen-16 ratio (per mil)	29	-6.39	-5.83	-5.73	-5.40	-5.24	-5.05	-4.67	-4.56	-4.23
Uranium (µg/L)	29	<0.04	<0.04	0.13	0.25	0.35	0.45	0.86	1.00	1.67