MISSOURI BUREAU OF GEOLOGY AND MINES

H. A. BUEHLER, Director and State Geologist.

VOL. XII, SECOND SERIES

The Geology of the Rolla Quadrangle

BY

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THE HUGH STEPHENS PRINTING COMPANY

JEFFERSON CITY, MO.

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ACKNOWLEDGMENTS.

The author is particularly indebted to Dr. E. O. Ulrich, not only for information here presented in regard to the nomenclature proposed by him for the Cambro-Ordovician series, but also for many hints and suggestions regarding the segregation and distribution of the cherts, and the cryptozoans and concerning the fossils found in the series.

The nucleus of the work in the area was done by the author in the Newburg district for the St. Louis and San Francisco Railroad Company, to whom thanks are given for the use of the information obtained in that part of the area. The author is indebted to coworkers on the staff of the Bureau, especially to V. H. Hughes, for stimulating discussion of many subjects. Acknowledgment is due also to Dr. A. X. Illinski for analyses and tests.

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LETTER OF TRANSMITTAL.

Missouri Bureau of Geology and Mines,
Rolla, Mo., June 1, 1913.

To the President, Governor Elliott W. Major, and the Members of the Board of Managers of the Bureau of Geology and Mines:

Gentlemen—I have the honor and pleasure to transmit herewith a report upon the geology of the Rolla Quadrangle by Mr. Wallace Lee.

This quadrangle is located in Phelps and Dent counties, and the geology, as described in this report, may be used as a key in studying the formations of adjoining counties.

Respectfully submitted,

H. A. BUEHLER,
Director and State Geologist.

The Geology of the Rolla Quadrangle

By

Wallace Lee

INTRODUCTION.

The present volume covers an area in the Central Ozark region to the southeast of Miller, Morgan, and Moniteau counties, reports of which have already been published by this Bureau.

The stratigraphy of the Central Ozark plateau is well shown in these reports; the formations described constituting the upper portion of the Cambrian succession in this region. The lower formations, extending from the Potosi to the underlying granites and porphyries, are described in detail in our report on the Disseminated Lead Deposits of St. Francois and Washington Counties; volume 9, 2nd series.

In Shannon county there are several hundred feet of strata which do not outcrop in the areas covered by the above mentioned reports. Dr. E. O. Ulrich, of the United States Geological Survey, has included these beds under the name of Eminence chert, after the county seat of Shannon county, in the vicinity of which they are well developed. The exact relation of this formation to those above has not been definitely established, although it is probable that the Proctor formation, exposed over limited areas in Miller and Morgan counties, is the upper part of the Eminence. Detailed mapping in Southeast Missouri will be necessary to establish this fact.

In the columnar section, on page 8, is given the new classification of Dr. E. O. Ulrich in which he groups formations, designated as Middle and Upper Cambrian in volume 9, 2nd series, into Upper Cambrian, Ozarkian, and Canadian, giving each of these divisions equal stratigraphic weight. Whether or not diastrophic movement has been sufficient to warrant a division of this character requires regional study and can not be determined by detailed work in a restricted area. In the present report the nomenclature, as given in volume 9, 2nd series, has been followed.

The contact between the Roubidoux and Jefferson City formations presented the same difficulties in mapping as in the counties to the northwest. This contact is seldom exposed and is difficult to determine. For field use, the logical separation occurs at the top of the upper, heavy sandstone member which outcrops so conspicuously throughout this region. However, heterogeneous beds containing a Roubidoux fauna occur above this sandstone and the contact has not, therefore, been changed from that described in the former reports although it does not coincide with the striking physical features which are easily distinguishable.

H. A. B.

CHAPTER I.

PHYSIOGRAPHY, DRAINAGE, AND SPRINGS.

Geographically the Rolla quadrangle occupies the central and western parts of Phelps county in the central part of southern Missouri. Physiographically it lies in the northeastern part of the Ozark plateau region just west of the divide between the Gasconade and Meramec rivers.

Fig. 1. Sketch map showing location of the Rolla quadrangle.

DRAINAGE.

The drainage of the area is emptied into the Gasconade river which flows northward in broad meanders across the northwestern corner of the quadrangle. The greater part of the drainage is gathered by Little Piney creek which, entering in the southeast corner, flows north to the center and turning west joins the Gasconade river. Several smaller creeks lying entirely within the area collect the drainage of the southern and eastern parts and add their waters to that of Little Piney. These are: Mill creek, with its tributaries Kaintuck and Hardester hollows, draining the southwestern quarter of the quadrangle; Corn creek draining the south central part of the area; and Beaver creek and Little Beaver draining the eastern and northeastern parts. The basin of Little Piney creek is limited on the north by Pea ridge only three or four miles distant. This ridge crosses the area from Rolla to the Gasconade.

The strip lying north of Pea ridge is drained by the heads of several small creeks whose waters are tributary to the Gasconade river. These are, from west to east: Tick creek, Camp creek, Wildcat branch, and Spring creek. A small area just south of Rolla is tributary to the Meramec river through Love and Deible branches of Little Dry fork.

The entire western part of the quadrangle is deeply dissected by short, abrupt, deeply cut drains separated by narrow ridges, seldom more than 1,000 feet wide even on the principal divides. The ridge tops are nearly level, continuous, and remarkably uniform in shape. They are covered with residual materials sometimes to depths of 30 feet or more. The larger valley bottoms are one-quarter to three-eighths of a mile wide with well-developed flood plains.

The lowest point in the area, 648 feet above sea level, is at Boulware ford in the northwest corner of the quadrangle, and the highest point, 1,244 feet, is Pilot Knob in the southeast quarter. The maximum relief is therefore 596 feet.

Benches.—The rise from the Gasconade river to the upland area about Rolla is accomplished in two irregularly defined steps not entirely due to the accidental effects of erosion but in part at least to the unequal resistance to erosion of certain horizons.

The lowest beds exposed in the area are those of the Gasconade which, consisting of crystalline dolomites and cherts, are rapidly degraded. These beds are overlain by the Roubidoux consisting of dolomite, cherts, and sandstones. The lower beds of this formation do not differ essentially from the Gasconade in their resistance to erosion but furnish far greater quantities of residual material. The second sandstone member of the Roubidoux is thick and massive and, when casehardened by exposure, resists erosion very effectually. The upper part of the Roubidoux like the lower produces great quantities of insoluble residual material and, except on steep slopes, the mantle of residuum protects the surface and prevents the rapid wearing away of the surface.

Erosion.—On account of their less resistance, the Gasconade and lower Roubidoux beds are eroded much faster than the thick, casehardened sandstone member above so that areas underlain by the former are deeply trenched and the slopes rising to the second sandstone member are always steep. The streams attain grade in the Gasconade faster than the head can cut back into the second sandstone member of the Roubidoux, so that the heads of the valleys are abrupt and often steep, due almost entirely to resistance to weathering of the upper beds and to the rapid cutting of the streams which traverse the lower ones. Even the smaller valleys whose stream beds are underlain by the Gasconade are U shaped rather than V shaped. The protection against erosion, provided by the heavy sandstone bed mentioned, causes the formation of a rough bench which slopes gently to the base of the Jefferson City in the east and forms the top of the ridges of the western two-thirds of the quadrangle.

The Jefferson City formation, which overlies the Roubidoux, is composed chiefly of soft, argillaceous, and crystalline dolomites and, as a whole, is not very resistant to erosion. It was formerly overlain unconformably by sandstone of Pennsylvanian age and patches of this material still remain at many points along the divide. The effect of this sandstone has been similar to that of the thick sandstone bed in the Roubidoux and the softer, more easily eroded Jefferson City formation has generally been gouged into steeply enclosed valleys, while the upland surface above the sandstone, until recently protected from the encroachment of the valley heads, is gently undulating and of low relief.

The upland forms the second bench in the rise east from the Gasconade river, the first being represented by the gentle slopes of the upper Roubidoux. The upper bench is strikingly indicated near Rolla on the topographic map of the quadrangle. That of the Roubidoux is best noted in the strip bordering the Jefferson City on the west. It constitutes the broad, gentle heads of streams and low dividing ridges and the dissected plateau surface of the ridges of the entire western portion of the area.

SPRINGS AND GROUND WATER.

Springs.—Springs are abundant in all parts of the quadrangle except the extreme south and west. They are especially common in the lower courses of the smaller drains lying in the Gasconade formation where they frequently occur at or near the contact of this formation with the Roubidoux, the sandstone providing, at the same time, a channel and a reservoir. The presence—to an unusual extent—of undissected plateau area, such as exists north of Newburg, is generally sufficient to raise the ground water so that springs occur at or even above the elevation of the second sandstone member of the Roubidoux. Farther east, in the Jefferson City beds, they do not appear to characterize definite horizons, and, although not uncommon, are less abundant than in the lower areas drained by Little Piney creek and the Gasconade river.

In the southwestern part of the area springs are rare even in the Gasconade and their occurrence in this vicinity seems to be the result of some special structure. There are one or two permanent springs in the lower part of Smoky hollow and seepage occurs along its tributaries. Near the base of the Roubidoux, in a gully draining into the King sink in sec. 36, T. 36 N., R. 10 W., there is a small spring and one or two occur near the head of Mill creek in Gasconade beds. A single perennial spring of small flow occurs high up in the Roubidoux at the head of Deep hollow in sec. 18, T. 35 N., R. 9 W. The area along the southwestern border of the quadrangle, however, is comparatively deficient and they occur low when present. The farmers of this area are chiefly dependent on cisterns for their water supply.

The great number of sink holes and depth of ground water indicate that the southwestern part of the area is drained by deep underground circulation to Piney river which is only one to two miles distant from the western edge of this part of the sheet. The ground water has consequently little opportunity to rejoin the surface waters within the limits of the quadrangle.

Above Yancy Mills, and for several miles beyond the limits of the quadrangle, Little Piney creek has the dimensions of a brook but at this point several large springs contribute their waters, transforming the brook into an important creek. The highest of these springs occurs on the farm of Isaac Brown just south of the mouth of Finn branch on the east side of Little Piney.

During the drought of 1911 it ceased to flow. Two others at Yancy Mills one of which furnishes power for the mill owned by W. H. Baker, although somewhat diminished, kept up a good flow during the season. A fourth spring which issues in a field owned by Mrs. Lane one mile below Yancy Mills doubles the volume of water in the creek at that point.

Underground Circulation.—Two distinct channels of underground circulation are indicated near the big spring on Isaac Brown's farm. Within 100 yards of it a second small spring issues from a crevice. Although 10 or 15 feet higher the latter was only slightly affected by the unusual drought of 1911 while the big spring only a few feet lower became a stagnant pool. The large springs at Yancy Mills are on both sides of Little Piney creek and appear to issue from bedding plane channels, no jointing being apparent at the point of escape. The water issues from all the big springs under a slight pressure causing a "boiling" appearance which is emphasized by the escape of abundant bubbles of air. The lack of dependence of these springs on the local circulation, the lack of them in the area to the south, the depth of wells in the same area, and the escape of the water under pressure seem to indicate that these waters are derived from a considerable distance and that they carry off the drainage of the elevated plateau region toward the southwest. This conclusion is supported also by the report that, at the time of the sudden formation of a surface sink a few years ago, the waters of a large spring five miles distant ran muddy. From the cessation of flow in the upper spring and diminished flow in the lower ones it is thought that the large springs at Yancy Mills represent the mouths of a well developed system of underground drainage so closely connected that with diminished volume in time of drought the lower springs continue to flow at the expense of those located at slightly higher levels.

Water for Wells.—Except along the western edge of the sheet and on the very narrow secondary ridges, water is generally secured, in drilling, at a depth of 100 to 125 feet and frequently at less depth. The most persistent water horizon and the one at which a strong supply may most confidently be expected is at the contact of the Gasconade and Roubidoux formations. The conditions are equally good at the horizon of the second sandstone member but although water is frequently encountered at this horizon it is generally too near the surface of ground water to provide a reliable or abundant flow of water. Along the western line of the quadrangle, however, on account of the deep drainage, water in sufficient quantity for domestic uses may not be expected with certainty at elevations above 950 to 1,000 feet above sea level, although it may be found locally in small quantities at higher elevations. In the head waters of Little Piney south of Yancy Mills it appears unlikely that water will be encountered beneath the ridges at an elevation much above 950 feet above sea level except perhaps locally.

Artesian Water.—Artesian water occurs at shallow depth in the faulted block south of Newburg. The unequal settling of the block has caused strong inclination of the strata which dams back the ground water and near the Hickory Point school provides a head sufficient to raise the water several feet above the surface. It is not probable that artesian water, sufficient to cause surface flows, will be found at other points without similar special geological structure. Although the beds of this area rise gently toward the south the surface in this direction does not attain a sufficient altitude to provide the necessary head for artesian flow. There are no beds below the Gasconade of sufficient porosity or continuity to provide the necessary conditions for circulation.

CHAPTER II.

GENERAL GEOLOGICAL HISTORY.

The Ozark uplift, in the northern part of which the area studied occurs, is underlain almost exclusively by bedded rocks of the earliest periods of the Paleozoic era. While the succession of formations of this region (with the possible doubt of the equivalence of two of them) are definitely known, the areal distribution of each has not yet been worked out in detail.

Prior to 1908 the group was roughly classified as Cambro-Ordovician but in 1908 the entire series was referred provisionally to the Cambrian, that portion of the series occurring in the Rolla quadrangle being referred to the Upper Cambrian by Dr. E. R. Buckley in volume IX, 2nd series of the publications of this bureau. In the table of formations, on page 15 of that volume, it is stated that the Upper Cambrian in Missouri corresponds to the "Ozarkian" of E. O. Ulrich and the Middle Cambrian to the "Cambrian restricted" of the same author.

In a recently published work,* Dr. E. O. Ulrich has indicated inconsistencies in the old standard of classification and he proposes to differentiate out of the Upper Cambrian and lower Ordovician two new systems which he has named "Ozarkian" and "Canadian." Both of these periods are represented in the Rolla quadrangle.

The following geologic section indicates the succession of formations at and below the surface of the Rolla quadrangle and shows both the old classification and the new, with some authorized modifications of the latter based on unpublished work in the State by Dr. Ulrich in 1912.

*Ulrich, E. O., Revision of the Paleozoic Systems: Bull. Geol. Soc. of Am. 1911.

Classification as accepted by Dr. E. R. Buckley.				Classification of Dr. E. O. Ulrich.
Pennsylvanian		Cherokee.		
		Unconformity.		
Mississippian	Lower Mississippian	Undifferentiated sandy and cherty limestone.		Waverlyan
		Unconformity.		
Cambrian	Upper Cambrian	Jefferson City. Roubidoux.		Canadian
		Unconformity.		
		Gasconade		Ozarkian.
		Unconformity (?)		
		Eminence	Proctor of Miller county and the west, probably included in the upper Eminence.	
		Potcsi.		
		Doerun	Elvins of E. O. Ulrich.	Upper Cambrian.
		Derby		
		Davis.		
	Middle Cambrian	Bonneterre limestone		
		Lamotte sandstone.		
		Unconformity.		
Pre-Cambrian		Granite.		

PRE-CAMBRIAN.

The Pre-Cambrian granites, with associated porphyries, comprise the basal rocks on which the sedimentary deposits of the region are laid. Prior to the deposition of the first sediments the surface of Missouri had been land for a long period and the higher hills of the old surface remained as islands for a long time before their final submergence beneath the sea and burial by the series of formations about to be described. Neither the granites nor the other formations below the Gasconade are represented at the surface in the Rolla quadrangle.

CAMBRIAN.

Lamotte Formation.—The Lamotte sandstone was the first sediment deposited on the submerged land. On account of its very rough and irregular surface the thickness of the Lamotte is extremely variable. It is composed chiefly of sand but at the base and at some places higher there are beds of fine to coarse conglomerate which often contain boulders of granite and porphyry. The thickness varies from nothing to 250 feet.

Bonneterre Formation.—The Bonneterre formation consists chiefly of dark and light gray, crystalline dolomite. The lower part is in places sandy and argillaceous. The upper part also is often argillaceous. The normal thickness of the formation in the Flat River district is approximately 360 feet though it is subject to considerable variation.

Davis Formation.—The Davis formation, although containing light colored, crystalline dolomite and argillaceous dolomite, is composed chiefly of abundant layers of bluish shale which vary from a few inches to three or four feet in thickness. The average thickness in the Flat River area is 160 feet.

Derby Formation.—The Derby formation at Flat River consists of 40 feet of fine-grained, crystalline, slightly calcareous dolomite. The color varies from light gray to reddish brown.

Doerun Formation.—The Doerun formation consists of alternating beds of argillaceous dolomite, finely crystalline, dense dolomite, and soft, finely porous dolomite. The thickness at Flat River is from 50 to 60 feet.

Potosi Formation.—The Potosi formation consists of very silicious, cherty, and drusy dolomite though some of the beds are frequently silicious. The weathered blocks, characteristic of the formation, consist of chert the openings being lined with coarse crystals of quartz. The thickness is reported to be about 300 feet.

Eminence Formation.—The Eminence formation consists of cherty dolomites not easily distinguished lithologically from the overlying Gasconade. The chief lithological distinction lies in the character of the chert which is generally light, soft, and porous although certain horizons contain extremely dense layers of white chert. The fossils, however, constitute the most important criterion by which the series is distinguished from the Gasconade. The thickness of the Eminence at the type locality in Shannon county is not less than 300 feet. An unconformity or period of emergence probably marks the contact between this formation and the Gasconade. Certain horizons of the Eminence are very sparingly silicious and particularly on bluff exposures give the appearance of being non-cherty. Such beds occur especially in the upper part. Although carefully searched no fossils have been found in them.

Proctor Formation.—The exposures of the Proctor formation, underlying the Gasconade in the basin of the Osage river, occur chiefly on bluffs. They are non-cherty, entirely without fossils, and resemble in character the bluff exposure near the top of the Eminence formation at the type locality. For this reason and because it underlies the Gasconade with similar relations it is thought to be the equivalent of the upper part of the Eminence formation. While the evidence of the identity of the two formations is of a negative character, this conclusion is very strongly suggested. Both the Eminence of Shannon county and the Proctor of the Osage basin are capped by a sandstone member which, in the case of the Proctor, has been called the Gunter and has generally been regarded as the basal member of the Gasconade. The Gunter sandstone is well bedded and friable, when not case-hardened, and often has a thickness of 10 to 12 feet. The sandstone overlying the Eminence, however, is thinner (usually only 4 to 5 feet), and frequently altered to quartzite.

Gasconade, Roubidoux and Jefferson City Formations.—The Gasconade formation in the Newburg area consists of 350 feet of cherty dolomites which, together with the following formations, will be described later in detail. Overlying the Gasconade and separated from it by a gentle unconformity is the Roubidoux formation with a thickness of 120 to 160 feet which, in turn, is overlain by the Jefferson City consisting of cherty, crystalline dolomites and cotton rock and various thin sandstone lentils. As exposed in this area the Jefferson City formation has a thickness of about 240 feet although between 800 and 1,000 feet of the same formation is known to be present in the southern part of the State. During the deposition of these formations there were many periods of emergence and all of the sediments clearly indicate that they were deposited in shallow water.

After the deposition of the Jefferson City the region suffered a general emergence, and no record has been left either in the Rolla quadrangle or in the greater part of the Ozark region of the history of the area during the Ordovician, Silurian and Devonian periods. The net result of this hiatus was the erosion of a considerable thickness of Jefferson City beds (possibly 600 feet) though the amount is yet uncertain.

POST-CAMBRIAN.

Mississippian.—The last interval was followed by the Mississippian period during which the area was again beneath the sea and sedimentation was probably long continued. Subsequently the surface was again elevated above the sea and the greater part of these sediments were worn away.

Pennsylvanian.—Deposition was resumed during Pennsylvanian times but the thickness of the deposits during this period can only be surmised for the area has been continually above the sea since that time and all but a few small areas of these sediments have been cut away and removed by the action of decay and erosion.

Post-Pennsylvanian.—While the Ozark area has probably not been below the sea since Pennsylvanian times there is considerable evidence of changes of level during the long period represented in the time scale by the Mesozoic and Cenozoic eras some of which are still indicated by topographic forms.

THICKNESS.

The thickness of the formations underlying the Gasconade is not known in this area but a recent drill hole at Salem in Dent county, twelve miles southeast of the southeast corner of the quadrangle, penetrated a depth of 1,500 feet below the top of the Gasconade and throws some light on the thickness of corresponding beds in this quadrangle.

Unfortunately no cuttings were saved above a depth of 800 feet and it can only be stated that the combined thickness of Gasconade, Eminence, Potosi, Doerun, and Derby formations is 966 feet. The following thicknesses were determined:

Gasconade, Eminence, Potosi, Doerun and Derby....	966 feet
Davis	169 feet
Bonneterre	265 feet
Lamotte (still in sand)........	100+ feet

It is evident from the consideration of the thicknesses at the type localities that the total of 966 feet from the top of the Gasconade to the base of the Derby is too low for these formations without at least some of the beds having suffered thinning. The aggregate thickness of the beds concerned at the type localities, including 350 feet for the Gasconade, is 1,060 feet. The thickness of the Gasconade in Shannon county is probably not much more than 100 feet, so that it is probable that a part, at least, of the 94 feet difference between the calculated and actual thickness of these beds is due to thinning in the Gasconade toward the southeast. The hole was started 50 feet below the top of the Gasconade and is 1,450 feet deep. It is probable that the granite would have been penetrated within a further depth of 150 to 200 feet.

Another deep hole drilled 14 miles north of Rolla was started near the top of the Gasconade and passed into granite at a depth of 1,700 feet.

CHAPTER III.

THE GASCONADE FORMATION.

The Gasconade is the lowest and oldest formation exposed in the quadrangle and is the uppermost formation here known of the Ozarkian period of Dr. Ulrich.

Areal Distribution.—Beds of this formation appear in the lower parts of all valleys in the western, southern, and central parts of the area, but, although they are found in nearly every section in the west and south and have an average exposed thickness of over 150 feet, the surface underlain is comparatively small on account of the steep slope of its exposures.

Thickness.—The entire thickness of the formation is not exposed within the quadrangle. The maximum exposure is on the bluffs of the Gasconade river opposite Jerome, where 215 feet of cherty dolomites are to be seen. None of the beds are distinctive, the chief lithological variations consisting of the thickness of bedding, fineness of crystallization, and chert content.

Three holes drilled south of Newburg by the St. Louis and San Francisco railroad penetrated a sandy horizon 350 feet below the Gasconade-Roubidoux contact. This is thought to represent the Gunter sandstone which elsewhere is found to lie at the base of the Gasconade. The Gasconade has been reported 290 feet thick in Morgan county and 250 feet thick in Miller county. In Shannon county its thickness is little more than 100 feet. The sandy horizon at the base of the formation does not appear from the drill cuttings to be more than five feet thick which is somewhat thinner than in the reported exposures in Miller and Morgan counties. The lower beds of the Gasconade penetrated by the drill holes are denser and contain more dense, bluish chert than the upper part of the section.

Composition.—The formation consists of massive beds of dolomite, and interstratified beds and sheets of dense, bluish white chert, some of which appear to be special forms of nodules which are also abundant. No beds of sandstone, such as have been else-

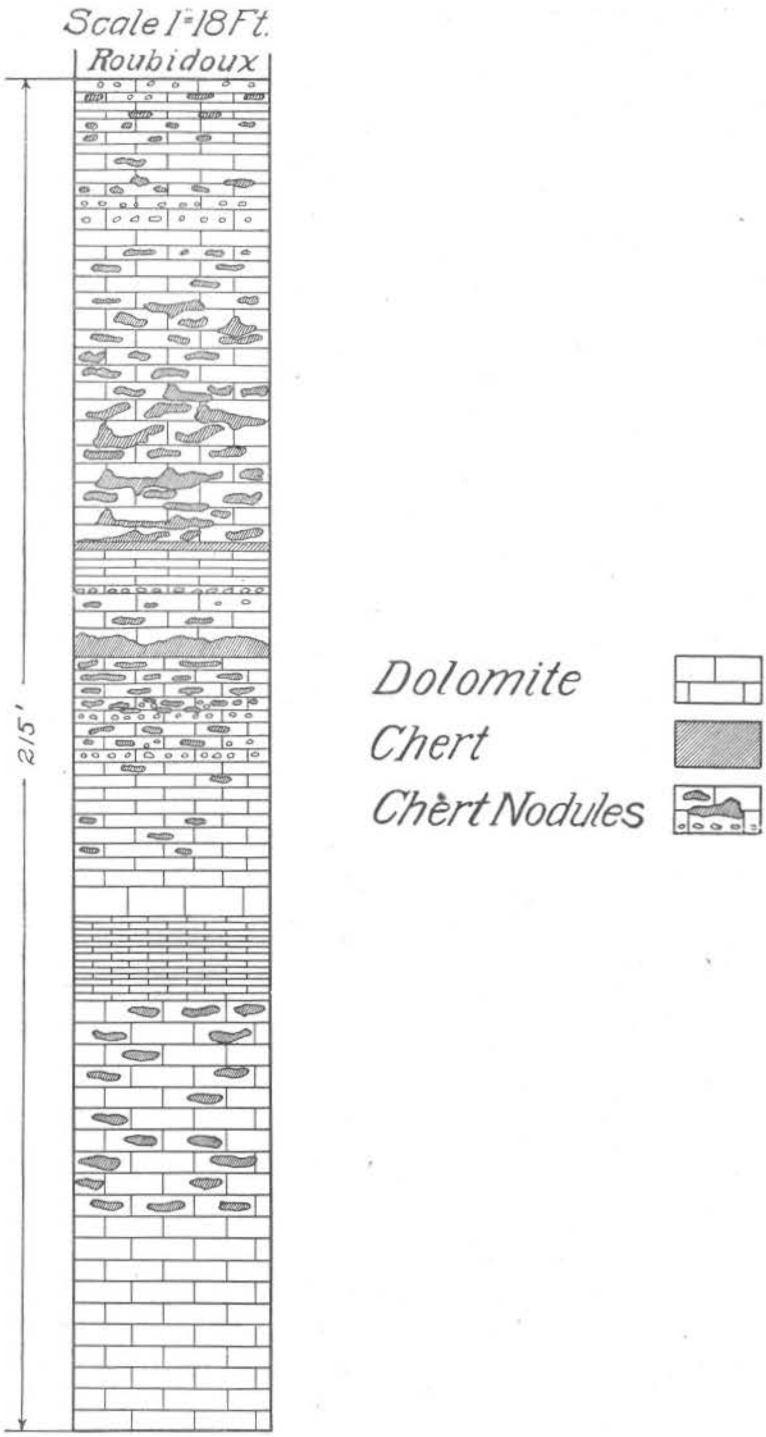


Fig. 2. Section of Gasconade formation at Arlington.

where reported in this formation, were observed in the Rolla quadrangle.*

The formation was deposited in very shallow water. Sun-cracks in dolomite have been observed in the lower part of the formation indicating at least temporary emergence. The lower beds in places show very fine lamination on fresh exposures and shale partings also occur locally. A short distance east of the quadrangle cross-bedding was observed in a thin bed of dolomite in the middle part of the formation. It is highly probable that, but for the character of the rock, evidences of shallow water and temporary emergence would be much more conspicuous in this formation though probably less so than in the two formations which overlie it.

Dolomite.—The dolomite is generally a coarse-grained, crystalline, magnesian limestone containing something less than the theoretical amount of magnesium for pure dolomite. When fresh, the color is generally clear white to light gray. On weathered surfaces, it is lead gray to dove color. The texture is sometimes medium-grained though some beds are fine-grained. The bedding varies from thin plates to six feet and more, though the former is rare.

The following analyses were made from drill cuttings. They indicate the general composition of the formations and include the chert as well as other silicious contents.

Depth.	Insoluble.	$(Fe \cdot Al)_2O_3$	$CaCO_3$	$MgCO_3$	Total.
60-65'............	9.70	1.24	54.04	34.73	99.71
170-175'............	11.78	1.26	51.25	36.16	100.45
215-220'............	12.06	0.86	50.28	37.06	100.26
305-310'............	2.21	0.44	56.19	41.30	100.14
335-340'............	6.24	0.60	54.48	37.80	99.12

Chert.—The cherts occur as massive beds, which in certain horizons are eight to ten feet thick and of persistent extent. Thin layers and sheets are common but are generally less continuous. Nodules are abundant, special forms of which are present in considerable variety. The bedded cherts have a lighter color and are occasionally white as, for example, the heavy bed at Newburg.

