Guidebook to the Geology of the Rolla Area Emphasizing Solution Phenomena

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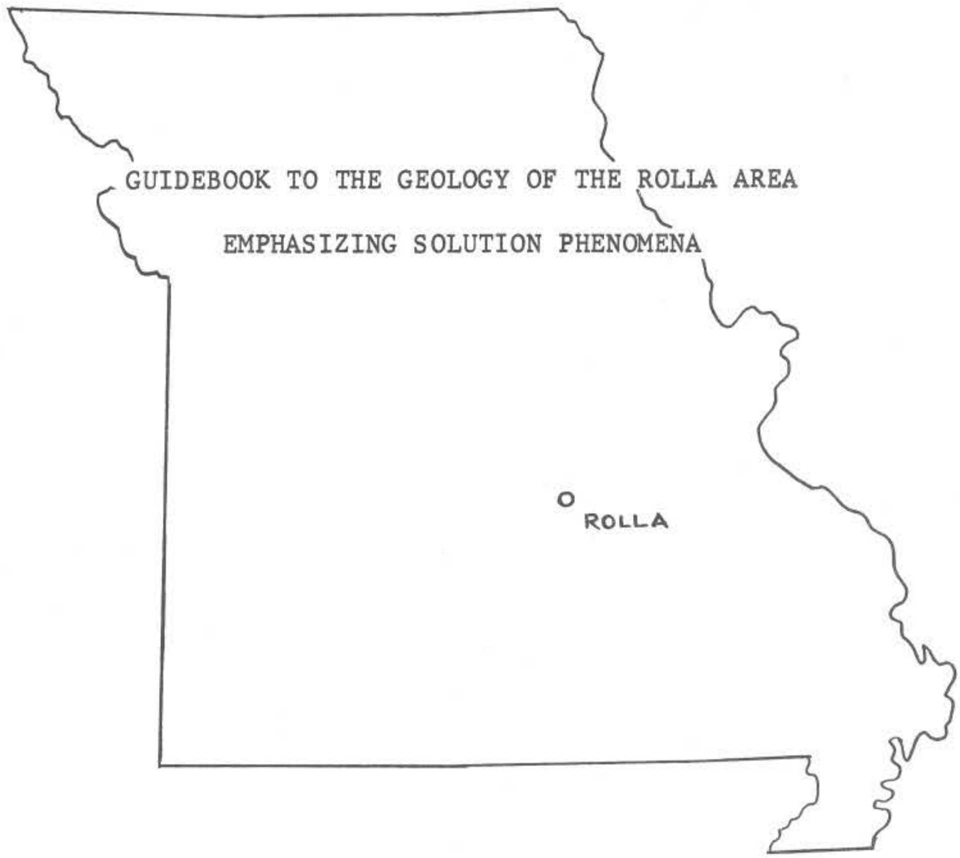
GUIDEBOOK TO THE GEOLOGY OF THE ROLLA AREA

EMPHASIZING SOLUTION PHENOMENA



December 1, 1960

Prepared for the Fifth Annual Midwest Groundwater Conference
Field Trip conducted by staff geologists
of the
Missouri Geological Survey and Water Resources, Rolla, Missouri

INTRODUCTION AND GEOGRAPHIC SETTING

by

T. R. Beveridge, State Geologist

This guidebook is prepared specifically for the Fifth Annual Midwest Groundwater Conference field trip with an emphasis on karst topography and solution phenomena. It is written with an effort to make it sufficiently flexible for use by others interested in the general geology of the Rolla area because the standard reference (Lee, 1913) has long been out of print.

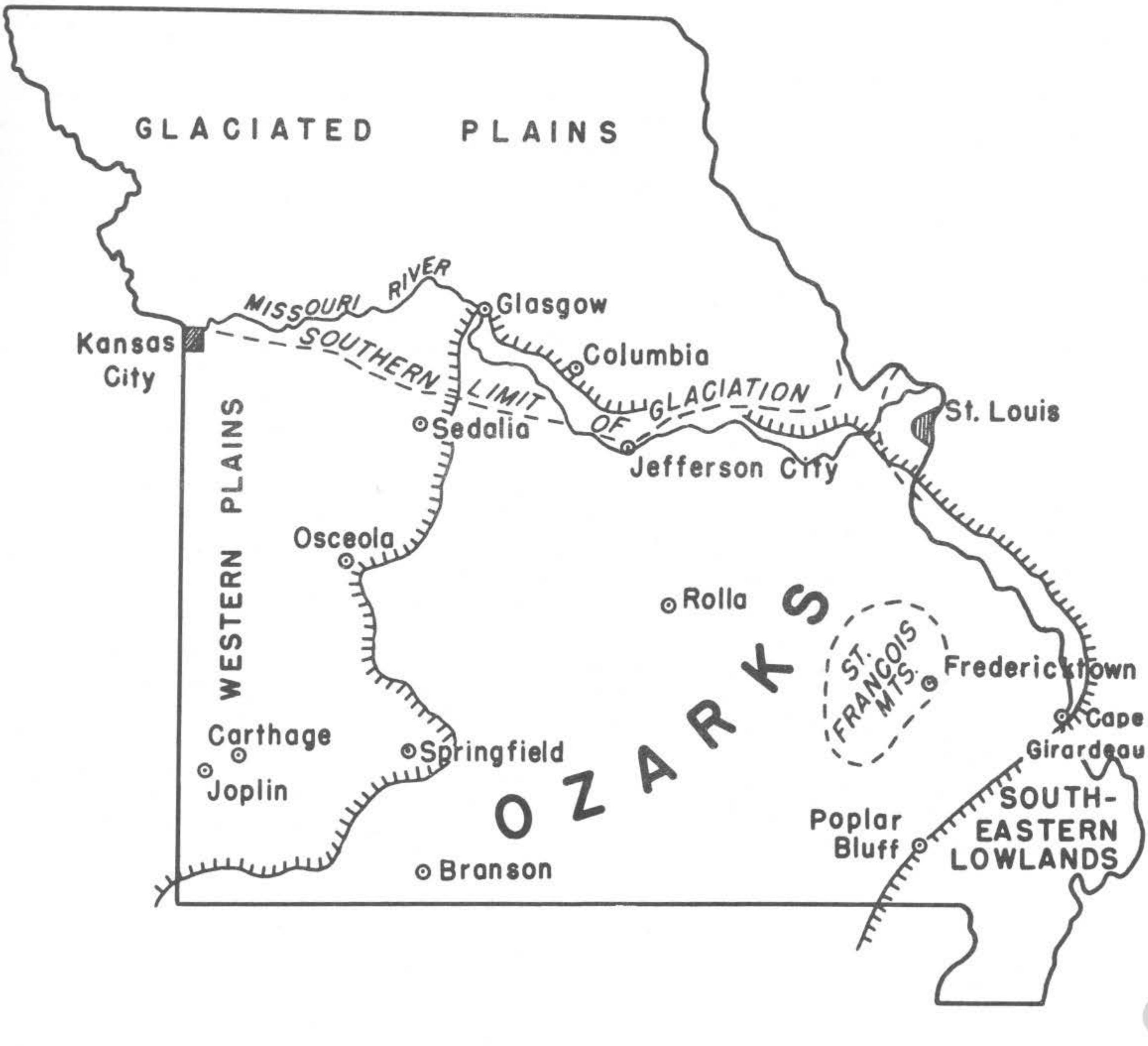
As shown in Plate 1, Rolla is near the central part of the Missouri Ozarks and elevations in the immediate area of the city are between 1050 and 1180 feet above sea level. The greater part of the surface water in Rolla flows into the Meramec River, which in turn empties into the Mississippi River at the south line of St. Louis County. A very small part of the drainage in the extreme west and north edges of town feeds tributaries of the Gasconade River which flows northeastward and enters the Missouri River west of Hermann.

The origin of the connotation "Ozarks" is not certain. One of the most popular hypotheses holds that it is a corruption of "Aux Arks", a French contraction of the early-day references to the Arkansas Mountains.

The Ozarks. There is no general agreement concerning the boundaries of the Ozarks, especially the western margin. As shown on Plate No. 1, the Ozarks are defined by the Missouri Geological Survey as being bounded on the north by the north bluffs of the Missouri River valley. The eastern margin is a line extending from St. Charles southward into Illinois, following the hills adjacent to the Mississippi River. At a location approximately east of Cape Girardeau, the boundary returns to Missouri. It then swings southwesterly along the bluff line through Poplar Bluff into Arkansas.

