DESCRIPTION OF THE GALENA AND ELIZABETH QUADRANGLES.

By Eugene Wesley Shaw and Arthur C. Trowbridge.[1]

INTRODUCTION.

GENERAL RELATIONS OF THE QUADRANGLES.

The Galena and Elizabeth quadrangles are bounded by parallels 42° 15′ and 42° 30′ and by meridians 90° and 90° 30′. Together they include one-eighth of a "square degree" of the earth's surface, an area, in that latitude, of 441.56 square miles. They are in the northwest corner of Illinois (see fig. 1), their northern borders being only half a mile south of the Wisconsin boundary, and they lie wholly within Jo Daviess County, except the southwest corner of the Galena quadrangle, which extends across the Mississippi and includes parts of Jackson and Dubuque counties, Iowa. The city of Galena is in the northwestern part of the Galena quadrangle, and the town of Elizabeth is in the southwestern part of the Elizabeth quadrangle. The quadrangles are named from these places.

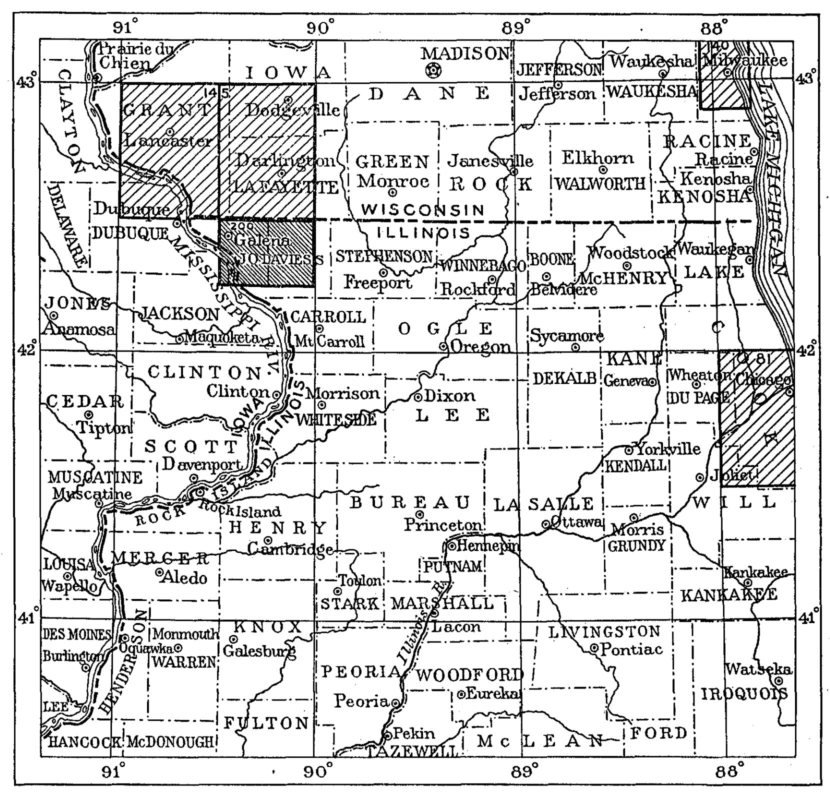


FIGURE 1.—Index map of northern Illinois and portions of adjacent States.
The location of the Galena and Elizabeth quadrangles (No. 200) is shown by the darker ruling. Published folios describing other quadrangles, indicated by lighter ruling, are Nos. 81, Chicago; 140, Milwaukee; 145, Lancaster-Mineral Point.

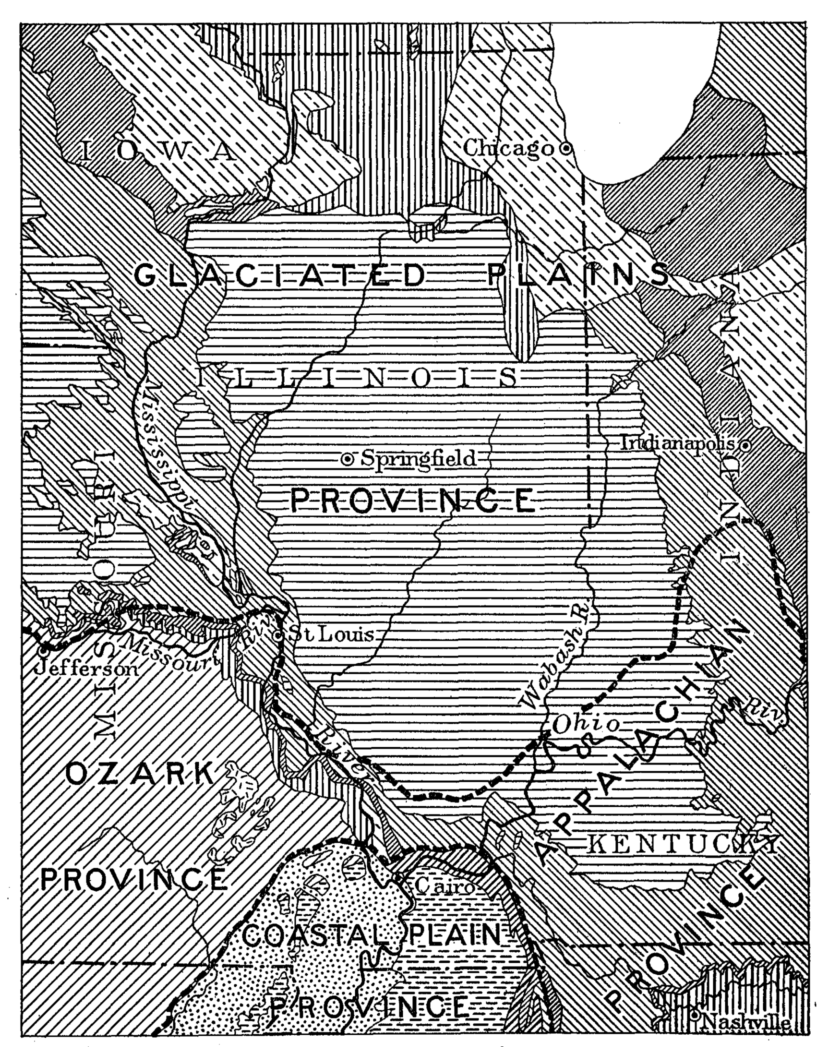


FIGURE 2.—Geologic map of Illinois and surrounding regions; shows also physiographic provinces.
The indefinite boundary between the Ozark and Appalachian provinces coincides approximately with the southeast boundary of Illinois. Geologic map copied from map of North America, U. S. Geol. Survey Prof. Paper 71, 1911.

In their physiographic and geologic relations the quadrangles form part of the Glaciated Plains, which lie between the Appalachian province on the southeast, the Ozark province on the southwest, and the Great Plains on the west and extend northward beyond the boundary of the United States. On the south they are separated from the Gulf Coastal Plain by a narrow strip that joins the Ozark and Appalachian provinces. (See fig. 2.) Near the middle of the Glaciated Plains there is an area of about 10,000 square miles which was not covered by ice and which therefore contains no glacial drift. As the geologic history of this driftless region is in other respects similar to that of the surrounding territory it is regarded as a part of the Glaciated Plains. The Galena and Elizabeth quadrangles lie almost wholly within the driftless region. (See fig. 3.)