Clay.—About 150 feet below the top of the formation a few beds of lean clay occur. None of the beds observed had a thickness greater than 12 to 18 inches, though greater thicknesses have been reported.

*Ball, S. H., and Smith, A. F., Geology of Miller County: Missouri Bureau of Geol. and Mines, vol. I, 2nd series, p. 37.

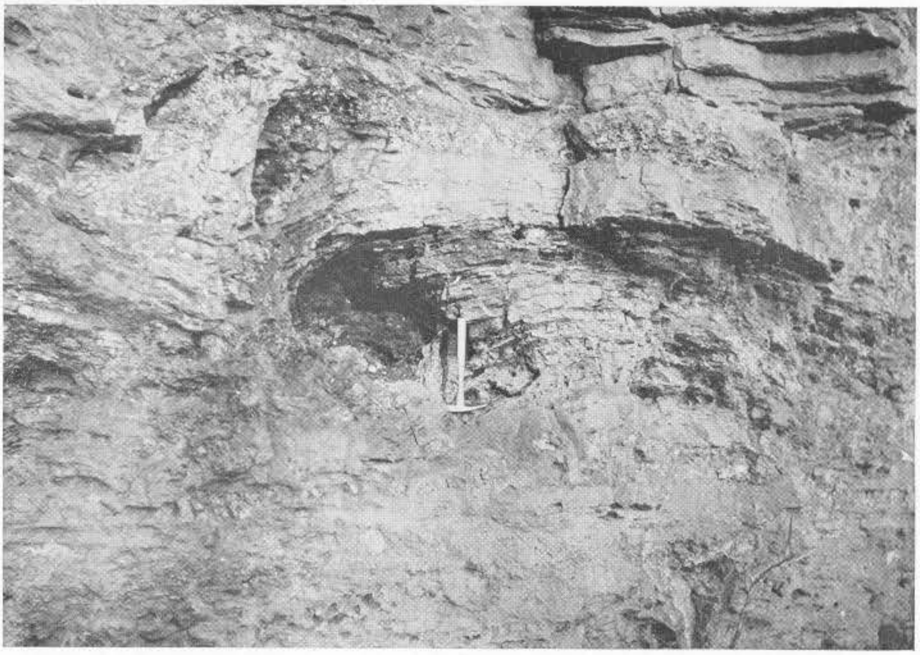


Fig. 1. Concentrically banded chert exposed in cross-section.

Fig. 2. Concentrically banded chert exposed in stream bed.

CHERT.

The origin of chert has long been a subject of conflicting opinion and many theories have been advanced in explanation of the various phenomena observed. It is quite probable that no single theory will suffice to explain its formation under all circumstances but that different methods are involved under different conditions. Without entering into a detailed discussion of these theories nor advancing any explanation to account for the bedded cherts of the area, one phase of chert formation pointed out by Dr. E. O. Ulrich* deserves particular discussion since the phenomena associated with its origin are in evidence on every hand in the older formations exposed within the area.

Segregation of Silica.—As has already been mentioned, the dolomites of the district are in genèral silicious, but the silica in the freshly quarried rock, except in segregations, is not visible because disseminated through the rock in microscopic particles or in chemical combination. On weathering, however, the silica gathers in nodular forms at and near the weathering surface. This is apparently a form of metasomatic replacement, possibly effected by diffusion through the medium of capillary water whereby the disseminated silica becomes segregated in nodules and rough chert masses.

Conditions of moisture appear to play an important part for it has been noted that continually moist places are apparently unfavorable to chert formation at the surface and result rather in its decay. Alternating wet and dry conditions in the rock, such as occur on gentle, thinly covered slopes, appear most favorable. It is thought that conditions of continual moisture generally exist beneath deep deposits of soil and that where the surface of the rock is deep there is no tendency toward the segregation of silica into nodules.

Evidence of Segregation of Silica.—Evidence of the surficial segregation is abundant. Coarse chert float of distinctive character is often found leading up to apparently non-silicious dolomite beds, but on close examination it can generally be observed that the weathered surface of the bed contains large and small shapeless forms of the chert which give every indication that they are at present in process of growth. The broken surface of a nodule can often be seen to grade off into an indeterminate mass of silicious dolomite.

*H. Foster Bain and E. O. Ulrich, Copper Deposits of Missouri: Bull. 267, U. S. G. S.; pp. 27 and 29.

Freshly cut surfaces of such beds in quarries and road cuts do not show chert. The comparative absence of chert on bluffs in comparison to the same series of beds seen on roads and gentle slopes indicates that the process of erosion at the former localities progresses faster than the segregation of the silica into dense masses of chert. On gentle slopes (particularly noticed in gullies and road drains) cherty layers and nodular beds are exposed in great abundance because here the segregation of the silica is not exceeded by the erosion. The nodules are roundish in form in some beds and ragged and shapeless in others. Certain beds and horizons, apparently lacking in silica, do not develop nodular chert and this fact affords a criterion often useful in identifying certain beds.

Since it is inconceivable that this coarse material could have been deposited with the original rocks, and as they are not observed on the fresh rock surfaces, it is concluded that their development is a phenomenon of weathering. Examples of chert formation in this manner are more frequent and striking in the Jefferson City possibly because the slopes of this formation are more gentle but the phenomena are by no means lacking in the Gasconade. The segregation of the silica into nodules near the surface and its absence in this form in the freshly cut face is illustrated in Pl. I, Fig. 1.

Conglomerates.—Beds of coarse and fine conglomerate and breccia occur at many horizons interbedded with dolomite, particularly in the upper formations. That the breccias are of the nature of conglomerates can sometimes be demonstrated by the occurrence of fossils in the interstices between the angular pieces.

In the long struggle when sea and land fought for the possession of the surface the sea bottom was many times exposed to atmospheric weathering. During these periods of exposure and erosion the silica was forming into nodules and broken into chips and fragments as it is today. The surface during times of emergence thus became littered with chert fragments which were buried on the return of the water, often with little or no wear. How quietly this was sometimes accomplished is occasionally shown by the close association of banded fragments imbedded in the first succeeding sediment.

PRESERVATION OF FOSSILS.

Fossils are rarely found except in the chert. Those that occur in the limestone are seldom well preserved and are generally only rough molds. Fossils found in the chert on the contrary (often in the same bed) are abundant in certain layers and are frequently well preserved.

Recrystallization.—It appears that in the recrystallization (which all these beds have suffered) a homogeneity of texture (perhaps even of chemical composition) has been attained which destroyed all original macroscopic differences between the fossils and the enclosing sediment. While this alteration destroyed the original texture of the rock and the consistency of the fossils, it appears not to have effected destruction or deformation of the form or outline of the fossils, or of the dolomitic materials of which the rock was composed when these were clastic.

Silicification.—The original outlines of the fossils are reproduced by the chert when it replaces the limestone and the casts of the fossils are faithfully restored by subsequent differential weathering. The restoration is, however, not confined to the shells for even the original form of the particles of clastic sediments are faithfully reproduced. The chert nodules on weathering sometimes display silicious oölite and occasionally the weathering of the chert indicates that the original rock of the parent ledge was a conglomerate composed of fine or coarse subangular and roundish fragments of dolomite. Occasional beds of dolomite are to be noted in which this structure is indicated by simple differential weathering, but the outlines are blurred and indistinct in the same manner as the ill defined fossil molds already mentioned.

While chert exhibiting the phenomena above described is abundant in the Gasconade formation, the heavy bedded chert, the thin sheets, and perhaps many of the nodules which are characteristic of it, can scarcely be considered to have been formed in this way for some of the chert sheets are continuous over wide areas and apparently unassociated with any of the phenomena of unconformity or surface weathering. In their general character these bedded cherts do not resemble the cherts segregated at the surface nor do they appear to be fossiliferous. In the vicinity of Newburg and lower Mill creek a heavy bed of chert, in places ten feet thick, lies 100 feet below the contact, and is persistently exposed usually forming a narrow bench on the upper slopes.

Cryptozoa.—Among the common and interesting forms of chert* are certain foliated, shelly, concretion-like forms which are thought to be of organic origin. They are referred to as crypto-

*H. Foster Bain and E. O. Ulrich, Copper Deposits of Missouri: Bull. 267, pp. 29-30 zoans and, though it has been denied that they are of fossil character, their associations and manner of growth in colonies seems to leave little doubt on this point. Several forms are represented in the formations of this area and the different formations are characterized more or less sharply by the presence of different types. They are supposed to have grown in the shallow waters and, where conditions of growth were favorable, they were present in great numbers and appear to have formed reefs. Molluscan life, at times, found refuge between the growing cryptozoa, and their fossil shells are occasionally found in that position. Some cryptozoans resemble in form the round tops of closely growing barrel cacti sometimes slightly modified where many are crowded together. While generally of fairly uniform size certain individuals have sometimes developed at the expense of less hardy neighbors. Another common form of cryptozoan consists of two six-inch parallel arched lamellae fastened together at the ends by massive chert columns, the plates being separated in weathering by open spaces of varying thickness. The latter type is most common in the Gasconade formation. Small nodule-like forms two to three inches in diameter which occur crowded in bands are also probably referable to cryptozoans.

Chert of similar structure, the diameter of whose arches in places attains a span of three to ten feet is illustrated in Plate I. Whether these may be referred to the cryptozoans with propriety, however, is questionable. When exposed in the bed of a stream these forms are often scoured out in kettle-shaped hollows. On bluffs the laminae are banded like inverted festoons. Two of these beds, each about three and one-half feet thick, occur 50 and 75 feet below the top of the formation in the vicinity of Newburg. Near the south boundary of the sheet a similar bed was seen at several points in a corresponding position but the arches or inverted festoons are eight feet or more in length. Weathered dolomite beds having the same structural character can be observed on some bluff exposures and the chert beds are probably the silicification of the dolomite structures.

Another characteristic chert of the Gasconade is light and porous and has been described as ropy or as worm-bored, for the openings are suggestively vermicular. When in an intermediate stage of decomposition this chert closely resembles a coarse pumice.

WEATHERING.

The two factors which most clearly affect the weathering of the Gasconade are bedding and chert content. The dolomite is generally heavy bedded and massive but there are occasional thinly laminated beds which are closely jointed. The chert content, an important factor in resisting erosion, varies widely. The less silicious layers and the thinly bedded dolomites yield most rapidly to disintegration and it is not surprising to find the unequal resistance to weathering expressed in projecting ledges, undercutting, and caves. This difference is not sharp enough, however, to make any of these phenomena particularly remarkable. They are seen to best advantage on the bluffs bordering the Gasconade river and Little Piney creek. Beds of chert more than two or three feet thick often form benches or arrested slopes. Occasionally on low extended ridges, bare, soil free balds occur as described in the Miller county report.

The weathered surface of individual beds varies greatly. The dolomites seldom weather to a smooth surface but are diversely pitted and dissolved. The most common and characteristic weathering takes the form of roundish pittings like impressions of small irregular marbles impartially distributed over the surface. This is most common in the non-silicious beds. Frequently, particularly on the joint faces of the upper beds, these pittings are arranged in rows parallel to the bedding and indicate original lamination not otherwise distinguishable. Pot holes from a few inches in diameter to considerable cavities (transitional to caves) are common. Occasionally on slopes the weathered surface takes on a hackly or scoriaceous surface from the segregation of disseminated silica. In places the hackly surfaces are blackened in weathering and are then sometimes mistakenly regarded by the inhabitants as evidence of vulcanism to which they have no relation.

In continually moist positions of weathering the binding material between the dolomite crystals is removed leaving the rock in a friable condition which without close inspection may easily be taken for sandstone. Fine crystals of dolomite in some places coat the weathered surface of certain exposures, the binding material having been dissolved before the crystals.

Differential weathering is everywhere to be observed where chert and dolomite are associated. The gradual segregation of silica together with the solution of the dolomite leaves the fine chert aggregations standing out sharply on the surface and finally results in the varied skeleton forms already described.

The rotten surface of the dolomites and chert frequently contains dirty green particles of chlorite which form the basis of occasional false reports of silver and copper discoveries.

TOPOGRAPHY.

The Gasconade beds do not occur in this area apart from the overlying Roubidoux and the formation does not in consequence display here a characteristic topography. The Roubidoux formation is marked by heavy sandstone beds which form a very enduring capping and have not yet been completely removed from any part of the area.

The Gasconade dolomite is eroded chiefly by solution which is everywhere abundantly in evidence. Fragments of dolomite are rarely found more than a few feet from their source. The slopes are strewn with porous residual chert which is broken up and carried downward on the steep slopes and removed by the streams at the base of the exposures.

The disintegration of the Gasconade proceeds more rapidly than the overlying casehardened sandstone beds. The latter frequently remain until undercutting or solution at the base causes the sandstone capping to settle and break into blocks which may then accumulate in the heads of the ravines where it continues to assist in the preservation of the overlying formation.

The effect of this disproportionate erosion is to produce valleys of low gradient in the Gasconade bounded by steep chert slopes rising to the base of the Roubidoux. Where streams of sufficient volume occur to carry away the descending talus, the overhanging slopes become steeper, and bluffs extending to the base of the Roubidoux are frequent. In such cases the valleys become widened, and the flood plains are developed through which the streams take a more or less meandering course. The smaller and steeper valleys, however, are generally clogged with the accumulated talus, not only of the Gasconade but often with the chert, sandstone and quartzite of the Roubidoux as well.

CAVES.

The Gasconade is the only formation in the area in which caves are found. They vary in size from enlarged pot holes to chambers and galleries several hundred feet in length. (See page 61.)

CHAPTER IV.

THE ROUBIDOUX FORMATION.

The Roubidoux is the next formation above the Gasconade. It is the oldest member here exposed of the Canadian period as defined by Dr. Ulrich.

Areal Distribution.—It is the most widely exposed formation in the quadrangle. Except in the extreme northeast corner, there is not a section in which it does not occur. Where associated with exposures of Gasconade it caps the ridges but elsewhere it underlies rolling surfaces.

Thickness.—The top of the formation has been eroded from the greater part of the area but the entire thickness is present in the eastern part of the quadrangle where it is overlain by the Jefferson City beds. The thickness, which is variable, is estimated at 115 feet in the north and 150 feet in the south part of the area. Except along the eastern margin of the quadrangle the overlying Jefferson City beds and generally the upper part of the Roubidoux have been removed so that comparisons of thickness depend in part on observations of the lower part of the formation. The lower part of the formation, including the two principal sandstone members, varies considerably. North of Newburg this part of the formation has a minimum thickness of 50 to 55 feet, increasing gradually but irregularly toward the south where it attains a thickness of 90 feet at the southern edge of the area. The variation is due chiefly to the irregular thickness of the basal member of the formation though in part also to the thickening of other members and to the introduction of sandstone lentils.

General Description.—The Roubidoux formation consists of a much more varied series of beds than the Gasconade and is distinguished by two striking sandstone members and several other distinct but less important sandstone beds separated by dolomite and chert. The dolomite members considered collectively present a gradual though fluctuating change in lithological character from the underlying Gasconade to the overlying Jefferson City. The dolomite at the base of the formation, where exposed, can with difficulty be distinguished from the Gasconade while that at the top, containing cotton rock, closely resembles certain beds of the Jefferson City. The cherts are in great variety. The cryptozoans are well rounded forms, generally less than eight inches in diameter. The foliation is coarse and the chert of which they are composed is not particularly dense. The thinning and thickening of the beds and their laterally changing character, together with the scarcity of exposures for certain horizons, and the almost total absence of complete sections, render the careful study of this formation a matter of difficulty.

Limits of the Formation.—The bottom of the Roubidoux, as mapped, has been taken at the lowest bed of sandstone exposed in the area, since the presence of sandstone here marks a change in sedimentation after the long period of limestone deposition of Gasconade time. Additional grounds for this division lie in the abrupt change in the fauna and in evidence of unconformity which will be discussed later.

Difficulty has always been experienced in determining the top of the formation; first, because the series of beds between the second sandstone member of the Roubidoux and the pitted series of the Jefferson City is seldom exposed and second, because these beds are heterogeneous, and in general nonpersistent, shallow water deposits. The upper limits assigned by Ball and Smith in the report on Miller county are too indefinite to be applied in detailed work. For convenience in mapping it would have been desirable to consider the top of the heavy sandstone member as the top of the formation. This would have been desirable also on lithologic grounds for the cotton rocks so characteristic of the Jefferson City first appear above this sandstone member and are unknown below. Such a separation, however, is prohibited by the occurrence above this horizon of rare but distinctly Roubidoux fossils. Unfortunately the fossils are not in sufficient abundance to mark a sharp division and there are several almost equally available points of separation. In consequence the top of the formation has been placed somewhat arbitrarily at the top of a sandstone layer above the known occurrence of Roubidoux fossils and below the distinctly Jefferson City pitted dolomite series. This bed is persistent over the whole area and lies 25 to 30 feet below the base of the easily distinguished Quarry ledge of the Jefferson City.

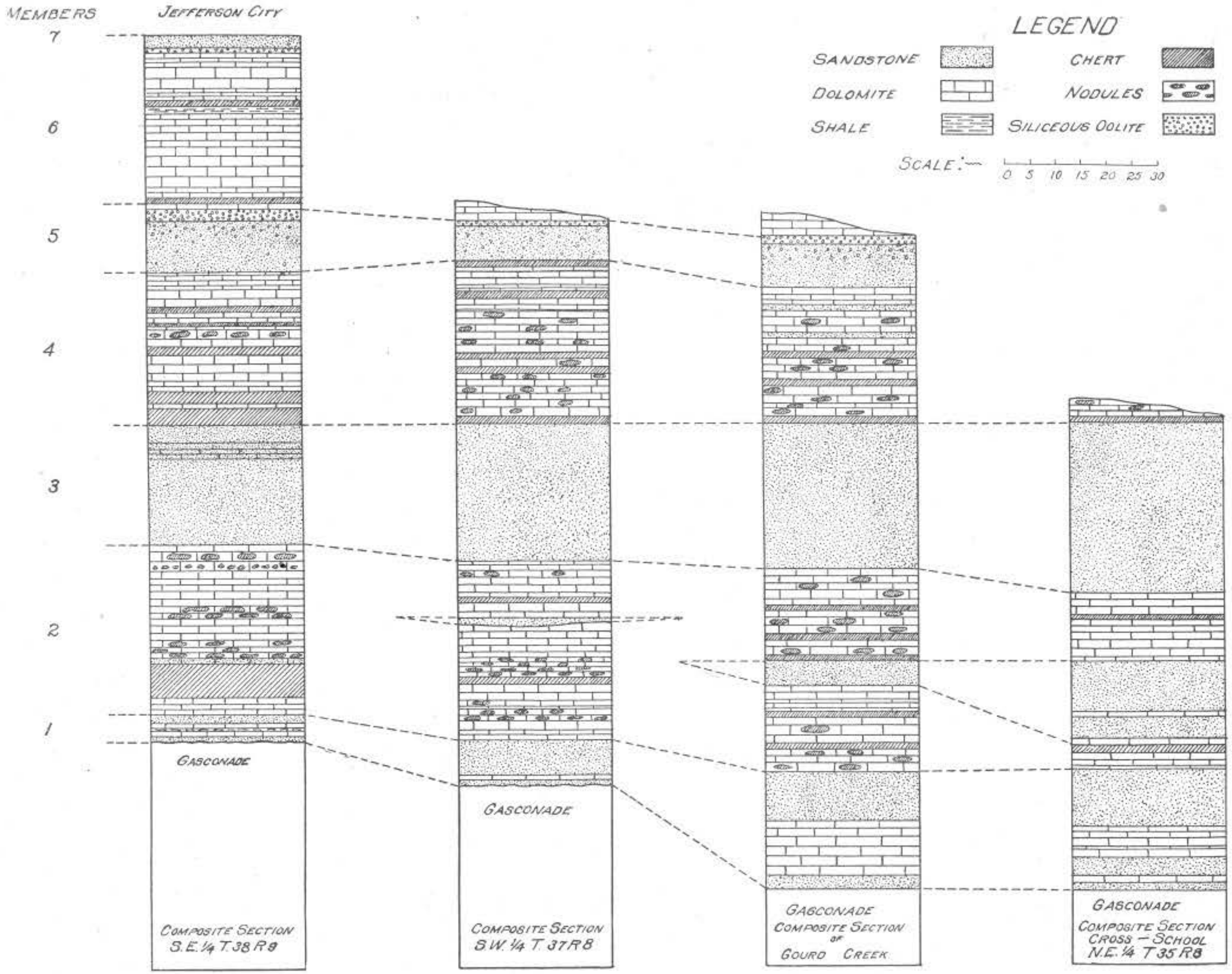


Fig. 3. Sections of Roubidoux.

Members.—The formation has been divided into seven members by four sandstone horizons. These are arranged below in the order of deposition, the first deposited being at the bottom of the list.

SECTION FROM TOP DOWNWARD.

	Feet	
7.	1–3	Sandstone, white ripple-marked, with chert grains.
6.	30	Dolomite, gray, finely crystalline, soft, interstratified with thin chert and sand stone sheets, silicious oölite, cotton rock, and sandstone lenses.
5.	2–10	Sandstone, and oölitic sandstone, reddish-brown to pink, medium-grained.
4.	30	Dolomite, gray, medium to finely crystalline.
3.	20–30	Sandstone, reddish-brown, medium-grained, ripple-marked, cross-bedded, and sun-cracked.
2.	35–45	Dolomite, gray, medium crystalline, somewhat cherty, interstratified with thin sometimes thick, lentils of sandstone and beds of chert.
1.	3–20	Sandstone, sun-cracked and ripple-marked, interbedded with dolomite.

Correlation.—To what extent some of these divisions may be serviceable in mapping outside the limits of the Rolla quadrangle is uncertain. Wherever the pitted dolomite series of the Jefferson City occurs it is probable that the upper limit of the Roubidoux may be established more or less sharply by its relation to the Quarry ledge of the Jefferson City formation which is widely recognizable on the northern slope of the Ozarks. The wide distribution of the second sandstone member provisionally correlated with the Bolin creek member of Miller county gives promise of being a valuable datum plane wherever the formation may be recognized. The sandstone at the base of the formation will undoubtedly be widely useful but due to the character of the underlying surface will be subject to much variation.

The other sandstone members while easily distinguishable within the Rolla quadrangle are less promising as datum planes though they may have better development toward the south. The sandstone lenses occurring in the second member of the formation have also a markedly greater development south of the Rolla quadrangle and may become co-ordinate with other divisions of the formation in that area.

THE MEMBERS IN DETAIL.

First Member.—The first sandstone member is not a homogeneous member like the succeeding sandstone beds. It consists of thin bedded sandstone at the base overlain by dolomite and capped by a bed of sandstone of greater thickness than that below. Its thickness varies from three feet in the north to 27 feet in Beaver creek. North and northwest of Newburg the lower sandstone has a thickness of only two to three feet and contains a thin bed of dolomite in the middle. At one point in the E. ½, sec. 2, T. 38 N., R. 9 W., six inches of shale were noted in the intermediate bed. Near the Cross school in sec. 11, T. 35 N., R. 8 W., and in the lower part of Beaver creek secs. 2 and 3, T. 26 N., R. 8 W., this member contains three beds of sandstone and displays thicknesses of 20 and 27 feet respectively. In the former locality the surface of the basel bed shows sun-cracks and other evidence of emergence.

In Beaver creek there is some question as to the propriety of referring the highest sandstone layer to the lower group and it is possible that it is a lense belonging in the next member above.

The grains of quartz sand of which these sandstone beds consist are clear and angular though there are some rounded grains. The grains are weakly cemented with iron oxide which gives the beds a brownish color. The sand is rather weakly compacted and contains small cavities about the size of the sand grains, which, when filled with iron oxide, give the freshly broken rock a speckled appearance. While this feature is not always exhibited, the speckled appearance, where noted, is sufficient to distinguish the lower beds from the sandstone members lying higher in the formation. In certain localities the sandstone is dirty or argillaceous though this is not general. An important feature is the occasional presence in the lower bed of flat angular to slightly worn pieces of chert having a maximum length of two inches. These occur in bands two to six inches thick along bedding planes. They occur in some places in the middle of beds but are more common at their base. In some localities silicification has altered the beds to quartzite.

The dolomite is of the prevailing Gasconade type. If it were not for the presence of the sandstone it would be difficult to make a sharp separation between the formations.

Second Member.—The next member above consists chiefly of cherty dolomite with thin, non-persistent sheets of sand, quartzite, and chert. At the southeast edge of the area a bed of sandstone 15 feet thick occurs in the middle of this member but thins toward the north. The chert beds and the cherty dolomites are somewhat variable and as they are rarely well exposed it is not possible to correlate sections even short distances apart. Most of the dolomite resembles that of the Gasconade but the beds are commonly less cherty and thinner.

The chert of this member takes a variety of forms. Besides the nodules, chert beds, and cryptozoans, it appears in a number of special forms. Drusy quartz and bands of chert line small cavities. It also occurs filling the minute interstices of the rock, in broken nodules, in small septarions, in silicious oölite, and in cherty sandstone. Calcite is of common occurrence filling the vugs and cracks in the dolomite. At the north edge of the area a bed of chert five to six feet thick occurs 10 feet above the base of the member. This bed is generally closely brecciated in the exposures.

Third Member.—This is the second sandstone member. It is the most striking and, from a topographic point of view, the most important bed in the formation. While it has not been traced across the area between Phelps and Miller counties, a distance of only 12 miles, it seems probable from its position in the section and its general lithological characteristics and relations that it is the same bed referred to in the Miller county report as the Bolin creek sandstone. Its thickness is 30 feet at the south edge of the sheet and about 20 feet in the area north of Newburg. The thickness is subject to little variation and the change from point to point is imperceptible.

The top of the sandstone is in many places silicified and altered to quartzite. In the area between Little Piney and Beaver creeks the upper bed is sprinkled with roundish pebbles some of which are two inches or more in diameter. The sand is medium to fine-grained and, while sorted, does not present any systematic variation. The grains are uniformly clear and angular, showing crystal facets possibly due to secondary growth. Iron oxide is present in sufficient quantity to give a reddish-brown discoloration to the sandstone but this is not abundant enough to bind the grains into a very coherent mass. The fresh rock is soft and friable. Occasionally the bed is clean and white on fresh surfaces. The lower part contains sparing fragments of fine, angular chert. In the upper part these particles, which are of uniform size, become gradually more abundant and coarser (seldom more than one-fourth inch in diameter) and south of Newburg are a prominent constituent. In the same locality, notably at the mouth of Treable hollow, 12 to 18 inches of thinly bedded, very fine sandstone weathering in thin, projecting, casehardened edges occurs near the middle of the member, dividing it into two parts. Vertically symmetrical, silicious concretions sometimes develop in the upper part of the sandstone and by their removal are thought to cause the flat bottomed, cylindrical, niche-like cavities resting on the fine sandstone layer of this area, a feature characteristic of the second sandstone. Both

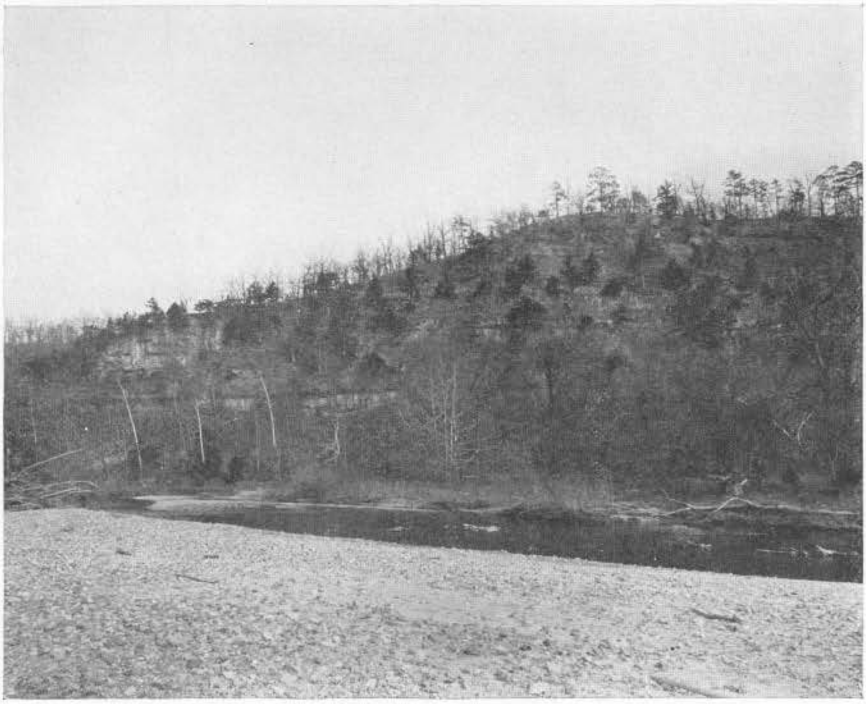


Fig. 1. Bluff on Little Piney, showing characteristic topographic relations of Roubidoux and Gasconade.