It is just as difficult to give a short definition of the characteristics of the Ozark area as it is to define the limits from a physiographic standpoint. The major feature of the Ozarks is that of relative high local relief as contrasted with nearby areas in the Midwest. The vertical distance between an Ozark stream and the adjacent uplands may be as much as 400 feet or in the igneous knob area of the St. Francois mountains as great as 800 feet. In the Rolla area along the Gasconade River, 300 feet is a fairly average figure for local relief.

Plate I
MAJOR GEOLOGIC REGIONS of MISSOURI



It should be emphasized that the Ozarks cannot be defined as being a large area all of which is higher than the remainder of Missouri. It is true that the porphyry knob, Taum Sauk Mountain in Iron County, is the highest known point in the state with an elevation of 1772 feet above sea level. Large areas in the Ozarks are at an elevation of over 1400 feet, but there are also appreciable areas less than 1000 feet above sea level within this area while outside the Ozarks, significant areas in Missouri are at elevations exceeding 1200 feet. Associated with the high local relief are other characteristics of repeated uplift and erosion such as entrenched meanders, superimposed streams, and prominent ridges and upland areas.

Indurated rocks in the Ozarks area are predominantly Precambrian, Cambrian, and Ordovician, and the carbonate rocks are a large part dolomites rather than limestones. Chert is especially common in the sedimentary rocks and because solution is such an important factor in development of the landscape, thick sections of residual chert and other forms of insoluble silica are very common.

Because solution is such an important factor, solution phenomena such as springs, caves, sinks, natural bridges and natural tunnels are very common in the Ozark area. The presence of many springs and the lack of thick organic topsoils, coupled with a tendency for surface water to move through the residuum and thus be filtered, has resulted in exceptionally clear streams in the Ozark area.

The combination of thin topsoils, relatively rugged topography and acid soils has in general made the upland area less desirable for farming than areas outside of the Ozarks. This fact, coupled with the features of terrain and vegetation which have encouraged hunting and fishing have created a culture and an economy peculiar to the Ozarks. Although this culture has lost some of its color as a result of modern highways, the Ozarks still have retained their charm and beauty as contrasted with areas outside the Ozarks which may be more suitable for agricultural purposes, but do not have the more primitive beauty.

A SUMMARY OF THE INDURATED ROCK STRATIGRAPHY OF THE ROLLA AREA

By

Mary H. McCracken, Research Geologist

Surface rocks in the Rolla area consist predominantly of strata of Lower Ordovician age. Pennsylvanian sandstones, shales, and conglomerates in the immediate Rolla area are patchy in distribution, but become more continuous and thicker to the north and east in the fire clay district. Small Mississippian outliers near Rolla have been described by Lee (1913, pp. 41-43) and Bridge (1917, pp. 558-575). A Devonian outlier a short distance northeast of Rolla was described by Bridge and Charles (1922, pp. 450-458). These Ordovician rocks are largely magnesium carbonates with minor amounts of chert, shale, and sandstone. Data on subsurface rocks and stratigraphy in the Rolla area are based on deep well information. An example of a well which penetrated 1745 feet of strata is the City of Rolla No. 3 Well, sec. 11, T. 37 N., R. 8 W. Samples from this well were studied by Charles Gleason in 1934 and restudied by Earl McCracken in 1937, and showed the following section:

	From	To
Ordovician System (Lower)		
Jefferson City formation	0'	50'

These rocks consist of dolomite with chert as nodules and lenses. The chert is often oolitic. Green shale partings and sand are present along bedding planes but are not subordinate. Fossils are rarely found. The beds are thin except for one rather thick bedded zone about 20 feet thick, the "Quarry Ledge", lying thirty feet above the Roubidoux formation. Much of the dolomite is earthy and weathers to a buff stone locally called "cotton rock". The Jefferson City forms the tops of the uplands in the Rolla area.

	From	To
Roubidoux formation	50'	255'

Of Lower Ordovician age, this formation consists of one, two, or three well developed sandstone beds with interbedded chert and dolomite beds. The cherts are often oolitic and sandy. The sandstones tend to form red-stained outcrops and the dolomite dissolves away when weathered, giving one an exaggerated impression of the sandstone ratio. Subsurface studies show that in some areas to the southwest of Rolla, the sandstone is of minor importance and that the Roubidoux is mainly a cherty dolomite. In general the Roubidoux forms a pronounced upland surface.

	From	To
Gasconade formation	255'	570'

The Gasconade consists of two units; an upper unit of a series of beds of coarsely crystalline dolomite with very small amounts of greenish quartzose chert, and a lower part characterized by a cherty horizon at the top thought to be a cryptozoan reef. The upper unit tends to be cavernous and is readily leached by ground water. The steep walled valleys of the Gasconade and Little Piney rivers are developed in this upper portion of the formation. Several other cherty horizons occur in the dolomite of the Gasconade formation. The chert is characterized by its white color, smooth to tripolitic texture, and the presence of oolitic and dolomoldic cherts.

Gunter sandstone member	535'	570'

The Gunter is essentially a basal sandstone which varies regionally from a sandy dolomite to a true sandstone. It does not crop out in the Rolla area. It is the base of the Ordovician System.

Cambrian System (Upper)		
Eminence formation	570'	830'

This highest Cambrian formation is a coarsely crystalline, thick bedded dolomite with sparing amounts of chert. It does not crop out in the Rolla area, but within it are formed many of the larger caverns and springs of the state.

Potosi formation	830'	1125'

This unit consists of a series of tan to brown, coarsely crystalline dolomites with cherts containing drusy, quartz-lined cavities. The Potosi carries most of the barite deposits of the state and upon being struck with a hammer gives off a distinctly fetid odor. This is the lowermost formation to contain chert in abundance.

Derby-Doerun formation	1125'	1225'

The Derby-Doerun is a light grey finely crystalline dolomite with very small amounts of silica and green shaly partings.

	From	To
Davis formation	1225'	1400'

Shale, silt, and very fine sandstone with glauconite and much limestone comprise the Davis. It contains the "salt and pepper sand", a mixture of glauconite and quartz sands, and several intraformational conglomerates.

Bonneterre formation	1400'	1650'

The Bonneterre is essentially a silty dolomite with glauconite and brown shaly partings. In some areas limestone beds and oolitic limestone are present. Algal reef limestones are locally present.

Lamotte formation	1650'	1745'

The Lamotte is a coarse and subrounded sandstone, in part arkosic which grades into arkose at the base. It contains some iron stained beds and red shale partings.

The base of the Lamotte was not reached in this well. Usually in the Rolla area this formation should be about 300 feet thick. The thickness varies from 0 feet to about 400 feet in Missouri. The Lamotte is of questionable upper Cambrian age and rests upon Precambrian metamorphic or igneous rocks in all cases. The depth to the Precambrian in the Rolla area is estimated to be 2,000 feet.

GROUNDWATER HORIZONS IN THE ROLLA AREA

By

Robert D. Knight, Senior Geologist

Rolla and the surrounding Ozark area enjoys an abundance of potable ground water. Shallow aquifers produce enough for ordinary small farm and domestic use. An abundance of water for the larger farms, country clubs, and small industries is found at a little greater depth and the still deeper water horizons furnish enough water for cities and the larger industries if wells are properly spaced.

In the upland areas, the average depth to the shallow water horizon (the Roubidoux formation) that is considered safe for human consumption is approximately 150 feet. The base of this formation is approximately 250 feet in depth. This formation consists of sandstone horizons between dolomite and some chert. The first major sandstone is at the middle of the formation and is approximately 25 feet thick. The second major sandstone horizon is at the base of the formation and is approximately 10 feet thick. All of these shallow wells should be cased to the top of the Roubidoux to exclude upper shallow waters.

The Roubidoux produces approximately 20 gallons of water per minute, which is enough for ordinary household and small farm use. Approximately 150 feet below the top of the underlying Gasconade is a 50 to 75 foot fractured chert horizon which produces approximately 25 gallons per minute and is an adequate water horizon for small farms and industries when large yields are not required. This is also a reliable zone where the Roubidoux is found to be near the surface and subject to contamination.

The Gunter, which is a 25 - foot thick basal member of the Gasconade, is approximately 300 feet below the base of the Roubidoux. In the Rolla area it is a slightly sandy dolomite, but the sand-dolomite ratio varies greatly throughout the state. This formation generally can be expected to yield 50 gallons per minute; however, one well in the area produces 100 gallons of water per minute.