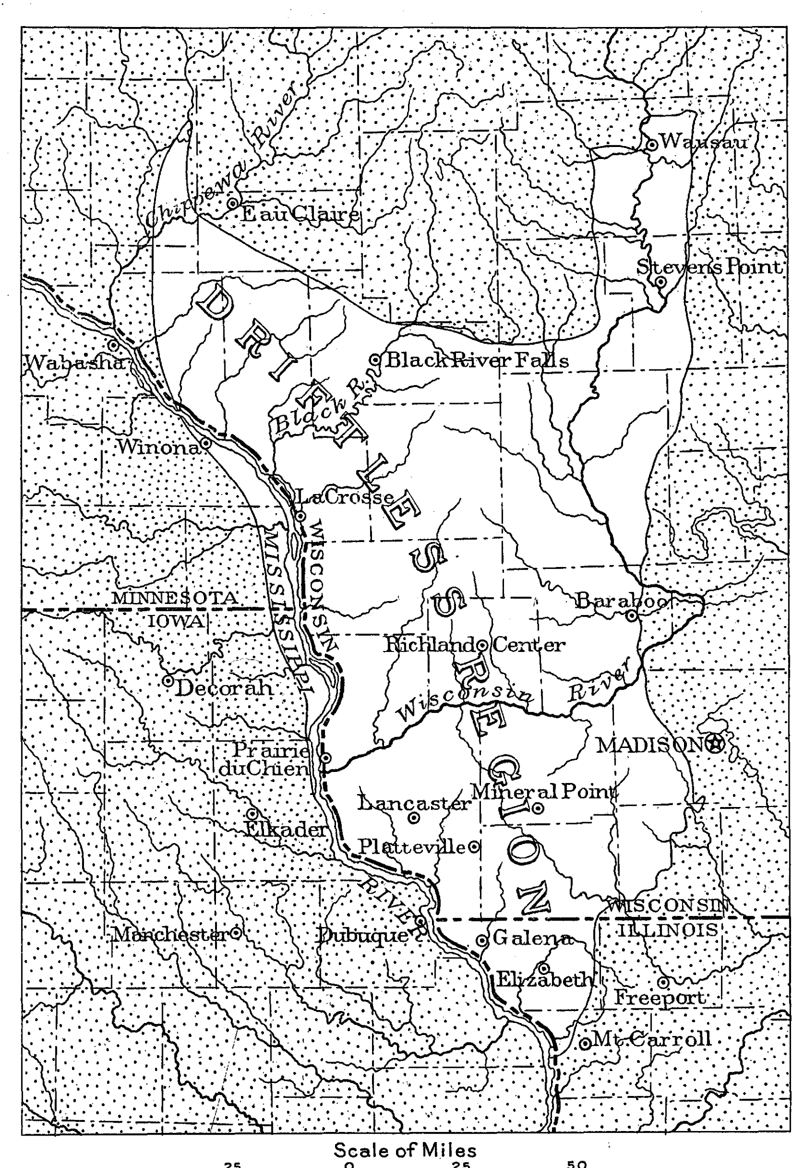


FIGURE 3.—Map of the driftless region in southwestern Wisconsin and parts of adjacent States.
Area covered by Pleistocene glaciers and now largely covered by glacial till is shown by the dot pattern.

GENERAL GEOGRAPHY AND GEOLOGY OF THE GLACIATED PLAINS.

Relief.—The Glaciated Plains, a broad rolling tract lying in general 500 to 1,500 feet above sea level but presenting in its different parts considerable diversity in the form of its surface, ranges in altitude from about 300 feet above sea level in the Mississippi River channel at the southern extremity of the province to about 2,000 feet along its western border and in the upper peninsula of Michigan. In some parts of the province the relief—that is, the height of the hills above the valley bottoms—is less than a hundred feet; in others it is several hundred feet. The valley of the Mississippi within the province is fairly regular in shape—from 3 to 6 miles wide and 200 to 400 feet deep—but most of the tributary valleys are irregular in width and depth and have indirect courses. In general the basin of the Great Lakes is forested and that of the Mississippi is not. Thus about half the province is prairie.

Drainage.—The part of the Glaciated Plains that lies within the United States includes the southern part of the Great Lakes-St. Lawrence drainage basin and much of the basin of the Mississippi above Cairo, although the southern tributaries of the Ohio and the western tributaries of the Missouri drain parts of adjacent provinces. The run-off of the western, central, and southern parts of the province flows to the Gulf of Mexico by way of the Mississippi and that of the northern and eastern parts flows into the Great Lakes and thence by way of the St. Lawrence to the Atlantic. The divide between the two drainage basins is very irregular and indefinite and is so low as to be scarcely perceptible.

A comparatively narrow belt along the western and southern sides of the province was not covered by any of the later ice sheets and is well drained, but in much of the province the streams have irregular courses and lakes and swamps are numerous. The poor drainage of this part of the province is due to its invasion by the ice, which blocked many drainage lines and on melting left a sheet of débris reaching in places a thickness of several hundred feet and filling many of the old valleys. Where the drift is thick the drainage was wholly changed and is only slowly regaining a more normal condition. In western Illinois there are several till sheets, laid down in as many different ice epochs, but the well-drained belt mentioned above, which is in the southern and western parts of the State, was covered only by one of the earlier glaciers. In this belt the streams have become almost readjusted but throughout most of the province they have irregular courses and profiles and the drainage systems show little symmetry.

The average discharge of the Mississippi at Quincy, Ill., just above its confluence with the Missouri is estimated at 72,900 second-feet. The area of the drainage basin above that point is 135,500 square miles, and the run-off per square mile is thus 0.538 second-foot. Many careful measurements show that the river carries annually past Quincy about 8,540,000 tons of sediment, in suspension, and about 14,630,000 tons of matter in solution. The surface of the basin above Quincy is thus being lowered at the rate of 1 inch in 1,100 years.

Stratigraphy.—The rocks underlying the Glaciated Plains range in age from pre-Cambrian to Recent, or from the oldest known rocks to the youngest, but many geologic epochs are not represented by deposits, for the region has been at several times for long periods above water, so that many of the formations overlap much older ones. The province emerged from the sea in late Paleozoic time and has since been a land area almost if not quite continuously.

The pre-Cambrian formations are made up of igneous, sedimentary, and metamorphic rocks and exhibit a complex structure. Their upper surface seems to have been long subjected to erosion, so that throughout extensive areas it was reduced almost to a plain, which formed a floor on which the later strata were deposited. The pre-Cambrian rocks thus underlie all the later sediments—the shales, sandstones, limestones, and unconsolidated rocks that crop out at innumerable places in the province.

Lower and Middle Cambrian rocks seem not to have been deposited in the Glaciated Plains province but Upper Cambrian strata probably underlie all of it except an area in its northern part from which they have been removed by erosion. They are generally more than 1,000 feet thick and consist principally of sandstone and shale, relatively little limestone having been formed in Cambrian time in this part of the United States.

The lowermost division of the Ordovician system in the province is a series of dolomites or dolomitic limestones containing some arenaceous beds and sandstone and is generally about 100 feet thick, but in places it reaches a thickness of 600 feet. This dolomitic series, commonly known in the early literature as the "Lower Magnesian," but more recently named Prairie du Chien group, is overlain, generally unconformably, by the St. Peter sandstone, which has an average thickness of about 100 feet. The next overlying formation is the thin-bedded fossiliferous limestone known in Wisconsin, Minnesota, Iowa, and Illinois as the Platteville limestone. It is about 50 feet thick and is overlain in at least part of the region by the Decorah shale, upon which rests the massive, highly crystalline Galena dolomite, 200 to 400 feet thick, containing Trenton fossils. An unconformity at the top of the Galena is suggested by the peculiar sharp lithologic contrast between it and the overlying beds, which are shale with thin layers of limestone and which are several hundred feet thick. Owing to uncertainty in correlation these beds have at different localities been called by different names, the exact synonymy of which has not yet been worked out, though the interrelations of many of them are known. The better-known names that have been applied to parts of the strata between the Galena (Trenton) formation and the overlying Silurian system are Cincinnati, Hudson River, Richmond, Utica, and Maquoketa. In Ohio this part of the section has been divided, in ascending order, into Utica, Eden, Maysville, and Richmond. Recent writers have classified the rocks in Indiana, from oldest to youngest, as Utica or Eden, Maysville or Lorraine, and Richmond.

[1] Surveyed in cooperation with the State of Illinois, Mr. Shaw representing the Federal Survey and Mr. Trowbridge, assisted by B. H. Schockel, representing the State Survey. The text of the folio has been written chiefly by Mr. Shaw. In its preparation free use has been made of previous publications dealing with the district, especially those of T. C. Chamberlin and R. D. Salisbury, of U. S. Grant and E. F. Burchard, of H. Foster Bain, and of G. H. Cox.

The rocks in Michigan have been divided by some writers into the Utica, Lorraine, and Richmond, and the beds in Iowa between the Galena and Niagara formations are known as the Maquoketa shale. The Maquoketa is generally regarded as of Richmond age.

The upper surface of the Ordovician rocks seems to have been considerably eroded and perhaps slightly warped before the Silurian beds were laid down, so that there is a great unconformity between the two systems. Throughout most of the province, as in the quadrangles here considered, the lowest Silurian formation is the Niagara limestone or dolomite. In Ohio and Indiana, however, there are older Silurian beds of limestone and shale which are regarded as the probable equivalent of the upper part of the Medina of New York. The Niagara is widely distributed and was probably once present, in whole or part, in all the province except a district near Lake Superior. Probably none of the older formations above the Cambrian was so extensive. It appears, however, that the Niagara was developed to its full thickness in only a part of the province, for in many districts certain beds found elsewhere and recognizable by their fossils are lacking. The Niagara in places reaches a thickness of nearly 500 feet and is overlain in the eastern part of the province by other strata of more or less dolomitic limestone. The overlying beds in Ohio and Michigan are called the Monroe group. Beds in the same position in Indiana and a part of southern Illinois, though perhaps not of exactly the same age, have been called the "Waterlime" and "Lower Helderberg." Generally there is an unconformity at the top of the Silurian, and perhaps the beds overlying the Niagara and even the upper part of the Niagara itself were removed by erosion from large areas before the succeeding Devonian strata were laid down. The Niagara dolomite is the youngest hard rock found in the Galena and Elizabeth quadrangles.