Fig 2. Second sandstone member of the Roubidoux, showing resistance to erosion and effect in preserving the upland surface.

upper and lower parts are often marked by cross-bedding. (Pl. II, Fig. 2.) Ripple-marks are common everywhere and sun-cracks are frequent. (Plate VIII, Fig 2.) .

Fourth Member.—The fourth member of the formation, which overlies the second sandstone member, is a heterogenous dolomite group about 30 feet thick. It is the uppermost recognizable group in the western and central parts of the area and, with the remnants of residual material of higher beds, caps the ridges of this territory. Exposures are uncommon, due to the accumulation of talus above the second sandstone member.

The base of the member is marked locally by a bed of honeycombed chert 12 to 18 inches thick. The "honeycombed chert" is hard, vitreous, and white to yellowish, honeycombed with round, vesicular openings seldom more than one-fourth inch in diameter. The structure suggests vaguely that of a sponge and often consists of little more than the partitions between the cavities. The latter are lined with tiny quartz crystals which flash in the sun. Occasionally the rock is seen almost destitute of openings and rarely with the openings closed by cementing material. It appears to have been formed by the solution of roundish pebbles of a conglomerate, the resulting holes having been later encrusted with the tiny quartz crystals while the matrix, sometimes oölitic, has been altered to a kind of cherty quartzite. The honeycombed chert at the base of the member has been seen in place only in the eastern part of the quadrangle, notably at the head of Gourd creek, but from its frequent occurrence in the float it is thought to be present in most places at the top of the second sandstone member though it is probably not a continuous bed. A bed of honeycombed chert occurs also near the middle of this member and while the float occurs very generally at this horizon it is found in particular abundance on the high land west of Mill creek.

Where seen, the dolomite is chiefly of the Gasconade type but it is thinner bedded and interstratified with beds of chert and sandstone. About 10 feet above the base of the member very dense, hard, conchoidal dolomite was observed in two localities: in the head of a small drain entering Coal Pit hollow from the north in the N. W. ¼, sec. 29, T. 36 N., R. 8. W.; and above the road, crossing the drain in the southeast corner of sec. 36, T. 36 N., R. 8 W. At the former locality it occurs associated in irregular shapeless splotches, probably dolomite conglomerate in a very fine-grained, gray, crystalline dolomite matrix. Fine-grained wavy lines developed by weathering are indicative of original lamination. At the latter locality the two varieties occur in thin bands frequently grading laterally into each other. The denser dolomite generally has a faint pinkish color. The total exposed thickness is about six feet and the bedding varies from six inches to two feet.

The fourth member of the formation is distinctly more silicious in the north central part of the area than farther south. Beds of chert and cryptozoa are a noticeable feature. In the center of the E. ½ of sec. 35, T. 38 N., R. 9 W. a 10-inch bed of shale, which contains sun-cracks and other evidence of more than temporary emergence, occurs a short distance above the base. Thin lentils of sandstone, bedded cryptozoans, and sandy dolomite characterize the same horizon in the drain in the center of the E. ½ sec. 9, T. 37 N., R. 8 W.

Fifth Member.—Overlying the fourth member lies a sandstone bed two to ten feet thick. The upper part is oölitic and in some localities contains little or no sand. The lower part closely resembles the second sandstone member from which it can only be distinguished in isolated exposures by its thickness or, doubtfully, by the presence of oölitic float above.

Exposures of this member are infrequent, and at many places, inconspicuous, but the float from it is found on the high ridges in the greater part of the area. The best exposures occur in the north central part of the quadrangle. A quarter of a mile west of the Oak Grove school, sec. 36, T. 38 N., R. 9 W., the oölitic sandstone is exposed in the road at the head of a small drain in which are also found exposures of the second sandstone. Outcrops also occur one-half mile north of this locality, in the head of a drain in the N. E. ¼ sec. 25, T. 38 N., R. 9 W., and at the Mount Olive church in sec. 11, T. 37 N., R. 9 W. A bed of sandstone at the same horizon was noted in the road in the center of the W. ½ sec. 12, T. 36 N., R. 10 W. Oölitic sandstone float and oölitic quartzite is commonly found on the upper slopes of the ridges in the southern part of the area and in particular at the head of Kaintuck hollow. On the west side of the ridge in the E. ½ sec. 23, T. 36 N., R. 8. W., in the upper part of Beaver creek partially silicified oölitic sandstone occurs in considerable boulders slightly below the horizon of this member. Extensive exposures of this member occur also in the bed of Beaver creek at its head in sec. 25, T. 36 N., R. 8 W. In the drain south of the railroad in the center of the N. ½ of sec. 15, T. 37 N., R. 8 W., it is very poorly developed and appears as a thin sand or sandy dolomite bed in which are a few oölites. Fragmentary exposures of thin bedded, brick pink sandstone containing oölites, thought to represent this member, were found at a number of high points in the southeastern corner of the quadrangle. Small slabs of the same sandstone were frequently noted on the higher parts of the ridges, among many other localities on the ridge northeast of Arlington and in sec. 5, T. 36 N., R. 8 W.

From the occurrence in place of the beds in the northern part of the area and the wide distribution in the south of material derivable from this bed it is concluded that it was formerly represented in all parts of the quadrangle although possibly not of uniform texture and certainly of variable thickness. It is possible that in some localities it may never have been deposited.

Sixth Member.—The exposures of the next overlying member are unsatisfactory and no continuous exposures of this horizon have been found. The beds of which it is composed have been entirely removed from the western and central parts of the area. It consists of a heterogeneous series of thin dolomite beds about 30 feet thick ranging from medium-grained, crystalline dolomites, like the Gasconade, to dense but soft, finely crystalline beds which, on fresh surfaces, resemble in texture the cotton rock of the Jefferson City.

The fine-grained beds are more abundant. They differ from the Jefferson City cotton rocks in not chipping or splitting in weathering and have generally a gray, dove color. The division includes also a few, thin, probably discontinuous, beds of vitreous chert and thin sheets of sandstone. Six inches of shale were noted near the middle in a section at the head of Beaver creek.

Seventh Member.—This member is a bed of sandstone and constitutes the uppermost member of the Roubidoux. Although thin and not often exposed, it has been found at the same horizon in every locality in which the top of the Roubidoux may be expected, from the head of Beaver creek, sec. 25, T. 36 N., R. 8 W., to the northern edge of the area in Camp creek, sec. 25, T. 38 N., R. 9 W. The thickness is only one foot in the head of Beaver creek while in Camp creek it is two to three feet.

The sand of which the bed is composed is medium- to fine-grained and subangular. With the sand are mingled numerous very fine particles of angular chert and noticeable but not abundant amounts of fine dust-like material thought to be comminuted chert. In the south, the sand grains are generally fine and the dust-like material is arranged in fine laminated lines. In the north the sand grains are coarser and the lamination is not so generally apparent. The bed is, in places, closely cemented and altered to quartzite.

The color is white and the rare iron stains which are banded parallel to the joints and surface appear to be due to infiltration. The top of the bed is generally ripple-marked. Silicious oölite is very abundant in some localities both above and below this bed.

WEATHERING.

The beds of the Roubidoux are, as a whole, nonresistant to weathering. Consisting as it does of alternating thin beds of chert, quartzite, sandstone, and thin bedded dolomites, the formation is easily broken down. The cherts and quartzite (in many cases already brecciated) are particularly susceptible to the action of frost. The dolomites are freely removed in solution while the sandstones, except where heavy bedded and casehardened, are easily crumbled. In consequence the Roubidoux horizon is generally marked by a heavy accumulation of fragmental material weathered from its beds.

Exposures except of the upper sandstone member are not usual. Even the lower sandstone layers, generally more than 10 feet thick, are not always exposed since it is commonly undermined by solution of the underlying dolomites and, occurring low in the topography, is generally covered with talus and seldom in situations permitting casehardening. As a result of the abundant residuum anything approaching a complete section is rare and only to be found along permanently flowing streams.

Casehardening.—The casehardening of the sandstone beds by which the rock is protected from ordinary atmospheric weathering is caused by the evaporation of moisture from the surface and replenishment from the store of capillary water held in the interstices between the sand grains. The moisture thus transferred to the surface from the inner part of the rock carries with it small quantities of iron oxide and silica in solution which in drying are deposited at the surface thus cementing the grains and forming a thin crust of ferruginous quartzite. When blocks of sandstone become detached from the main mass by fracturing, the fresh surface of the block is more rapidly worn than the old casehardened face, and results in the formation of the blunt wedge-shaped edge not infrequently observed in float.

Erosion of the Sandstone Ledge.—The blunt exposed face of the casehardened sandstone ledge yields to erosion chiefly by undercutting. The less resistant materials lying beneath become disturbed either by solution, erosion, or downward creep and cause the sandstone to crack, settle, and eventually to become detached in large and small blocks which endure for a long time in the heads of the drains.

TOPOGRAPHY.

The topography of the Roubidoux has two phases. The first is characteristic of its occurrence alone and the second where modified by the deep valleys of the Gasconade.

The Characteristic Phase.—The characteristic topography of the Roubidoux is expressed in gently sloping surfaces. The ridges are low and rounded. The valleys have gentle grades and the streams which traverse them in many places show small, though sharp, meanders especially in the upper reaches where removed from the influence of the Gasconade. The sandstones are generally covered by residuum and have not acquired the casehardening which on exposure renders them so effectively resistant. Residual chert and sandstone mingled with sand and soil, in part derived from the argillaceous limestone of the Jefferson City, cover the surface.

Topography Modified by the Gasconade.—The Gasconade dolomites are more freely removed by erosion than the Roubdioux beds, and the erosion of the underlying beds has a marked effect on the topography of the latter. Streams traversing the Roubidoux become steeper near the contact. The heads of small tributaries to streams flowing over Gasconade rocks end abruptly in the Roubidoux in steep, talus covered slopes. The tributaries are short and cut back sharply into the even topped ridges. The massive sandstone members exposed by the increased slope become casehardened. Their hardened faces are often 20 to 25 feet high and, although resisting surface erosion very effectually, succumb to undercutting. Below this sandstone rampart the brittle beds of chert and quartzite and the thin beds of dolomite break down freely, the Gasconade slope continuing without interruption to the base of the second sandstone member. When bluffs occur in the Gasconade, the talus slope begins at the base of the Roubidoux, the beds of which are not sufficiently massive to maintain a vertical face.

Resistance of the Sandstone.—On the lower ridges the second sandstone member and the lower sandstone by their increased resistance arrest the encroaching erosion of the Gasconade and allow the tops of the ridges to conform to the gentle topography of the Roubidoux. This is well shown in Pl. II, Fig. 1. It is probable

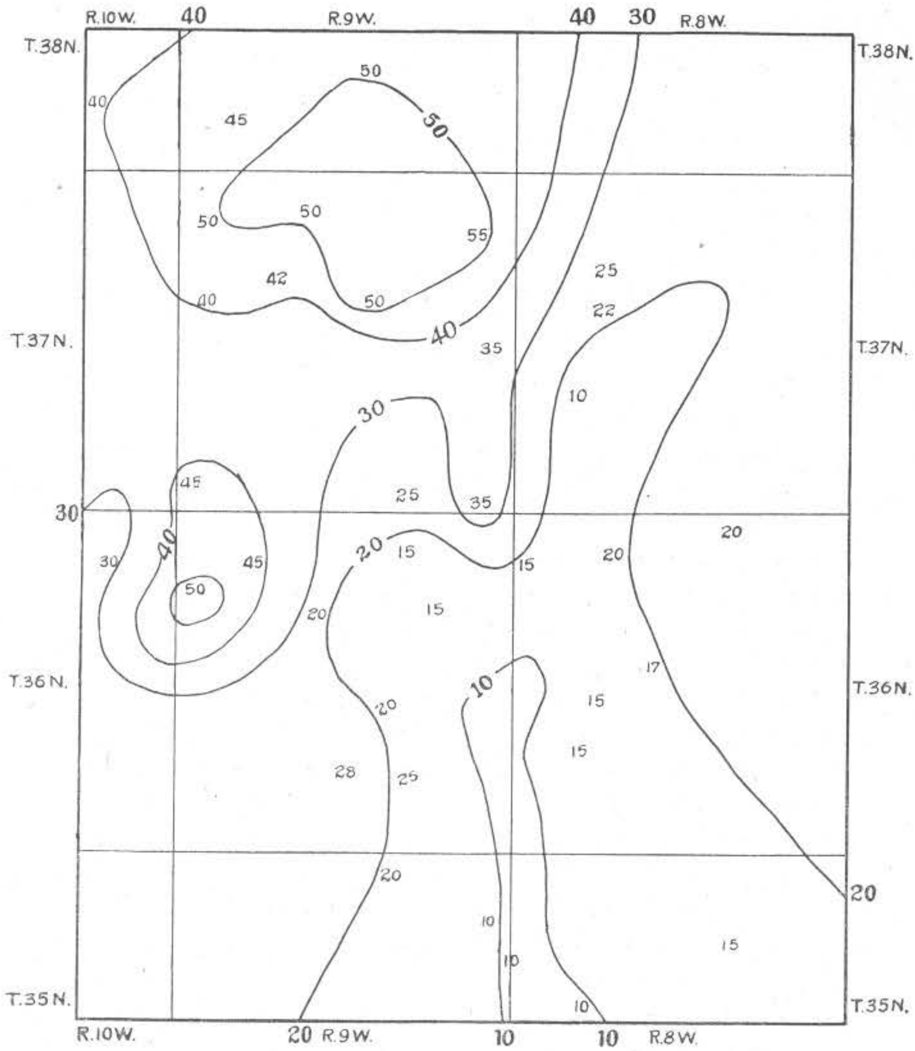


Fig. 4. Pre-Roubidoux surface of the Gasconade formation. (Figures represent elevations above an arbitrary datum plane.)

that, but for the presence of the second sandstone member, the topography would be much more ragged and the average elevation of the greater part of the area much lower than is actually the case. The protective influence is seen in Pl. II, Fig. 2. It is interesting to note the continuity of the Roubidoux beds, no considerable areas having yet been severed, island-like, from the main mass.

GASCONADE-ROUBIDOUX UNCONFORMITY.

The Roubidoux formation is separated from the Gasconade by an unconformity, the magnitude of which is at present uncertain. The phenomena marking the break in sedimentations are neither striking nor conspicuous.

Evidence.—Emergence is indicated by the sun-cracks which may be noted at many points in the basal member of the Roubidoux. That the emergence was not more than temporary is shown by the angular, subangular, and platy pieces of chert found in the sandstone immediately above the Gasconade. Further evidence of unconformity consists in the irregular thickness of that part of the Roubidoux formation which lies below the top of the second sandstone horizon. The top of this sandstone has been assumed to have been a horizontal, plane surface at the time of its deposition. First because the upper part is abundantly supplied with sun-cracks and second because of its regularity. Changes in thickness from point to point are not observable though thinning toward the north is apparent in comparing its thickness at different localities. The top of this member having been given a nominal elevation of 100 feet, the base of the formation has been plotted from observations on the thickness made at many points. The result is indicated by 10-foot contour lines in Fig. 4. This figure is thought to indicate roughly the surface of the Gasconade prior to the deposition of the Roubidoux. This presumption is supported by the distribution and thickness of the basal sandstone of the Roubidoux. In the drainage basin indicated in the southwest the thickness of this group is 15 to 20 feet, while on the high land in the north it dwindles to less than five feet. At intermediate points the thickness is from eight to ten feet. It may be argued that since the deposits indicate a general shallow water condition throughout the time of deposition that the irregularities should be attributed to irregular sedimentation. While this is possible, it seems unlikely that the plotted points in that case would indicate such a well defined erosion surface as that shown.

Further indication of unconformity is found in the very much greater thickness of the Roubidoux south of the area and in the southern part of the State. It is also indicated by the occurrence, in Bryants fork of White river and elsewhere south of the quadrangle, of fossil horizons identified by Dr. Ulrich as being below those found at the base of the formation in this area. For these reasons the sediments are supposed to overlap from the south and the sand is thought to have been driven from the east or west by the shore currents of the Roubidoux sea (and probably to have been derived from the southwest).

Conditions of Sedimentation.—During the whole period represented by the deposition of the Roubidoux beds of this area the water was very shallow. The sandstones and sometimes the dolomites and chert beds show ripple-marks. Fluctuations were frequent, for the sandstones, from top to bottom, are marked by suncracks so that the surface must have been many times temporarily above the sea. During a considerable period, particularly during the deposition of the sandstones, the waters were far from quiet. All the sandstones are at least locally cross-bedded and in many localities it is a characteristic feature of the beds. The ripple-marks show great variety in direction. At an exposure in a tributary to Hardester hollow the laminae within two inches of thickness show ripple-marks in four sharply different directions. Above the second sandstone member the succession of beds is somewhat different in different localities and succeeding layers occasionally show slight but well marked unconformities. This is well seen in the drain in the N. W. 1/4 sec. 9, T. 37 N., R. 8 W. It will be understood from the above that the Roubidoux represents a much longer period than would generally be understood from a simple statement of the thickness of the deposit for it represents also a great number of small hiatuses during which there was no deposition and during which there may have been at times some erosion.

CHAPTER V.

THE JEFFERSON CITY FORMATION.

The Jefferson City beds overlie those of the Roubidoux from which they are separated by a slight unconformity of the character already mentioned as occurring frequently within the Roubidoux. Many interruptions in sedimentation, of probably equal rank with those of the Roubidoux, occur in the Jefferson City beds so that the two formations are in effect conformable, the interruption between the formations being no greater than many interruptions within them.

Areal Distribution.—With two exceptions the Jefferson City deposits are confined to the eastern part of the area where they form the chief surface rock of the divide between the Gasconade and Meramec rivers. The exceptions are two small outlying areas associated with filled sink structures, one on Pea ridge, the other in upper Hardester hollow.

Thickness.—Recent work on the southern flank of the Ozark uplift has shown that the Jefferson City formation in the southern part of the State has a thickness of between 800 and 1,000 feet. Of this thickness only the lower part is now exposed within the Rolla quadrangle. The higher beds, if deposited at all in this area, were largely removed prior to the deposition of the Mississippian though there has been some erosion in more recent times. The exact thickness of the beds is difficult to determine for the formation occurs in the most notably warped portion of the area. The greatest thickness known to occur within the quadrangle is in the head of Little Beaver creek in sec. 3, T. 37 N., R. 8 W., where the beds, though dipping, appear to have a thickness of 240 feet. In section 25 in Spring creek the thickness seems to be about the same.

General Description.—From top to bottom the formation is composed of distinctly shallow water deposits. The dolomites are not only argillaceous and sandy but the sandstone and sometimes even the dolomites and cherts show ripple-marks and sun-cracks. Evidences of slight unconformities are seen at short intervals throughout the formation, not only in the sun-cracked sandstone but in the frequent occurrence of conglomerates composed of roundish but more often of angular pebbles. These conglomerates occasionally resemble breccias in the close association of originally united pieces. The origin of these breccia-like conglomerates has already been discussed on p. 16. The matrix is most frequently of argillaceous sand.

Discontinuous sandstone lentils, generally thin, occur at all horizons but are commonly more conspicuous in the lower part where they attain thicknesses up to 10 feet. In a few instances these lentils are recognizable over several square miles as in the head of Spring creek northeast of Rolla and in an area northeast of Sands Post Office. More commonly the thick beds appear and disappear with astonishing abruptness as in S. ½ sec. 36, T. 37 N., R. 8 W., and sec. 3, T. 37 N., R. 8 W. The sandy dolomites occasionally produce different kinds of surface rock under different conditions of weathering. The leaching of the dolomite cement produces a porous sandstone while the unleached rock gives the appearance, superficially at least, of an ordinary dolomite, particularly where the amount of sand is slightly lessened. Where silicification has taken place the same bed may have become a quartzite or a sandy chert.

DETAILED DESCRIPTION.

For descriptive purposes the formation, as known on the northern flank of the Ozark uplift, has sometimes been divided into a lower or pitted dolomite member and an upper or cotton rock member. The division is not a sharp one, characteristic beds of each appearing in the other.

Pitted Dolomite Member.—The lower or pitted member is 70 to 80 feet thick. In the lower 25 feet are several beds of cotton rock. These are not of general distribution but occur locally. This portion contains also a few thin beds of shale and stinkstone. The latter, when struck, gives off a putrid odor from the liberation of organic matter enclosed in minute quantities in the sediment at the time of its deposition. It is sometimes mistaken as an indication of petroleum of which the odor is suggestive. Five feet above the base of the formation, a bed of very finely crystalline dolomite with abundant tiny lath shaped cavities about one-eighth of an inch long, disseminated throughout, was observed at two widely

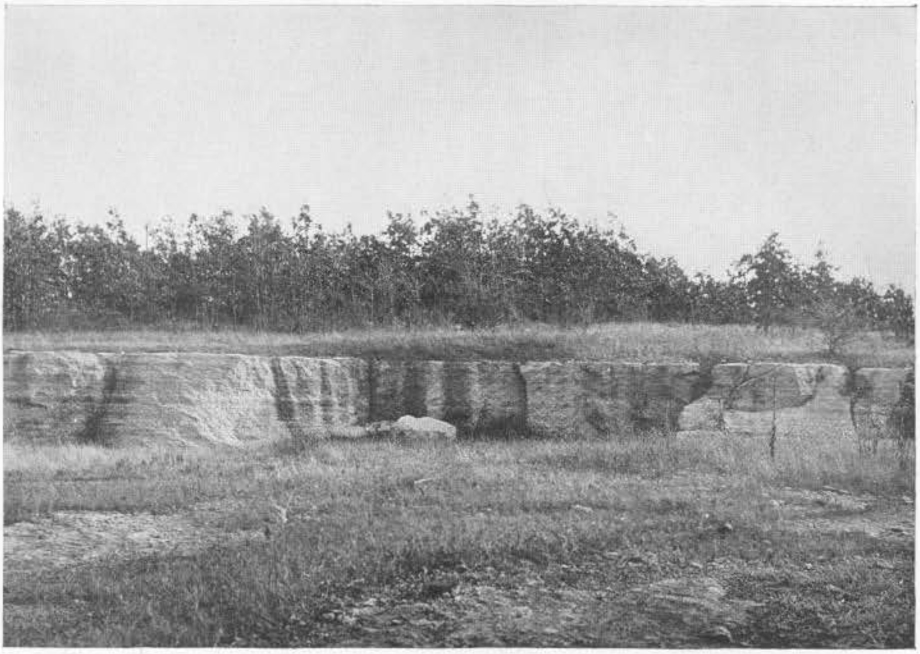


Fig. 1. Quarry ledge of Jefferson City formation; general view of quarry.

Fig. 2. Quarry ledge; near view.

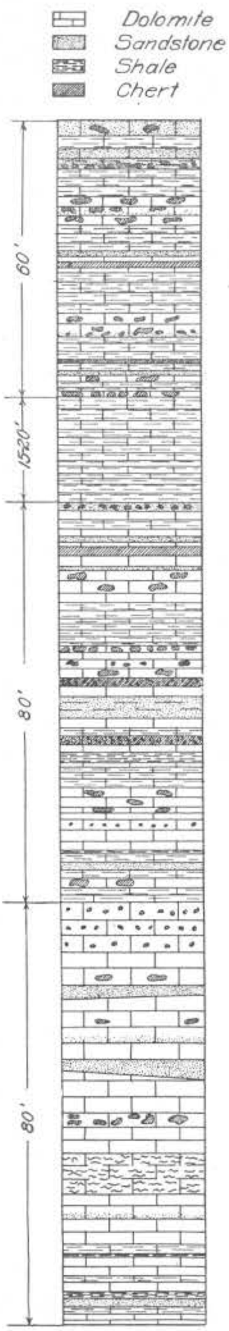


Fig. 5. Composite section of Jefferson City formation.

separated localities. Some of the dolomites of this horizon are sparingly sandy and at a few points thin sandstone lentils and thin dolomitic conglomerates were observed.

Twenty-five feet above the bottom is a five- to seven-foot bed of dolomite, illustrated in Pl. III. This ledge is a good building stone and is quarried at many places, and for this reason it will be referred to as the Quarry ledge. It is the most striking bed in the entire formation and on account of its frequent exposures and its persistence throughout the area is a very convenient datum plane. The rock is dense and very finely crystalline and is strikingly mottled by irregular pockets of fine, white, sugary, crystalline quartz disseminated through it. The ledge splits into slabs eight to fourteen inches thick. On exposure the sugary quartz patches weather out, leaving the surface rough and covered with slightly raised ridglets suggestive of worm borings. The texture, mottling, and peculiar weathered surface are highly characteristic of this ledge as these features are not exhibited in the same degree by any other bed. Six feet above the top of the Quarry ledge occurs a highly fossiliferous bed of dolomite weathering to ragged masses of chert. This bed is well distributed and always contains fossils.

South of Rolla, in the area about the head of Wolf creek and Abbott branch and somewhat farther south, there is a sandstone horizon 15 feet above the Quarry ledge. This bed is somewhat irregular in thickness ranging up to six feet or more. Locally it is somewhat conglomeritic displaying coarse, angular cavities from which the pebbles have been dissolved. In the southern part of this locality the sandstone is very irregularly distributed appearing and disappearing abruptly. In the area north and west of Rolla a similar sandstone occurs about 30 feet above the Quarry ledge. Good exposures occur in Sinkum hollow. It is not known positively that these beds represent different horizons but from the repetition of similar lentils higher in the formation it is probable.

The pitted dolomites near the top of this division yield boulder-like nodules of chert which contain an abundant fauna. These nodules are exceedingly hard and consist of small, irregular shaped, silicified pebbles mingled with the shells of cephalopods, gasteorpods, trilobites, and a few brachiopods. The interstices are often finely drusy. From the distribution of the float it seems not unlikely that more than one and perhaps several of the upper beds of this member yield these fossiliferous, conglomeritic nodules.

The pitted dolomite filling the intervals between the beds just described is less coarsely crystalline than the Gasconade which it somewhat resembles on fresh surface. The beds are seldom more than one and one-half to two and one-half feet thick. They are slightly cherty and are sometimes thin, sometimes sparsely sandy, and sometimes show small dolomite pebbles in a dolomite matrix. Cherty casts of the siphuncles of orthoceras are not uncommon on weathered surfaces.

Cotton Rock Member.—This member shows three minor divisions indicating varying conditions of deposition.

The lower division is a zone about 80 feet thick of medium bedded, rather cherty cotton rock with thin sandstone beds and sandy dolomites. There are also a few layers of crystalline dolomite and several thin layers of silicious oölite. But few fossils occur in this horizon although they are not entirely absent. About the middle of this group an 18-inch bed of soft brownish dolomite occurs which shows abundant fossil outlines and, on weathered surfaces, are found the silicified molds of siphuncles. The bed appears to be only very slightly silicious and on weathering the fossils are not preserved. About 50 feet above the crystalline dolomites a series of thin beds of cotton rock is often conspicuous. It is easily mistaken for the next group above. Thick sandstone lenses occur in the upper part of this group, notably in the N. ½ sec. 36, T. 38 N., R. 8 W., and the E. ½ sec. 26, T. 38 N., R. 8 W.

The middle division consists of a deposit of buff colored cotton rock 15 to 20 feet thick. The upper part is heavy bedded and has been quarried locally but the lower part is thin bedded and, at the bottom, platy. Near the middle of this horizon roundish cavities wholly or partly filled with crystalline concretions of milky quartz are a common feature. This horizon can generally be recognized in the Jefferson City sections but it is sometimes difficult to distinguish from some other cotton rock beds under certain conditions of weathering.

The remainder or upper division measures about 60 feet, and resembles in a general way the group overlying the pitted dolomite member. Like that portion of the section, it is rarely well exposed. There are a number of thin, non-persistent layers of impure sandstone and sandy dolomite. The beds are generally cherty and lentils of greenish shale, six to twelve inches thick, appear locally. At 10, 25, and 45 feet above the massive buff cotton rock, are distinctive but not striking beds of the same kind of rock one to two feet thick. These are brown on fresh surfaces and buff-maroon on weathered surfaces and on weathering show the outlines of what appear to have been pebbles of the same material.