Cities and industries in this area requiring large amounts of water drill to an approximate depth of 1050 feet through the Potosi formation. This formation is normally a dolomite with some drusy quartz ("mineral blossom") and a high porosity resulting from vugs. Because of this type of lithology and porosity the Potosi has an average yield of 450 to 500 gallons of water per minute. It has become a common practice to acidize the Potosi wells as a normal completion procedure. This generally increases production as much as 100 percent and sometimes as high as 150 percent.

Approximately 500 feet below the Potosi formation is the top of the Lamotte sandstone formation. This formation has been penetrated in several wells but due to its tight cementing material the Lamotte does not produce enough water to make it economically worthwhile to drill the extra 500 feet below the Potosi formation.

The City of Newburg well, approximately 8 miles southwest of Rolla, was drilled into the Lamotte sandstone and mineralized water was encountered. This anomalous and completely unexpected condition apparently resulted from a structural low (graben?) which trapped connate water.

THE CITY OF ROLLA WATER SUPPLY

By
Dale L. Fuller, Senior Geologist

The two principal problems in the development of a water supply for Rolla are construction of wells so that they will be free of contamination and obtaining adequate yield. To exclude contaminated surface water it is now the custom to case just through the Roubidoux formation and to pressure grout with cement returns to the ground surface. Two wells have shown contamination. Well number 3, originally cased to a depth of 395 feet and not pressure grouted, had become contaminated by 1959, 22 years after it was drilled. Recasing to a depth of 494 feet excluded the source of contamination. Well number 8, with 292 feet of casing, was producing contaminated water samples in less than four years after its completion. In 1958 this well was recased to a depth of 509 feet and no improvement was made in the quality of the water. Since it was not practical to case still deeper, a retention tank was constructed and the water from this well is chlorinated before it is put into the distribution system. The following data on Rolla city wells are summarized in tabular form:

	Date Drilled	TD	Bottoms In	Casing	SWL	Yield GPM	DD	Specific Capacity	Remarks
1	1907	930	Plugged		90'	200			
2	1929	1710	Lamotte	109'	270'	250	70	3.57	Acidized 1946
3	1934	1745	Lamotte	494'	291'	440	30	14.33	Recased 1956
4	1942	1175	Derby-Doerun	392'	245'	300	28	10.72	
5	1947	1078	Derby-Doerun	231'	165'	540	80	6.75	
6	1947	1150	Derby-Doerun	280'	245'	580	50	11.60	
7	1951	1215	Derby-Doerun	315'	378'	585	80	7.31	
8	1954	1125	Derby-Doerun	509'	240'	550	130	4.23	Recased 1958 Acidized
9	1960	1595	Lamotte	280'	250'	210	130	1.61	Acidized

Three of the city wells have low yields in terms of the other five. Well number 2 and well number 8 have been acidized in an attempt to increase their yield. The yield of well number 2 remained unchanged. The specific capacity of well number 8 was increased from 2.77 to 4.23. Well number 9, after having penetrated the Potosi formation, had a specific capacity of approximately 1.0. After acidizing, the specific gravity remained essentially unchanged. It was then deepened approximately 500 feet and again acidized. The resulting capacity is 1.61.

If the practice of proper spacing and systematic planning of the well field is continued in the Rolla area, there is no reason why the City should face a groundwater shortage in the forseeable future. Coupled with a planned program for the public water supply should be a continuation of the same program for any industries contemplating location in the area. Such industries anticipating large water consumption from privately owned wells are encouraged to work with the Survey in planning well locations and completion methods.

THE MINERAL INDUSTRY OF THE ROLLA AREA

By
William C. Hayes, Assistant State Geologist

Iron and Pyrite

Many of the sinks or sink structures in the Rolla area contain deposits of hematite and goethite and pyrite and marcasite. Most of the sink structures that contain economic deposits have been found near the Gasconade-Roubidoux contact. According to Grawe (1945, pp. 184-192), the original deposit consisted of an iron sulfide, probably a black powdery substance, that settled to the bottom of a sink structure or cavern and perhaps ultimately filled this cavity. The original iron sulfide probably consisted of both marcasite and pyrite. Most of the iron is thought to have been derived from the Pennsylvanian sediments that once covered the area. After the uplift in Tertiary and probably Quarternary times, deposition was halted and weathering of these deposits was begun. This oxidized the pyrites to hematite and some goethite. Most of this hematite was probably a red, fine-grained ore, and later recrystallization produced a dark blue to black specular hematite. Later oxidation changed some of the hematite to goethite. During erosion of the deposits, most of the soft red oxidized material was removed and the denser and harder more resistant specularite masses were left behind. This latter type of material is referred to by the miners as blue ore. These deposits have been referred to by Crane (1912, pages 84 to 106).

Some of the better known mines in the area are the Acid Mine near Stanton, Franklin County; Christy Bank near Butts in Crawford County; the Cherry Valley Mines near Steelville, Crawford County; and the Moselle No. 10 in Phelps County. The Acid Mine, Cherry Valley Mine, and the Moselle No. 10 were originally mined for the iron, but later were mined for the pyrites. The Moselle No. 10, located about ten miles south of Rolla, was opened originally in 1872. The mine was idled from the early 1900's to about 1933 when it was reopened with the thought of shipping the blue iron ore to steel furnaces in Granite City, Illinois. In 1934 production of pyrites began from this mine and in 1938 production was up to 3,000 tons a month. A cave-in halted operations during the latter part of 1939 when the mine was abandoned.

The Cherry Valley mines consisted of two large open pits known as the Cherry Valley No. 1 and the Cherry Valley No. 2. Iron ore has been mined from both, but the No. 2 has produced considerable pyrites. These pits were being worked as early as 1872 (Schmidt, 1872, pages 132-133).

By 1917 interest had developed in the pyrites and during 1918 approximately 3,000 tons were mined from Cherry Valley No. 2. Pyrites continued to be mined and some iron ore mined until 1939. In 1942 some of the dump material was treated for a period of about 6 months to recover the iron ore. The Cherry Valley No. 2 is the largest and most productive of all the sink structures in the Ozarks. The pit is some 900 feet long in a north-south direction, 500 feet wide, and ranges from 60 to 100 feet deep (Grawe, 1945, page 246). Drilling at Cherry Valley No. 2 indicates that the sink structure not only extends into the Gasconade, but through the underlying Eminence formation and into the Potosi.

The following historical data are taken from "The Iron Industry of Missouri", by A. B. Cozzens:

The first pioneer furnace in Missouri containing an output worthy of mention was the Meramec furnace established at the famous Meramec Spring (Beckman and Hinchey, 1944, pp. 94-97) near St. James in 1829 by Thomas James and Samuel Massey of Ohio. This was a very important iron furnace in this area in the early days and exerted considerable influence on the location of early roads of the state. As a result of the Jay Cook panic in 1876 the furnace was abandoned. The heirs of Thomas James, particularly the great granddaughter, Lucy Wortham James, reacquired much of the land-holdings in the area in 1912 and established the James Foundation in 1941. The James Foundation has restored many of the early buildings of the area and the furnace , and has provided a park which also serves as a trout hatchery and well-known trout fishing area of this part of the Ozarks.

The Ozark furnace was built two miles west of Newburg in 1873 by the son of Thomas James, William James, and by James Dunn. This was operated through 1874 mainly from ore from the Beaver Creek mine located some six miles southwest of Rolla. Most of the ore was of the soft red hematite in which there was some specular hematite and goethite. In 1874 the Midland furnace was established one mile north of Steelville. It was rebuilt in 1877 and had the first cylindrical stack in this part of the country.

In 1880 the Nova Scotia furnace was established in Salem in Dent County. It was the largest stack in the United States at that time and treated 150 to 175 tons of ore per day. It operated for some six months, and then because of the shortage of ore and technical difficulties, was abandoned.

The well-known Sligo furnace was one of the most successful later charcoal furnaces in Missouri, being established in Dent County in 1880. It was rebuilt in 1891 and had some 72 kilns for charcoal making and also produced alcohol. For a short time ore from the Lake Superior district was treated. It operated through the First World War and closed in 1921.

CLAY

Rolla is situated on the southwestern corner of the central Missouri fireclay area from which refractory grade clays have been mined since 1883 when the first firebrick plant was started near Vandalia in Audrain County. The major deposits in the Rolla area are to the north and east of Rolla, mainly north of U. S. Highway 66 and east of the Gasconade River. There is a small area of Pennsylvanian clays south of Steelville near Wesco in Crawford County.