The Devonian system is best developed at places in the eastern, southern, and western parts of the province, where it attains a thickness of 700 or 800 feet, though at other places in the province its thickness is much greater. In the northwestern part of the province it is absent and in the central part it is thin. The lower part of the Devonian generally consists of blue fossiliferous limestone, and the upper part of black, carbonaceous, and nonfossiliferous shale.

The Carboniferous system is divided into three series, the lower and the upper carrying little or no coal and the middle containing much valuable coal. In the eastern part of the province the lower, the Mississippian series, consists of shale or sandstone, but in the western part there are great bodies of limestone with which are interbedded lenses of shale and sandstone. The series in Ohio has been subdivided into the following formations, beginning at the base: Bedford shale, Berea sandstone, Sunbury shale, Cuyahoga formation, Black Hand formation, Logan formation, and Maxville limestone. In the States along Mississippi River the Carboniferous beds that are in general equivalent to these formations fall more naturally into four major divisions, known as the Kinderhook, Osage, Meramec, and Chester groups.

The middle Carboniferous or Pennsylvanian series is more uniform in a general way, though it is in places even more variable than the series below. It is made up largely of shale, but it includes much sandstone, limestone, and coal. Many of the beds are lenticular, though certain coal beds are continuous throughout hundreds of square miles. Along the eastern border of the province the Pennsylvanian series is subdivided into several formations. The oldest of these formations, the Pottsville, has been identified by means of its fossil plants at many places in Illinois, but the floras of the other formations are less distinctive, and the eastern and western formations have not been and perhaps can not be correlated.

A few small areas of red sandstone, shale, and gypsum that are now tentatively referred to the upper or Permian series are found in northwestern Iowa, but, though Permian rocks occur in neighboring provinces on both the east and the west, they seem not to have been extensively deposited in the Glaciated Plains province.

No Triassic or Jurassic sediments have been found in the province, and probably very little material was deposited there during those periods. Cretaceous beds of clay, sand, and gravel occur in the northwestern part of the Glaciated Plains and also just south of that province, in the Mississippi embayment, but there probably never were extensive deposits of Cretaceous age in the province except those in its northwestern part. The Tertiary deposits also are of small extent, being confined to scattered bodies of gravel and sand whose exact age has not yet been determined. They are important, however, in the study of the physiographic history of the province.

The Quaternary system is much more widely developed, mantling more than nine-tenths of the province. It consists of glacial, eolian, lacustrine, and fluvial deposits, generally almost wholly unconsolidated. In certain districts rock outcrops are numerous, but elsewhere, over whole counties and even groups of counties, the hard rocks are completely concealed by the mantle of unconsolidated material, which in places reaches a thickness of several hundred feet. Even within the Driftless Area much of the surface is covered with wind-deposited loess and stream deposits.

Structure.—The structure of most of the Paleozoic strata beneath the Glaciated Plains is comparatively simple. The strata lie nearly flat, and their regularity is broken only by small faults and low, broad folds. The pre-Cambrian rocks that outcrop in Minnesota, Wisconsin, and northern Michigan are, on the other hand, so complexly folded and faulted that their structure can be worked out only with difficulty. The major structural features consist of (1) a low broad arch known as the Cincinnati anticline, which lies in part in the Appalachian province and which is divided into two branches north of Cincinnati, where it is highest, one branch extending toward Lake Erie and the other toward Lake Michigan; (2) a shallow basin that is practically coextensive with the lower peninsula of Michigan; (3) another basin, which occupies most of Illinois and southeastern Indiana; (4) a still broader depression, which extends westward from the Mississippi across Iowa and Missouri into the Great Plains; (5) an uplifted area lying in Wisconsin and Minnesota.

Each structural basin contains a great coal field, the fields being known as the northern interior, eastern interior, and western interior fields, and the province is bounded on the east by another basin containing the Appalachian coal field. Around the basins the strata crop out in concentric belts, the youngest being in the middle and the oldest around the outer border, the strata dipping in general toward the lowest part of the basins. The geologic horizon of beds that lie 1,000 feet above sea level in northern Illinois is more than 3,000 feet below sea level in the south-central part of that State, and if all the beds found in Illinois were symmetrically extended northward with their normal dip the same horizon would be several thousand feet above sea level in central Wisconsin. From Wisconsin the strata dip similarly to the east and southwest.

The Galena and Elizabeth quadrangles are at the northern end of the eastern interior basin, not far from the crest of the arch between the basins in Iowa and Michigan; hence the rocks of the district dip in general southward, toward the center of the basin, which lies in south-central Illinois.

Driftless Area.—The Galena and Elizabeth quadrangles lie almost wholly in the Driftless Area, a high tract from which streams show a general tendency to flow out in all directions, though most of them run southward. Although all the surrounding country suffered glaciation this area was not covered by any of the great ice sheets, and its surface features therefore present a marked contrast to those of the surrounding drift-covered districts. Outside the Driftless Area the bedrock is covered with glacial drift, composed of a mixture of clay, rock flour, sand, gravel, and bowlders, in some places stratified but generally unstratified; the bedrock beneath the drift is commonly scratched, smoothed, or polished, and is clearly different from the overlying unconsolidated material; the surface of the ground at some places is rough and hilly, at others it is rolling, and at still others it is smooth; there is lack of system in the arrangement of the topographic features; and the streams wander about, in places in an apparently aimless way. Moreover, only the larger streams have well-defined valleys, and swamps and lakes are common. The surface is topographically young, at least in its minor features.

Within the Driftless Area, on the other hand, the bedrock is overlain by unconsolidated material derived directly from the disintegration of the rock; the underlying rock is not scratched or smoothed and is not sharply separated from the unconsolidated material above; the topographic features are systematic, and even the smaller streams have well-defined valleys and in places straight courses; there are few swamps and lakes, except along river bottoms; and the surface as a whole is topographically mature. With the exception of an area west of the Mississippi that bears scattered bowlders and thin deposits the Galena quadrangle lies wholly within the Driftless Area. In the eastern part of the Elizabeth quadrangle there is a thin fringe of drift and a few scattered and fragmentary outliers of drift lie west of the fringe.

GEOGRAPHY.

RELIEF.

General features.—The surface of the Galena and Elizabeth quadrangles is hilly and is well dissected by streams, the relief in almost every square mile being more than 100 feet. The extreme range in altitude in the area, however, is only 590 feet, the lowest point being in the channel of the Mississippi at the south side of the Galena quadrangle, at an altitude of 580 feet above sea level, and the highest being the top of Hudson Mound, at an altitude of 1,170 feet. Charles Mound, the highest point in Illinois, which stands 1,241 feet above sea level, is just without the northern margin of the area and just within the State boundary.

Upland.—The general surface is maturely dissected, and the slopes of the hills and valleys show a striking conformity to the nature of the rocks out of which they have been carved. The strata, which consist of two resistant formations of dolomite and an intermediate soft shale, slope gently southward. The upper dolomite is rendered especially resistant to erosion by the large amount of flint which it contains. In the uplands there are three principal kinds of hills—those capped with the uppermost hard layer of dolomite, those from which that layer has been removed, leaving them capped with nonresistant material, and those from which both the upper and middle layers have been removed and only the lower resistant rock remains.

The hills of the first class, the highest hills in the quadrangles, include two distinct types—small hills and larger flat-topped ridges—both of striking and unusual shape. The hills of the first type are more or less conical, rising 100 to 300 feet above the general upland, and are known locally as mounds. (See Pl. IV.) They stand singly or in groups and are found only in the northern part of the area, for the reason that in the southern part the upper dolomite, to which they owe their existence, is too low to give rise to such features. They are so striking that most of them have received names. Pilot Knob, 3 miles south of Galena, is an old landmark for navigators on the Mississippi, and Horseshoe Mound, Scales Mound, Hudson Mound, Mount Sumner, and others are also well known. The hills of the second type also capped with the upper dolomite member, are flat-topped ridges with lateral finger-like spurs. Hills of this type, are especially numerous near Elizabeth. Their tops are among the flattest parts of the district, and for this reason almost every one is traversed by a wagon road.

Together the hills of these two types constitute what has been called the Niagara escarpment or cuesta, as the dolomite that caps them is of Niagara age. Viewed from a point at a little distance to the north they appear as a frowning, almost unbroken ridge trending somewhat south of east. In a very general way the cuesta has an abrupt slope or escarpment facing the north and a long gentle slope to the south, but its outline is irregular and deeply serrated and many outlying areas of the dolomite are disconnected from the main mass. The detached portions, which are long and trend more or less parallel to the escarpment, are, like the whole, commonly unsymmetrical, having a short, steep slope facing north and a long, gentle slope facing south. This form is well shown by the divide 2 to 6 miles southwest of the town of Scales Mound. In general, the Niagara escarpment presents a steep wooded slope marked by scattered small cliffs and detached blocks of dolomite and is 60 to 150 feet high.