The dolomite beds from 25 to 45 feet above the buff cotton rock resemble dark weathering cotton rocks but are inclined to be porous. They are generally stained a light limonite-brown on fresh surfaces and show white calcite in tiny veinlets.

At this horizon a number of fossils are found including Bigranosa liaspira and a number of species of hormatoma. The hormatoma, which have been found chiefly in float, occur in various matrices but chiefly in oölite. Other fossils have been found in the float of this division but so rarely as to make their accurate position in the member a matter of some doubt.

The upper 30 or 40 feet of the formation is masked by residual material. It is probable that this contains one or more sandstone beds but, on account of its close association with the Pennsylvanian deposits, this is uncertain.

WEATHERING.

In decomposing, the cotton rock even where thick bedded split into thin slabs and plates which litter the steeper slopes. The gentler surfaces are covered with argillaceous residuum with which is mixed the sand and chert derived from other layers. The pitted dolomites leave little residuum and are rarely covered with more than a few inches of cherty soil.

Segregation of Silica.—Good illustrations of the phenomena of surface segregation of chert may be seen in the fossiliferous bed five feet above the Quarry ledge in the drain in the E. ½ sec. 4, T. 38 N., R. 8 W., and ragged masses of bluish fossiliferous chert can be traced to this source. At the surface only sparsely distributed large and small nodules of chert are seen in process of enlargement, while the fresh dolomite is apparently non-silicious. Fossils are secured chiefly from the chert.

The boulder-like nodules of the upper part of the pitted dolomite furnish another instance of the same process. Here the silica is more sparingly disseminated and the segregations generally take on roundish forms. The source of this material was for a time in doubt, since it is not commonly seen attached to the parent rock in large nodules. Not only the fossils, but the original fragmental character of the bed as well, have been restored, and the usual medium-grained crystalline dolomite is seen from the chert to have been originally highly conglomeritic and to have consisted of abundant shells and small irregularly shaped pebbles (probably limestone) up to three-eighths of an inch in diameter.

Close examination of the cherts from other recrystalized beds shows oölitic structure in the cherts of several dolomite beds.

TOPOGRAPHY.

Two phases of topography are developed from the Jefferson City beds. On the west side of the divide near Rolla the drainage has cut deeply into the rocks, and the beds of this formation form fairly steep slopes. On the east side the slopes are comparatively gentle. The pitted dolomite is somewhat resistant and forms gentle step-like slopes rising more steeply above the upper Roubidoux bench. The cotton rock which extends to the top of the divide has rounded surfaces and rises rather steeply to the crest. On the east side of the divide the surface is in marked contrast to other parts of the area. It is for the most part not deeply dissected. The Jefferson City areas here are gently sloping and the low, partly isolated hills have rounded crests.

The sandstone beds of the formation are not sufficiently thick or continuous to affect the topography.

CHAPTER VI.

YOUNGER FORMATIONS.

PRE-MISSISSIPPIAN UNCONFORMITY.

The period of emergence which preceded the deposition of the Mississippian formations was one of long duration. The original thickness attained by the Jefferson City deposits in this area can not, at this time, even be conjectured, though further studies in the eastern and western areas of the formation may throw some light on the subject. It is also unknown whether the St. Peter sandstone was deposited here, though this seems probable since it occurs in the eastern part of this State and in northern Arkansas. Of the later sediments of the Silurian and the Devonian beds no record has been left and it is possible that they were never deposited within the area.

MISSISSIPPIAN.

The Mississipian rocks are found only as float, but in some localities this is so abundant that it seems certain that remnants of the formation yet remain in place.

Louisiana Limestone.—In two localities, notably in the S. W. ¼ S. E. ¼ sec. 25, T. 38 N., R. 8 W., and in the N. W. ¼ S. W. ¼ sec 24, large boulders of dense, dove gray limestone of extremely fine texture have been found. No fossils could be discovered but, as in both localities this rock appears only near the base of slopes covered abundantly with the very fossiliferous, fine-grained, sandy, residual material of Mississippian origin, it is thought to lie beneath the latter. On account of this and because of its close lithological resemblance it is referred provisionally to the Louisiana limestone.

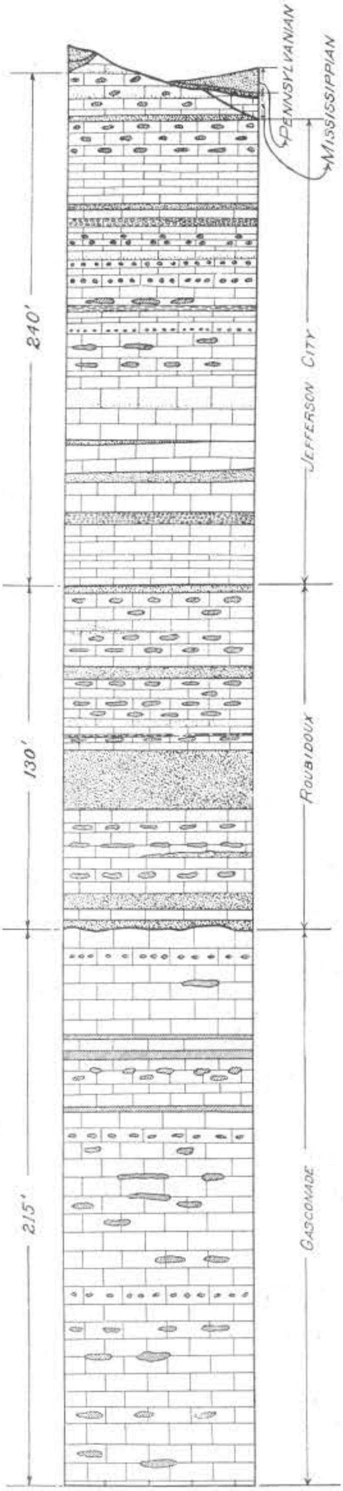
Undifferentiated Mississippian.—Fossiliferous material of definite Mississippian age is found very generally along the divide in the vicinity of Rolla, and farther south. There are three classes of this material: (1) coarsely crystalline, fossiliferous limestone with a large percentage of clear, very fine, angular sand grains, which weathers to a porous sandy quartzite; (2) white to brownish, fossiliferous chert; and (3) fossiliferous, silicious oölite.

Of these, the first is the most widely distributed and abundant. The weathered blocks usually show no lime but calcareous boulders occur in the S. W. 1/4 sec. 24, T. 28 N., R. 8 W. and in large masses at other points. Two classes are recognized: the first occurs in sandy plates, and the fossils consist almost entirely of brachiopods, which lie in particular abundance on the bedding planes of the slabs; the second, lithologically like the first, consists of coarse and fine sandy blocks and ragged masses containing a much more varied fauna. In the float this is associated with the slabby material which occurs in minor abundance.

The white to brown stained, fossiliferous chert was found at only one locality, in the S. E. 1/4 S. E. 1/4 sec. 28, T. 38 N., R. 8 W. It is here associated with the boulder form of sandy float.

The silicious oölites are abundantly associated with the sandy material but fossils were found only in the S. W. 1/4 S. E. 1/4 sec. 36, T. 37 N., R. 8 W. Here the interior of the larger masses shows limestone filling the interior of the oölites, while the interstices between the oölites and the outer crust of the oölites themselves are silicious, even in the freshest specimens obtained. The weathered pieces are light, soft, and porous and are composed of the outer, silicious covering of the oölites. Occasionally the rock is completely silicified, the interior of the grains having been filled by silica. Its stratigraphic position with respect to the fine sandy masses is indeterminate but from the association of the float it is thought to underlie the latter. The oölite is provisionally referred to the Short creek oölite on lithologic grounds.

On the low divide in the N. W. 1/4 N. E. 1/4 sec. 5, T. 37 N., R. 8 W., conglomeritic sandstone is found associated with the sandy Mississippian float. The conglomerate is peculiar in that the pebbles consist of small worn fragments and grains of bluish green shale. The pebbles are occasionally one-fourth to three-eighths of an inch in diameter. While the source of the conglomerate, as well as the shale, is in doubt the fact that it occurs in association with the Mississippian boulders at least suggests the derivation of the shale pebbles from the Hannibal shale. If this were the case, which, however, is by no means certain, it would represent a period of erosion subsequent to the deposition of the Hannibal and prior to the formation of the sandy Mississippian material.



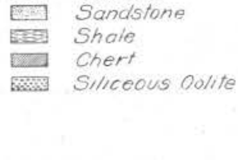


Fig. 6. General geologic section.

Pennsylvanian.—Consists of sandstone, sandstone conglomerate, purple to green clay-shales and flint fire-clay.

Mississippian.—Consists of coarsely crystalline, fossiliferous sandstone, (with a large percentage of sand grains) which weathers to a porous quartzite; white to brown fossiliferous chert; and fossiliferous, silicious oölite.

Jefferson City.—This formation is divided into a lower, or pitted dolomite, member and an upper, or cotton rock, member. The lower member consists of uniform finely crystalline dolomite, and is 70 to 80 feet thick. The upper member consists of rather cherty cotton rock with thin beds of sandstone and sandy dolomites, having a thickness of about 160 feet.

Roubidoux.—The Roubidoux is distinguished by two striking sandstone members and two dolomite members in which are several distinct, but less important, sandstone beds. The dolomite members considered collectively present a gradual change from the underlying Gasconade to the overlying Jefferson City.

Gasconade.—This formation consists of massive beds of dolomite with several interstratified beds of dense, bluish-white chert. The dolomite is generally coarse-grained and crystalline.

PENNSYLVANIAN.

Resting unconformably on the Jefferson City, and containing, at one point in its basal conglomerate, fragments of the Mississippian, is a series of shales, clays, and sandstones of Pennsylvanian age. Occasionally these deposits occur so closely associated with the Mississippian float as to suggest that it is in contact with remnants of the latter. (See Fig. 6.)

Distribution and Thickness.—These deposits occur only in the northeastern part of the area and lie in small patches on the crests or upper slopes of the hills and form the backbone of many of the low ridges of the upland area in the vicinity of Rolla. The thickness of the exposures is rarely more than 20 to 25 feet though many of the clay pits are much deeper. That owned by Mr. David Cowan in the S. W. 1/4 S. W. 1/4 sec. 1, T. 37 N., R. 8 W., is reported to be over 100 feet deep. As the Pennsylvanian was laid on an extremely irregular surface, wide variation in the thickness of the remnants is to be expected.

Description.—Since the surface, on which the Pennsylvanian deposits were laid, was extremely rough, it is rather remarkable that the basal deposits, which are all that remain of the formation in this area, should show any definite sequence of deposition. While not striking there is, however, an order of deposition, the thickness of the layers being the chief variation.

The base is marked by conglomerate, rarely over one or two feet thick, composed of chert boulders chiefly of Jefferson City material in a matrix of clay shale. The chert pebbles in places, as in the railroad cut sec. 36, T. 38 N., R. 8 W., contain Jefferson City fossils. This is succeeded by sandy clay and by laminated, purple to greenish clay which may be the horizon that gave rise to the thick deposits of fire clay (described in Chapter X) where the topography was favorable. Above the fire clay the beds become increasingly sandy and soon consist entirely of sandstone and sandstone conglomerate. An average section taken in the center of sec. 36, T. 38 N., R. 8 W., is as follows:

PENNSYLVANIAN SECTION.

Railroad cut center sec. 36, T. 38 N., R. 8 W.

Feet	Inches	
2		Talus, sandstone, quartzite, chert, and clay.
1	6	Fire clay, thinly laminated, purplish, with bands of sand.
	8	Sandstone, pink, argillaceous, irregularly laminated.
	4	Chert, white to gray.
	6	Fire clay, purple, laminated.

Fig. 1. Fissure in Gasconade dolomite filled with sandstone conglomerate.

Fig. 2. Sandstone cave deposit exposed by erosion of enclosing Gasconade dolomite.

Feet	Inches	
1	3	Sandstone, slightly argillaceous; conglomeritic at base, containing angular and roundish chert pebbles.
	6 to 24	Fire clay, purplish, laminated, interbedded with lentils of sand and chert.
	4 to 12	Sandstone, argillaceous, silicified.
	6	Fire clay, white, laminated.
	6 to 12	Conglomerate, angular cherty pebbles.
	6	Clay, finely laminated, light greenish.
1	6	Conglomerate, with bands of sand and clay surrounding angular and roundish chert pebbles.
4		Fire clay, white, gritty, well laminated and platy.
	6	Sandstone, thin-bedded, slightly argillaceous, partly silicified.
	6	Conglomerate or brecciated chert layer.
1		Conglomerate, subangular, wine-colored, chert pebbles in light greenish clay.
8		Jefferson City cotton rock.

Among the conspicuous boulders which characterize the Pennsylvanian talus are massive blocks of ferruginous sandstone. The iron content is segregated in small balls of hematite the size of a pea or larger, which tightly cement the enclosing sand grains. In weathering, these concretions stand out in tiny knobs and occasionally they are so abundant that they overlap and entirely enclose masses of the sand. This peculiarity is not limited to the Pennsylvanian sandstones for nodules of this kind, though generally larger and less crowded, have been observed in the Roubidoux. Similar characteristics, though less frequent, have been observed in the coarser fossiliferous sandstone of Mississippian age.

In the N. W. ¼ sec. 32, T. 38 N., R. 8 W., the Pennsylvanian deposits form the crest of a high hill whose slopes indicate, by their steepness, the protecting effect of the outliers. The base of this outlier is perhaps a little lower than the outliers on the divide and indicates that the pre-Pennsylvanian surface has a relief of approximately 100 feet within the limits of the quadrangle.

Though no fossils have been found in them, the outliers of this area are assigned to the Pennsylvanian because of their lithological resemblance to the base of that formation in the eastern part of the State north of the Missouri river, and on account of the similarity in their occurrence to outliers in that region. While coal has not been found in this area a small pocket two miles east of St. James which lies eight miles east of the northeast corner of this quadrangle, shows carbonaceous sandstone and fire clay. This forms the connecting link with the coal pockets in Crawford county to the east and similar outliers to the north.

CAVE CONGLOMERATES.

Distribution and Description.—At many points in the area, large and small masses of sandstone conglomerates occur in the bedded rocks. They lie chiefly in the western part of the area, and, though principally in the Gasconade, they are not unknown in the Roubidoux and Jefferson City. These conglomerate masses represent the filling of underground openings and are the result of underground disposal of residual materials in the development of sinks as described on page 60. Excluding the so-called "blossom rocks," which are of similar origin, these deposits have a maximum observed thickness of 30 feet. The fragments consist of large and small particles of chert and quartzite in a sand matrix and the deposits closely resemble in their constituents the soft material now being deposited in the channel of Gourd creek and other caves. In the Jefferson City formation these deposits contain cotton rock in abundance. The fragments are generally coarser and contain less sand. Pieces of dolomite and cotton rock three to four feet in diameter have been observed. These conglomerates generally resist weathering better than the enclosing rocks and are noticeable, if not always conspicuous features. Where they occur in the Jefferson City they weather less prominently because less silicious.

Age.—From their general nature it is apparent that such deposits must have been formed to some extent during all periods in which caves and sinks were being formed. As there is little evidence of sink formation or underground drainage prior to the close of the Mississippian most of the deposits must be referred to the interval between the Mississippian and Pennslyvanian and to post-Pennsylvanian times. Deposits of this kind, not yet exposed, are certainly being formed today in the sink hole area of the southwestern corner of the quadrangle. Since none of the deposits observed were found to contain Mississippian chert it is probable that many, if not most of them, are of post-Pennslyvanian age.

FILLED FISSURE.

A particularly interesting form of this deposit occurs filling a fissure in the bed of the creek in the S. E. ¼, S. E. ¼, sec. 31, T. 37 N., R. 8 W. The fissure or rather series of enlarged joints extends for over 1,000 feet as shown in Pl. IV, Fig. 1 and Fig. 7. The deposit is from two to four feet wide and in form and exposure resembles a dike.

BLOSSOM ROCKS.

Among the rocks referred to cave deposits are certain large sandstone masses locally called "blossom rocks" found enclosed in the Gasconade and higher formations. They differ from the cave conglomerates in the absence of coarse materials. The sand of which they are composed is angular to subangular and the grains are clear. With the sand there is generally a subordinate amount of fine, angular chert. Locally both sand and chert are coarser, the chert grains being in places one-eighth of an inch in diameter.

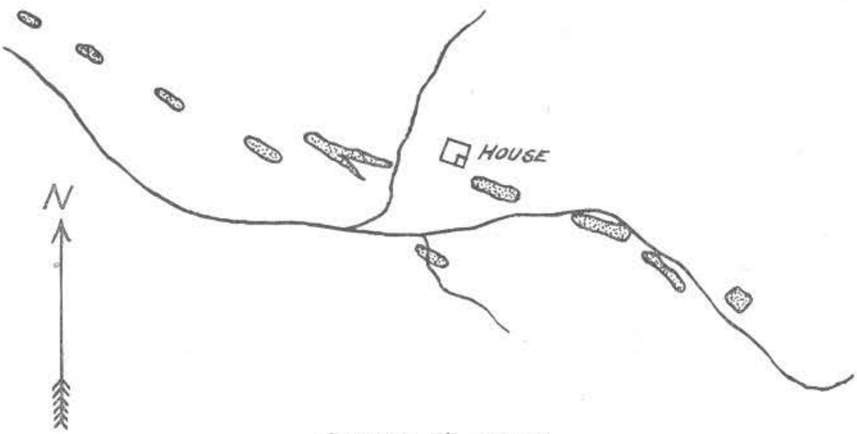


Fig. 7. Outcrops of conglomerate filling fissure in S. E. ¼ S. E. ¼ Sec. 31, T. 37 N., R. 8 W.

Of the six exposures in this quadrangle two lie in the Gasconade, two are near the contact of the Gasconade and Roubidoux, one in the Roubidoux, and one in the Jefferson City. They indicate a vertical range of deposition of 250 feet.

Yancy Mills Exposure.—This is a sandstone mass situated on the upper slope of the ridge in the southeast corner of sec. 32, T. 36 N., R. 8 W., just below the Gasconade-Roubidoux contact. Its form is roughly conical, the top being irregularly weathered as seen in Pl. IV, Fig. 2. Its base, which is ellipitical, with the long direction down hill, is 120 feet by 60 feet. The greatest thickness observed is 55 feet. As is usual with these deposits no exposures occur in the immediate vicinity. The mass is entirely without bedding and is marked by a network of silicified cracks. The joints are without system, although there is a suggestion of it in their radiation from a central area.

The crystalline grains are poorly sorted. Small chert grains occur subordinately. There is no coarse or conglomeritic material; the mass is slightly iron stained and the silica and iron in spots form tiny nodular concretions on the surface.

Peter Hollow Exposure.—This mass occurs at the point of a hill about 50 feet below the Gasconade-Roubidoux contact just east of the center of sec. 30, T. 36 N., R. 8 W. The exposure is 55 feet thick, about 100 feet long, and 70 feet wide and is slightly wedge-shaped, the outline, however, not being sharply marked. The material of which it is composed is similar to that of the Yancy Mills exposure but the mass is distinctly bedded. A gentle syncline and anticline are noticeable in the exposed face which are thought to have resulted from the slight folding in the enclosing beds which dip away from the exposure on both sides. The mass is marked by the silicious cracks which have already been described.

Corn Creek Exposure.—This outcrop has been called the "Devil's Punchbowl" from its basin-like form. It is situated on the upper slope of a hill, well below the contact of the Gasconade and Roubidoux formations in the N. E. corner of sec. 36, T. 36 N., R. 9 W. The exposure, 100 feet by 125 feet, is roughly circular with the long extension on the slope. It has the form of a rough, truncated cone but is higher on the hill side than on that of the drain. The total height is 40 feet. It is markedly laminated, though not strikingly split into beds. The laminae dip sharply toward the center with an average angle of 25 degrees. The dip is probably due to secondary solution beneath the mass and settling. This is also held to be the cause of the cracks which are conspicuous about the edges. The network of quartzitic seams occurs only to a distance of about 20 feet from the rim of the mass and gives the outer part much greater resistance to weathering than the interior. The inside, in consequence, has been scoured out accentuating the basin-like form given by the tilted laminae. The joints are roughly radial and parallel to the edge of the exposure. The grains are well sorted and contain a number of sheets of coarse sand with which are associated bands of angular chert particles about one-eighth of an inch in diameter.

Vessie Exposure.—This mass is found on the north side of a narrow ridge in the S. E. ¼ N. E. ¼ sec. 18, T. 36 N., R. 8 W. The mass extends from a few feet above the drain in the upper part of the Gasconade to the top of the ridge almost to the elevation of the second sandstone member. On the south side of the ridge, not more than 200 feet distant, the Gasconade and Roubidoux beds appear in place and the deposit is practically enclosed on three sides and open only toward the drain. The thickness is about 70 feet and the width about 100 feet.

The material of which this deposit is composed is similar to that at Yancy Mills but here there is very little chert. There is no bedding or lamination. The quartzite seams, though present, are not conspicuous and the joints are without system.

Kaintuck Hollow Exposure.—This mass occurs on the lower slope of a ridge at the horizon of the lower sandstone of the Roubidoux in the southwest corner of sec. 9, T. 36 N., R. 9 W. The exposure is small and only 30 to 40 feet in diameter and 25 feet high. It is similar in every respect, save size, to the Yancy Mills exposure.

Rolla Exposure.—On the slope of the divide in the southwest corner of sec. 11, T. 37 N., R. 8 W., lies a mass of sandstone similar to those already described. It lies in the beds just above the pitted member of the Jefferson City and, although not a large deposit, exhibits the usual phenomena of irregular ragged masses of nonbedded sandstone. The deposit lies below and not far distant from a fire clay pit.

ORIGIN.

From the dimensions and topographic position of these deposits it does not appear possible that they could have been deposited subaerially. The Vessie exposure, for example, a homogenous nonbedded mass of sandstone, is enclosed on three sides by regularly bedded deposits of the Roubidoux and Gasconade formations.

The geological relations of the other exposures are not so well marked but they lie for the most part in such thick masses and in such relations to the enclosing rocks that it appears impossible that they could have been deposited in surface channels, however, deep and sharp, without having left other outliers of such resistant materials in the vicinity. The small size of the deposits together with their great vertical range is thought to be sufficient to disprove any suggestions of sink hole deposition during known periods of sedimentation.

The evidence of deep solution of the rocks and the formation of deep caves, later to be presented and discussed, makes it appear likely that these deposits represent the filling of subterranean caverns either during their formation or at some subsequent period. If the caverns were filled during a period of submergence it is difficult to account for the few cases of lamination and bedding which are much less common elsewhere than in the representatives of these deposits in this area, as well as for the transportation of the material in the quiet water which must then have filled the underground openings. If they had been formed during a period when the surface was strewn with conglomeritic material, as it is today, conglomeritic material must have been a more conspicuous feature of the deposits. This kind of material is conspicuously absent. It follows, therefore, that the surface which contributed its detritus to the filling of the underground openings must have been one predominantly sandy. The only known formation overlying the Jefferson City that could have contributed this material is the Cherokee occurring at the base of the Pennsylvanian. It is believed that these curious sandstone masses were deposited during the erosion of the Cherokee. The possibility that the St. Peter or Pacific sandstone furnished the sediments is disproved by the character of the sand and other relations.

The chert particles which occur subordinately with the sandstones form a constituent not generally associated with the Cherokee and must have been derived from less abundantly exposed formations or from the walls of channels.

A comparison of Plate IV, Fig. 2 with the illustrations of so-called Graydon sandstone in the reports on Miller and Morgan counties and the general description of these deposits in the reports mentioned and in the Moniteau county report leaves no doubt that they are essentially of the same character and relation. The Graydon sandstone, however, as described by Shepard is micaceous and contains well rounded and water worn pebbles, characteristics not developed either in this quadrangle nor in the counties mentioned. The Graydon sandstone of Shepard is also bedded and cross-bedded while the deposits under discussion are typically massive. It seems extremely questionable therefore whether these deposits should be referred to the Graydon since the only characteristics in common appear to be the character of the sand grains and the meagre iron content.

None of the features of the deposits described in the reports mentioned are inconsistent with the theory here advanced. In fact the theory of subaerial deposition is distinctly at odds with some of the occurrences described. The interrupted trail-like deposits can equally well, if not better, be assigned to deposition in underground water courses whose existence is attested in this area and in many other parts of the region by large and small fissures filled with sandy conglomerate. Lamination would be developed where currents were suitable but in the larger chambers, the filling of which forms the greater part of these deposits, regular bedding would probably not occur.

During the development of the caverns and underground passages the deposits would consist of the sand and insoluble materials derived from the erosion of the walls of the openings, and it is hence not unlikely that some of the cave conglomerates represent the basal deposits of the sandstone masses. Cave conglomerates were observed to underlie the so-called Graydon sandstone in Miller county both conformably and unconformably. When surface erosion uncovered an opening connecting with one of these trunk channels the material derived from subterranean sources would become inconsiderable when compared with the volume of material furnished from the surface. With the surface composed chiefly of sandstone the material presented for underground disposal would be easily transported and there would be a minimum possibility of clogging the passages until they were completely filled.

Outside the areas already mentioned these deposits have been observed abundantly in the Jefferson City formation at Cuba and in the Gasconade formation in Dent county south of Salem. Similar deposits occur in the Yellville formation in northern Arkansas where, however, they have been thought to be of St. Peter age. As the deposits are nonfossiliferous there is little evidence to determine the age. The occurrence of Pennsylvanian fire clay in a deep solution chamber near Newburg suggests that the formation of the caves forming the site of deposition in both cases were contemporaneous but this may have been either pre-Pennslyvanian or post-Pennslyvanian. The occurrence of Burlington chert in some of the deposits of Miller and Morgan counties places the date as certainly post-Mississippian and considerations of the source and mode of deposition suggest that the date both for the formation of the caves and their filling is post-Pennsylvanian and occurred during the erosion of the nonmicaceous Pennslyvanian sandstones which once covered the area.

CHAPTER VII.

PHYSIOGRAPHY.

Probably the most striking feature of the physiography of the area lies in the marked difference in topography east and west of the divide near Rolla, as may be seen by reference to the map. This advantage is not assignable to inclination of the strata for the prevailing dip is northward, but is due chiefly to the relative distances of the Gasconade 12 miles distant on the west and the Meramec which attains the same level 20 miles to the east, as well as to the relative size and transporting power of the two streams. The sharpness of the slope on the west is probably accentuated at Rolla by deposits of Pennsylvanian sandstone which formerly formed the crest of the divide and which are now represented only by small outliers of sand and clay. The influence of these sandstones is conspicuous in preserving the surface from erosion as may be seen in the steep slopes below the hill in the N. W. 1/4 sec. 32, T. 38 N., R. 9 W., and by their presence on the low ridge exposed in the railroad cuts east of Rolla.

EROSION CYCLES.

For several reasons it is thought that the region has been re-elevated more than once since the period of base-leveling supposed to have taken place during Cretaceous times. (See Fig. 8A.)