The refractory clays may be divided into four main types (McQueen, 1943, pp. 149-172): (1) Flint clay, which is a very hard non-plastic, smooth-textured clay, breaking with a conchoidal fracture; (2) Burley clay contains rounded particles or lumps ranging in size from small shot-like particles to pisolites up to an inch in diameter; (3) Diaspore clay with a high aluminum content is confined essentially to the southern part of the clay district and occurs chiefly in sinkhole type deposits; and (4) Plastic or Semi-plastic clay, ranging from a soft to hard, somewhat semi-flint fireclay with a characteristic plastic texture.

The clays are associated with sink structures in the Ordovician dolomites which have been partly filled with the clay and other Pennsylvanian sediments. The Cheltenham clays are considered to be Atokan by W. V. Searight, Principal Geologist of the Missouri Geological Survey.

Numerous fireclay pits have been located in the vicinity of Rolla, best known of which is the Forbes pit approximately one mile north of the Rolla city limits.

Much of the fireclay of the district is trucked to Owensville where the General Chemical Division of Allied Chemical Corporation has a chemical plant.

STONE

Crushed stone. -- The location of Rolla near the center of the Ozark uplift results in it being some distance in any direction from limestone suitable for agstone. Instead of limestone, the Ordovician dolomites, particularly from the Jefferson City formation, have been used in much of of the area for crushed agricultural lime. Two quarries are currently being operated for crushed stone; the Bray quarry two miles south of Rolla on Highway 63, and the Nivens quarry seven miles southeast of Rolla on Highway 72. Both of these quarries are in the Jefferson City formation.

Building stone. --Much of the local building stone is obtained from the Jefferson City formation and from the Roubidoux formation. The "Quarry Ledge" in the Jefferson City formation is a well-known building stone in the area and many small quarries have been opened in the vicinity of Rolla. Several of the older buildings on the School of Mines campus have been constructed from stone obtained from the "Quarry Ledge". The old School of Mines quarry located some two miles southwest of Rolla provided stone for much of the building on the campus (Buckley and Buehler, 1904, pp. 101-102).

In many places the sandstone beds of the Roubidoux formation split into slabs two to four inches thick. Many of these are used as a flagstone type building stone and for exterior walls in which the slabs are placed in a vertical position. Some of the thicker sandstone beds are shaped and used in the horizontal position in some buildings.

SAND AND GRAVEL

Sand and gravel bars occur at many points along the Little Piney and Big Piney rivers and along the Gasconade River. Many of these are used locally, but some of the deposits are extensive enough to be worked commercially. Just off Highway 66 near the Jerome turnoff is a small sand and gravel operation. The Little Piney Sand Company is dredging from gravel bars of the Big Piney River near the final stop of the trip. Some of the deposits along the Gasconade and Big Piney are fairly extensive and are remarkably consistent in their sand and gravel content and size of grain.

MISCELLANEOUS

Rolla is situated midway between the main barite producing area of the state centered in Washington County to the east and the Central Mineral District (barite-lead-zinc) in the Lake of the Ozarks area of Morgan, Moniteau, Miller, Cole, and Camden counties to the northwest. Small crevices and fractures that contain some barite are known in Maries and Miller counties to the northwest of Phelps County. The local term "tiff" has replaced the term barite in much of the mining area of Washington County. In the Tri-State district of Missouri, Oklahoma, and Kansas, calcite is frequently called "glass tiff".

Within a 25-mile radius of Rolla there are many small clay-filled crevices and fractures containing galena and some sphalerite and pyrite (Lee, 1913, pp. 96-102). There are no known commercial deposits of lead or zinc in this area.

Approximately 40 miles to the southeast of Rolla, extensive lead exploration is in progress from the village of Viburnum southward. A 3,000-ton per day mill has been constructed at Viburnum by the St. Joseph Lead Company. The milled ore is trucked to Bismarck where it is taken by rail to St. Joseph Lead Company's smelter at Herculaneum, some 20 miles south of St. Louis.

A ground magnetic anomaly was noted near the town of Bourbon by the Missouri Geological Survey in 1930 and was drilled by the U. S. Bureau of Mines in 1943 and 1944. Aeromagnetic surveys conducted in 1948 disclosed a large anomaly in Washington County southeast of Sullivan. Exploration drilling by the St. Joseph Lead Company disclosed a magnetite deposit in the Precambrian from depths of 1300 feet below the surface extending to a depth of 2800 feet. The Pea Ridge iron ore deposit is now under development by the Meramec Mining Company, a joint venture by the St. Joseph Lead Company and the Bethlehem Steel Corporation.

ROAD LOG

By
Thomas R. Beveridge, State Geologist
and
William C. Hayes, Assistant State Geologist

STOP 1. Road cut on U. S. Highway 66 at the Vichy Road overpass at Rolla (see frontispiece), NE 1/4 SW 1/4 NE 1/4 sec. 2, T. 37 N., R. 8 W., Phelps County.

The following description is quoted from Muilenburg and Beveridge, (1954, pp. 14-15).

"Excavation for the relocation of Highway 66 uncovered an excellent example of a filled sink structure. The sink structure at this point resulted from the collapse of the roof of a cavern in the Jefferson City formation. Pennsylvanian sandstone and shale overlying the Jefferson City was let down gradually into the cavern opening as solution progressed. The central part of the "fill" is almost horizontal, parallel to the highway but has a considerable dip to the south. At the east end, the Pennsylvanian strata show strong dips as the result of drag as the roof settled. At the west end, the drag is not as conspicuous. The bottom of the sink fill which was visible before the road construction was completed, consists of broken masses of Jefferson City cotton rock. The depth of the sink, from the top of the south bank to the bottom of the road cut is 65 feet. This sink is one of several in the immediate vicinity. Another one, a quarter of a mile farther southwest along the highway, shows sandstone without apparent bedding in the center of the fill. Pockets of flint clay were encountered when the road cut was excavated. There are indications of another one about 50 yards south of the overpass on Vichy Road where massive Pennsylvanian sandstone crops out in the east bank of the road. At the intersection of U. S. Highway 63 and Vichy Road, 400 yards south of the overpass, flint clay occurs in the ditch at the south side of the highway. Several prospect holes drilled in the wooded area now part of the Catholic church property adjoining the highway showed from 15 to 30 feet of highly ferruginous flint clay."

A sketch of this filled sink by John W. Koenig is the frontispiece of a later report by Searight (1959). Filled sink structures in the Rolla area have been described in detail by Lee (1913), McQueen (1943), Grawe (1945) and Bretz (1950).

0.4 Pennsylvanian-filled sink on south side of highway.

0.5 Junction with Highway E.

1.2 Missouri State Highway Patrol buildings to right.

1.8 to 1.9 Cherty dolomite with some green shale beds on both sides of road. Some of this dolomite is of the argillaceous very fine-grained variety colloquially called "cotton rock" in the Ozarks.

2.0 Junction with City Route 66.

2.4 "Quarry Ledge" dolomite in low cut on the left. Cullison (1944, pp. 13-19 and figures 1 & 2) proposed that the "Quarry Ledge" be called the School Mine Ledge, because it crops out conspicuously at the experimental mine of the Missouri School of Mines and Metallurgy, but the proposed name, despite its merits, has had difficulty in winning recognition because the older appellation has become so well established. This ledge of pitted dolomite was very popular in the past for dimension stone and may be seen in many of the older buildings in Rolla and surrounding areas. It is also a most convenient unit for field mapping in the area because the top of the Roubidoux formation is approximately 30 feet below it. Long abandoned quarries to the south of this outcrop furnished much of the stone used in the area. Cullison, in the same publication, proposed that the Jefferson City be raised to the rank of group and divided into two formations, the Rich Fountain and the unconformably overlying Theodosia, but complete acceptance of this proposal has likewise not been reached. Overlying the Jefferson City is the Cotter formation which in general tends to be more thin bedded than the Jefferson City and contains sandstone units of considerable lateral extent. The stratigraphy of the Cotter has been described by Cullison (1930) and Grawe and Cullison (1931). Because exposures are poor and fossils are scarce over great areas of the Ozarks, the Cotter and the Jefferson City are often lumped together in field mapping under the single name of Jefferson City.

2.5 In nearly all directions one can see accordant elevations conforming to the one we are now on. These surfaces are approximately the top of the Roubidoux formation and the tendency of this relatively resistant formation to form such a surface has been well described by Lee (1913, pp. 31-52-54).