There are only a few hills of the second class—those capped by the shale—because after the upper dolomite has been removed by erosion the shale is rapidly worn down. There are two types of these hills also. One is seen in mounds from which the resistant cap has been removed but a short time, in the geologic sense. Good examples are found a mile southwest of the town of Scales Mound and at Mount Pleasant School, southeast of Galena. The other type is seen in broad divides composed almost wholly of the lower dolomite and merely capped with the lower part of the shale. These divides have steep sides and flat or slightly rounded summits. In the northern part of the Elizabeth quadrangle there are many such divides. As a result of their breadth and of the resistant rock of which they are chiefly composed, the central parts of their flat tops are somewhat protected against severe erosion, so that lenses of less resistant material remain in such places much longer than in more exposed positions.

The hills of the third class, formed only of the lower dolomitic layers, resemble in shape those that bear only a thin cap of shale. They represent a somewhat later stage of erosion. Isolated hills of this class are not common in the quadrangles, but numerous spurs show the typical form and structure.

Mississippi Valley.—The most striking topographic feature of the quadrangles is the flat-bottomed but youthful-appearing valley of the Mississippi, a trench nearly 400 feet deep and scarcely 2 miles wide except at the south side of the area, where it widens to 3 or 4 miles. Its walls are steep, in places precipitous (see Pl. IX), and its bottom is nearly flat, though diversified by numerous long, shallow depressions—abandoned channels of the river—many of which contain water. These depressions are crescentic in shape and give the flood plain an irregular, fluted appearance. Most of the bottom land lies between 580 and 600 feet above sea level. At Bellevue, near the south side of the area, the altitude of low water is 578 feet and that of high water is 598 feet. At some places on the flood plain sand dunes rise above the 600-foot contour, and generally at such places a terrace also rises to a height of about 640 feet.

Tributary valleys.—The upland is broken by valleys which, like the divides, show the influence of differences in the hardness of the rocks. The larger tributaries of the Mississippi are bordered by narrow flood plains, and with the exception of Galena River they flow in fairly direct courses. Along many of them there are terraces whose height above the streams is 50 feet where they enter the valley of the Mississippi but becomes progressively less toward their upstream ends. The terraces are well developed in and near Galena and Hanover. Plate VII shows a terrace and flood plain near the mouth of Tete de Mort River, on the western border of the area.

A part of the valley of Apple River immediately southwest of Millville is narrow and canyon-like. It is really a trench connecting the old Apple River with the upper part of a neighboring drainage system on the northeast whose outlet was blocked by Illinoian drift. The origin of these features is considered under the heading "Geologic history" (pp. 9–10).

Other notable features are the gullies occupied by the smaller streams. Nearly all of them are cut in unconsolidated material and some reach a depth of 15 feet. They begin at the extreme heads of the small valleys or the steepest part of the slopes of the divides, and they end where the streams reach bedrock.

DRAINAGE.

The quadrangles are well drained, swamps and standing water being found at few places except in the Mississippi bottoms. The whole area is drained to Mississippi River, which crosses the southwestern part of the Galena quadrangle. The principal tributaries of the Mississippi in that quadrangle are, on the Illinois side, Sinsiniwa and Galena rivers, Smallpox Creek, and Apple River, which receives good-sized streams from Snipe, Long, and Irish hollows. On the Iowa side are Tete de Mort River and Spruce and Mill creeks. Most of the Elizabeth quadrangle is drained by Apple River, the principal tributaries of which in the quadrangle are Mill Creek, Hells Branch, Coon Creek, and South Fork. The southeastern part of the quadrangle drains into Big and Little Rush creeks, Camp Creek, and Plum River, which discharge into the Mississippi at points outside the area. About 2 square miles in the eastern part of the quadrangle is drained through Yells Creek to Pecatonica River.

The average width of the Mississippi is about one-fourth mile, but this estimate must be qualified by the statement that it is a braided stream, having numerous and changing channels. The fall of the stream between Dubuque and Bellevue, a distance of 20 miles, is 6.75 feet, or about 4 inches to the mile.

The other streams in the quadrangles seem to have fairly adjusted gradients, but show one peculiar feature—the lower part of each, that part along which the terrace is developed, has but slight fall. In the lowermost 8 miles of Galena River the fall is only 17 feet, whereas in the next 8 miles above it is nearly 100 feet. The lower part of Apple River falls only 44 feet in 16 miles, but in the next 16 miles above its fall is 240 feet. The significance of these differences is pointed out under the heading "Geologic history."

CLIMATE AND VEGETATION.

The quadrangles lie somewhat west of the middle of a great area in the northeastern part of the Mississippi basin which receives from 30 to 40 inches of precipitation a year. About two-thirds of this falls between the end of March and the first of October, in most years affording a bountiful and well-distributed supply for agriculture. The mean temperature and the range and variations of temperature are like those of the adjacent North-Central States.

The area once bore a heavy deciduous forest throughout, and still includes much woodland, especially on the steeper slopes. During the last quarter of a century considerable areas have become reforested. Probably because of extensive clearing, cultivation, and overpasturing, erosion of the smaller and steeper valley bottoms has lately been accelerated, so that recent gullies are abundant.

CULTURE.

The quadrangles are rather thickly though not densely populated. Galena, the county seat of Jo Daviess County, with a population in 1910 of 4,835, is in the west-central part of the Galena quadrangle. The other principal towns of the area are Bellevue, Iowa, and Hanover, Scales Mound, Elizabeth, Apple River, and Stockton, Ill., each of which has several hundred inhabitants.

Most of the surface is under cultivation, but woodland tracts are abundant and some areas that were formerly cultivated are being allowed to return to forest. Agriculture is the principal industry, but several hundred men are engaged in zinc and lead mining. Indeed, many men who have some other principal occupation spend part of their time prospecting for lead and zinc ores. The railroads also furnish employment to a large number.

The area is well provided with lines of transportation. Several railroads radiate from Galena; the Illinois Central crosses the northern part of the district, and the Chicago Great Western crosses the southern part; the Chicago, Burlington & Quincy runs along the foot of the bluff on the east side of the Mississippi, and the Chicago, Milwaukee & St. Paul along the west side of the river. The Chicago & Northwestern runs north from Galena along Galena River. Wagon roads, generally on divides or in valley bottoms, are numerous.

DESCRIPTIVE GEOLOGY.

STRATIGRAPHY.

The exposed rocks of the Galena and Elizabeth quadrangles are wholly of sedimentary origin and consist in part of indurated strata of Ordovician and Silurian age and in part of unconsolidated surficial deposits of Quaternary age. The Ordovician and Silurian rocks are chiefly dolomite and shale but include a subordinate amount of limestone. The Quaternary rocks comprise glacial drift, loess, dune sand, and terrace deposits of Pleistocene age, and travertine and alluvium of Recent age.

Beneath the outcropping Ordovician strata, in places penetrated by borings, though nowhere exposed in the quadrangles, lie earlier Ordovician sandstones and dolomites, beneath which again lie sandstone beds of Cambrian age, which have not been reached by borings in the quadrangles, but whose general character is known from outcrops not far north of the area. The Cambrian strata undoubtedly rest on a floor of deformed and metamorphosed pre-Cambrian sedimentary and igneous rocks, whose general character also is known from outcrops not far north and northeast of the area.

The several formations will be described in order of age, the description beginning with the rocks that are not exposed in the quadrangles, but that are believed to lie not far beneath the surface.

ROCKS NOT EXPOSED.

PRE-CAMBRIAN ROCKS.

The pre-Cambrian rocks probably nowhere lie more than 2,000 feet below the present surface. They doubtless consist of igneous and metamorphic sedimentary rocks, chief among which are granites, gneisses, schists, and quartzites. Their nearest outcrop is about 70 miles northeast of the quadrangles, about Baraboo and Devils Lake, Wis., where considerable areas of quartzite (Baraboo quartzite) and smaller areas of igneous rock have been exposed through the removal by erosion of the overlying Paleozoic strata.

CAMBRIAN SYSTEM.

The Cambrian system is represented by 600 to perhaps 1,000 feet of sandstone, as a rule poorly consolidated, and minor amounts of shale and dolomite, all of Upper Cambrian age. In the reports of the Wisconsin Geological Survey the name Potsdam sandstone has been applied to the beds, most of which, however, are known to be older than the Potsdam sandstone of New York. The top of the Cambrian strata is probably less than 400 feet below the bottoms of some valleys in the northwestern part of the Galena quadrangle, but elsewhere it is considerably farther below the surface.

ORDOVICIAN SYSTEM.

Upon the Cambrian sandstone lies a group of strata, commonly ranging in thickness from 150 to 250 feet and composed largely of dolomite, to which the name Prairie du Chien group has been applied, as it is well exposed near the town of that name. The group has generally been known in the upper Mississippi basin as the "Lower Magnesian limestone." It consists almost wholly of dolomite and is separable into two formations, the Oneota dolomite below and the Shakopee dolomite above.