The evidence of the movement lies in the dissected plateau of the western part of the area, most conspicuous south of Newburg. For a distance of six or eight miles on both sides of the Gasconade river the ridges are remarkably uniform in elevation. Wide and narrow portions of the ridges do not differ perceptibly in elevation and it is apparent from the uninterrupted sky line that, before the present development of the deeply cut drains, outlying areas of formations represented on the divides had already been removed. On both sides of this central basin the Jefferson City is well de-

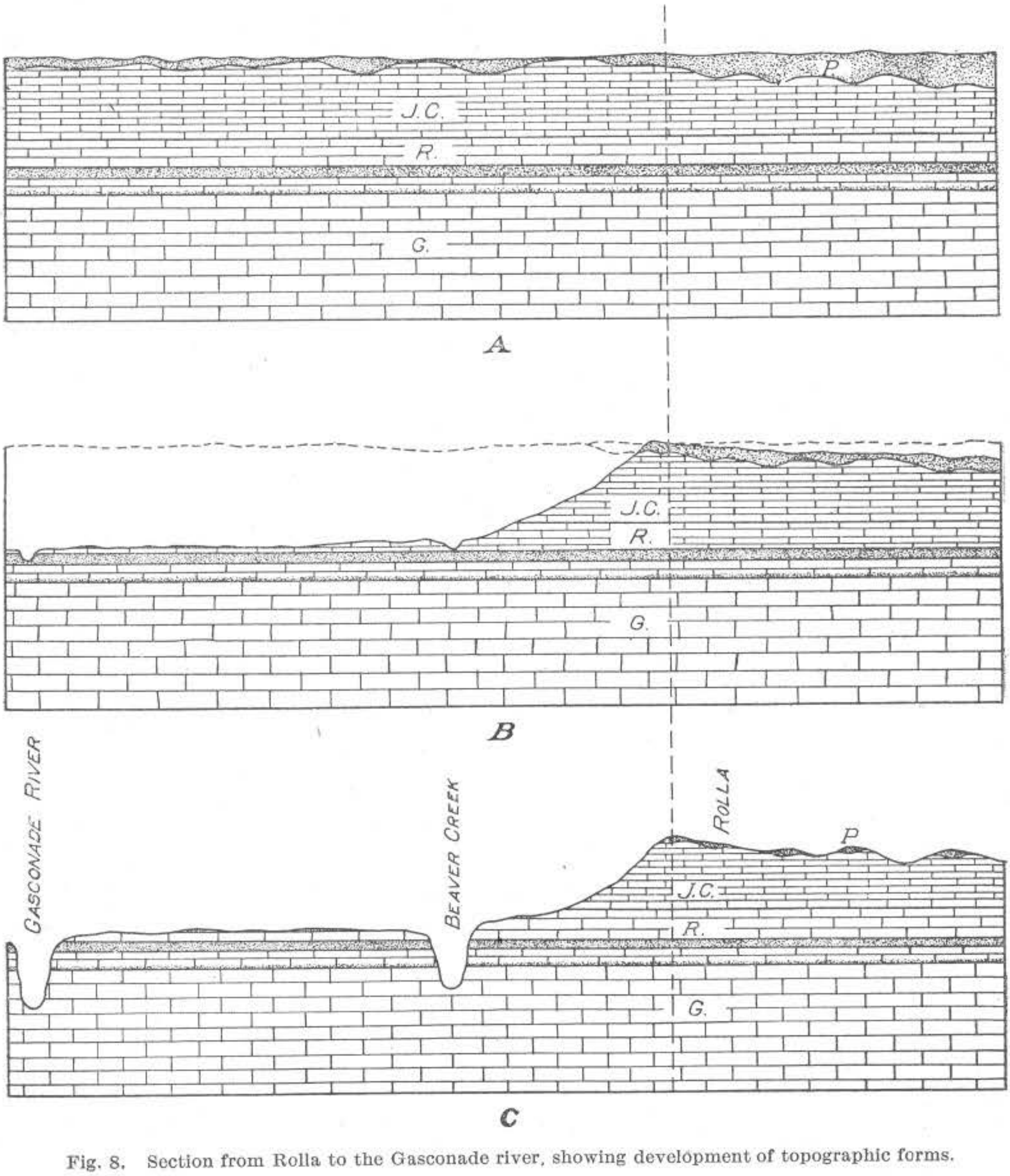


Fig. 8. Section from Rolla to the Gasconade river, showing development of topographic forms.

veloped and outliers of Pennslyvanian deposits are found capping the higher points.

The meandering course and narrow valley of the Gasconade itself suggests a maturity of erosion entirely inconsistent with the present topography of the area. There can be little doubt that its tortuous course was developed where its valley was much broader and that later change in elevation has incised the old bed in the underlying, rapidly eroded dolomites. The courses of the Osage and other rivers in the Ozarks are also marked by incised meanders and secondary dissected plateaus.

At the close of this cycle of degradation a section across the northern part of the area would have appeared roughly as in the cross section B, Fig 8. The land was then re-elevated and streams were rejuvenated and cut deeply into the underlying rocks carving out the deep bluff lined valleys of the present day as shown in cross section C, Fig. 8.

Influence of the Roubidoux.—While the development of the plateau surface was independent of the resistance of the Roubidoux sandstones as indicated by the equal elevations of wide and narrow parts of the ridges, its preservation is due largely to the effective resistance offered by the heavy sandstone members of this formation. It has already been stated that but for the Roubidoux sandstones the topography would probably be much more broken and the plateau surface would probably be recognized with difficulty.

RECONSTRUCTION OF EARLY BASE LEVEL.

In order to obtain some idea of the configuration of the old basin, the surface has been reconstructed and is shown by contour lines in B Fig 9. For the construction of this figure the high points of the ridge lines have been used both in the plateau area of the west and along the divide south of Rolla although the latter has suffered greater relative erosion than the former since the period represented.

It will be noted that, along the eastern margin of the area, the surface rises gently to a range of low hills and that the surface of the basin slopes gently toward the north. A drainage basin corresponding roughly with the valley of Little Piney is indicated in the southeast by the sweep of the contour lines. The marked northward dip observable in the sketch together with the inclination of the strata in the same direction suggests that the one might be the cause of the other, particularly since there is scarcely

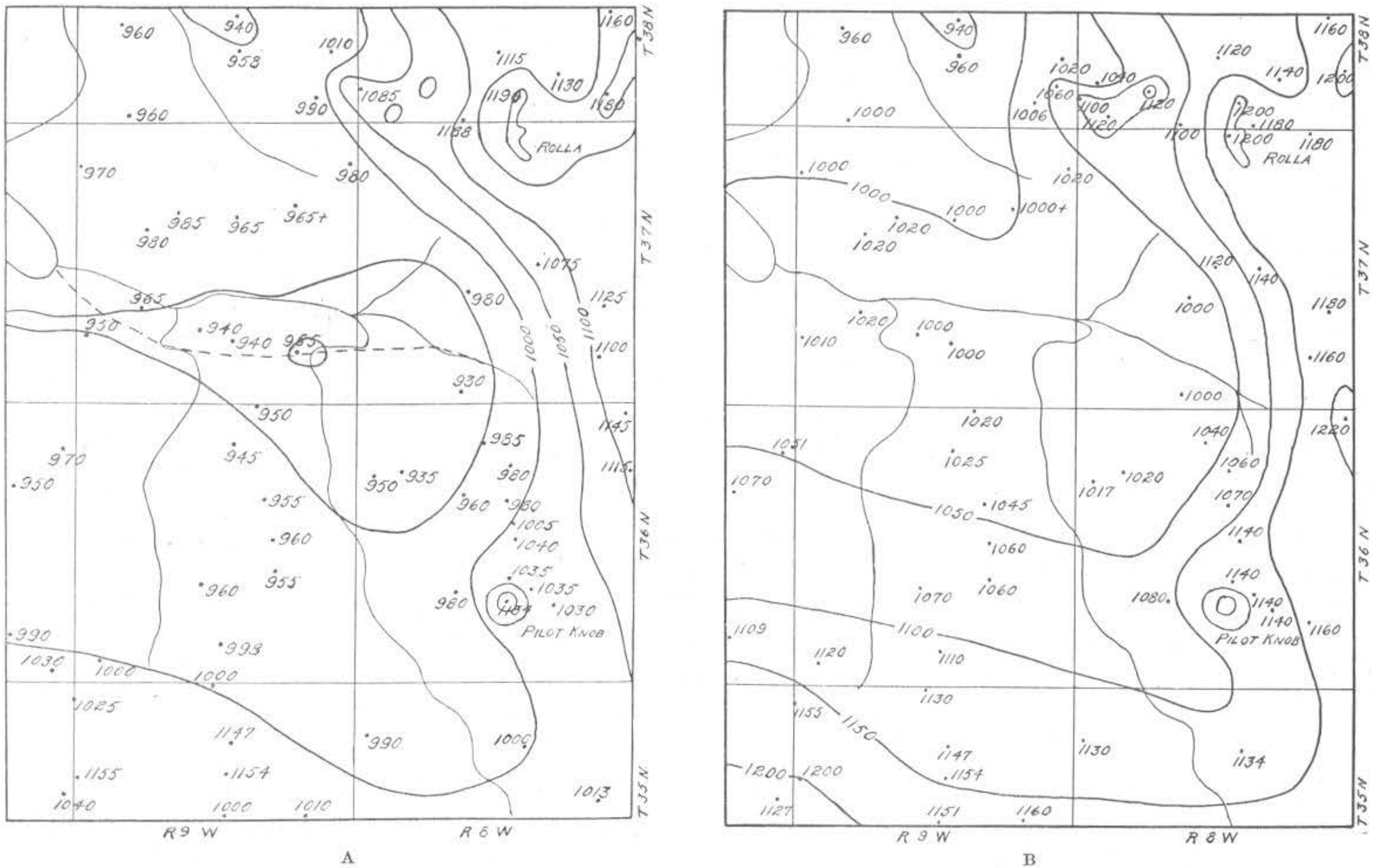


Fig. 9. Sketch showing topography at the stage represented in Fig. 8 B; A before tilting, B after tilting.

any notable difference in the thickness between the surface and the upper sandstone member on the ridge in the southern and northern parts of the area.

Tilting.—In order to see what effect the correction of the northward dip might have had on the configuration of the surface and on the drainage, Fig 9A. was constructed. The average total dip northward amounts to 160 feet within the limits of the quadrangle. With this as a basis the elevations of the same points utilized before were corrected differentially to restore horizontal bedding. The northern boundary was assumed constant, points on the south line were lowered 160 feet, and intermediate points corrected differentially. The results indicate a surface rising gently from the valleys of the Gasconade and Piney rivers toward the east to a range of low hills. The steeper slopes on the east are the expression of the difference in resistance to erosion already discussed between the upper Roubidoux and Jefferson City below, and the Pennsylvanian deposits above as shown in the Fig. 8B. The drainage basin of Little Piney is strikingly restored. On the western margin of the area the slope northward is approximately six feet to the mile. The corrected surface shows the hills in the south to have been notably lower than the hills which at Rolla are characterized by a capping of Pennsylvanian sandstone. The lower elevation of points in the south may consequently be attributed to the fact that at the time of the uplift Pilot Knob and other points to the south had already suffered considerable erosion below the Cretaceous base-level. The high points in the vicinity of Rolla are thought to be the outliers or monadnocks of the early base-leveled surface, probably owing their preservation to the resistant Pennsylvanian sandstone capping.

While the results attained in correcting for the northward dip of the beds are perhaps not entirely conclusive, the striking restoration of Little Piney basin is at least suggestive of a certain measure of truth. Of the two surfaces indicated, that shown in Fig. 9A appears to be best adapted to the particular features possessed by the old river valley: i. e., a perfectly level plain still covered to a depth of 20 or 30 feet with residual debris through which flowed a broadly meandering river.

While it was probable that the beds of the area were not perfectly horizontal before the uplift which rejuvenated the drainage, it appears very likely that much, if not the greater part, of the tilting took place about this time and that the restoration of the beds to a horizontal position at least represents an approach to the structure at the time of the formation of this early valley plain. It is probable that the tilting which raised the surface was gradual and it may not have been equal at all points.

Marbut in his Morgan county report* noted two denudation plains probably corresponding to the two described in this area. He found them to lie vertically closer together than here, and mentions that these plains diverge in elevation toward the southern part of the State. This would indicate, as was mentioned above, that at least part of the tilting of the Ozark uplift occurred before the valley forming period.

PHYSIOGRAPHIC HISTORY.

The recent history of the area supplied by the topography, supposed a period of partial or complete base-leveling or plaination subsequent to the Pennsylvanian period (possibly during Cretaceous times), represented in Fig 8A.

This was followed by an uplift perhaps with slight deformation during which, if not previously, the main drainage areas of the region were determined.

During a period of quiet or very slow movement the base-leveling proceeded to late maturity or old age. A ridge of low hills standing 250 to 275 feet above the valley plain was formed at the eastern margin of the area. The surface sloped gently westward forming a broad flat valley through which the forerunners of the Gasconade and its tributaries found sluggish drainage in broad meanders.

Outlying hills of Jefferson City beds which must have been a feature of the early part of this period of degradation were all removed from the valley before this cycle was interrupted. Residual materials of chert, sandstone, and quartzite derived from the wearing away of the neighboring hills accumulated in the valley to a depth of 20 or 30 feet at least and are still found on the ridges.

The age of this movement is indeterminate from the evidence now available. This and subsequent movements constitute the Ozark uplift which are thought by some to have taken place in late Tertiary times. The elevation of the surface at this time was not great but since the Gasconade valley plateau lies some 275 feet below the hills of the time (as shown in Fig. 8B,) it can not have been less than this distance above the sea and was probably somewhat, but not much, higher.

*Marbut, C. F., Geology of Morgan Co.; Missouri Bureau of Geol. and Mines, vol. VII, 2nd series, 1908, pp. 8 and 9.

Before erosion had accomplished peneplaination the degradation of the surface was interrupted by a second gradual uplift accompanied by a tilting of the beds toward the north. The drainage was rejuvenated with gradual elevation of the region and the streams cut deeper into the underlying rocks preserving the stream meanders of the old valleys. At Jerome a former bed of the river is indicated by a gravel bank in a railroad cut some 50 feet above the present river level.

The total elevation caused by the second uplift is unknown. That it was at least 350 feet in this area is indicated by the fact that the Gasconade now flows that much below the old valley but it may have been somewhat greater. (Fig. 8C.)

Readjustment of Drainage.—Coincident with the warping of the surface there was probably a readjustment of certain drainage lines. Beaver creek is thought originally to have flowed westward from a point near the Point Bluff school and to have passed across the gap in sec. 30, T. 37 N., R. 8 W., through the sharp bend of Little Piney, then through the gap in the ridge between Little Piney and Mill creek, thence to the Gasconade as shown in the dotted lines in Fig. 9A. Little Beaver may have utilized the lower course of Little Piney. Probably at an early period before the channels were deeply cut the divides between the drains were destroyed. Little Piney and Mill creeks, utilizing parts of the old channel, found new exits in a more northerly direction and the lines of drainage were gradually established as they are today.

An instance of later change of drainage is to be seen near the mouth of Gourd creek in the southern half of sec. 19, T. 36 N., R. 8 W. Coal Pit hollow originally found exit to Little Piney. The rapid development of a tributary of Gourd creek due to some cause not now apparent (perhaps an underground channel) captured the drainage of Coal Pit hollow, leaving the old exit marked by a low saddle.

The unusual drainage in sec. 2, T. 35 N., R. 8 W., is due to the presence of a large well defined sink structure. The drainage in the upper part of Corn creek in sec. 14, T. 35 N., R. 9 W., has been directed by a similar disturbance but the meandering course of the stream, as a whole, is thought to be that imposed by former drainage.

The course of most of the principal creeks, particularly the upper part of Beaver, upper Little Piney, Kaintuck hollow, Caves Spring creek, and Camp creek have been determined by the old and gentle synclines of folds described in chapter IX.

CHAPTER VIII.

SINKS AND CAVES.

The chief agent in the formation of caves and similar openings in limestone and dolomite is the carbonic acid derived from the atmosphere and introduced by rain water to subterranean circulation. Pure water is not a very effective solvent for limestone but with the addition of carbonic acid the solvent power, although not quantitatively great, is much increased. The relative weakness of the solution is offset by the great quantities of water constantly in circulation. It is estimated that 50 to 60 per cent of the total rainfall in this region (about 42 inches) finds its way to the sea by underground drainage.* A much greater part of the rainfall enters the ground through the abundant openings of the surface and induced in part by the retarded circulation of increasing depth and in part by hydrostatic head is forced to the surface at a lower elevation where it escapes as springs.

Circulation.—Where the ground is saturated, the water utilizes all available openings in the rocks for its circulation. It is evident, however, that the larger openings in proportion to their size and to the means present for direct circulation convey much greater quantities of water than the small openings. The gaping joints and other abundant and connected openings of the surface give way in depth to cracks and closely restricted passages. Bedding planes, however, are subject to less variation with depth and, while they constitute a negligible part of the available channel at the surface, they assume relatively greater importance in depth by reason of the decrease in size of vertical channels.

Beds of sandstone, breccia, and conglomerate also become of more importance for water channels as depth increases. It follows, therefore, that as downward circulation is retarded, there is a growing tendency toward lateral circulation along bedding planes and porous strata.

*Newell, F. H., Results of Stream Measurement: 14th Annual report U. S. Geol. Survey, pt. 2, 1894, plates V-VI.

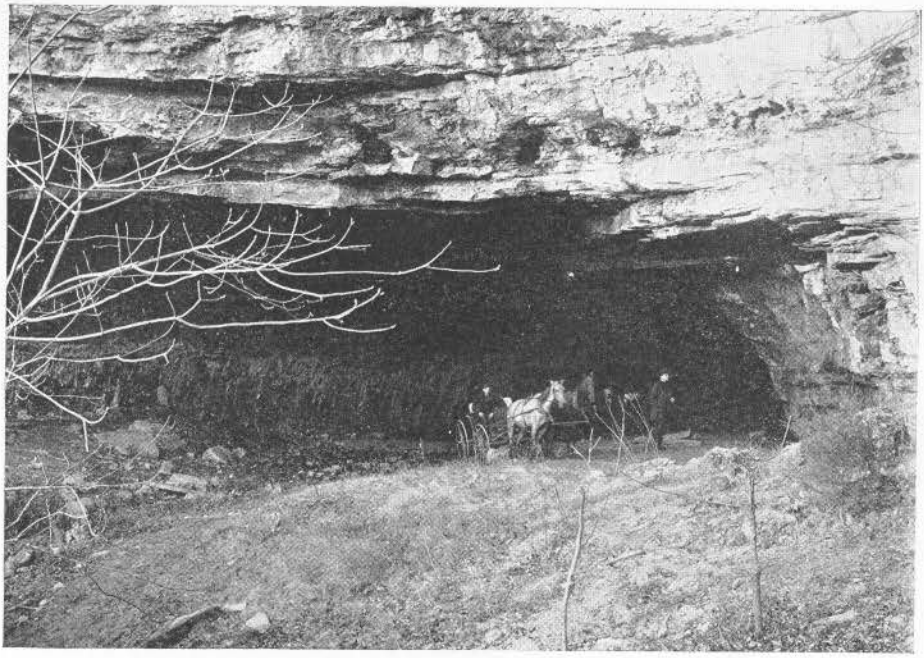
Localization of Solution.—Maximum solution of a limestone formation probably takes place at the surface but its effects are distributed through countless small openings of the surface rocks and tends rather to honeycomb them than to produce notable cavities. With depth, on the contrary, the movement of the water is localized in more or less definite channels and, while its solvent powers may be less vigorous, its effect is more striking since the solution takes place along definite lines of circulation producing the varied phenomena seen in caves and galleries. In such situations the greatest solution takes place where greatest amount of effective solvent is in circulation. Hence it happens that many of the larger underground openings occur at the intersection of joints or fissures since circulation is here most active.

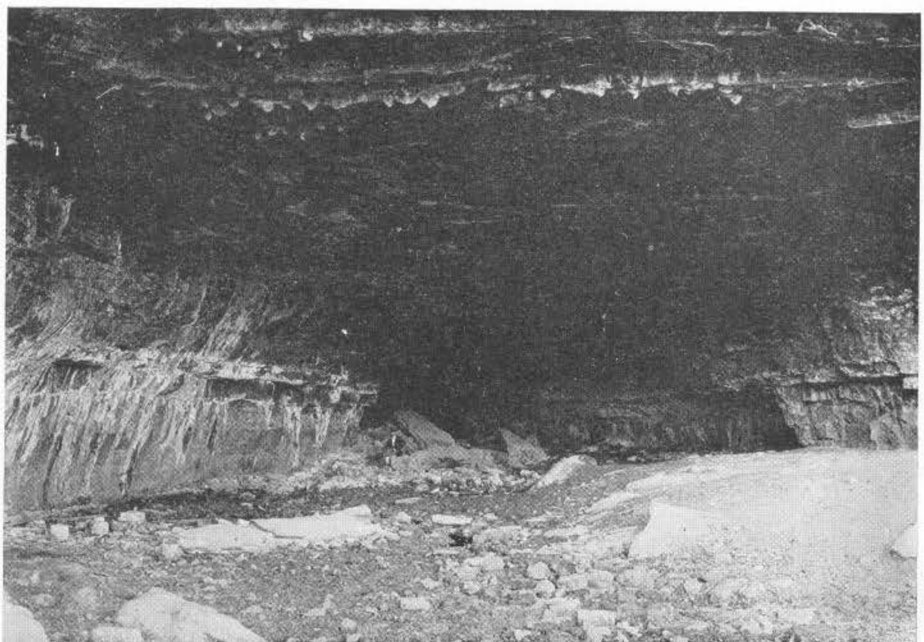
Generally, underground caverns are connected by ramifying passages with other similar openings more or less distant through which currents of air enter, in some cases issuing with considerable velocity through small vents located higher up. A drilled well in the S. E. ¼ sec. 35, T. 37 N., R. 9 W. penetrated such an opening from which a strong current of air issues, reported to be of such velocity at times as to sound a jew's-harp.

Underground Erosion and Transportation.—In addition to simple solution the enlargement of subterranean openings is assisted to some extent by underground erosion. Insoluble materials, such as chert and sand, worn from their beds are often carried to the surface by springs. If an upward movement of waters is involved the larger boulders and pebbles accumulate as conglomerate in some enlarged part of the channel or are worn down by abrasion, the smaller particles being carried out in suspension by the current as in boiling springs. The amount of underground erosion possible is obviously limited by the amount and rate of solution since otherwise the channels would become choked as indeed they sometimes do.

SOLUTION PHENOMENA.

The phenomena produced in this region by subterranean solution may be divided into two classes: the first includes caves and other underground openings and topographic or surface sinks; the second comprises the phenomena styled "filled sinks" although the phenomenon occurring in this area might be more properly described as filled caves.





Views of Gourd creek cave.

CAVES.

As surface rocks are cut away by erosion and solution, openings in the rock formed at various depths appear from time to time at the surface. If the entrance to a cave is so situated that detritus is not directed into it, the cave will exist until erosion has removed is roof, but, if the opening is in such a position as to allow detritus to enter it, the cavern will exist only until it becomes filled.

Caves are not unusual in the district but remarkable development is not common. They occur only in the Gasconade probably because this formation is topographically favorable to their preservation. The dependency on jointing is evident in most cases but some appear to have been formed by laterally moving waters and their position to have been decided by the presence of closely jointed or brecciated beds. In a series of heavy and thin bedded dolomite interstratified with chert layers of varying thickness joints appear to have been more abundantly formed in some beds than in others. At these horizons, where water has penetrated by lateral circulation, chambers and passages of considerable size have developed apparently independent of jointing in the immediately overlying beds. This is the case at the Gourd creek cave situated near the base of a bluff on the north side of Gourd creek near its junction with Little Piney.

The Gourd Creek Cave.—The mouth of the cave (Pl. V.), which is 100 feet wide and 22 feet high, occurs near the foot of a bluff and is the opening to a chamber 185 feet long. A short bend at the back of this cavern unites it with a tapering gallery which may be followed about 400 feet. The passage continues still farther in a tight wedge-shaped channel about 18 inches high. The gallery conveys a perennial stream of water and is clearly an enlarged joint but the great chamber at the mouth of the cave presents a smooth unbroken roof and it is evident that the opening which permitted the deflection of the water from the gallery to the cave proper did not extend upward into the overlying beds. A smaller joint crosses the gallery diagonally and its enlargement forms two short branches in the passage. The cave is a favorite resort for picnics and it is possible to drive a wagon directly into it. It is said to have been a favorite resort of Indians in former times. Near the mouth two to four feet of wood ashes, in which skulls and bones are reported to have been found, cover about one-sixth of the floor of the great chamber.

Natural Tunnel.—In the N. E. 1/4, sec. 16, T. 36 N., R. 9 W., a similar phenomenon is exhibited in a natural tunnel which has captured the drainage of one fork of a tributary to Kaintuck hollow. The opening is about 10 feet wide, 6 to 8 feet high, and 100 feet long. There is no evidence of jointing in the roof.

Joint Caves.—Many caves also occur in the vicinity of Yancy Mills but, in these, jointing is generally manifest. A small cave occurring at the top of a steep ridge in the S. E. 1/4 sec. 4, T. 35 N., R. 8 W., is worthy of special mention on account of the development here of stalactites and stalagmites in varying forms, no where else so well developed within the area. The mouth of the cave is small and entrance is difficult.

TOPOGRAPHIC SINKS.

If, when an underground cavern is brought to the surface by erosion, the mouth is so related to the topography that the detritus of weathering is washed into the opening, the proper conditions exist for the formation of a topographic or surface sink. Material washed into the now subaerially exposed cavern is either carried downward into the lower portions of the subterranean water course with which it is connected or lodged temporarily in the cavern itself.

In the first case the vent becomes enlarged by the weathering away of the edges and the detritus is removed subterraneously as completely and expeditiously as conditions permit. Generally, as in the second case, this does not take place fast enough to prevent the accumulation of material in the bottom of the basin thus developed and the result is a more or less rounded depression covered with residuum and without superficial drainage. Caverns not immediately at the surface may also cause the formation of sinks if a direct connection to the surface is established by an open passage. The opening from the surface downward serves as a more convenient and direct means of disposing of the products of weathering than that offered by surface drainage, the cavern and connecting galleries forming a repository for the waste. Such a sink begins with the weathering of the edges of the connecting aperture. A talus slope soon follows which, with the hole connecting to the cavern below, has a cross-section resembling that of an hourglass. This seems to be the origin of the smaller sinks in the sandstone areas of the southwest quarter of the quadrangle.

When more material is presented to underground drainage

Fig. 1. Sink, gradually filling from deposition.

Fig. 2. Slaughter sink, four miles south of Arlington. This sink is nearly one-half mile long by one-fourth mile wide.

than can be disposed of or, if for any reason, the passage or cavern becomes clogged by too rapid accumulation of waste the formation of the surface depression comes to a halt and the sink begins to fill up. The sink shown in Pl. VI shows no gullies and may be said to have reached old age. A long continued cessation of the underground disposal of residuum results in the complete mantling of the site of a former sink leaving little or no evidence of its former existence at the surface. From time to time, if the congestion of the underground passage is relieved, a new cycle of sink development may begin with the renewal of drainage through the old opening followed by the cutting of channels in the accumulated material. Pl. VII shows two views of such a sink. The sudden formation of small sinks in this way or by collapse of the roof over a new or rejuvenated passage is not an uncommon event and has been noted at a number of places in the southern part of the area within the past ten years.

Location and Distribution.—Sinks occur in unusual abundance in the southwestern quarter of the area in all stages of development from simple depressions in the residuum to sharp, abrupt holes over one hundred feet deep. Pl. VI Fig. 2 shows a view across one of the largest of these. The steep bluffs and large extent resemble a deep valley rather than a sink. The surface of the area in which the sinks occur is underlain by the Roubidoux formation but this is not due to any peculiarity of the formation but because the Roubidoux comprises the only level surface, the Gasconade being confined to the stream beds and the steep declivities which confine them. Two of the deeper sinks extend below the top of the Gasconade and the rocks of this formation are exposed on the steep slopes of the sinks. The level of ground water in this area is deep and springs are almost entirely absent. This is due to the presence of Piney river, one to two miles distant from the western border of the quadrangle, and to the sudden break of over 300 feet in the topography at the bluffs which border this stream.

Although a considerable portion of the Roubidoux formation consists of limestone beds and, although it is probable that openings formed in these beds may have provided means of disposing of the residuum in some of the smaller sinks, it seems more likely that most of the residual material finds redeposition in caverns and trunk channels in the Gasconade formation. The reasons for believing this are the deep circulation and the scarcity of springs and caves in the Roubidoux. Many of the sinks occur near the horizon of the second sandstone member and the casehardened face of this bed can often be observed at the bottom or sides of the smaller sinks. It is sometimes seen forming a complete rim about the edges of the larger ones. Some of the sinks like that north of the Western Star school, sec. 11, T. 36 N., R. 10 W., are shallow and have basins in no way different from the heads of drains but end abruptly at one end in an ill-defined choked opening. In the case of the sink in sec. 6, T. 35 N., R. 9 W., drainage appears to have been checked for water stands in the basin and the enclosing slopes have taken a rounded, mature form in sharp contrast to that of the neighboring drains. The sink in sec. 1, T. 35 N., R. 10 W., presents a similar appearance and although it is filling up, drainage has not completely ceased and its character is intermediate between that of a normal drain and a mature sink. The accumulation in the bottom represents the difference between waste supplied and that disposed of. The sink in sec. 14, T. 36 N., R. 10 W., near the Western Star school, appears to have passed through a period of rest during which it was partially filled up by soil and residuum. It is now enjoying a period of rejuvenation fresh drains having cut new channels in the old filling. Twenty feet or more of the soil and residuum are exposed in steep banks at the bottom of the sink. The sink in sec. 36, T. 36 N., R. 10 W., is sharp and steep. It appears to occupy the site of a former large and persistent joint. Not only the Roubidoux but also Gasconade rocks are exposed in bluffs on the enclosing slopes and there is little or no accumulation of talus in the bottom though no point is distinctly marked as the disappearance of drainage. The heads of some of the drains of this area appear to be former sinks later captured by surface drainage.