2.8 to 2.9 Roubidoux sandstone to right in road cut. Heller (1954) has discussed the stratigraphy and paleontology of the Roubidoux in detail. In isolated exposures it is not always easy to differentiate the Roubidoux sandstones from sandstones of the stratigraphically higher Cotter formation, a problem which is of course aggravated in areas of faulting.

3.2 Cross-bedded and ripple-marked Roubidoux sandstone well exposed in bed of small stream on right. In addition to being a widespread aquifer, the Roubidoux has long been used as a source of dimension stone where the sandstone is sufficiently casehardened to be durable. In the past it was stood on edge to form a crazy quilt pattern, but many of the newer buildings are being built from sawed strips of Roubidoux laid parallel to the bedding.

3.5 Old Corral farm to right. This farm is so-named because it was a corral for horses of the Union troops which were camped along the approximate route we are now following. Rolla was a railhead during the War Between the States (also called Civil War) and the numerous springs from this point on downstream were ideal for campsite areas.

3.9 Roubidoux sandstones on left followed by spring house at Martin's Springs immediately west of outcrop. To the right in the stream bed, Gasconade dolomites are exposed. This is essentially a Gasconade-Roubidoux contact spring. In 1935 after an unusually heavy rain it had a flow of 1.3 second-feet (Beckman and Hinchey, p. 92) and .13 second-feet in 1946 (Bolon 1952, p. 914).

Springs are considered such an important natural resource in Missouri that the Missouri Geological Survey in cooperation with the Water Resources Branch of the United States Geological Survey published a volume on the large springs of Missouri in 1944 (Beckman and Hinchey). This volume has proved to be very popular with the layman as well as useful in answering other inquiries such as sources of water for industry, trout hatcheries, and cooling purposes. A first magnitude spring is defined as one which has an average flow of 100 second-feet or more. The Snake River Basin in Idaho is cited as having 15 such springs and the Ozark region of Missouri is in second place with 12. The Missouri publication describes 195 large springs and we now know that there are more of a similar size which have not been described, as well as innumerable smaller springs. The spring report is still available and may be obtained from the Missouri Geological Survey.

4.2 Roubidoux dolomites on right. Because Cambro-Ordovician dolomites in the Ozarks are monotonously similar and very difficult to identify in isolated outcrops or in well cuttings, the Missouri Geological Survey has for many years studied cuttings and correlated isolated exposures using the insoluble residue technique devised by H. S. McQueen. This technique is described in publications by McQueen (1931, 1937) and Grohskopf and McCracken (1949). It consists of dissolving the soluble material in the cuttings using diluted hydrochloric acid and microscopically studying the remaining insolubles which have characteristics peculiar to various stratigraphic horizons such as types of chert and forms of quartz, percentage of silt and shale, etc.

4.4 Roubidoux sandstones on right show tendency of formations to dip into the valleys in the Ozarks. This phenomenon which is probably in part the result of solution, poses a problem in field mapping of distinguishing tectonic dips from solution structures. Similar tendencies of the Roubidoux to follow the topographic slope (or vice versa?) may be seen for the next mile. The Roubidoux-Jefferson City contact is at the contact of the highest thick sandstone bed with a nodular tripolitic white to smooth gray chert.

4.5 STOP 2. Collapse filling in sink developed in the basal part of the Jefferson City formation, SW 1/4 SW 1/4 sec. 8, T. 37 N., R. 8 W., Phelps County. This structure is visible on both sides of the road but is best studied on the right hand side where large blocks of the "Quarry Ledge" are easily identified. It is rather difficult for the writers to agree with Bretz (1950) who considers that pre-existing sink holes filled by collapse is not the case and that filling was by "..... slow subsidence underload ...." and that "cavity-making and fill-making therefore were contemporaneous." (p. 795). The visible portion of this filled sink is in the Jefferson City, of which a maximum of 23 feet is exposed in this cut.

4.7 to 5.5 Exposures of Roubidoux sandstone. Cross-bedded Roubidoux sandstones are well-exposed on the loop of old Hwy. 66 a quarter of a mile to the south.

5.8 Thin-bedded Jefferson City dolomites.

6.4 Junction with Highway T.

7.4 to 7.9 Intermittent exposures of Roubidoux sandstone.

8.2	Roubidoux sandstone on right.
8.25	Junction with Highway C.
8.7	Roubidoux dolomite on right followed by spotty exposures of Roubidoux residuum for next mile.
10.1	Roubidoux sandstone to right and left.
10.4 to 11.9	Spotty outcrops of Roubidoux dolomite, sandstone, and chert.
12.4 to 12.5	Roubidoux sandstone on both sides. (Beacon Hill).
13.0	Poorly exposed Gasconade cherts.
13.1	Cross Little Piney River.
13.5	Junction with Highway D.
13.6	Gasconade dolomite on right.
13.8	Stony Dell Resort. The columns of the tavern and filling station are built of Roubidoux sandstone alternating with blocks of Precambrian granite from southeastern Missouri. It has been reported that the fireplace in the tavern is faced with beautiful specimens of drusy Potosi quartz, as well as excellent specimens from the Joplin Lead-Zinc District such as galena crystals, sphalerite crystals, dogtooth spar, dolomite with chalcopyrite and calcite and with bladed barite from Washington County, Missouri. Ripple-marked Roubidoux sandstone is well exposed in the wall opposite the swimming pool. The pool is fed by a spring-fed stream between the two highway lanes. Professor A. C. Spreng (oral communication) reports a fault with more than 20 feet displacement in the Gasconade and Roubidoux formations which form the high ridge on the right. The well at Stony Dell is artesian and flowed 30 g. p. m. when drilled in 1936. This well is 230 feet deep and bottoms in the Eminence.
13.9 to 14.4	Exposures of Gasconade dolomite on right.

14.6 Cryptozoan reef cherts of the Gasconade at right.

14.8 Roubidoux sandstone residuum lying on dolomite very close to Gasconade-Roubidoux contact on right. The Gasconade-Roubidoux contact is cleanly exposed in a cut on the north side of the east-bound lane to the south.

14.9 Roubidoux sandstone at right.

16.0 Motel at right faced with Roubidoux sandstone.

16.6 Powellville Restaurant faced with Roubidoux sandstone and blocks of Northview (Kinderhookian) siltstone with well developed worm burrows and cauda-galli (rooster tail) markings.

17.3 Turn right on gravel road to Boiling Spring.

17.5 STOP 3. SW 1/4 sec. 34, T. 37 N., R. 10 W., Phelps County. Conical Sink on south (left hand) side of road and Slaughter Sink one tenth of a mile north of road. The bottom of Conical Sink is 100 feet below road level. Walk north over Roubidoux sandstone slabs to Slaughter Sink. This sink is 175 feet deep, measured from the northwest rim, and approximately a quarter of a mile in maximum diameter. The elevation of the bottom of the sink is approximately 816 feet above sea level, or 145 feet above the Gasconade River. It is of interest to note that the log of the Powellville well half a mile north and slightly east of this sink had a static water level of 807 feet above sea level at the time it was drilled. The log of the Powellville well No. 2 is as follows:

Location - NE 1/4 SE 1/4 NW 1/4 sec. 34, T. 37 N., R. 10 W., curb elevation 1019, logged by R. D. Knight, 1954.

Roubidoux residuum	0 to 55 feet
Roubidoux formation	55 to 100 feet
Upper Gasconade	100 to 165 feet
Lower Gasconade	165 to 360 feet
Gunter member of Gasconade	360 to 385 feet
Eminence	385 to 412 feet (T. D.)

This well has 94 feet of casing and yielded 10 gallons per minute.

Slaughter Sink is developed in the Gasconade formation, as is Conical, and the upper rim is Roubidoux which has been breached through collapse as the Gasconade was dissolved away. King Sink, which is very similar in size, scenic virtues, and geologic setting, is seven miles south and slightly east of Slaughter. It is located in the SW 1/4 sec. 36, T. 36 N., R. 10 W. These sinkholes are of interest to botanists because asylum flora are often preserved in the uncultivated bottoms. Slaughter and Conical sinks are along a line trending slightly east of north as shown on the Dixon 7 1/2 minute quadrangle.