The Prairie du Chien group was penetrated in an artesian well in sec. 16, T. 28 N., R. 1 E., a short distance north of Galena, at a point where the surface is 600 feet above sea level. The well is owned by D. A. Taylor, who furnished the following record:

Section in well near Galena.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface wash	25	25
Gravel	30	55
Limestone; water at base [Platteville]	65	120
Sandstone [St. Peter]	30	150
Dolomite [Prairie du Chien]	103	253

The lowermost stratum, the dolomite, belongs to the Prairie du Chien group, the next overlying stratum is the St. Peter sandstone, and the third is the Platteville limestone. The gravel is a Pleistocene valley filling and the surface wash is at least in part of Recent age.

Resting unconformably upon the Prairie du Chien group is a comparatively thin sandstone long known as the St. Peter sandstone, from its occurrence along the lower course of St. Peter (now known as Minnesota) River. Its thickness ranges from 35 to 175 feet and averages perhaps 100 feet. The differences in thickness are due mainly to irregularities in the surface of the underlying formation. The top of the sandstone likewise may have been somewhat eroded before the Platteville limestone was laid down upon it, though positive evidence of discordance of stratification has not been observed.

The base of the St. Peter formation nearly everywhere is a foot or two of bluish-green sandy clay shale, the rock above which is practically pure quartz sandstone containing in places more than 99 per cent of silica. The grains are well worn and of medium fineness, the greater part of them passing through a screen having 40 meshes to the inch. The sand is at most places poorly cemented, so that the rock crumbles readily. The transition to the overlying Platteville limestone is marked by a bed of blue sandy shale, called Glenwood shale by the Iowa State Survey, ranging in thickness from a few inches to 5 feet or more.

The St. Peter sandstone is a formation of wide extent in the upper Mississippi basin. In the Ozark region it is represented by the sandstone which immediately underlies the Joachim limestone and which has frequently been called the "First Saccharoidal" sandstone. In the Galena-Elizabeth area there may have been an interval of emergence between the deposition of the St. Peter sandstone and that of the Platteville limestone, an interval represented in the Ozark region by the Joachim limestone.

ROCKS EXPOSED.

GENERAL SECTION.

The sequence, general character, and approximate thickness of the exposed formations are shown graphically in the accompanying columnar section (fig. 4).

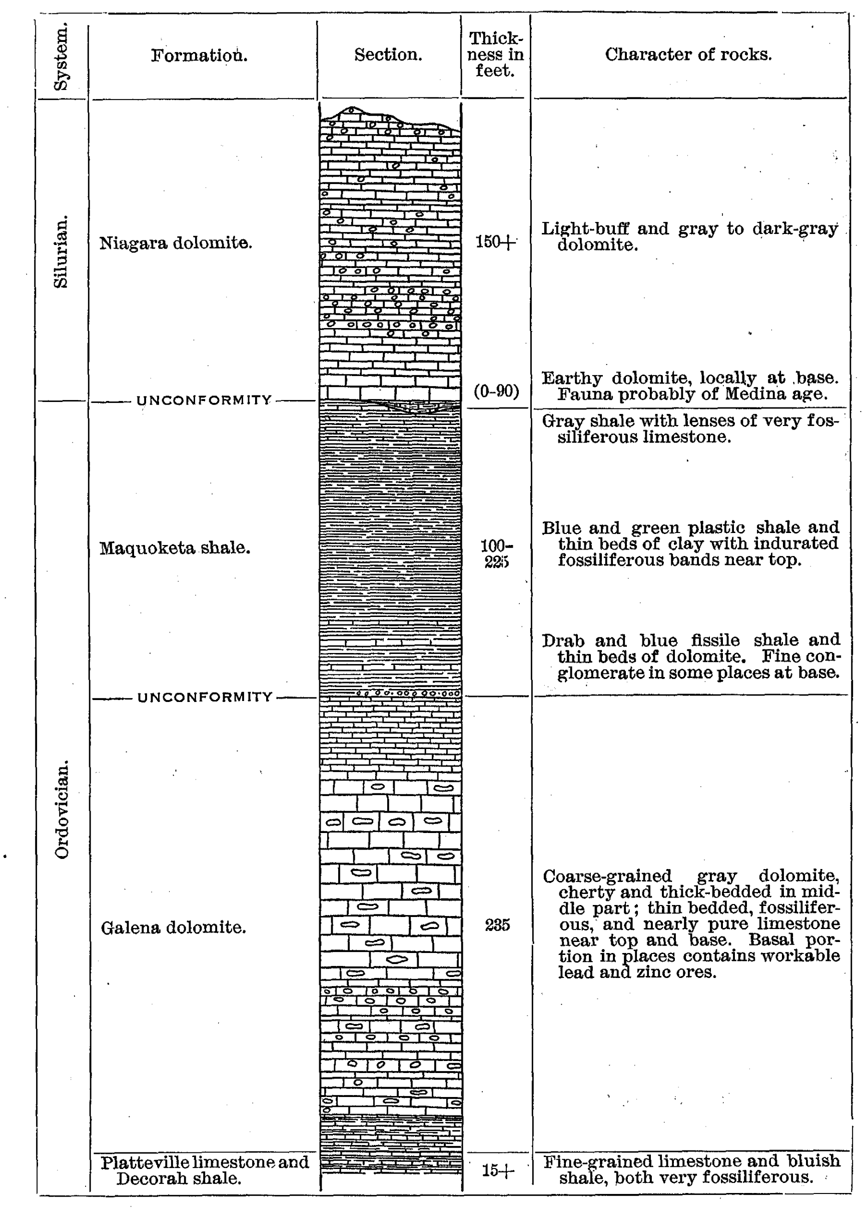


FIGURE 4.—Columnar section of the rocks exposed in the Galena and Elizabeth quadrangles.
Scale: 1 inch=100 feet.

ORDOVICIAN SYSTEM.

PLATTEVILLE LIMESTONE.

Definition and distribution.—The Platteville limestone consists largely of nonmagnesian or only slightly magnesian limestone, in which respect it differs notably from the other calcareous formations in the area. In earlier reports on the district it was called the Trenton limestone, but since 1905 the name Platteville has been applied to it, as it is now known to be older than the Trenton. It is typically exposed in its entire thickness along Little Platte River west of Platteville, Wis., from which place it is named.

The average thickness of the formation is 40 feet. Only its uppermost part is exposed in the quadrangles in the valley of Galena River, 3 to 4 miles above Galena. Because of the small size of this outcrop it is mapped with the overlying Decorah shale.

Character.—Where the formation crops out immediately north of the quadrangles it consists of a thick-bedded magnesian limestone or dolomite member, 15 to 25 feet thick, below, and a thin-bedded, brittle, fine-grained limestone member, 15 to 25 feet thick, above. The beds of the lower member range in thickness from 6 inches to 2 feet and are composed of coarse earthy magnesian limestone of blue-gray color when fresh. The upper member is commonly made up of beds 1 to 3 inches thick having a wavy appearance and separated by thin shale partings. Most of the beds are of dense, fine-grained gray to light-brown limestone that breaks with a somewhat marked conchoidal fracture.

Fossils and correlation.—The formation is nearly everywhere highly fossiliferous, more so than any other in the area except possibly the Maquoketa shale. The following species are common and are characteristic of the formation: *Thaleops ovatus* Conrad, *Leperditia fabulites* Conrad, *Protowarthia rectangularis* Ulrich, *Orthis deflecta* Conrad, *Orthis tricenaria* Conrad, *Orthis perveta* Conrad. The first four are, so far as at present known, confined to the Platteville, the others are not found below the Platteville in this area but extend up into and are found in small numbers in the lower part of the Galena.

The Platteville is regarded as equivalent to the Lowville limestone of New York, a formation whose fossils are recognizable throughout a large area in the eastern States and in places in the Mississippi basin.

DECORAH SHALE.

Definition and occurrence. — The Decorah shale consists largely of greenish clay shale interbedded with limestone, which generally occurs in thin beds and which greatly resembles the basal limestone layers of the Galena dolomite above. Hence it is difficult to draw the boundary between the two formations on purely lithologic criteria. With the aid of fossils, however, which are generally abundant, the beds above and below the contact may commonly be distinguished. A long-hinged variety of *Orthis* (*Dalmanella*) *subæquata*, which is broadest in a 3-foot layer somewhat above the middle of the formation, is very abundant in the Decorah and appears to be confined to it. *Stictoporella frondifera* and *S. angularis* are also found in almost every outcrop of the Decorah but not in formations above or below it.

The Decorah shale is named from the town of Decorah, in Winneshiek County, northeastern Iowa, where the formation is well developed and much thicker than it is in these quadrangles. In its type locality the formation consists principally of shale, but in the area here considered a part of it is limestone.

The Decorah presumably underlies the entire area of the Galena and Elizabeth quadrangles except a small tract along Galena River, though the formation is generally more or less deeply buried beneath higher formations. It outcrops in only one small district, along Galena River north of Galena, where it is mapped with the Platteville limestone, the best exposures being on the west side of the stream at the base of the valley side in sec. 3, T. 28 N., R. 1 E., and in sec. 34, T. 29 N., R. 1 E. The formation appears to range in thickness from 1 to 10 feet, but is nowhere completely exposed. The freshest and most extensive exposure is on the Chicago Great Western Railroad at a place 1½ miles north of Furnace School.