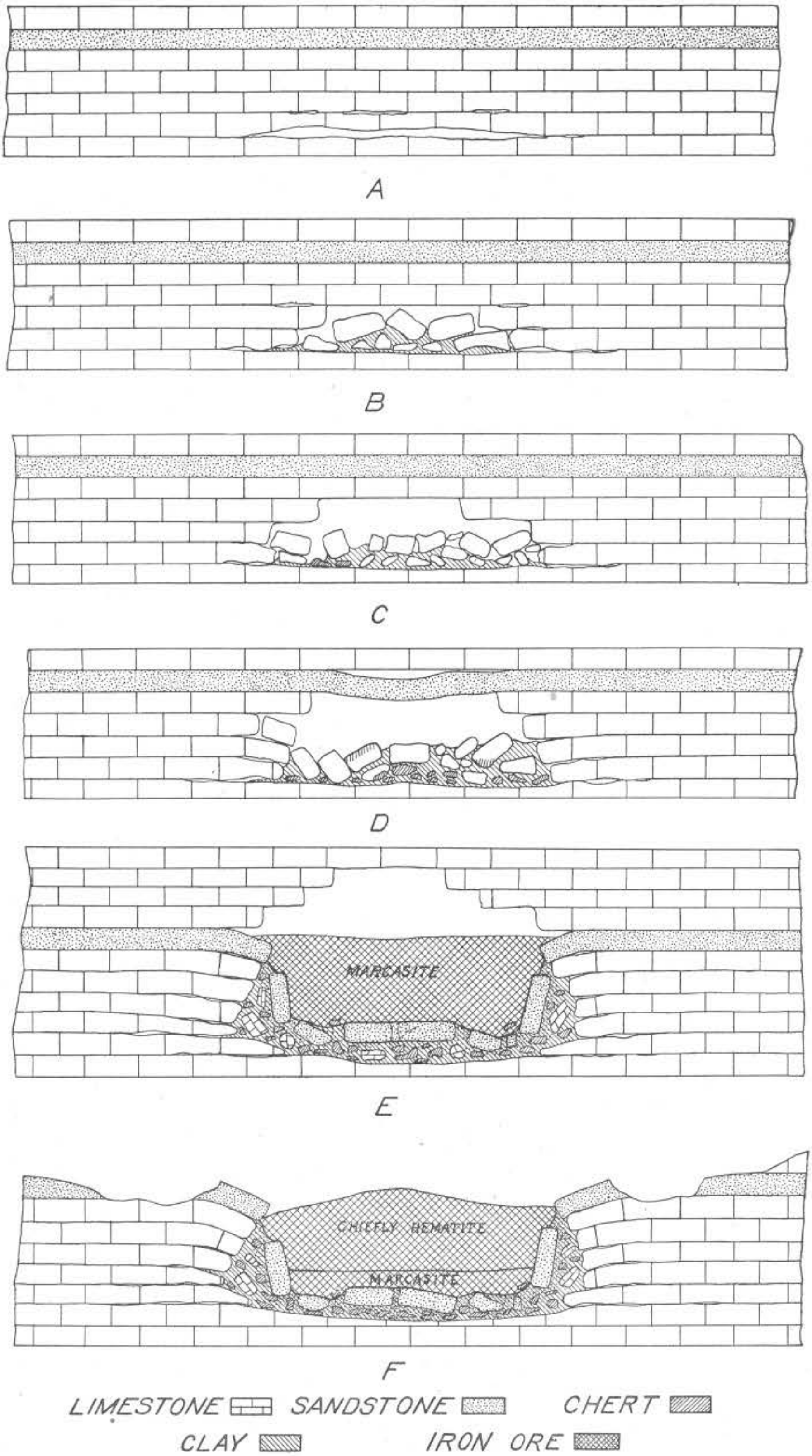
Sinks, while no where else attaining the number and development which they have in the southwestern quarter, are also known in the southeast quarter of the area and north and northwest of Newburg. These all occur at or slightly above the contact of the Roubidoux with the Gasconade and are in no way different from the larger sinks in the southwest corner of the area. No sinks have been observed in the Jefferson City formation in this quadrangle although they are not uncommon in other parts of the Ozarks.

FILLED CAVE STRUCTURES.

Character of Circulation.—As has already been stated, the movement of water below the ground water table is essentially lateral. When carbonated matter moves in a broad sheet on the

Fig. 1. Rejuvenated sink, showing recently cut gullies.

Fig. 2. Center of above sink, showing banks of residual material, 20 feet high, through which the rejuvenated drainage has cut.



G—5 Fig. 10. Sketch showing general development of structural sinks.

bedding planes of a limestone formation solution along the channels may be expected. If solution were equal at all points, as should be the case under uniform conditions, a gradual and simultaneous settling might take place over the whole area affected. Where, however, lateral circulation is more abundant for any reason in certain limited areas than elsewhere the resulting phenomena are of a different kind.

Concentration of circulation under these conditions is favored in the vicinity of fault planes, open fissures or trunk channels; in the synclines of gentle or sharp folds; where variable stratification is expressed in the wedging out or thickening and thinning of certain beds, and where (but not necessarily in depth) unconformable relations offer natural drainage on the old surface; or by any combination of these conditions.

Solution.—In such situations, as elsewhere, solution is most active where circulation is greatest. The openings formed are irregular in shape and of a roughly lenticular form as in Fig. 10A. Such hollow lenses of small dimensions are not uncommon in caves. A small though suggestive occurrence is to be seen in the end of the gallery of the Gourd creek cave already described. The form is that of an elongated lense about 18 inches high tapering wedge-like into the inner recesses of the channel. The shape of the opening is slightly modified by the sagging of the bed forming the roof which has parted several inches from the next bed above. The height of such chambers must be dependent on their lateral extent and the character of the overlying beds, its thickness, joints, and elasticity.

Development of Caverns.—Probably the most favorable condition for a stable limestone roof would be found in a thick, massive, unjointed crystalline limestone bed (an improbable condition). Even under the most favorable circumstances, however, the roof must eventually fail if the limits of the opening continue to extend. Failure would probably take place in a thick elastic bed by sagging but with thin bedded or jointed rocks the roof would probably yield by rupture, and this is no doubt most frequent. (Fig. 10B.) After the collapse, the broken edges of the fallen roof offer abundant points of attack, the water which traversed the overlying bedding plane mingles with the current which originally traversed the chamber and the two co-operate in attacking the sagged and broken beds and in extending the limits of the original opening. It is possible that the same forces which formed the first opening may have duplicated the phenomena at the same time between other overlying beds thus hastening the result. With continued enlargement of the opening the support of the new roof is weakened and yields to the same forces which destroyed the first.

The roof finds readjustment after each failure in a natural arch the stability of which may be many times destroyed as subsequent enlargement of the cavern undermines the base. The soluble parts of the material which fall to the floor of the chamber are taken into solution. The insoluble chert and sandstone fragments either accumulate on the floor of the cave or are swept away and deposited underground in more favorable localities while the finer particles may be carried to the surface in springs. A process of enlargement is thus instituted which somewhat resembles stoping. Continually higher beds are affected as the natural arch adjusts itself to the widening base. The water turned from the overlying bedding planes into the chamber assists in removing the debris and extending the base of the cavern. In the center of the cavern, where the roof is probably most often broken, the chief phenomena are the rupture and collapse of the beds forming the successive roofs and here coarse blocks of insoluble material accumulate. Around the edges of the structure on the contrary the adjustment demanded between succeeding periods of equilibrium is less pronounced and accommodation to the changing conditions takes the form of gradual and differential settling. (Fig. 10E.)

Surface Phenomena.—Actually, as might be expected, the broken beds, where these have become exposed to the surface by subsequent erosion show but slight disturbance about the rims of these structures and evidences of greater movement are increasingly apparent as the center is approached. The arrangement of beds in these structures corresponds in position to a flat inverted cone of irregular form whose center is occupied by the residual blocks and fragmental material which at one time formed parts of the vaulted roof.

The sizes of the structures as noted in the field vary from a few hundred feet in diameter to half a mile or more. The smaller ones have the typical inverted cone structure more sharply developed and are more easily recognized. Some of the larger ones are saucer-shaped and the sandstone beds by which the phenomena are generally most sharply indicated appear not to have been broken. In such cases the solution underneath appears to have passed the limit of any possible arch and has allowed the surface of a considerable area to subside gradually without rupture.

RELATIONS TO STRUCTURAL CONDITIONS.

Relation to Topographic Sinks.—It does not seem probable that the continued growth of these structures by subterranean solution alone is competent to form surface sinks, for both solution and erosion are at a maximum at the surface and these forces operating above ground would probably more than keep pace with the results effected below by the same means. It is not impossible, however, that settling might form sink-like depressions in this way where the relief is low and where insoluble beds which overlie soluble members are exposed subaerially. It is more probable, however, that where sinks have occurred in connection with these structures, that direct connection has been established with the surface through joints in the settling beds of the roof. The products of weathering are then washed into the underlying cavern and as weathering proceeds the roof yields to the destructive agencies and the cavern is laid bare. Insoluble beds, such as sandstone, which have adjusted themselves funnel-like to the growth of the cave by settling are said to occur in Crawford county covered by detrital material and subsequent unconformable deposits.

Relation to Filled Sinks.—In Crawford county structures of this nature are reported of immense size. These structures, after reaching maturity, appear to have become connected with the surface and subsequently converted into surface sinks as described, for which reason they have been termed "filled sinks." The structures of this area while closely related genetically to those in Crawford county represent in general an interruption at an earlier stage of development and might more properly be called filled caves since there is no evidence of subaerial exposure prior to their filling.

Relations to Ground Water.—The filled caves present great variation with respect to geological horizon, size, development, filling, and topographic position. Many of the structures lie within, and involve the beds of Gasconade limestone. There are a few, however, which lie wholly within the Roubidoux and whose development does not seem to have been effected by solution of older beds.

As the underground circulation of water is retarded on reaching ground water level and is much slower at greater depth, and since the more deliberate movement affords time and opportunity for the exhaustion of its remaining solvent power, it seems probable that the development of caves, particularly those produced by lateral circulation, may be regarded as a rough indication of the level of ground water at the time and place of their development. Dipping beds in the structure crossed by Gourd creek (elevation 850 feet A. T.) in sec. 20, T. 36 N., R. 8 W., are 140 feet below their original position indicating a depth of solution certainly well below the present level of ground water. A hole drilled in the structure in sec. 24, T. 37 N., R. 9 W., was still in broken material associated with fire clay at a depth of 240 feet, about 600 feet above sea level. A drilling south of Newburg penetrated openings up to three feet in diameter at a depth of 190 feet or about 600 feet above sea level. As the elevation of the Gasconade river at Arlington is 674 feet it is apparent that the level of ground water at the time of the formation of these caverns must have been much lower than it is today.

Depth of Ground Water.—There is reason to believe from the material (the fire clay for instance) found filling some of the deeper openings that at least some of them are of pre-Pennsylvanian age and, as, during this period, there were present in the region the uneroded beds of the Gasconade, Roubidoux, and Jefferson City the distance of these openings below the surface must have been much greater than below the present surface. From the deepest known effects of solution in these caves to the top of the Jefferson City beds including 300 feet of the Gasconade is a vertical distance of 500 to 550 feet. It follows, therefore, that the depression of ground water was probably at least this distance below the surface, and it is possible that the land was at the time somewhat more than this distance above the sea level. It appears, further, that the conditions of ground water drainage were very different at the time of the solution of the deeper caves from what it is today. The deep underground drainage can not be attributed to relief at the time of the formation of the caves for the geological history of the area and of the whole Ozark region indicates that the drainage of the present has cut much deeper than during any previous cycle of erosion. It seems within the range of possibilities, therefore, to refer their development to a period of aridity during which the rainfall was not sufficiently abundant to maintain the water level nearer the surface.

If this be assumed it may be supposed that the difference in stratigraphic horizon between the various filled sinks observed may be attributed to fluctuating levels of ground water dependent on elevation above sea and climatic variation of precipitation.

Interruption of Development.—There are a number of methods by which the development of the structures might be arrested before being converted into open sinks. Circulation might be stopped or diverted by the choking of trunk channels. The extension of the structure might be limited by the size and form of the feature which directed the convergence such as the width of the syncline or the form of the drain of an unconformable surface if either of these were the direct cause of convergence of water. Deformation during the development of the structure might turn the drainage to new areas. Climatic changes would be effective in changing the level of ground water and in altering the quantity of carbon dioxide present and hence the efficacy of the water to dissolve would be affected.

Age.—While the structures may still be in process of development deep below the present surface most of those now exposed were formed at a much earlier period. In all the structures examined the circulation which caused their formation has ceased and, except for the influence of the deformed and titled beds in deflecting surface waters, they have no influence on the present drainage. Coal and clay were found in prospecting one of these sinks in Miller county and, near Newburg, fire clay (probably of Pennsylvanian age) was found in a filled cave of this type at a depth of over 200 feet. For these reasons it is thought that at least some of the structures now exposed belong to the period of emergence between Mississippian and Pennsylvanian sedimentation. This is supported by the character of the pre-Pennsylvanian surface which was marked by numerous sink holes now filled with deposits of fire clay. The filled cave on the line between secs. 5 and 8, T. 36 N., R. 8 W., is of the same character having a maximum deformation of about 70 feet. These structures are thought to have resulted from solution over so broad an area as to cause a gradual subsidence of the whole region affected without rupture of the upper beds. In these areas there are no exposures of beds lower than the second sandstone member of the Roubidoux in the center of the structure. Beds down to and including the upper beds of the Gasconade show around the edges a marked dip toward the center of the disturbance.

In most of the structures noted in this quadrangle, however, the sandstone beds have been broken and dip steeply toward a central area of greatest disturbance. The area of greatest disturbance, however, is sometimes decidedly eccentric. Great blocks and slabs of the sandstone and overlying beds are sometimes to be noted in perpendicular positions and the central area referred to is generally one of highly broken beds and unsorted coarse conglomeritic material associated with more or less intimately mixed sand and clay.

ECONOMIC VALUE.

The deeper filling in the caves is not exposed to examination and only the upper beds are commonly seen. Few of the structures in the Rolla quadrangle have been prospected and consequently little is known of their economic value. The exploitation of hematite iron ores, found in the structures, has demonstrated that some were originally filled with iron sulphide from which the ores were derived.

PHASES OF DEVELOPMENT.

The sizes of the structures vary from a few hundred feet in diameter to sometimes nearly a mile and the limits of the larger ones sometimes appear vaguely to overlap each other. The smaller areas affected are more sharply developed and the beds are more steeply inclined than the larger ones, but the latter are none the less distinctly marked by the same features which characterize the smaller filled caves. The second sandstone member of the Roubidoux is often the only bed that can be recognized and its unmistakable thickness, homogeneity, and universal exposures render it unusually serviceable in the study of these structures.

In the larger areas affected, the sandstone sometimes appears in an uninterrupted, unbroken sheet forming a saucer-shaped basin. This is the case in the structure in sec. 9, T. 37 N., R. 9 W., where the deformation is more than 100 feet. A hole drilled in the structure in sec. 24, T. 37 N., R. 9 W., as already mentioned, proved the existence of a considerable quantity of fire clay filling the openings from 215 to 240 feet below the surface. That openings not directly open to sedimentation may also carry coal has been shown by the discovery of coal and shale pockets beneath Gasconade limestone in Miller county.* It is probable that in some of the sinks the broken material of the overlying rocks may constitute the entire filling.

*Buckley, Smith, and Ball, Geology of Miller county: Mo. Geol. Survey, vol. I, 2nd series, pp. 108-109.

RELATIONS TO STRUCTURE.

The determining features which gave rise to filled caves and sinks is not always clear. The sinks do not appear to bear any relation to the folding although some lie in the synclines of folds. There is, however, a tendency toward elongation of the larger structures in the direction of major folding.

Possibly the concentration of drainage thought to be necessary for the development of these structures may be, in part, due to the unconformable surface between the Gasconade and the Roubidoux. The distribution of the structures, however, does not correspond to what is supposed to have been the drainage of that surface and as they occur at various horizons, and generally involve beds of the Gasconade, this origin is not considered probable, although possible in a few cases. It is probable that concentration was effected in different cases by different means.

In sec. 35, T. 37, N., R. 9 W., at the mouths of the drains east and west of the Hickory Point school, the exposures of the second sandstone member dip toward the drains. It is apparent that the fault plane presenting a trunk channel for the collection of underground drainage was chiefly responsible for the initiation of these small structures. Faulting seems to have been a determining factor also in the sink in sec. 1, T. 36 N., R. 9 W.

The cause of the structure in sec. 9, T. 37 N., R. 9 W., is less evident. There is associated with it a fault of small displacement but this is thought to have been a result rather than a cause of the structure. The structure occurring in sec. 24, T. 36 N., R. 10 W., is remarkable for the fact that the exposures lie entirely in the Roubidoux and involve also Jefferson City beds. There are no structural features with which this isolated structure may be associated. Its age certainly antedates the period of the removal of the Jefferson City from the upland area in the western part of the quadrangle. A small structural depression was noted in N. E. 1/4 N. W. 1/4 sec. 10, T. 36 N., R. 9 W., but was considered too small to deserve a place on the map. A similar disturbance was also noted in the N. W. 1/4 S. W. 1/4 sec. 32, T. 37 N., R. 9 W.

The beds in the sink structure near the Cross school in sec. 11, T. 35 N., R. 8 W., have a displacement of at least fifty feet. The altered and broken position of the heavy Roubidoux sandstone member has had a marked influence on the drainage of the creek which traverses the area giving it an unusually tortuous course.

Several small structures were noted north of Rolla in the Jefferson City beds. The absence of the sandstone beds makes the exposures less striking and they cannot be considered in any sense typical examples. They are indicated in part by dipping beds and in part by exposures of extremely coarse masses of dolomite breccia.

Certain sharp dips in the Jefferson City beds between Cave Spring creek and Little Beaver may be evidences of deeply buried structures. The lack of order in the dip at these points may be due to the fact that undermining by solution took place at such a depth that the form of opening is imperfectly registered in the upper beds. They are, however, probably better assigned to adjustment of the strains of cross-folding. An area of three or four square miles just north of Newburg has been notably lowered but does not present any feature typical of filled sink structure. As stated, this and several similar depressions are thought to be due to the intersections of folds.

OCCURRENCES IN OTHER REGIONS.

The presence of the easily recognizable beds of Roubidoux sandstone makes the study of these structures possible and the resistance of the casehardened beds is a very important factor in indicating unique feature of the structure. Without these sandstone beds the essential character of the filled cave structure would hardly be recognized, their detection in the Jefferson City beds being difficult and unsatisfactory.

This being the case it seems extremely probable that they occur in other deeply dissected limestone regions where the absence of a striking insoluble datum plane, such as the sandstone of this area, has prevented their recognition.

CHAPTER IX.

STRUCTURE.

FOLDING.

The folding in this area is not conspicuous and can not be observed in the field except in a few instances as in the Beaver creek syncline where the dip is sharp enough to indicate vaguely the character of the structure.

Aneroid Observations.—The differences in the elevation of critical horizons due to folding are ordinarily so small within moderate distances as to fall within the capricious variations of the aneroid barometer. In order to avoid this error the usual method of correcting observed elevations was applied with as great care as possible.* Several thousand readings on datum planes were taken and the points plotted to show the structure. In plotting the structure surface the elevations in the vicinity of the filled cave structures have not been taken into account since they are of distinctly separate origin.

Structure Map.—The result is indicated in Fig. 11 by contour lines showing the base of the Roubidoux. This surface, although regarded as an unconformable one, originally departed but slightly from a plane. The maximum relief being only 40 feet with the irregularities greatly distributed, as shown in Fig. 4, but

*At setting out from a bench mark the time and elevation were noted. The time of all subsequent elevation readings was recorded and on returning to the bench mark the time and change in barometric pressure were observed. The error in elevation thus determined at the bench mark was then distributed to all the elevation readings in proportion to the time distance from the first bench mark reading. This manner of distributing the error is based on the assumption that the change is equal for equal parts of the time. While this is generally not strictly true the error involved for short time intervals is generally not serious. On account of this unproprotional rate of error, however, it was necessary to check up very often on bench marks in order to minimize the difference between the regularly varying error assumed in the applied corrections and the more or less abrupt changes known to occur. The periods elapsing between checking were made as short as possible and generally did not exceed one or one and one-half hours. The instrumental errors corrected, generally ranged as high as 20 to 30 feet per hour for certain parts of the day, while abnormal differences of 60 to 100 feet per hour were noted under adverse weather conditions. In the latter case the corrected observations were considered unreliable and have not been used.

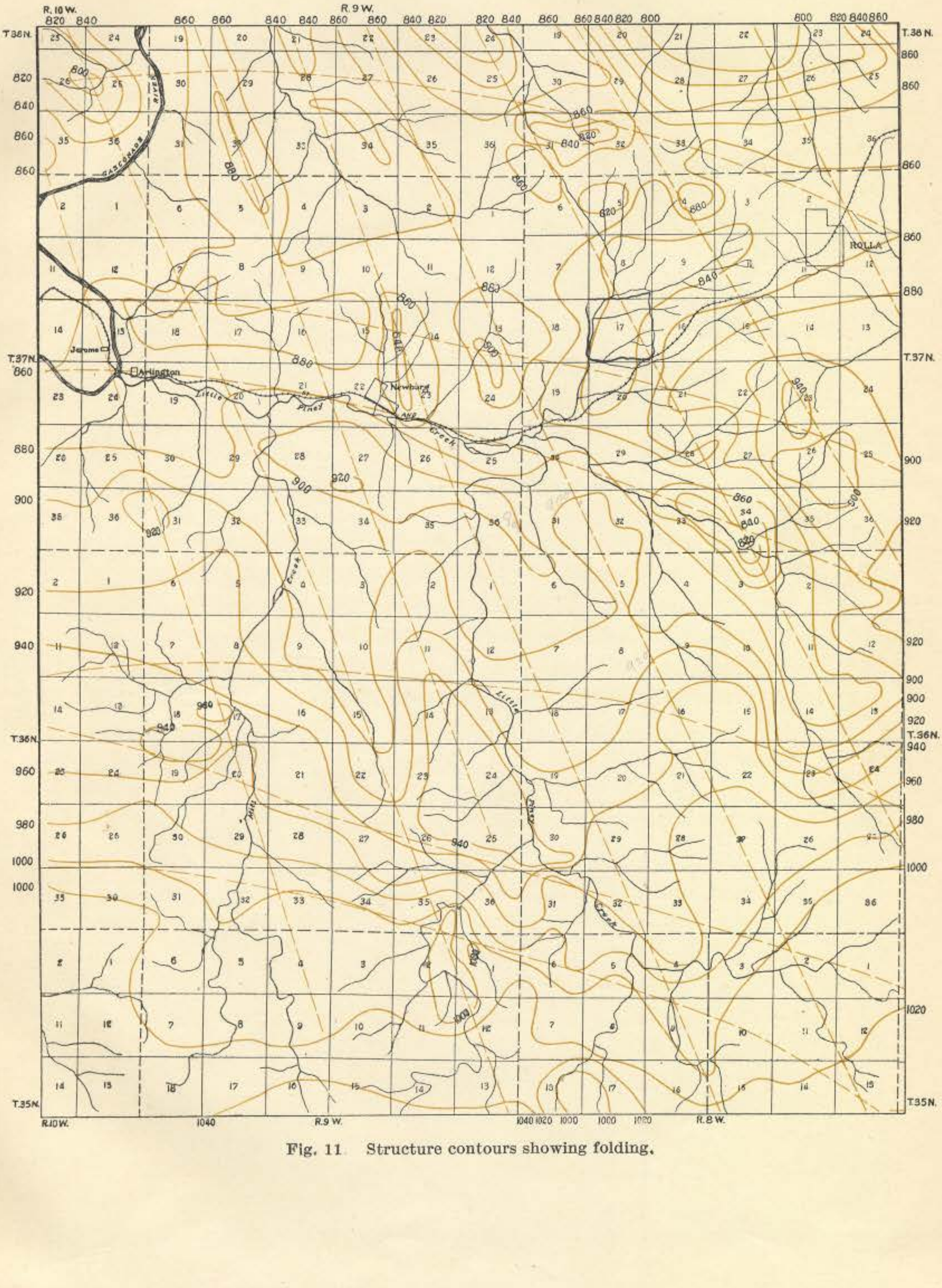


Fig. 11. Structure contours showing folding.

little error is introduced in the conception of the structure. A comparison of the two figures will show that there is no resemblance in the two surfaces, the original configuration having been entirely altered by the folding. The folded structure along the eastern margin of the sheet has been inferred from observations on the Quarry ledge, and the structure thus indicated has been reduced with suitable corrections to the plane already referred to.

The most marked structural feature is the dip northward amounting to a maximum of 260 feet between the high anticlinal area on the southwest and the synclinal depression north of Rolla. The difference indicated on the axes of folds is 220 feet in the Beaver creek syncline and 180 feet on the anticline separating Kaintuck hollow and Little Piney creek which suggests that the direction of the northward dip lies somewhat northeasterly.

Two systems of folding, complicated by many minor structures, can be observed. The first series trends N. 20°-30° W. and is crossed by a less pronounced series which appears to bow slightly toward the north striking approximately N. 78° W. on the eastern border of the sheet and nearly west on the opposite side.

Northwest-southeast Folds.—The first group of folds comprises a series of three synclines which are occupied respectively by the valleys of Beaver creek, Little Piney, and Kaintuck hollow. They are separated by well marked anticlines but the anticlinal areas to the southwest and northeast of these folds are not sharply marked. Northwest of Rolla, on the northern margin of the sheet, is a deeply depressed area which probably represents a fourth syncline not sufficiently extended within the area to indicate positively its character.

East-west Folds.—The cross folding is in general not sharply marked, partly because the folds are slighter and partly because the general dip northward gives the folds, such as they are, the character of being only variations in the degree of the northward dip. At the northern boundary of the area the strata rise markedly toward a line passing from the northwest corner to a short distance north of Rolla, rising thence southward more gently toward an anticline just south of Pea ridge. Little Piney creek in its lower course appears to occupy a low syncline for the datum plane rises again toward the south in a low anticline. Thence southward to the margin of the sheet the surface rises with gentle fluctuations but showing a marked monoclinal rise along a line extending through upper Mill creek school and Yancy Mills. Farther south the surface continues to rise slowly.

Intersections of Folds.—A number of minor features also characterize the structure of the area. These consist in minor domes, and structural depressions of a kind not readily associated with the sink structures. Some of the depressed areas noted in Jefferson City beds may represent the surface expression of deep seated sink structures. It is worthy of note that the more striking areas of the kind mentioned, such as the basins at Newburg, at the junction of Abbott branch and Beaver creek and at the Mungy school, and the domes east and west of Newburg, south of Ozark, etc., occur at or near the intersections respectively of synclines and of anticlines. The irregular and eccentric positions of some of them in relation to the exact points of intersections are thought to result from the unsymmetrical adjustment of the complex strains resulting from the cross-folding of an already folded area.

In the northern part of the Beaver creek syncline a number of small subsidiary folds are observable which along Beaver creek and Little Beaver creek suggest the development of a synclinorium. In some cases, as near the Big Fill and in upper Beaver, the subsidiary folds are more conspicuous in the field than the broader folds. In Crawford county, east of the quadrangle, folding in a general north-south direction has been observed. The east-west folds have not been observed in that locality though their extension in that direction is probable.

JOINTING.

As might be suspected from the complex folding of the area the joints do not display any very decided systems of direction or pairing. Observations on jointing were made in all parts of the quadrangle but chiefly on those affecting the sandstone of the Roubidoux. Of those noted exactly 50 per cent lie between the directions N. 20° E. and N. 20° W., a range of 40°. The remainder are about equally divided and equally distributed between the directions N. 20° W. and West on the one side and N. 20° E. and East on the other side. While there is the greatest variation in the angles between the joints at any point it may be said that where they occur in pairs they intersect each other at angles of 65° to 80° the acute angle being open toward the north, one side generally lying within the range of 20° on either side of north as noted above. The relation of this pairing to the structure is not clear.

FAULTS.