RETURN TO CARS and proceed westward on road to Boiling Spring. Take fork to right at

18.0 Onyx Cave is on the left hand side of the road a short distance southeast of Boiling Spring. This cave has been discussed by Bretz (1957 pp. 411-412). A 126-foot shaft was opened in the early 1900's for the mining of cave onyx. This shaft, with large slabs of the cave onyx lying around it, is a short distance to the left of the road at

18.4 The project was not economically feasible and met the fate of similar projects in other onyx caves of which Bretz names six in Missouri.

18.9 STOP 4. Walk to lookout over Boiling Spring, NW 1/4 sec. 33, T. 37 N., R. 10 W., Pulaski County. The two flow measurements given on this spring by Beckman and Hinchey (1944, p. 63) were identical. The flows in 1923 and 1932 were 65 second-feet or 42 million gallons per day. A condition of subterranean stream flow which may be similar to Boiling Spring is described in the following resume' by Harry C. Bolon of the U. S. Geological Survey:

SUBTERRANEAN DRAINAGE OF THE GASCONADE RIVER BETWEEN HAZLEGREEN AND WAYNESVILLE, MISSOURI

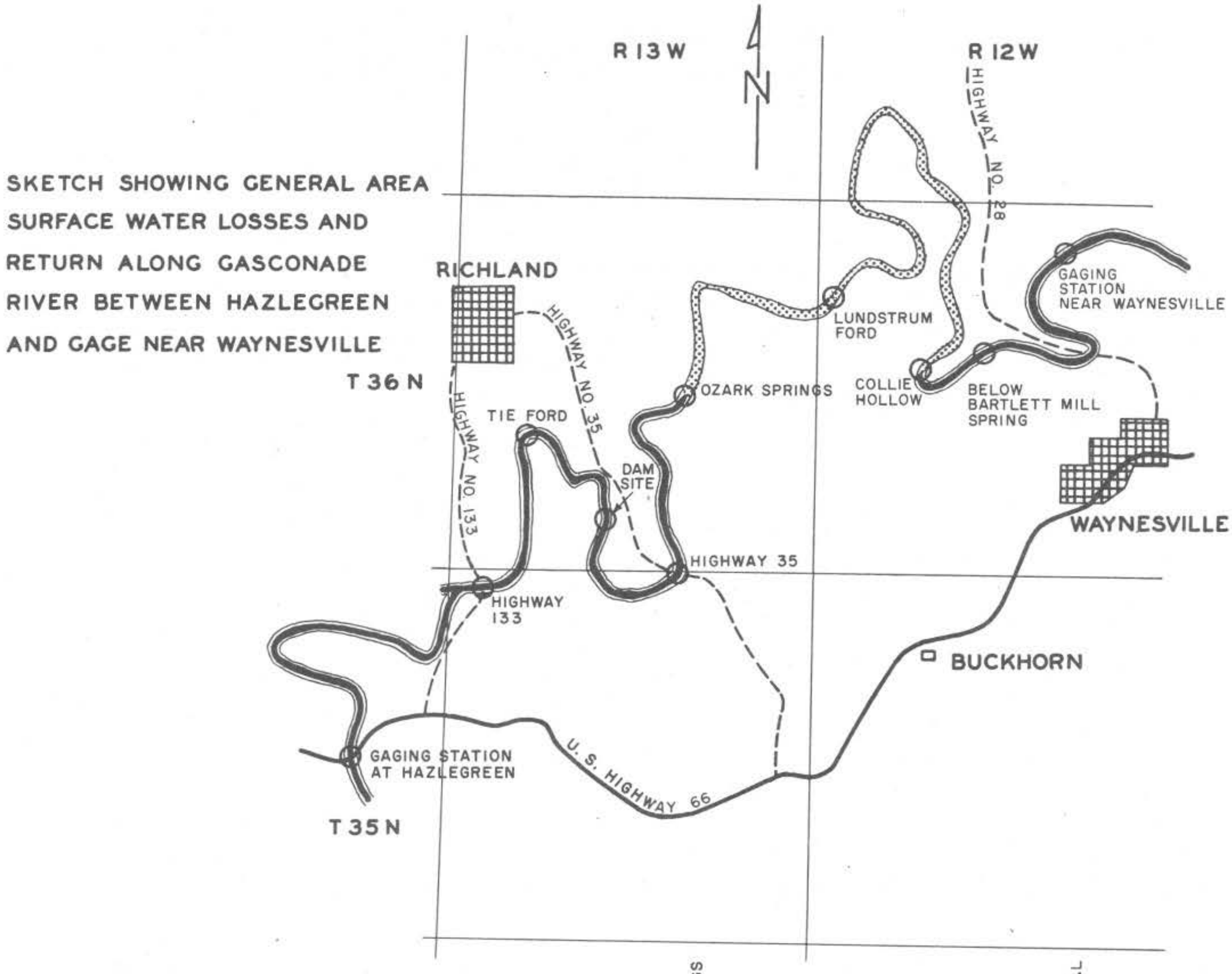
By
Harry C. Bolon, District Engineer, Surface Water Branch,
U. S. Geological Survey

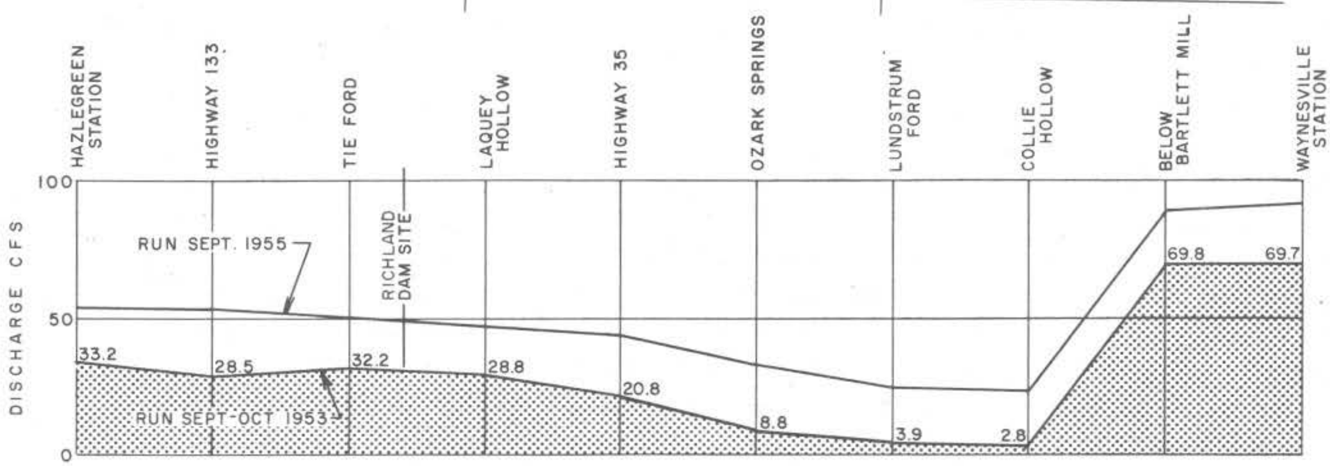
In the fall of 1953 the time was appropriate to determine several facts concerning the flow of the Gasconade River and tributaries, one of which was to have on record the flow at various points during a serious drought. The flow ~~was~~ very steady over the entire basin and near a record low, as may be seen by the following table:

Stream	Period of Record	Minimum on Record		Sept. 16, 1953
		Date	Flow(cfs)	Flow (cfs)
Gasconade - Hazlegreen	1929 to date	Aug. 1936	18	35
do - Waynesville	1921 to date	Aug. 1936	50	70
do - Jerome	1923 to date	Sept. 1936	294	370
do - Rich Fountain	1921 to date	Aug. 1934	276	390
Big Piney - Big Piney	1921 to date	Aug. 1934	75	110
Little Piney - Newburg	1928 to date	Aug. 1936	24	45
James River - Galena	1921 to date	Aug. 1936	22	50

Two parties were organized and on September 17 and 18 about 50 measurements were made. The results caused us to make 13 additional measurements below Hazlegreen on the main stem and tributaries.

It was startling to find that the Gasconade River is, to use an Ozark coloquialism, a "sinking river." Between Tie Ford (see map) near Richland and Lundstrum Bridge southeast of Swedeborg the flow diminished from 32.2 to 3.9 cfs with most of the loss occurring between Mokane Bridge and Ozark Spring. Other measurements showed that within the 3/4-mile reach just below the mouth of Collie Hollow to just below Bartlett Spring at Pippin's Lodge the flow increased from 4.3 to 69.8 cfs. Most of this increase could be seen boiling up through the gravel in and adjacent to the channel. Other flow issued from Creasy, Falling, Bartlett Mill, and other deep-rooted springs, so called deep-rooted because of their temperature of 56 or 57 degrees. The temperatures of the gravel boils were about 5 degrees warmer, which implied that the water had not traveled far enough underground to assume deep-ground temperatures. Water cress, which usually identifies what is normally thought of as a true spring, is absent at these boils.