Section of Decorah shale and associated beds 1½ miles north of Furnace School, near Galena.

	Feet.
Galena dolomite:	
Massive dolomite	2
Thin-bedded, fossiliferous limestone inclosing lenses of dark brown, oily shale (the oil rock)	14
Decorah shale:	
Shale	1
Decorah shale or Platteville limestone:	
Fossiliferous, thin-bedded limestone; resembles the glass rock	13
"Glass rock"?, beds 1 to 1½ feet thick, compact, chocolate-colored, fine grained; breaks with conchoidal fracture	3

The most characteristic part of the formation is composed of beds of limestone known to the miners of the lead and zinc district as "glass rock." The name probably arises from the fact that the rock is dense, hard, and fine grained, breaks with a conchoidal fracture, and rings when struck with a hammer. When fresh it is of light chocolate color, but on weathering it changes rapidly to very light gray or white. It occurs typically in strata that range in thickness from 3 to 8 inches and are separated by thin partings of chocolate-colored shale or oil rock. The lower beds at some places have a peculiar mottled appearance, and at many places a few thin layers of oil rock directly underlie the glass rock.

The main glass rock ranges in thickness from 18 inches to 4 feet. It strongly resists weathering, so that where it lies at or near the surface exposures and fragments of it are easily found. A chemical analysis of the rock gave the following result:

Analysis of glass rock.

[By E. T. Sweet, Geology of Wisconsin, vol. 2, p. 681, 1877.]

Silica (SiO_2)	6.160
Alumina (Al_2O_3)	2.260
Ferric oxide (Fe_2O_3)	.950
Calcium carbonate ($CaCO_3$)	85.540
Magnesium carbonate ($MgCO_3$)	3.980
Water (H_2O)	.930
Phosphoric anhydride (P_2O_5)	.055
	99.875

At the top of the formation in many places there is a blue calcareous shale or blue clay, which ranges in thickness from a few inches to 3 or 4 feet, and is in part highly fossiliferous. This shale is widely distributed in Iowa and Minnesota, where it is known as the Stictoporella zone of the Decorah shale.

Fossils.—The characteristic fossils of the glass rock and interbedded chocolate-colored shale are *Buthograptus laxus* and other delicate plumose marine algæ. The top shale, or Stictoporella zone, which is provisionally referred to the formation, everywhere contains great numbers of a large and rather transverse variety of *Dalmanella minneapolis*, which is confined to that horizon. (See Pl. XII.) There are only a few other species, but one or both of the bryozoans *Stictoporella frondifera* and *S. angularis*, which occur only in the shale bed, may usually be found wherever that bed is well developed. These fossils therefore furnish a criterion by which the formation may be easily separated from the main body of the overlying Galena dolomite—a criterion which is of use in geologic mapping as well as in locating a horizon that is important in mining. The fauna indicates that the Decorah shale should be correlated with late Black River beds of New York.

GALENA DOLOMITE.

Definition and distribution. — The Galena dolomite was named from its typical exposures at Galena. It immediately underlies the surface throughout most of the northern half of the quadrangles and crops out extensively in the southern half. It is not only the thickest formation that is fully exposed in the area, but it comprises by far the most important ore-bearing rocks in the district. In fact, nearly the whole of the lead ore that has been produced in the region and the main part of the zinc ore has come from the Galena dolomite, especially from the lower part of it.

The thickness of the formation in the area is comparatively uniform and averages about 240 feet.

Character.—The formation consists of porous, coarse-grained crystalline dolomite, which weathers into exceedingly rough pitted and irregular forms. Hand specimens commonly show small open cavities, many of them lined with crystals of dolomite. In weathering it breaks down at once in some places into coarse yellow dolomitic sand. Except in its extreme upper and lower parts the formation is of fairly uniform lithologic character throughout, the principal differences being in the proportion of chert. As a whole it is massive, the beds ranging in thickness from 1 to 4 feet, but the beds near the bottom and the top are thinner. Nodules of chert are common in its middle part, and at many places, especially in its upper part, thin seams or partings of clayey material, a little darker than the main mass of the rock, separate it into irregular layers. Where unweathered the dolomite is commonly light bluish-gray, but at some places, especially in its upper part, its tinge becomes gray, and at some places in its lower part it is notably blue. The weathered rock is light yellowish gray or buff and in its most weathered parts is somewhat brownish or reddish, the exact shade depending on the amount and character of the iron oxide it contains. Nearly all the beds are intersected by joints, which trend and dip at different angles.

The accompanying analysis of a composite sample of the fresh rock from several Wisconsin localities gives a general idea of its composition. As the sample includes no nodules of chert and practically no clayey partings nor nondolomitic basal material, the average Galena rock contains a larger proportion of alumina, silica, and calcium carbonate than that shown by the analysis.

Analysis of Galena dolomite from Wisconsin.

[By W. W. Daniels, Wisconsin Geol. and Nat. Hist. Survey Bull. 9, p. 15, 1903.]

Calcium carbonate ($CaCO_3$)	54.33
Magnesium carbonate ($MgCO_3$)	41.56
Ferric oxide (Fe_2O_3)	.90
Alumina (Al_2O_3)	.99
Silica (SiO_2)	2.10
	99.88

An analysis of Galena dolomite from eastern Iowa is given below:

Analysis of Galena dolomite (used for burning into lime) from Eagle Point quarry, Dubuque, Iowa.

[By J. B. Weems, Iowa Geol. Survey Ann. Rept. for 1899, vol. 10, p 567, 1900.]

Water (H_2O)	0.02
Insoluble	2.15
Calcium oxide (CaO)	30.72
Magnesium oxide (MgO)	19.90
Carbon dioxide (CO_2)	45.91
Ferric oxide (Fe_2O_3)	.82
Phosphorus pentoxide (P_2O_5)	.60
Organic	.13
	100.25
Dolomite	94.14
Limestone	2.47

Divisions.—The formation can be separated into five divisions, shown in the following generalized section:

Generalized section of Galena dolomite.

	Feet.
Dolomite, earthy, thin bedded	30
Dolomite, coarsely crystalline, massive to thick bedded, noncherty	70
Dolomite, thick to thin bedded, coarsely crystalline, chert bearing	100
Dolomite, thick bedded, coarsely crystalline, nonfossiliferous, noncherty	40
Limestone, thin bedded, with highly fossiliferous and, in part at least, carbonaceous shaly partings, constituting the oil rock of the miners	20
	260

The lowest division in the above section is exposed in the bottom of Galena River valley a few miles north of Galena, and all but its lowermost part is exposed on Sinsinawa River west of Galena. (See Pl. I.) A characteristic part of this division is the "oil rock" near its base, and just above this oil rock most of the lead and zinc ore is found. A typical exposure of the next highest division—the 40 feet of dolomite—which occurs in the valley of Apple River, is shown in Plate III. The overlying dolomite (100 feet thick) is coarse grained, porous, and thick bedded and contains nodules of chert ranging in diameter from a few inches to a foot, many of them lenticular. The chert is ordinarily distributed in layers and at some places is so abundant that layers 1 to 3 inches thick may be traced for considerable distance through the dolomite. The top bed consists of thinner-bedded earthy dolomite and limestone. The beds are usually separated by shale partings that range in thickness from 2 to 12 inches, the thinner being near the top. This member is found only at some places, particularly in the north-central part of the area. It is the most easily differentiable member of the formation and is doubtless the same as the stratum called by Sardeson the Dubuque limestone.

The following sections illustrate the character of the Galena dolomite at several places:

Section of the Galena dolomite exposed near Galena.

	Feet.
Limestone, in part magnesian; beds 3 to 12 inches thick, earthy, noncrystalline; upper part in places shaly	30
Dolomite, beds 1 to 2½ feet thick, nonresistant, in places cavernous	10
Dolomite, alternating thick and thin beds; few fossils	25
Dolomite, single resistant bed, commonly making bench on hillsides	6
Dolomite, thin beds with *Receptaculites oweni*	4
Dolomite, beds 6 inches to 3 feet thick, nonresistant, contains scattered chert nodules	40
Dolomite, single resistant bed, commonly making bench on hillside; no apparent chert	6
Dolomite, 2 inches to 1 foot thick, nonresistant	20
Dolomite, 2 to 10 feet thick, with scattered *Receptaculites oweni* and a little chert	20
Dolomite, beds 2 inches to 3 feet thick, with many chert nodules	30
Dolomite, beds 2 to 4 feet thick, containing generally *Receptaculites oweni*	10
Dolomite, beds 2 inches to 2 feet thick, very few fossils	35
Limestone, in part magnesian, in thin irregular beds, very fossiliferous, shaly, bluish, interbedded with one or more layers of chocolate colored carbonaceous shale known as oil rock	5
	241

Section of Galena dolomite exposed near Scales Mound.