The recognition of faults in the Gasconade and Jefferson City formations is attended by considerable difficulty on account of the lack of lithological differentiation of the beds. Where exposures are obscured by residual materials, as is generally the case, it is probable that many faults avoid detection. In the Roubidoux, with its striking and abundant exposures of sandstone, the conditions are more favorable. Because this is the prevailing formation and because in it displacement finds more conspicuous expression than in the other formations most of the faults noted are in this formation. It is probable that the other formations have been similarly disturbed. All the faults noted have a general northwest strike although there is much variation in direction.

Newburg Fault Zone.—The largest area of faulting occurs in a belt in the center of the quadrangle about two miles south of Newburg. A series of faults beginning in the upper part of Treable creek, in sec. 6, T. 36 N., R. 8 W., extends northwestward to the southwest corner of sec. 27, T. 37 N., R. 9 W., a distance of nearly four miles. This faulted zone may be divided into three distinct but overlapping divisions. These are the Treable creek division at the southeastern end, the Hickory Point division at the northwest possessing markedly different strikes, and an intermediate transition zone of small faults.

The Treable creek division is confined to the valley of Treable creek. It consists of two presumably parallel faults striking N. 55° W. The block between these faults has a width of about 600 feet and has been dropped down leaving the formation on either side undisturbed. The maximum displacement (which is 60 feet) occurs on the southeastern end of the block in the S. W. 1/4 N. E. 1/4 sec. 6, T. 36 N., R. 8 W., near where the fault is exposed just above the detritus of the valley. From here the fault can be followed for a mile to the northwest. In this direction the displacement gradually diminishes and finally dies out in a scarcely perceptible anticline in the second sandstone member of the Roubidoux at the head of a small tributary to Treable creek in the S. W. 1/4 sec. 31, T. 37 N., R. 8 W. While the fault shows only a few small escarpments it is readily followed and its existence demonstrated by the repetition of the lower Roubidoux members and the Gasconade within the faulted block. The sandstone in the vicinity of the fault is partially silicified and marked by rhomboidally arranged quartzite seams. At the point of the greatest displacement the line of faulting is accompanied by boulders of conglomeritic sandstone evidently derived from a deposit in the once open fault fissure. With the sand which forms the greatest part of these boulders are pieces of angular chert and quarzite. The exact position of the fault in the northeast side of the displaced block is uncertain since the slope of the hill on which it occurs is thickly covered with the usual Roubidoux residuum. Exposures of the lower sandstone member indicate a displacement of 40 feet. The ridge on which this exposure occurs is surrounded by the stream bottom, in consequence of which its linear extension is also indeterminable. It probably dies out within short distances in both directions. In the N. W. ¼ sec. 5, T. 36 N., R. 8 W., a block of sandstone with a faulted face is exposed dipping steeply southwest and striking N. 68° W. The faulted face is quartzitic and shows the quartzitic seams, later to be described, which generally accompany the faulted sandstone in this area. The displacement is indeterminable, though small. It is probably related genetically to the Treable creek faulting.

The intermediate division occupies the end of the ridge between Treable creek and Little Piney creek. As may be seen on the map the faults are short and discontinuous. The maximum throw does not exceed 15 feet and most of the displacements are even less. The strike ranges in direction from N. 40° W. to N. 70° W. The faults are all indicated by small sandstone escarpments presenting flat silicified faces sparsely plastered with fine conglomeritic particles of sandstone, quartzite, and, in some exposures, bits of chert. The two faults occurring on the bluff in N. W. ¼ S. E. ¼ sec. 36, T. 37 N., R. 9 W., are the most prominent faults of this zone. Between these faults at the top of the bluff, a wedge shaped block five hundred feet wide has been displaced 15 feet downward. The fault on the south side of the block dips 50°, N. 30° E. and strikes N. 60° W. The south side of this block can be traced southeast for half a mile. The north fault has a downthrow of 15 feet on the south side, strikes N. 55° W., and dips approximately 70° toward the southwest.

The principal fault of the Hickory Point division begins on the east side of Little Piney and extends N. 58° W. across Little Piney to a point 300 yards east of the Hickory Point school. Here it changes its direction and continues N. 72° W. dying out in the drain in the southwest corner of sec. 27. The fault is nearly perpendicular and the downthrow is on the southwest side. The dis-

Fig. 1. Newburg Fault escarpment, near Hickory Point school.

Fig. 2. Sun cracks in second sandstone member of the Roubidoux.

placement east of Little Piney does not exceed 20 to 30 feet and the line of faulting is not sharply marked. At a few points small exposures of sandstone with the characteristic fault faces and quartzite seams indicate the position and the direction of the fault. West of Little Piney the displacement increases, attaining a maximum of 100 feet near the Hickory Point school. This part of the fault is not very sharply marked and is recognized chiefly by the displaced sandstone. West of the Hickory Point school the displacement diminishes but shows greater movement at some points than at others. At the mouth of the ravine west of the Hickory Point school the displacement is 60 feet. The escarpment near this point is shown in Pl. VIII, Fig. 1. Where the fault crosses the divide in the N. E. 1/4 sec. 34, the throw probably does not exceed 30 feet. At the head of the next hollow to the west, the movement is about 50 feet. The displacement in the southwestern corner of sec. 27 is about the same. Farther west the fault passes into the Gasconade formation and is no longer recognizable. Its presence is possibly the cause of the drain into the slopes of which it disappears. The fact that the points of greatest displacement lie where the fault crosses drains suggests that a part of the subsidence of the block is secondary and due to solution in the limestone of the faulted block.

South of the Hickory Point school, a zone of distributive faulting forms the southwestern side of the faulted block bounded on the northeast by the fault just described. The distance between this fault at the Hickory Point school and the nearest observed member of the group of minor faults is 1,200 feet. These faults are parallel with each other, strike N. 58° W., and have a downthrow to the north of 20 to 40 feet. They are not individually very persistent and none appear to extend more than half a mile. This distributive faulting downward on the north can be traced from Little Piney creek to the S. E. 1/4 sec. 35. West of this point the beds do not appear to have been faulted and the stress caused by the displacement on the northeast side of the block has been relieved by folding. This is also the case to some extent in the zone of distributive faulting for the blocks between the faults frequently show a decided dip northward.

The features that mark this faulted area are characteristic of all the faults which cut the Roubidoux sandstones but are particularly well developed in the Hickory Point fault zone. The escarpments which attend the faults, although sometimes slickensided, are generally rough plane faces plastered unevenly with sand, quartzite, and scattered pieces of angular chert derived from the brecciation of the walls of the fissure during faulting. The exposures of these escarpments are generally not very large but near the mouth of the hollow west of the Hickory Point school, the second sandstone member forms an escarpment 20 feet high. The face is roughened by conglomeritic particles. For several feet back from the face the sandstone is marked by a series of quartz seams forming a roughly rhombodial network which becomes less marked away from the fault plane. These seams are thin but weather out sharply on the surface showing raised lines about the thickness of a lead pencil. This ribbing appears often to have no definite direction but at some exposures the seams parallel the fault plane. Sometimes where the escarpment itself is not apparent the parallel seams near the fault give the appearance of a block of bedded sandstone standing on edge. This is the case at several points in the N. W. 1/4 N. E. 1/4 sec. 34, and S. W. 1/4 sec. 27. Faces of sandstone cut by the fault are generally silicified and not infrequently quartzite is found generally in shapeless angular forms within the sandstone. Slickensides occur but are not so common as might be expected. The faults of this area are nearly perpendicular with sometimes a slight inclination toward the faulted block.

Other Faults.—Near the mouth of a tributary to Beaver creek in the N. W. 1/4 sec. 11, T. 36 N., R. 8 W., there occurs a series of small faults in the sandstone, which are remarkable for the distinctness of their exposures. The average strike in N. 89° W. Only one of the faults is persistent. This one crosses Beaver creek and on the west side of the creek attains a downward displacement on the south of 50 feet. The other faults of the group have slightly differing directions but do not depart widely from that of the fault described. Their relation may best be seen in the section (Fig. 12.)

In Peter hollow in the N. E. 1/4 sec. 29, T. 36 N., R. 8 W., a small fault occurs in the sandstone. The strike is N. 65° W. and dips slightly northeast. It has a downward displacement on the north of only five feet and is exposed for a length of about 200 feet. Although the intervening area is covered with residuum it is probably connected genetically at least with the small faults of Coal Pit hollow. The movements in Coal Pit hollow are slight but sufficient to cause silicification of the sandstone. The strikes are N. 80° E. and N. 70° W. In the first the displacement is 15 or 20 feet down on the north. In the second the displacement is two or three feet down on the south. It is thought that these faults which were probably joints or fissures during the period of the Hickory Point faulting probably owe their displacement to the subsidence of the beds during the formation of the Gourd creek structural sink.

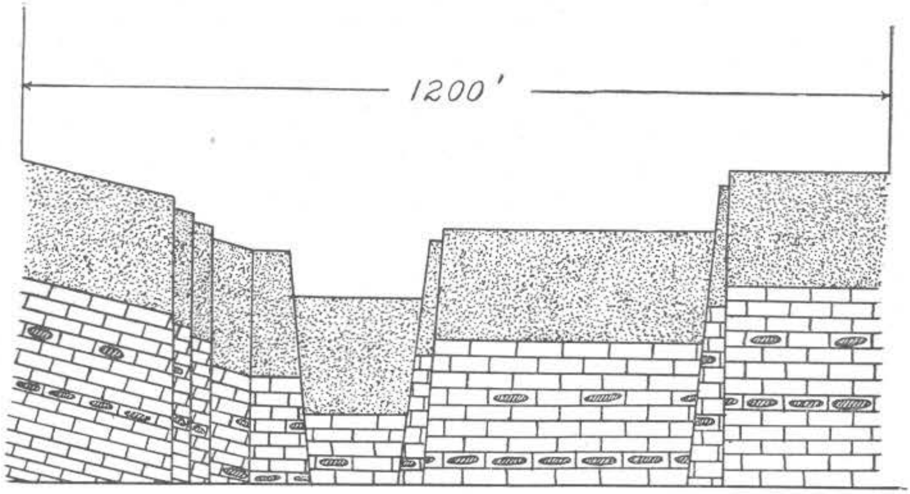


Fig. 12. Section showing faults in N. E. ¼ Sec. 11, T. 36 N., R. 8 W.

Northwest of Newburg in sec. 9, T. 37 N., R. 9 W., a fault having a throw of 20 to 30 feet with a downward displacement on the northeast is to be seen striking toward the point of greatest displacement of the filled sink structure of the same section. The strike is not clearly marked but lies between N. 55° W. and N. 50° W. The southeastern end is marked by a small series of sink hole depressions 30 to 50 feet in diameter and five to ten feet deep and by a displacement of the beds northeast of the line of faulting. In the small drain in the center of sec. 9, an escarpment presenting the usual features is exposed forming a dry cascade. The face is warped and the exact direction of the fault is consequently uncertain. The downward displacement on the north side is 30 feet at this point. It is thought that the fault originated as a joint or fissure and that the displacement in sec. 9 took place later during the subsidence coincident with the development of the filled sink structure.

North of the Gottschall school in the northwest corner of sec. 5, T. 37 N., R. 9 W., occur two small faults. The exposures are small and can not be traced beyond the point of discovery. The first strikes N. 55° W. and dips northeast 55° from the horizontal.

On the northeast side there is a downward displacement of 10 feet. The second, about a quarter of a mile distant, has a downthrow on the southwest side of 10 feet and strikes northwest. It is not known whether these faults form the limits of a faulted block but, although no other faults were definitely located, it seems probable that they form two of a group of faults of similar strike and small displacement. No faulting was observed in secs. 29 and 32, T. 38 N., R. 9 W., but the frequent presence of rhomboidally seamed sandstone float combined with the general depression of parts of the area is thought to indicate slight faulting accompanying the dipping of the beds.

In the S. W. 1/4 sec. 1, T. 35 N., R. 8 W., in the upper part of Finn branch a fault striking N. 78° W. is exposed near the head of a small drain. The downward displacement on the south is indeterminate but probably does not exceed 10 or 15 feet. The fault face, three or four feet high, is warped but its general direction is determined by its persistent exposure for about 200 feet.

Near the center of sec. 2, T. 35 N., R. 8 W., the sudden appearance of beds of the second sandstone of the Roubidoux in the bed of Finn branch strongly suggests the presence of a fault but no escarpment or other evidence clearly marking the line of movement could be discovered. Similar exposures are also to be found in the Riley branch and in Williams creek, and evidence of movement was seen in the next hollow northwest. It seems probable that the phenomena observed are to be attributed to relief from strain, partly by faulting and partly by dip. The displacement from both causes is 35 to 50 feet. The theory of faulting is supported by the occasional presence of quartzite-seamed float in the vicinity, although this might be attributed to the stress of folding. The strike is N. 51°-52° W. and its rough alignment with the faulting of Treable creek, as well as the similarity of strike is suggestive of a common origin.

A small fault with a throw of about two feet was observed in the Gasconade on the bluff above the railroad track just east of Newburg. The strike is not determinable but is roughly northwest. In the railroad cut west of Rolla a slight movement in the Jefferson City can be noticed. The displacement is not more than one foot and is so slight as scarcely to deserve mention. It is probable that small displacements of this character are extremely common although seldom occurring under such favorable circumstances for observation.

Attention is called to the correspondence in direction of the faults of the Rolla quadrangle with those in Miller county and with those in the Flat River quadrangle.

Sections.—Figures 13, 14, 15 and 16 are structure sections across the area along the lines indicated.

CHAPTER X.

ECONOMIC GEOLOGY.

Although a considerable number of mineral products are represented within the Rolla quadrangle and the area of which it is representative, there are comparatively few which occur in sufficient quantity or purity to render them commercially valuable.

BARYTES.

Barytes (barium sulphate) is a heavy, opaque, white mineral which occurs in crystalline and granular masses. In certain places (though seldom in this area) it has an earthy texture. In the Rolla quadrangle it is often associated with galena (the sulphide of lead) which alters in oxidizing to the sulphate of lead. This alteration product closely resembles the earthy variety of barytes which, however, is not quite so heavy.

Although barytes has been found in a number of localities in the area very little has been mined and, so far as known, none has been marketed. It occurs, with a few exceptions, in the residual clays of the Gasconade formation and has been observed chiefly in the area about Newburg, though it is found also in other parts of the district under similar circumstances. Occasionally it occurs in cracks (generally in Gasconade cherts) where it is associated with lead and not uncommonly with zinc minerals.

Like many mineral products, the market value is largely dependent on purity, a small percentage of foreign material, if difficult of separation, being sufficient to render it unmarketable. Such materials as lead and zinc minerals must be separated, but if the barytes occurs in coarse lumps, as is often the case, this can be done easily by hand sorting. Where, however, the barytes is more or less intimately mixed with other minerals as is locally the case at Newburg and elsewhere in this vicinity the separation is more difficult and requires mechanical concentration. The erection of machinery for such small deposits of barytes as occur here would be unprofitable and the development of the barytes industry depends on the discovery of coarser and purer deposits than have heretofore been found.

The rewards are not sufficient to warrant much expenditure in prospecting. Where indications are found, however, it is well worth while to investigate, remembering that the payable deposits are always shallow and generally not extensive.

FIRE CLAY.

The deposits of fire clay are all associated with the remnants of the Pennsylvanian deposits. Most exposures of the Pennsylvanian show more or less clay interbedded with shale and sandstone. The clay is quite impure in places and it appears to have been deposited in thickness and purity only in particularly favorable localities, chief of which were the sink holes of the old surface. Other deposits were laid above but they have nearly all been cut away leaving the remnants of fire clay, shales, and sandstone in all conceivable relations to the present drainage.

Water circulating between the old surface and the later deposits has dissolved the limestones below allowing the sandstones, shales, and clays of the Pennsylvanian to settle into the wedge-shaped basin, in some cases with marked crumpling of the beds giving some of the deposits a striking resemblance to "filled sinks." Many of the railroad cuts east of Rolla show the crumpled beds of this formation capping the low ridges.

The residuum on the upland surface is from 10 to 30 feet deep over most of the area and in consequence the Pennsylvanian can be recognized with certainty only under the most favorable circumstances though its presence is suggested at many points by characteristic float, such as the hematite speckled sandstone or the purple shales which impart a purple color to the soils. The Pennsylvanian, and consequently at times deposits of fire clay, concealed by soil and residuum probably underlie many parts of the upland surface. Where the cryptozoans and other cherts of the Jefferson City are found in the float the probabilities are against the presence of Pennsylvanian deposits below. The avoidance of such areas and the prospecting of recognizable areas of Pennsylvanian and the lower soil covered ridges should be the chief reliance in searching for new clay deposits.

The following analyses of a sample of clay from the deposit of Mr. David Cowan in S. W. 1/4 sec. 1, T. 37 N., R. 8 W., is representative of the chemical nature of the clays though the alumina content sometimes goes above 40 per cent.

		No. 1.	No. 2.
Moisture	(—105°)	0.65%	0.98%
Moisture	(+105°)	11.49	12.27
Silica	(SiO_2)	50.42	45.09
Iron Oxide	(Fe_2O_3)	0.73	0.87
Alumina	(Al_2O_3)	35.64	38.67
Lime	(CaO)	0.32	0.17
Magnesia	(MgO)	0.00	0.00
Totals		99.25%	98.05%

Sample No. 1, 20 to 28 feet beneath surface.
Sample No. 2, 40 to 48 feet beneath surface.

The refractory qualities of the clay, however, are dependent on the physical properties, as well as on the chemical composition, the fineness of grain being a particularly important factor. The fire clays which occur in this district are called flint fire clays on account of their non-plasticity and resistance to weathering.

The clay deposits of this area are always underlain by thin, impure sandstone and sandy clay. Very little can be seen of the deposits now for none have been operated recently and the banks are caved and the pits filled with water. The following data are taken in part from an account of the clay pits of Phelps county by J. W. Cronk in a thesis submitted to the Missouri School of Mines.

ROMINE PIT.

This pit is located one mile northeast of Rolla in the N. E. ¼ sec. 1, T. 37 N., R. 8 W., at the base of a gently sloping hill. It is 75 feet long, 50 feet wide, and 10 feet deep. Above the water which stands in the pit, the clay is stained red, purple, and bluish by iron. On the east side a small outcrop of sandstone dips toward the pit.

KELLY PIT.

This pit is located one mile southwest of Rolla in the S. W. ¼ sec. 11, T. 37 N., R. 8 W., near the crest of a gently sloping hill. It is about 100 feet long, 40 feet wide, and 12 feet deep. The clay appears not very pure and is slightly stained with iron which is banded and shows fine lamination very distinctly. Slickensides and small faults are seen in hand specimens. Sandstone outcrops on the north and east sides, and dips into the pit at an angle of 30°.

CEMETERY PIT.

The location of this pit is about one mile south of Rolla in the N. E. ¼ of sec. 14, on the south slope of a gently sloping ridge.

The pit is circular in form, about 30 feet in diameter, and 10 feet deep. The sandstone which outcrops on all sides of the pit dips toward the center. No outcrops of clay are visible except on the east side where there is a small outcrop of clayey sandstone.

COWAN PROSPECT.

This deposit lies but a short distant east of the St. Louis and San Francisco railroad track in the S. E. 1/4 of sec. 1, T. 37 N., R. 8 W., near where the proposed Missouri, Arkansas, and Gulf railroad effects a junction. The construction work of the latter exposed fire clay within a few inches of the surface and, as reported, drilling indicates that it extends to a depth of 100 feet, which is a deposit of considerable size. Analyses from this deposit have already been given.

Fire clay has also been observed at the following points, some of which have been prospected. At most of these places the exposures were badly iron stained but prospecting may reveal clay of sufficient purity below or in the vicinity.

N. W. 1/4, S. E. 1/4, Sec. 25, T. 38 N., R. 8 W.
N. W. 1/4, N. E. 1/4, Sec. 36, T. 38 N., R. 8 W.
S. W. 1/4, S. W. 1/4, Sec. 36, T. 38 N., R. 8 W.
E. 1/2, N. E. 1/4, Sec. 32, T. 38 N., R. 8 W.
S. E. 1/4, S. W. 1/4, Sec. 34, T. 38 N., R. 8 W.
N. E. 1/4, N. W. 1/4, Sec. 3, T. 37 N., R. 8 W.
Center N. E. 1/4, Sec. 10, T. 37 N., R. 8 W.
S. W. 1/4, N. W. 1/4, Sec. 23, T. 37 N., R. 8 W.

LIME.

The magnesian limestones of this area are unsuitable for the manufacture of commercial lime on account of impurities which impart a dark color. Lime for local uses, however, has been burned at many points. The Quarry ledge of the Jefferson City has been used most frequently though the crystalline beds have also been utilized. Near Yancy Mills and elsewhere the Gasconade dolomites have been used. The small outliers of Mississippian limestone, that elsewhere yield excellent material for lime manufacture, are unsuited for this purpose here, because it contains a high percentage of fine sand which forms an inconspicuous, but disqualifying impurity.

The lime from the Jefferson City quarry bed* is dark in color and, although of poor appearance, is exceptionally strong when hardened. It works very cool and, because of its original content

*Buehler, H. A., Lime and Cement Resources of Missouri: Missouri Bureau of Geol. and Mines, vol. VI, 2nd series, 1907, p. 122.

of silica, will not carry a large percentage of sand. It could be utilized to a much greater extent locally than at present.

BUILDING STONE.

Building stone of good quality is found in the bed heretofore referred to as the Quarry ledge (Pl. III.) which appears in the lower division of the Jefferson City formation. A number of quarries have been opened at this horizon in the vicinity of Rolla where the stone has been used extensively in foundations and sidewalks. The ledge, which is six to eight feet thick, outcrops frequently in convenient situations for quarrying. The stone works well in heavy masonry and is very durable. Its crushing strength* is 8,486 pounds per square inch and its tensile strength is 200 pounds per square inch, figures which fall somewhat below the average of the bulding stones of the State.

Other beds in the pitted member and in the Gasconade have been used locally although they are much less suitable. The heavy bedded cotton rocks described (p. 38) as occurring in the upper part of the Jefferson City have been used to some extent and possess the property of being easily worked. On account of its softness and its tendency to spall and crack and on account of occasional fine pyrite crystals which, in weathering, streak and corrode the stone, it is unsuitable for most purposes though in other localities in the State it has been used extensively.

The huge blocks used in constructing the abandoned Ozark smelter between Arlington and Newburg are said to have been quarried from the beds of the upper Roubidoux south of the railroad track in the northeast corner sec. 20, T. 37 N., R. 8 W. The stone appears to be very durable and has not the mottled surface of the pitted dolomite.

The massive laminated sandstone beds of the Roubidoux split in weathering into casehardened slabs from a few inches to several feet in thickness suitable for rough masonry. They have been much used for flagging, light foundations, and chimneys for which purpose they are well adapted since they require little or no dressing. The properties possessed by this stone are dependent on weathering and it can not, therefore, be taken from quarries beyond the influence of surface jointing and casehardening.

*Buckley, E. R., and Buehler, H. A., The Quarrying Industry of Missouri: Missouri Bureau of Geol. and Mines, vol. II, 2nd series, 1904, p. 101. For comparative strength: Idem. Table VI, p. 316.

IRON.

The iron ores of the Rolla quadrangle, as well as of the adjoining counties, consist of two types: secondary limonite and hematite. The former occurs in residual clays and conglomerates. It is derived from marcasite or sulphide of iron which was originally deposited in caves, fissures, and small cavities but erosion has now removed it from the enclosing rocks leaving the iron embedded in the residual materials. During the process of erosion the marcasite has been oxidized and the material changed to limonite, though the alteration is often not complete. It is for this reason and because the deposits are, for the most part, small and generally at some distance from the railroad that they have not been developed, though doubtless some will be found to be available in the future. The limonite occurs in the residual materials of the Jefferson City, Roubidoux, and Gasconade formations though the accumulations are larger and more frequent in areas underlain by the last. They are not associated with recognizable topographic or structural features.

The hematite ores are confined to the so-called filled sink structures which have already been described in detail (Chap. VIII) although in some of the deposits located in the Roubidoux the structure is not strikingly apparent. The ores were originally deposited as sulphides in caverns in these structures,* as shown in figure 10. The time of deposition can not be said to be finally determined, though it was probably during, or subsequent to, the Pennsylvanian period. Oxidation has altered the sulphides to red and specular hematites of excellent quality. During the two decades preceding 1890 iron was an important product of this area, as well as of the surrounding counties. The decrease in the price of iron and the long haul from most of the banks to the railroad caused a cessation in mining, and market conditions and transportation facilities have never since improved sufficiently to warrant resumption of operations, though the district is by no means exhausted and many promising localities are yet unprospected. Most of the structures are indicated on the map, though all the structural sinks are not equally promising.

*Crane, G. W., Iron Ores of Missouri: Missouri Bureau of Geol. and Mines, vol. X, 2nd series, 1912, p. 97 et seq.

SECONDARY LIMONITE DEPOSITS.

The following are the principal deposits of secondary limonites observed. None have been worked. There are hundreds of localities in which it occurs more or less sparingly at the surface but no particular end can be served by enumerating such abundantly distributed localities. The residuum is generally not thick at any of the places noted.

AGRICULTURAL COLLEGE LAND.

N. E. 1/4, N. E. 1/4, Sec. 13, T. 37 N., R. 10 W.

This deposit occurs on the south side of the mouth of a ravine. The limonite is found in large boulders on the surface but the locality is chiefly remarkable for a fissure 18 inches or more wide which is filled with sulphurous limonite. The ore is rather cherty.

LITTLE PINEY NO. 2.

N. E. 1/4, N. E. 1/4, Sec. 11, T. 36 N., R. 9 W.

A ledge of limonite three feet long is exposed beside the branch of a ravine, tributary to Little Piney, for a distance of eight feet. A great many boulders probably derived from this exposure occur in the drain below. Over 50 boulders from one to three and one-half feet in diameter were counted within 300 feet. The bank is located in an area of minor faulting.

LITTLE PINEY NO. 1.

Sec. 2, T. 36 N., R. 9 W.

This deposit is in the upper slope of the south fork of a ravine tributary to Little Piney creek and covers an area several hundred feet in diameter. The ore is chiefly stalactitic and contains scattered fragments of chert. Some of the limonite is sandy. It rests on, and appears to be derived from the Roubidoux.

OZARK BRANCH.

N. E. 1/4, S. W. 1/4, Sec. 16, T. 37 N., R. 9 W.

This deposit is not large. It lies in the upper part of a small drain on the east side of Ozark branch. Here the Gasconade dolomite for some distance along the slope is covered with large and small boulders of stalactitic and crystalline varieties of secondary limonite.

Fig. 1. Beaver creek iron bank.

Fig. 2. Gravel bank near Newburg.

STRAHAN LAND.

Center Sec. 25, T. 38 N., R. 9 W.

Here boulders of secondary limonite are scattered over several areas on the crest of a narrow ridge. The Jefferson City beds underlie the surface and the residuum is shallow.

HEMATITE DEPOSITS.

SEE BANK.

S. E. 1/4, Sec. 36, T. 36 N., R. 8 W.

This bank is on the east side of a small ravine tributary to Perry branch. Development consists of a shallow pit 60 feet in diameter on the south margin of a small "filled sink" in the lower Roubidoux. The ore consists of red and specular hematite with a small amount of ochre. A small amount of ore has been shipped. The deposit is not large though it may prove to be the key to the location of additional deposits in or about the same structure.

STRAWHUN BANK.

N. W. 1/4, Sec. 2, T. 37 N., R. 9 W.

This deposit is located in the gentle slope of a small ravine tributary to Tick creek. Development consists of several pits not over six feet deep from which some second grade red and specular ore has been taken. The deposit occurs in the upper Roubidoux beds but on account of the abundance of residual materials the structural relations can not be observed. The soft red hematite has been used locally for paint. The extent of the deposit can only be discovered by prospecting.

BEAVER CREEK MINE.

S. 1/2, Sec. 33, T. 37 N., R. 8 W.

This bank (Pl. IX Fig. 1) is located on the crest of a divide on the eastern edge of an unusually large, well developed sink structure. The structural relations at the bank are not at present clear, the sides having caved. Interbedded shales and chert, badly caved, form the walls. Near the cut, at the west side, these layers are warped and dip markedly toward the southwest although the sandstone below the pit (probably the heavy sandstone horizon of the Roubidoux) appears to lie nearly horizontal. The relations suggest that more ore might be found in similar relations to the large sink structure, at the edge of which this deposit lies. The ore consisted chiefly of soft red hematite with which were associated minor amounts of limonite and specular ore. The pit is over 400 feet long, 250 feet wide, and 50 or more feet deep, and is reported to have produced 49,000 tons of ore. It furnished the chief ore supply for the abandoned Ozark smelter between Arlington and Newburg.