GRAPHICAL PRESENTATION OF LOW WATER FLOW OF THE GASCONADE RIVER — HAZLEGREEN TO WAYNESVILLE, MO.

At Ozark Spring an appreciable flow from the Gasconade can be seen entering a sinkhole at the west side of the river immediately north of the approach to the bridge.

Additional series of measurements were made through this reach which implies that the underground channel, or channels, carry a relatively constant flow (from 18 to 30 cfs) regardless of stage of the main river.

It so happens that our gaging stations at Hazlegreen and below Waynesville straddle this reach and, therefore, are not affected by these underground channels. However, what happens in this reach of the Gasconade River causes us to believe similar conditions might well exist anywhere in the carbonate area of the Ozarks, and in fact does occur on Osage Fork of the Gasconade River above Big Spring near Morgan. There, too, the Osage Fork flows, then goes dry, for a stretch just above Big Spring, some distance above Missouri Highway 5.

The area which Mr. Bolon describes is some 15 miles upstream as the crow flies, but much greater than that distance in terms of river miles because of the meandering course of the Gasconade. The Gasconade River has been cited often as an exemplary stream for entrenched meanders in the Ozarks. Five miles northwest of Waynesville, a loop of the Gasconade is five miles long and the cutoff distance would be only two tenths of a mile (Richland 15' quadrangle). This stream is also a favorite for "float" trips -- a method of fishing especially popular in the Ozarks. Floats are generally made in flat-bottomed boats capable of navigating the swift, shallow, and sometimes treacherous shoals. Outboard motors for speeding the trips through eddies are optional. The "average" (a somewhat meaningless term in this case) length of a day's float is ten to fifteen miles. A float may last several days with night camps on gravel bars. The experienced floater is prepared for both casting and fly fishing and often carries a gun for shooting frogs in season.

RETURN TO U. S. HIGHWAY 66 and turn right onto the highway at

20.6 As we leave an area of closely-spaced solution features, it is in order to mention some others in the state. Many of our streams follow courses which are in part surface and part subsurface so that flowing water may suddenly disappear from sight and reappear downstream, as in the example cited by Mr. Bolon. Other such cases are described by Dake and Bridge (1923).

One of the Ozark's most spectacular and scenic examples is Sinkin Creek which follows a natural tunnel in a cutoff through a spur in Shannon County. This tunnel has been described in detail by Bridge (1930, p. 35). Sinkin Creek derived its name from its indecision about following a surface or subsurface course. Missouri is known to have at least two dozen natural bridges and tunnels and a card index of these unusual features is on file at the Missouri Geological Survey. In addition, the state has some unusual sink phenomena such as Grand Gulf in Oregon County west of Thayer near the Arkansas line. Grand Gulf has been described by Beckman and Hinchey (pp. 90-91) and Bretz (1956, p. 355). Grand Gulf is an elongated collapsed cavern more than half a mile in length, from 50 to 200 feet wide, and more than 120 feet deep. Where collapse has not been complete it is spanned by a natural bridge.

Unusually deep and precipitous sinkholes are notorious habitats of the Devil, as evidenced by Devil's Icebox in Boone County, Devil's Well in Shannon County, and Devil's Den in Webster County, as well as another Devil's Den in Howell County.

Although solution phenomena have certainly posed problems in contamination of water wells and have required hundreds of feet of casing for some individual wells, one solution feature has been used as a natural pipeline. The City of Springfield obtains part of its water from a spring-fed reservoir. Water from this reservoir is piped into the bed of South Sac Creek at a point where the stream flow disappears in a fissure. The water from the reservoir flows through this fissure to a large spring at the city pumping station three miles westward where it is treated for consumption. It was suspected that not all of the water from this fissure was recovered at the spring and chemical tracers were introduced. These tracers showed that the fissure divided and that part of the water continued southwestward for another mile to be recovered at a spring feeding another city reservoir. How many municipalities have such a natural underground distribution system?

21.1 Roubidoux sandstones to right.

21.2 Junction with Highway J.

21.3 Short stretch of blacktop. This short stretch has been a perennial engineering problem because the fill material contains a relatively plastic clay which has tended to flow and cause gradual settling of the highway. The blacktop is to eliminate the resulting dip. Residual clays in the Ozarks can create engineering problems because of their tendencies to flow when wet and to shrink greatly when dry. Modern methods of fill construction have eliminated some of the failures, but not all of them.

21.9 to 22.5 Intermittent exposures of Roubidoux sandstone.

22.9 Gasconade dolomite to left with very uneven surface. The depressions visible in this surface were apparently created by solution and are filled with residual material which tends to flow when lubricated by ground water. As a result, it has been a routine part of maintenance for many years to remove the material flowing from these filled depressions into the ditch.

23.1 BEAR RIGHT on Hooker road which is the loop of old Highway 66. Straight ahead is the deep cut on Highway 66 which is portrayed in many of the Ozarks picture cards. This cut is in the Gasconade formation with the Gasconade-Roubidoux contact exposed in the upper part. It has long held the record for being the deepest cut in the Ozarks, but it is now yielding this honor to a cut at Pacific, Missouri for Interstate Highway 44.

23.7 Gasconade dolomite to right.

24.3 Cross bridge.

24.7 Calvary Baptist Church to left.

24.9 STOP 5. Long-range view of Gasconade-Roubidoux contact in west bluff of Big Piney River, NW 1/4 sec. 7, T. 36N., R. 10 W., Pulaski County.

This is an excellent opportunity to see the variation of vegetation with underlying soil and rock types. Sycamores are prominent in the bottom lands and cedars are especially fond of the bare dolomite which occurs at the top of the Gasconade formation. The Gasconade forms the essentially vertical bluffs with the Roubidoux contact being represented by a much more gentle slope. Pine trees grow well on the sandstones of the Roubidoux, but where the pine has been cut the oaks tend to take over. Truncated spurs are especially well-developed in many of the Ozark streams and an excellent example of one may be seen straight ahead. The Big Piney River received its name, as did the Little Piney, from the original pine forests on the Roubidoux sandstone in the upper drainage area of these streams to the south.

25.4 STOP and turn right on U. S. Highway 66.

25.6 Cross Big Piney River.

25.8 Roubidoux-faced cabins to right in valley.

26.8 Slides have been a problem in this stretch of highway because of inadequate provision for drainage in the original design. The fill material, as well as some of the original undisturbed residuum, was lubricated by water in the south ditch of the east-bound lane and the shoulder of the west-bound lane was destroyed by sliding at several localities.

26.6 Junction with Missouri Highway 28.

26.8 CAUTION. TURN LEFT onto gravel road.

27.2 Sand and gravel plant to left.

27.4 Turn right before crossing railroad tracks.

27.5 STOP 6. Residuum and highly polished gravel locality, NW 1/4, SW 1/4, NE 1/4 sec. 24, T. 36 N., R. 11 W., Pulaski County.

The gravels on the right are very highly polished in the lower part of the exposure. Pebbles and cobbles with similar high polishes have been found in Ozark caves and in some of the more boisterous springs. Similar very highly polished material has been encountered in well cuttings in areas of "open ground" where sinkholes, caves, springs, and solution channels are common. The exact mechanics of polishing this material is not known, but in a spring environment it may be polished by running water, or in a cavernous environment by running water in conjunction with the very fine unctuous cave clays which might act as a jeweler's rouge.

To the left of these very highly polished pebbles is an exposure of unusually thick residuum and still farther to the left, or south, is a normal section of the Gasconade formation. Roubidoux sandstones are preserved in the upper part of the residuum section and the cryptozoan chert reef is represented by large blocks of chert in the lower part. Shanghai Spring is a quarter of a mile to the south of this locality on the same side of the road.

Turn cars around and return to highway.