	Feet.
Limestone, thin bedded, argillaceous, in places magnesian, fossiliferous, one of the most common forms being *Lingula iowensis*	25
Dolomite, thick bedded (a few beds 1 foot or less thick), without chert, upper part nonresistant	45
Dolomite, thick bedded to massive, coarse grained, with *Receptaculites oweni*	10
Dolomite, thin bedded, commonly cherty, nonresistant	20
	100

Section of Galena dolomite exposed within 5 miles south of Apple River.

	Feet.
Limestone, impure, thin bedded, and fossiliferous	25
Dolomite, beds of medium thickness, fairly uniform, with scattered specimens of *Receptaculites oweni*	40
Dolomite, mostly heavy bedded, hard, and crystalline, with much chert in places, few fossils, and numerous small irregular cavities	125
Dolomite, beds 6 to 24 inches, somewhat cherty and differing in appearance with amount of weathering; a few specimens of *Receptaculites oweni*	15
	205

Oil rock.—The material commonly called oil rock in the district is a finely laminated brown to black but generally dark chocolate-colored shale. When burned it gives off an odor of petroleum, hence its name. It is made up of fragments of rather hard rock and a matrix of softer material. The hard fragments are fractured, bent, and broken, and the soft material has evidently been squeezed in between them. The blue clay bed beneath the main oil rock contains numerous small black rounded, pebble-like bodies made up of calcium phosphate. As they include pieces of fossils it is supposed that they either represent fossils themselves or are concretionary masses of rock derived from fossils, but they may be phosphatized pebbles of fossil-bearing rock.

The typical oil rock is one of the most interesting materials found in the region and it appears to bear an important relation to the ore deposits. Its significance in relation to them lies in its capacity to furnish a large amount of material that is especially well suited to precipitate metallic salts as sulphides. The rock is porous and light, having a density of only 1.98, and yields gas bubbles when placed in water. One volume of the rock, when heated to redness in a vacuum for two hours, gave 57.46 volumes of gas. An analysis of the gas gave the following result:

Analysis of gases derived from oil rock of Galena dolomite.

[By Rollin Chamberlin.]

Heavy hydrocarbons	15.11
Methane (CH_4)	35.98
Hydrogen sulphide (H_2S)	6.79
Carbon dioxide (CO_2)	18.12
Carbon monoxide (CO)	8.40
Oxygen (O_2)	.26
Hydrogen (H_2)	13.18
Nitrogen (N_2)	2.21
	100.05

When the shale is leached with ether it yields a thick, heavy oil, which is doubtless the most abundant element in the volatile matter and which contains an appreciable amount of sulphur.

Examination with the microscope of thin sections of the oil rock shows that it is made up largely of minute flat, generally oval and discoid translucent bodies, of brilliant lemon-yellow color, which are highly refractive, the refractive index being 1.619. They range in horizontal diameter from 8 to 62 microns and in vertical diameter from 5 to 20 microns. Many of these bodies are lenticular and are irregularly rounded at the edges, but most of them are nearly oval and when seen in vertical section seem to be horizontally matted with other sediments and with crystals of later formation, their appearance suggesting forest leaves beneath the winter snow. The nature of these singular bodies is not known, though it is generally believed that they are of vegetal origin. They are regarded by David White as probably either plant spores richly protected by a resin-like secretion, or the fossil remains of microscopic unicellular algæ, comparable to the living Protococcales.

The oil rock derived its volatile hydrocarbons from these fossil plant products, which in places form more than 90 per cent of its mass. It is thought that they were derived from floating plants whose débris accumulated in large quantities on the bottoms of shallow basins in early Galena time. The deposits were originally thicker than now, their thinning being due to actual compression and to the loss of some of the volatile hydrocarbons. It is thought by some that as the gases passed upward into the other beds of the formation they played an important part in the precipitation of the lead and zinc sulphides.

Fossils.—Some beds of the Galena contain abundant organic remains, but the main body of the formation contains but few recognizable fossils. However, the basal limestone and shale are highly fossiliferous and contain a number of brachiopods and pelecypods, the more important of which are *Orthis tricenaria*, *O. pectinella*, *O. testudinaria*, *Plectambonites sericea*, *Leptæna charlotta*, certain varieties of *Rafinesquina alternata*, and *Strophomena incurvata*, *Ctenodonta astartiformia*, and *Vanuxemia niota*. Most of these species are common and, except the first, which occurs also in the Platteville, are highly characteristic of this horizon. Judging from its fossils these basal beds are more closely allied to the Decorah shale of Iowa and the "Upper Blue" of the Wisconsin section than to the Galena proper. Their stratigraphic position corresponds to that of late Black River beds of New York State.

A peculiar fossil known as *Receptaculites oweni* Hall, commonly called the "lead fossil" and the "sunflower coral" (see Pl. XII, figs. 1 and 2), occurs somewhat sparingly throughout the Galena formation above the basal member. It is especially abundant in two beds that are from 1 to 4 feet thick, and thus affords a ready means of determining the geologic horizon of the outcrops in which it occurs. The lower bed is 35 to 50 feet above the base of the formation and marks rather closely the separation between the 40-foot division and the 100-foot division shown in the generalized section of the Galena given on page 4, the lowest chert in the formation being within a few feet of its horizon. It is well exposed in and around Galena and at several other localities. The upper bed is about 60 feet below the top of the formation, or 30 feet below the top of the 70-foot division given in the section, and is even more distinct than the lower one.

A large species of Lingula, known as *Lingula iowensis* (see Pl. XII), is commonly found in the top division of the formation where it is present, but as that division seems to be absent from the section at many places the two horizons of Receptaculites just described furnish in these quadrangles the principal evidence afforded by fossils for the separation of the main body of the formation into members. The Galena dolomite with the exception of its basal beds is correlated with the Trenton limestone of New York.

Relations.—As already stated (see p. 4), it is difficult to draw the boundary between the Decorah shale and the Galena dolomite on purely lithologic criteria. The separation is particularly difficult in the basin-like areas (corresponding to the productive mineral areas) in which thin beds of limestone and shale are most fully developed both above and below the contact. In the anticlinal areas between the productive basins there is less shale. Here and there a thin layer of "oil rock" occurs in the Decorah, but the true oil rock belongs in the basal beds of the Galena.

A careful study of the fossils rarely fails to fix the contact rather closely, and in places an actual physical break between the two formations may be observed. At many places the lowermost few inches of the Galena is more or less clearly a reworked deposit, and at some places it contains fragments of fossils, more perfect specimens of which occur in the beds just below. A mile north of Furnace School the lowest bed of the Galena consists of yellow to white clay, called "pipe clay," underlain by an inch or two of dark carbonaceous clay.

Topographic expression.—The beds in the 70 and 100 foot divisions of the generalized section (see p. 4) constitute the characteristic part of the formation. The hard, massive beds of dolomite stand so far above the Mississippi base-level throughout most of the area that erosion has produced in them the rugged walls, crags, and "towers" that are prominent about midway up the bluffs. The precipitous sides and sharp angles of these striking products of erosion are due to the breaking down of the rock along joints.

MAQUOKETA SHALE.

Definition.—The Maquoketa shale is named from Little Maquoketa River, along which it is typically exposed. It is known in the Wisconsin State reports as the Cincinnati shale. Its thickness in the quadrangles ranges from 108 to 209 feet, the minimum thickness measured being at the Chicago Great Western Railroad tunnel southeast of Galena.

According to the testimony of experienced drillers the change from the overlying beds to the Maquoketa as well as that from the Maquoketa to the underlying beds is everywhere sharp and easily recognized in borings. The beds are nearly level and the evidence furnished by drill records is therefore probably reliable. The base of the formation is well exposed at many places, particularly along the railroads, and is marked by the presence of numerous small calcareous and phosphatic pebbles or pellets, one-fourth to one-half inch in diameter, and by characteristic and well-preserved fossils. At Scales Mound on a divide 950 feet above sea level a cut shows 35 feet of Maquoketa shale over several feet of Galena dolomite. At Hanover the same beds are exposed in the river bank at a level of 620 feet. A mile east of Woodbine the formation boundary is just below the level of the track, or 870 feet above sea level. The sharp lithologic change at this horizon, together with certain distinguishing fossils, makes the boundary fairly easy to find. The base of the Maquoketa is important to miners, as it marks the top of the Galena and indicates within a few feet the depth to which a drill must be sunk to reach the bottom of the ore-bearing beds.

Distribution and occurrence.—The formation is confined to the higher land in the northern part of the quadrangles and to the middle and lower slopes in the southern part. Throughout a considerable area it is so deeply covered by soil or by loess that outcrops are difficult to find, and its presence must be determined by examining material passed through in drill holes, wells, or prospect pits. Outcrops are, however, fairly abundant in the southern and southeastern parts of the area.