BUCKLAND BANK.

N. E. 1/4, S. W. 1/4, Sec. 20, T. 37 N., R. 8 W.

This bank is situated in the bottom of a ravine about 1,000 feet south of the St. Louis and San Francisco railroad track from which there was formerly a spur to the bank. The pit which is 150 feet long, 70 feet wide, and 30 feet deep lies in the lower beds of the Roubidoux, but the deposit extends downward into the Gasconade. The structural sink is not marked though a certain amount of displacement is apparent. Nason* reports masses of tenacious black clay exposed in the cut but this is no longer exposed. The ore consists of soft red hematite. The production is reported at 5,500 tons. Recent drilling in the pit by the Commercial Acid Company of St. Louis shows 32 feet of marcasite at a depth of 13 feet. The property is being developed for the production of sulphide ore for use in the manufacture of sulphuric acid.

HUDGEONS MINE.

N. W. 1/4, Sec. 31, T. 37 N., R. 8 W.

This deposit lies a short distance above the road on the end of a ridge west of Treable creek and a few hundred yards from its mouth. It occurs at the horizon of the Gasconade beds but is enclosed by strongly dipping beds of the Roubidoux formation. The center of the structural sink appears to have been somewhat farther north in what is now the flood plain of Little Piney creek and the northern half or even more has been cut away by erosion. The ore is found in the uneroded southern side of the structure. The opening is 65 feet long, 20 feet wide, and 12 feet deep. A small amount of soft red hematite and specular ore has been mined. The ore is rather silicious and spongy, and sintery masses of chert are found from which the marcasite crystals which were originally enclosed have been dissolved. Mr. B. W. Hudgeons, the owner, reports that in workings now caved a 35-foot face of ore was shown. No shipments have been made.

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*Nason, F. L., Iron Ores of Missouri: Missouri Geol. Survey, Vol. II, 1892.

HORSE HOLLOW BANK.

N. W. ¼, Sec. 1, T. 35 N., R. 8 W.

This bank is situated on the side of a small ravine on the east side of Horse hollow. The opening, which consists of a shallow cut 30 feet long and 20 feet wide, is at or just below the Gasconade-Roubidoux contact. The attitude of the beds above it indicate a small elongated and very narrow structural depression. Several prospect pits have been sunk in the vicinity with poor success. The ore is red and specular hematite of good grade, but very little was taken out and none shipped.

KELLY MINE NO. 1.

E. ½, Sec. 18, T. 36 N., R. 8 W.

This mine is situated near the summit of a ridge above the heavy sandstone member in the upper part of the Roubidoux formation. Its structural relations are very similar to the Beaver creek bank, in that it lies above only slightly disturbed beds and on the edge of an unusually large and well developed sink structure. In this case the deposit lies between two decided disturbances of this kind in an area greatly affected by settling. The bank is now caved and the structure is not exposed. Nason reports a thick layer of white clay mixed with broken chert on each side of the ore and outside of this a mass of yellow sand and red loam free from chert. In the ravine below to the northwest, the heavy sandstone bed of the Roubidoux is warped downward but does not appear to have been broken at any point. The ore resembles that of the Beaver creek bank, consisting chiefly of soft red hematite with subordinate specular hematite. Nason reports a production of 3,000 tons.

In digging a cistern in residual material on the ridge 1,000 feet west of the bank, fragments of specular hematite were found near the bottom. This supports the theory that prospecting would develop further deposits about the rims of the larger sink structures as mentioned in reference to the Beaver creek bank.

MOSELLE MINE NO. 10.

N. W. ¼, N. E. ¼, Sec. 20, T. 36 N., R. 8 W.

This mine is situated in a ravine tributary to Gourd creek. It lies at the elevation of the Gasconade but is enclosed by the lower and middle beds of the Roubidoux which have dropped from originally higher positions. The usual funnel shaped arrangement of the enclosing beds is evident but not marked. The east wall of the pit is massive, vertical sandstone, containing fragments of chert. The other walls are not now exposed. While it exhibits to a minor degree the filled sink structure so characteristic of these deposits its relation to the large Gourd creek sink structure is more marked. Like the Kelly No. 1 bank it lies on the rim of this structure though at a much lower horizon. The ore consists of red and specular hematite with some ocher and limonite. Nason reports a production of 10,000 tons of ore. It is probably not entirely exhausted.

The following small deposits of hematite ores have been also noted in the district. They do not present any unusual features and have been previously described.*

Moselle Mine No. 1, S. E. 1/4, Sec. 26, T. 36 N., R. 8 W.

Ozark Mine, N. W. 1/4, Sec. 3, T. 35 N., R. 9 W.

It will be observed that some of the hematite deposits described, while associated with structural sinks, lie on the margins of the areas. This is particularly the case where the areas are large as the Gourd creek and Iron ore hollow structures. It is evident that when a structure has become enlarged and the arch has become incapable of supporting the roof that large openings are likely to remain between the former side of the cavern and the fallen roof, whence the location of certain deposits on the rim of the large structures. This relation appears much less likely to be maintained in the deposits occupying smaller caves where the deposits might be expected (as is the case) to lie in the central part. The relations of certain deposits suggest that normal or joint caves with little or no subsidence of overlying beds have sometimes favored the deposition of iron. The Buckland bank seems to be an instance of this comparatively rare circumstance.

SAND.

Sand bars occur at many points in Little Piney creek and some of the smaller streams. The sand is derived chiefly from the weathering of the sandstone beds of the Roubidoux formation. It is clean and the majority of the grains have not been much worn so that they preserve for the most part the angularity of grain which characterizes the freshly crumbled sandstone.

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*Crane, G. W., Iron Ores of Missouri: Missouri Bureau of Geol. and Mines, vol. X, 2nd series, 1912.

The sandstone beds in place are casehardened at the surface and have the appearance of being much harder than they really are. When broken the sandstone crumbles easily and has been crushed and used satisfactorily for mortar at several localities in other parts of the State. For this purpose it is better suited than most stream sands for the grains are sharply angular and the material contains no dust. In Wright county the thick sandstone of this horizon is crushed for engine sand for which it is said to be very desirable on account of the sharpness of the grains. While the weathered surface is heavily iron stained the fresh surface is much cleaner and the iron content is so low as to cause only a slight yellowish discoloration. In places the sand is quite white containing little iron and, as the impurities consist only of a few rare chert grains, it may be possible to use it in the manufacture of glass in which the color is not of prime importance.

GRAVEL.

Gravel is obtained in abundance in Little Piney creek at Newburg; in the Gasconade river at Jerome; and in Love branch near Rolla. From Jerome and Newburg 50 to 75 carloads are shipped yearly to points in the southwestern part of the State. There is opportunity for the extension of this industry since gravel is increasing in demand for concrete, road construction, and railroad ballast. There are few places on the St. Louis and San Francisco railroad where it can be loaded so easily as at Newburg and Arlington. Pl. IX, Fig. 2, shows a gravel bed near Newburg.

ROAD MATERIALS.

The roads of the district are generally poor and but little attention has been given to improving them permanently though something in this direction has been done near Rolla within the past few years. The ridge roads are often good but in wet weather the residual clays, which form the surface of the upland, render the roads almost impassable and, on account of poor drainage, mudholes endure for a long time. The valley roads are generally rough and in wet weather are also muddy, while the slopes are much affected by gully washing.

Fortunately materials for permanent road construction are not only convenient but abundant and will render the improvement of the roads comparatively easy. The creeks furnish abundant supplies of gravel for road purposes. In the smaller ravines the material, while abundant, is generally so ill-sorted as to require rough screening since pebbles over two and one-half inches in diameter are unsuited for surfacing.

For the future macadamizing of the roads good material is available for foundations in the frequent rock exposures along all the roads. Crushed stone can be obtained with little haulage at all points by the use of a portable stone crusher. The dolomites are too soft for surfacing and where used in road improvements should be capped by a layer of river gravel. The latter is very resistant and will hold a good wearing surface for a long time. Under the abrasive action of ordinary travel the limestones of the area are soon ground to a dust.

LEAD AND ZINC.

Lead and zinc mining has always been a subject of interest throughout the Central Ozark region by reason of the frequent discovery at or near the surface of large and small pieces of the ore of these metals. Since the days when the pioneers were accustomed to smelt this lead float in hollow logs to obtain lead for bullets, prospecting has been carried on almost continuously. As it was possible in the early days to extract in a few days by primitive methods a quantity of lead, which could otherwise have been secured only by weeks of travel, it was natural that the deposits should obtain a certain celebrity. Such deposits, however, could not be worked with the profits now demanded of mining operations and, in general, reports of the reputed richness of early mines do not take account of the altered economic conditions.

MINERALS.

The lead and zinc minerals usually found in the area are galena, and sphalerite ("jack") the sulphides respectively of lead and zinc. Less common are the minerals cerussite and smithsonite (the carbonates of lead and zinc respectively), anglesite (the sulphate of lead), and calamine (the silicate of zinc).

TYPES OF DEPOSITS.

While the lead and zinc minerals are found in more or less abundance at all horizons the deposits fall into four distinct classes. Every prospect in the area may be assigned to one of the following groups: (1) joint deposits, (2) deposits in residual materials, (3) deposits in vesicular chert beds, and (4) deep deposits in dolomite. The first three types are principally of lead though often with subordinate quantities of zinc. The last as far as known is almost entirely zinc though it is probable that lead also occurs similarly either alone or with the zinc.

In order to convey some idea of the different processes of concentration it is necessary to explain that the limestones and dolomites of the entire region contain minute amounts of lead and zinc which can be detected chemically but are not visible to the naked eye.* Winslow and Robertson in 1894 assayed a number of dolomites of the Ozark region each of which contained a very small percentage of lead and zinc. These minute mineral particles are presumed to have been deposited in the dolomites at the same time that the rocks themselves were forming. An imperfect idea of the fineness of the particles and their distribution is conveyed by the statement that some 600 cubic feet of dolomite would be required to yield one pound of galena.

Underground percolating waters dissolve these fine minerals in certain situations and deposit them again in special places which, for any reason, favor precipitation. By this method the minerals, formerly distributed in minute particles through the rocks, become concentrated into visible masses.

Deposits in Joints.—These deposits may occur at any horizon in the Cambrian sediments in this area but they are most common in the Gasconade. The deposits have been known to have a width of a foot or more at the surface for short distances but are commonly not more than a few inches wide. They diminish rapidly both in width and lead content and vanish at shallow depths (generally within a few feet of the surface.)

This form of deposit has been observed in nearly every county in the Central Ozark region and, although occasionally yielding a few tons of ore, has always been found to be of too superficial a character to mine extensively.

The formation of these deposits is due to leaching during weathering of the finely distributed particles of lead distributed through the dolomites. By the erosion of the dolomite the lead content originally contained in many thousand cubic feet of rock has been set free and has been carried downward in solution. Whenever the solutions have entered cracks or joints and found conditions suitable to precipitation, deposits of the kind under discussion have been formed. A deposit of this class was discovered

*Winslow, Arthur, and Robertson, J. D., Lead and Zinc, II: Missouri Geol. Survey, vol. VII, 1894, pp. 479-482.

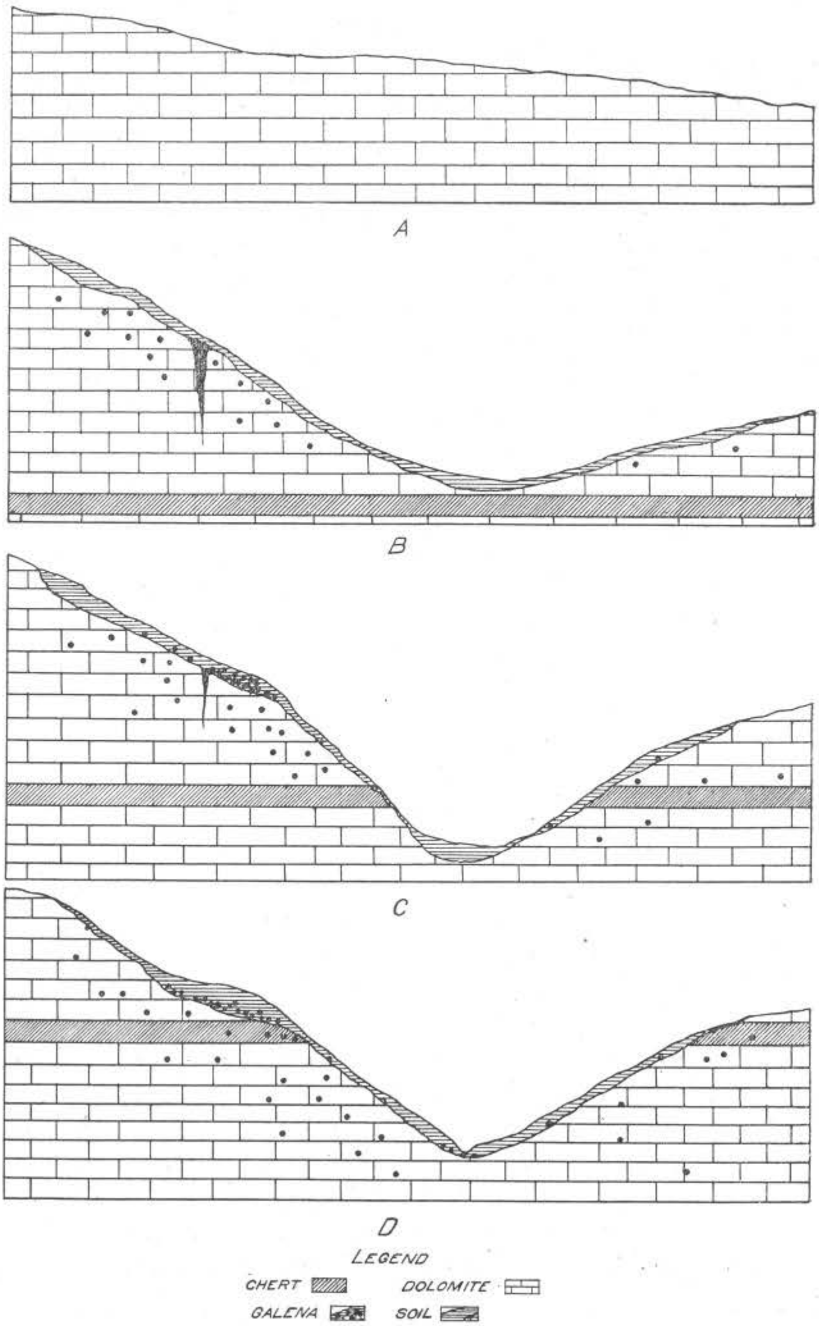

Fig. 17. Sketch showing origin of deposits of "Cog" mineral.

a few years ago in sec. 33, T. 37 N., R. 9 W., and they have been known also in the neighborhood of Yancy Mills.

Residual Deposits.—The segregation of the finely distributed metallic particles into joints and cracks, as described above, is accompanied also by deposition to a greater or less extent in various cavities in the rocks where conditions favoring precipitation exist. Subsequent erosion removed the enclosing dolomite and because of the relative insolubility and weight of the mineral, it remains embedded in the residual materials of the soil. (Fig. 17.) The size and value of a deposit of this character will depend upon the number and character of the mineral bearing cavities of the limestone formation.

Occasionally the surface of the rock underlying these deposits is found to contain a network of fine seams of galena and this has lead many to believe that the residual deposits represent the upper parts of more extensive ore bodies. Prospecting in many cases has shown, however, that the galena does not usually continue to any considerable depth and the ore found in the fissures beneath such deposits may be attributed to the leaching and redeposition of the residual galena or they are the lower portion of the original fissure deposits. The facts of the occurrence of the first two groups of deposits have been demonstrated so often that it is to be regretted that the conditions are not more generally understood by those most interested.

Residual deposits have been opened and worked in many parts of the area. They appear to have been most productive in Kaintuck hollow in the northwest corner of sec. 15, T. 36 N., R. 9 W., although workings, from which considerable lead has been taken, also occur near the mouth of Merrill hollow (sec. 33, T. 37 N., R. 9 W.). More or less promising discoveries have been made near Newburg, in Corn creek, and in Gourd creek. "Cog" mineral is occasionally found in digging foundations, wells, and in other excavations and there is always a possibility of discovering bodies of sufficient extent to warrant mining on a small scale.

Deposits in Vesicular Chert.—This is a special form of the fissure type, the place and mode of deposition being its distinguishing characteristic. Fifty to sixty feet below the top of the Gasconade formation there occurs a bed of chert of peculiar open structure. On weathering, innumerable cavities form, particularly between the platy layers. These and accompanying crevices are partly filled with chalcedonic silica and quartz and sometimes with galena, sphalerite, and some barytes. When followed into the hill the bed usually becomes more dense and the mineral content may materially diminish. Near St. Clair such a bed, however, has shown mineralization underneath the ridge. The mineral has been introduced by downward circulating waters in the same manner as in the formation of fissure deposits, in this case the open nature of the chert bed being responsible for the concentration through deflection of the downward circulation of ground waters.

About 25 feet below the horizon just mentioned is another chert layer which sometimes shows similar deposits. Many of the prospects explored by tunnels in the Newburg district are in these two upper vesicular chert zones. Excellent examples of this method of mineralization may be seen in the workings at the mouth of Poole hollow S. E. 1/4 sec. 23, T. 37 N., R. 9 W. (Pl. X), in the N. W. 1/4 sec. 36, T. 37 N., R. 9 W., and at several points in secs. 3 and 10, T. 36 N., R. 9 W.

While this process of mineralization is particularly striking in the beds mentioned there can be no doubt that it takes place also to a greater or less extent along the edges of all vesicular beds in which mineral bearing solutions mingle with precipitating solutions. It is also concievable that precipitation might take place at points removed from the surface in any sort of material as dolomite or sandstone under the same conditions.

Deep Deposits in Dolomite.—These deposits are found, so far as known, only in the Gasconade dolomite well below the present level of ground water. The mineral content is largely sphalerite or "jack," the sulphide of zinc. There has not been any considerable amount of drilling done to determine the areal extent of these deposits. A number of holes have been put down along the Burbouse river north of Cuba. Small amounts of sphalerite were encountered in middle and lower Gasconade beds. Similar ore was discovered near Newburg in the lower dolomitic beds of the Gasconade and a shaft was sunk to a depth of 200 feet. Certain beds of the dolomite in this part of the formation are sparsely studded with coarse to fine roundish chunks of crystalline sphalerite partly filling what appear to be solution cavities in the rock. The zinc ore is embedded in a soft, white, clay-like material. The beds in which the zinc occurs are about 250 feet beneath the top of the Gasconade. In the workings south of Newburg the masses of sphalerite are often large and striking but they were not found to occur with sufficient frequency to raise the barren rock to a high enough grade

Fig. 1. Lead prospect at mouth of Poole Hollow near Newburg; mineralized vesicular chert bed.

Fig. 2. Same as above, showing general working face.

for mining. Taking the entire mass as mined the maximum content of zinc is still below one per cent.

The origin of these deposits is not well understood but since the ground water level is thought at one time to have been somewhat below the level of the deepest streams of today it seems not improbable that the vugs in which the mineral was subsequently deposited were formed at that time. Certain beds are more soluble than others and doubtless obscure relations of porosity and the association with adjacent beds were efficacious in localizing the solution as well as the deposition.

The deposition may have taken place by any one of the various methods. The intermingling of differently charged solutions arriving at the porous beds by different channels may have been the cause although this seems unlikely at this depth. Possibly organic matter contained in the beds themselves or in the thin clay beds and shale partings which characterize this part of the Gasconade may have been the means of precipitation.

The relation of the lead and zinc prospects of the area to the structure is too suggestive to be omitted. The chief prospects all lie in or near the axis of synclines which suggest a relation of deposition to underground circulation controlled by the structure. If this be true, favorable areas for these deeper deposits will lie in such marked synclinal areas as that north of Newburg (see Fig. 11), especially where the frequent discovery of minerals indicates that notable segregation of metallic content of the rocks has taken place. It must also be remarked that the valleys lie chiefly in the synclines and since exposures are best in the valleys, discoveries for this reason would more frequently be made in these places. It is possible, therefore, that the relation of the mineralization to structure may be only a seeming one.

ECONOMIC VALUE OF DEPOSITS.

While considerable prospecting has been done throughout the area, there has been practically no production. Small shipments have been made from a number of the residual deposits which have been worked to some extent in the past. These ores are easily mined and cleaned. The deposits are usually small and do not warrant large expenditures for prospecting. On the Niles land (sec. 33, T. 37, R. 9 W.) both the second and third types of deposits are represented, as galena occurs in the surface clays as well as in a broken flint horizon outcropping below the residual deposits.

Those belonging to the chert bed type warrant drifting to determine the richness and extent of the ore.

There is but little known in regard to the fourth type of deposit (deep ores in dolomite) as only one restricted area has been prospected in this quadrangle. It is not impossible that localities may be found in which these deposits occur in commercial quantities but so far they have not shown ore sufficiently rich to pay for mining and milling. Prospecting for these deeper ores is expensive and, in order to prove the field, a systematic campaign of drilling will be necessary. If the structure has materially influenced the concentration of these ores it is thought that the synclines afford the most favorable points for prospecting as they will probably accommodate the maximum of underground flow. These depressions are indicated on the structure map.

The faulted zone, south of Newburg, was thought to be favorable to conditions for ore deposition by permitting the commingling of solutions from different sources in the openings resulting from the fault movements. Three holes were drilled in this zone to the base of the Gasconade formation by the St. Louis and San Francisco Railroad but no ore was encountered. The cuttings showed a few "shines" but scarcely sufficient to indicate a trace in analyses made by Dr. A. X. Illinski, the chemist of this Bureau.

The principal development work of the area has been done on the Niles land by the Newburg Mining and Development Company.

This company sank a shaft to a depth of two hundred feet from the bottom of which several prospect drifts were driven. Some zinc was encountered. The ore consisted chiefly of crystals of jack embedded in decomposed portions of the dolomitic beds. Several holes were drilled in the area by this company.

The Little Piney Mining Company sank a shaft to a depth of 75 feet in the S. W. 1/4, S. E. 1/4, N. W. 1/4, sec. 29, T. 37, R. 9 W. The dolomite and chert were not brecciated and no ore was encountered.

Mr. J. F. Hughes opened a prospect for Alexander Bros., J. B. Holman, and J. F. Wash on the east side of Poole hollow east of Newburg. At this point the heavy flint ledges of the Gasconade contain lead, zinc, and barite. Plate X shows the workings at this point. One 40-foot shaft has been sunk and three drifts of 40, 20 and 10 feet have been driven into the hill. Shallow drifts and prospect shafts have been sunk at other points throughout the area but no work is being prosecuted at the present time.

COAL.

No coal was found within the area although thin deposits of rocks of the Pennsylvanian period or Coal Measures occur at a number of points. These rocks were laid down on a very irregular surface characterized by frequent sink holes, and in Crawford county and Phelps county, east of the Rolla quadrangle, coal is known to have been deposited in these pre-Coal Measures depressions. The deposits are chiefly of cannel coal and of such small dimensions as might be expected if present day sink holes were to become the site of deposition. Where known to exist they are a valuable local source of fuel even though of limited extent. While no coal deposits were found within the area it is possible, though not very probable, that coal pockets may be found beneath the heavy residuum of the upland surface in the northeast quarter of the quadrangle.

OIL AND GAS.

There is no hope for oil in this area, nor in any of the counties of the Central Ozark region.

Certain well known geologic conditions are necessary for the accumulation and retention of commercial pools of oil and gas. In addition to an adequate source for the fluid fuels there must be present, (1) a porous stratum that may act as a reservoir, (2) an impervious covering for retention, and (3) sufficient folding to facilitate accumulation.

The formations underlying the Rolla quadrangle consist chiefly of sandstones and dolomites. The Davis shale occurs near the base of the section overlying the Bonneterre dolomite. This formation is the only one that would afford an impervious stratum through which the oil and gas could not pass. The upper formations have been so fissured or broken by the movement which resulted in the Ozark uplift that any oil or gas that might possibly have accumulated would have escaped through these openings. There has not been the least evidence of oil or gas in any of the numerous holes drilled throughout the Ozark region, a number of which penetrated to the underlying granite.

The formations underlying the Ozark region are older than any in which oil or gas have been discovered. While it is possible that petroleum may occur in formations older than those in which it is now known to occur, present evidence points strongly to the fact that the older formations were deposited prior to the occurrence of conditions favorable for the formation of oil or gas.

Not a single bonafide occurrence of petroleum has ever been noted in the Ozark region notwithstanding the many drill holes, and the oil delusion has been sustained by unwarranted hopes bolstered by mistaken correlation of the Roubidoux and other sandstones with the younger so-called "oil sands" of the east or southwest.

Certain dolomites of the lower Jefferson City and Roubidoux formation of the Rolla quadrangle already described (p. 36) contain small amounts of organic matter and when struck with a hammer give off a fetid odor somewhat suggestive of oil. When pulverized with water they impart a similar odor to the pulp, which might easily be mistaken for indications of oil where a churn drill passes through such a bed.

In low places an iridescent scum is frequently observed on standing or stagnant water. This has often been interpreted as oil. It is, however, only one of the many manifestations of the oxidation of iron minerals and has nothing at all to do with oil.*

TRIPOLI.

The cherts of the Gasconade are altered in favorable spots to soft, light, porous masses known as "silica" or tripoli for which there is a limited demand in the manufacture of filters, blotters, polishing powders, etc. The alteration is effected by solution of a part of the cherty material which appears to take place chiefly if not entirely beneath the surface in places of continual moisture or abundant seepage.

Tripoli deposits depend for their value on their size, purity, and completeness of alteration. The conditions of transformation from chert to tripoli appear to lie near the junction of the chert layers and the water level. As the chert beds of the Gasconade are approximately horizontal, while the water table on account of the relief of the surface is generally highly inclined, it will be apparent that there is small opportunity for the extensive alteration of any particular bed.

The fact that the alteration generally takes place near the surface and that the material is soft and often permits of its erosion before the process of alteration has much effected any

*Buckley, E. R., Biennial Rept. to 42nd General Assembly: Missouri Bureau of Geol. and Mines, 1903, Gas and Oil, pp. 46-55.

particular chert horizon, makes both extensive and complete alteration highly improbable.

Excellent tripoli was observed at several points. None of the deposits observed are of sufficient size to warrant development and in most cases the alteration was complete only in spots, leaving masses and irregular patches of unaltered chert enclosed in the deposit.

Roubidoux cherts were also found to have been altered but the beds are thin and always highly stained with oxide of iron. Worn fragments of these sometimes closely resemble pieces of brick.

ONYX.

Onyx has been found at a number of points in the southern part of the quadrangle but as the deposits have never been prospected there is no means of knowing their extent. The onyx occurs filling channels and caverns in the Gasconade dolomites. Two localities deserve especial mention.

In the bluff on the west side of Little Piney creek in the S. W. 1/4 of sec. 4, T. 35 N., R. 8 W., considerable masses are exposed. Many of the pieces seen are dense and of good quality but unless larger masses can be discovered by prospecting beyond the face of the bluff the deposit can never be worked extensively.

On Dave Brown's farm in the N. W. 1/4, N. W. 1/4, sec. 2, T. 35 N., R. 9 W., in the north side of a small drain tributary to Corn creek is a considerable deposit of onyx which is exposed for 30 or 40 feet along the hillside. A small cave comes to the surface and may be followed about 15 feet. The walls are encrusted with onyx but whether the larger masses are free from included dolomite could not be determined.

It is very doubtful whether onyx, in an area so far removed from transportation facilities as the southern part of this quadrangle, can be profitably exploited.

GOLD AND SILVER.

The occasional unwarranted statements of the discovery of these minerals in this and adjoining counties renders it desirable to deny their occurrence again. Gold and silver occur in sedimentary rocks only under exceptional conditions. These conditions do not exist in Missouri and the reports of the discovery of gold and silver in the sedimentary rocks which underlie this and adjoining counties is so improbable as to deserve scant consideration. Prospectors have often been deceived by fine particles of pyrite, a chemical combination of iron and sulphur, whose yellowish color has earned it the name of "fool's gold."

Reports of silver have occasionally sprung from the observation of chlorite, a dull green colored silicate sometimes found in the weathered dolomites. It resembles only vaguely the chloride of silver for which it has been erroneously taken. The same mineral has also been mistaken for indications of copper because of the vivid green stains to which it bears little resemblance.

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