28.3 STOP and turn right on U. S. Highway 66.

28.4 BEAR RIGHT on Highway V.

28.7 Gravel operation visible to right in bottom lands of the Big Piney River.

29.0 Roubidoux sandstone on right.

29.1 Roubidoux sandstone on left.

29. Scenic pull out. **Park cars here for stop 6.**

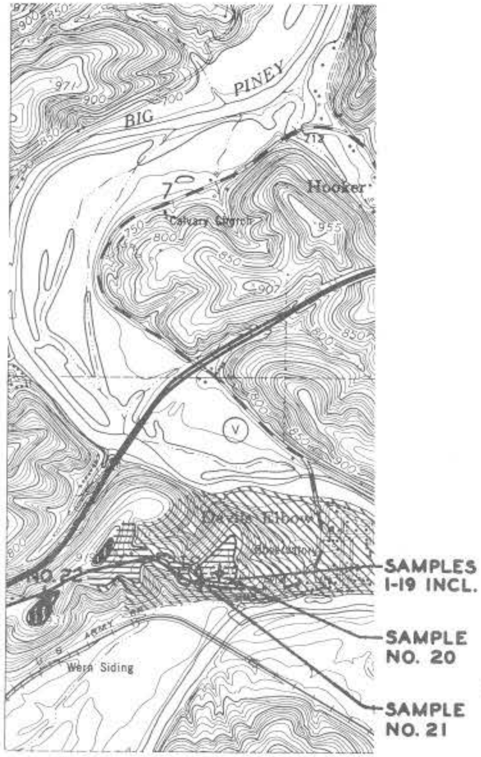
29.5 STOP 6. NW. 1/4, SE 1/4 sec. 18, T. 36 N., R. 10 W., Pulaski County. Residual material in contact with pinnacles of Gasconade dolomite.

This section has been studied in detail by K. H. Anderson, Subsurface Geologist of the Missouri Geological Survey. The accompanying diagram which he prepared shows that the 22 feet of residue material exposed represents approximately 260 feet of original bedrock section, including part of the Gasconade formation, all of the Roubidoux formation, and the lower part of the Jefferson City formation.

This exposure represents a natural insoluble residue and the residual material was compared with insoluble residues from a nearby well to determine the amount of original section. In addition to demonstrating how solution can remove tremendous amounts of carbonates, this exposure also shows how the insoluble material can retain much of its bedding as it is let down.

Such conditions create field mapping problems in parts of the Ozarks such as Dent County to the east of Phelps County. In that county much of the surface rock is Roubidoux sandstone, yet where bedrock is exposed it may be as old as Eminence with all of the Gasconade dolomites as well as the original Roubidoux dolomites removed by solution. The problem is thus posed as to whether to map the area as Roubidoux because of the preponderance of Roubidoux sandstone material, or to depict the highest preserved bedrock section which in some cases would be Eminence. In one particular area the problem was solved by making two geologic maps; one portrayed the youngest bedrock underlying the residual material, and the other map portrayed the rock at the surface whether it be residual or bedrock. In this particular case the geologic mapping was requested by the Forest Service and thus the type of material at the surface was of importance because of the ecological conditions for tree growth.

This stop also demonstrates a problem in engineering geology in areas of solution where the bedrock surface may be pinnacled.

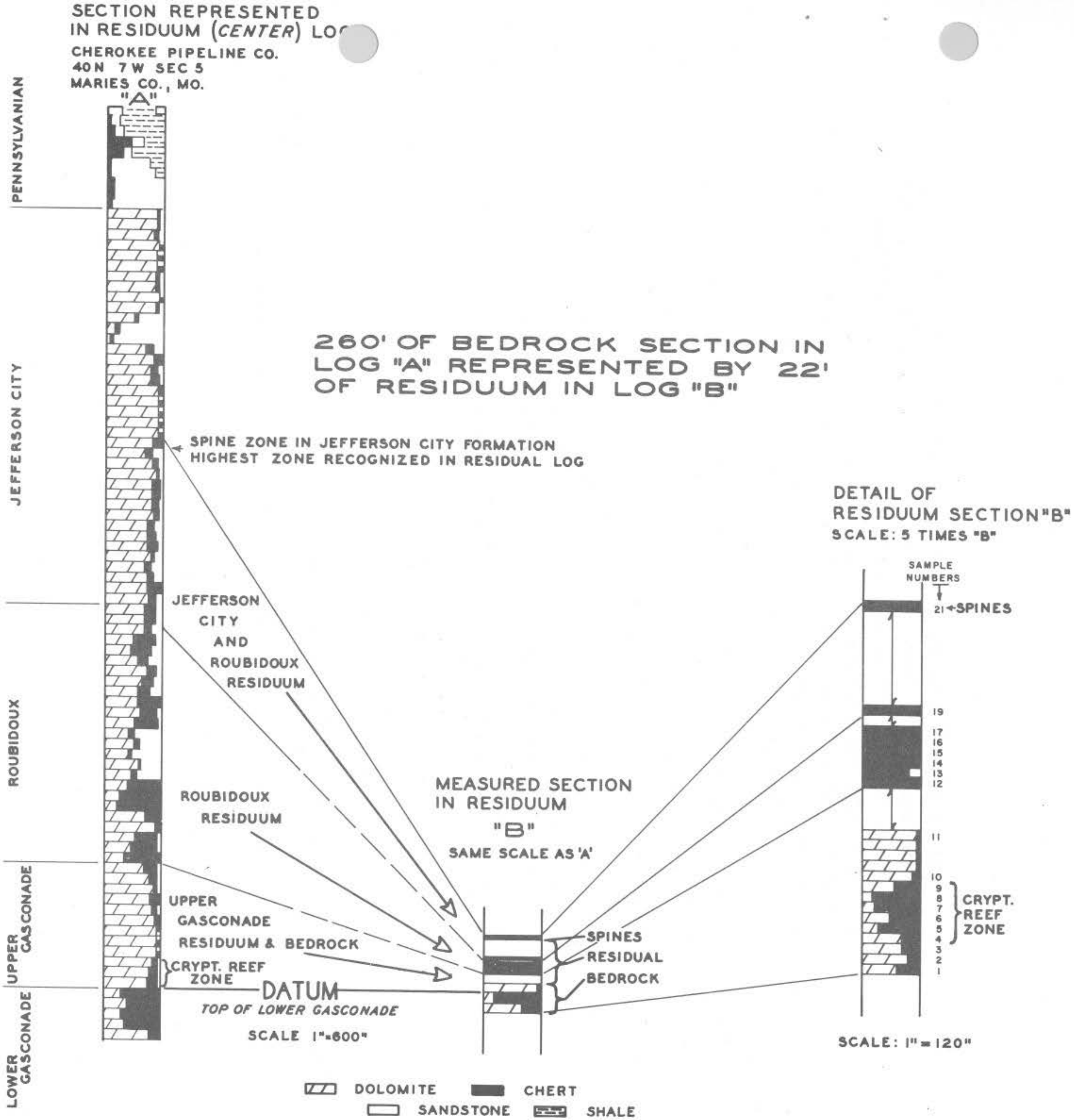


AREAL LOCATION OF MEASURED SECTION IN RESIDUUM
T36N R10W SEC 18

- RESIDUUM
- ROUBIDOUX
- GASCONADE *UPPER & LOWER*

AVERAGE THICKNESSES
FROM 15 WELLS IN THIS AREA

JEFFERSON CITY *SPINE ZONE TO BASE*	80'
ROUBIDOUX	120'
UPPER GASCONADE	60'



BY
K. H. ANDERSON

It is extremely difficult to predict the depth to bedrock in such areas because of the innumerable holes which would be required to map the bedrock surface. If pinnacling is encountered and pinnacles are relatively close together, it is impossible to remove the residuum completely with heavy mechanical equipment and a combination of scraping and blasting may be necessary -- a procedure which is quite expensive.

29.6 Vertical Gasconade bluffs of the Big Piney straight ahead. In these bluffs to the right is the Devil's Sugar Bowl, a rock formation with a tall cylindrical sugar bowl surmounted by a conical shaped lid.

29.7 Town of Devil's Elbow to right. Devil's Elbow is so-named because of the sharp bend in the river at this point. Logs and ties were rafted down the Big Piney and Gasconade rivers and produced a very colorful breed of tie rafters renowned for their prodigious strength, ability to consume whiskey and fight, and knowledge of the Bible. Upstream from Devil's Elbow is a rock promontory called the Devil's Tea Table.

29.9 Cross Big Piney River and leave Devil territory.

30.3 STOP. Junction with U. S. Highway 66.

Turn right to Rolla which is 20 miles to the east. Thank you very much for coming, and "Hurry back" as we say in the Ozarks.

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