The outcrop of the formation is characterized by gracefully rounded swells and long, gently rolling, cultivated slopes, bounded above by forested declivities of the Niagara escarpment, and below by steep bluffs of Galena dolomite. One mound just southeast of Galena has a rather pointed top, apparently because the overlying dolomite has only recently been removed.

Character.—The formation is much less uniform in character than any other in the area. Its lower part generally consists of drab and blue soft shale, its central part of interbedded soft shale and argillaceous dolomitic limestone and some thick beds of shale, and its upper part of soft shale, coarse fossiliferous limestone, and thin beds of compact dolomite. Marcasite and sphalerite occur in places. Individual beds can not ordinarily be followed far, though there seems to be a similarity between certain sections in separate parts of the area and a dissimilarity between those sections and other intervening ones. No definite statement can be made on this point because of the lack of good exposures and of trustworthy and complete records of borings. The following sections show the character of the formation at several places:

Section of Maquoketa shale near Galena.

	Feet.
Clay shale interbedded with thin layers of limestone and dolomite, most of which are compact, though some contain lenses of coarse fossiliferous limestone. This member has been removed by both pre-Niagaran and post-Paleozoic erosion from all but very small areas near Galena	60
Clay shale, soft, blue, nonfossiliferous, mostly rather massive but in places finely laminated and darker and harder than elsewhere; also contains local lenses of limestone and dolomite	95
Clay shale, with a 6 to 12 inch layer of unconsolidated material of sandy texture, loose fossils, considerable iron oxide, and particles and pellets of variable composition	2
	157

Section of Maquoketa shale in the southwest corner of the Galena quadrangle.

	Feet.
Shale, soft, blue or grayish blue, nonfossiliferous, weathering into irregular small blocks	50
Dolomite, discontinuous bed, very fossiliferous, a large cephalopod being most abundant	1
Shale, blue, soft, with earthy dolomite lenses in some places	45
Shale, soft, sandy, with pellets of phosphate and a few fossils, particularly Ctenodonta	1
	97

Section of Maquoketa shale exposed in Hanover district.

	Ft.	in.
Clay shale, yellow, very fossiliferous	2	0
Limestone, coarse, crystalline, very fossiliferous	1	0
Shale, blue, flaky, and hard		6
Limestone, hard, blue, fossiliferous	1	6
Shell rock, dark brown, porous, interbedded with blue shale; shells poorly preserved	2	0
Shale, blue		6
Limestone, fossiliferous	1	0
Yellow clay wash, shale?, weathering to yellowish clay	10	0
Limestone, coarse grained, fossiliferous; contains a large and small Orthis, Strophomena, and Lingulepis	1	0
Concealed. Washed material is yellow and blue clay, containing bowlders of coarse-grained crystalline limestone, which is highly fossiliferous	39	0
Shale and fossiliferous limestone alternating; shale yellow or blue; limestone in 1-foot beds 2 or 3 feet apart, containing orthids, Rhynchotrema, and bryozoans	11	0
Clay shale, yellowish	10	0
Limestone, coarse grained, containing bryozoans, orthids, and Rhynchotrema	1	0
Shale?, weathering to yellow clay and containing argillaceous limestone blocks and laminated sandstone from higher up	45	0
Concealed	15	0
Clay shale, blue, with some thin layers of argillaceous limestone; shale weathers to a stiff yellowish clay; limestone less than 6 inches thick	43	0
Limestone, impure, open, porous, but resistant rock made up largely of fossil remains; lamellibranchs, gastropods, Orthoceras		6
Clay shale, thin bedded, fine grained, slightly arenaceous, chocolate-colored, weathering to slate-colored; contains egg-shaped nodular masses of shale 1½ feet long	3	0
Concealed	3	0
	190	0

Section of Maquoketa shale exposed near Elizabeth.

	Feet.
Clay shale, with thick, coarse grained, fossiliferous limestone layers and many bryozoans. (This member is not found at a few land places north of Elizabeth)	35
Limestone, thin, somewhat magnesian; contains some chert and a few fossils; includes in places some shale, but is generally resistant, making benches on valley sides, like those 3 miles southeast of Elizabeth	40
Clay, weathering yellow, containing biscuit-shaped bryozoans	10
Shale, hard, bluish, poorly exposed	10
Shale and argillaceous dolomite alternating, not fossiliferous	30
Mostly concealed, but small exposures indicate soft blue shale	50
Unconsolidated ferruginous and fossiliferous bed (thin or wanting at a place east of Schappville)	3
	178

Section of Maquoketa shale exposed near Scales Mound.

	Ft.	in.
Clay shale, with several beds of coarse-grained, fossiliferous limestone and other fossiliferous layers, also fine-grained compact dolomite; bryozoans abundant in central part. (These beds absent except northeast of Scales Mound)	70	0
Clay shale alternating with thin beds of compact earthy dolomite	25	0
Clay shale, soft, with a few lenses of magnesian limestone	25	0
Clay shale alternating with compact brittle dolomite in beds 1 inch to 12 inches thick	20	0
Clay shale, soft, blue	10	0
Clay shale with a few thin beds of compact, fine-grained dolomite	10	0
Clay shale, bluish gray, soft, containing a few hard concretionary? bodies	33	0
Clay shale, reddish, with graptolites at base	3	0
Unconsolidated, ferruginous, fossiliferous bed having a sandy texture (many lamellibranchs)		11
Clay shale, soft, gray	3	9
Unconsolidated ferruginous fossiliferous bed having a sandy texture and containing loose particles and pellets of indefinite composition (no lamellibranchs)		6
	201	2

Section of Maquoketa shale exposed in district north of Stockton.

	Ft.	in.
Dolomite and limestone, thin bedded, yellow	1	6
Shale, calcareous, with beds of blue shale and yellow limestone, fossiliferous	4	0
Limestone, dolomitic, thick bedded, coarse, hard, reddish, fossiliferous	2	0
Shale lens		5
Limestone, massive, coarse, crystalline; some large calcite crystals; fossiliferous	4	0
Limestone, massive, crystalline, hard and slightly dolomitic, base cherty, fossiliferous	3	0
Limestone, thin, shaly, blue and earthy, separated by layers of blue shale, fossiliferous	3	0
Clay, containing numerous biscuit-shaped bryozoans	10	0
Concealed	90	0
Shale and limestone? weathering to sandy, calcareous clay	5	0
Concealed	11	0
Clay, weathering yellow, with 1-inch layers of fragile shaly limestone 1 foot apart	17	0
Concealed	42	0
	192	11

Sections of Maquoketa shale exposed in southeast corner of the Elizabeth quadrangle.

	Ft.	in.
I. Shale, calcareous shale, shaly limestone, some sandstone, and a small amount of chert; beds average not more than 3 inches thick; shales are yellow and deep blue, limestones are blue or black, and in places hard, compact, and crystalline; where shaly they are soft and easily weathered; upper 35 feet is fossiliferous in certain layers, both yellow shale and limestone	108	0
Float, and scattered exposures of clay, shale, and soft calcareous shale layers	20	0
Concealed	1+	
Clay shale and limestone, compact, argillaceous, alternating; shale beds average 2 feet thick, limestone beds average 2½ inches thick	41	6
Clay shale, dark gray or chocolate-colored, uniform; breaks in flattish bits with conchoidal fracture	8	0
Concealed	10	3

	Ft.	in.
Carbonaceous rock, soft, black, porous, containing lamellibranchs, rounded pieces of rock (waterworn pebbles?), gastropods and Orthoceras; all small forms	1—	
Clay shale, compact, blue, sticky	1+	
	190	9±
II. Shale and argillaceous limestone interbedded; shale blue, blue-black, and yellow; weathers to yellow sticky clay. Harder parts are shaly and impure but some layers are white, compact, and crystalline; limestone layers both fossiliferous and unfossiliferous; fossiliferous layers more numerous near top	96	0
Shale, bluish, and "soapstone"; all soft except an occasional few inches of harder material (well record)	50	0
Concealed	33	0
Shale, dark blue, with conchoidal fracture, weathering to thin brown layers	2	6
Concealed	14	
Shale, dark blue, with conchoidal fracture, weathering to thin brown layers		2
Impure limestone?, grayish black, cemented by iron; rusting of iron gives it a reddish color; rock crumbles between hands, giving a coarse cornmeal texture; is in very thin, shaly fissile layers; some small iron nodules		6
	196	2

The shale disintegrates rapidly and is therefore largely concealed by products of decay and by vegetation. Continuous vertical sections of any considerable thickness are found only along small streams that are vigorously scouring their beds or undercutting their banks, or in gullies that have been cut deeply into the shale.

Fossils and correlation.—Throughout the upper Mississippi basin the formation is in general notably fossiliferous. The shale at its base, measuring generally 2 to 5 feet, contains rather abundant fossils, which remain after the rest of the rock has weathered away. Among them are the following species, all small and most of them preserved as casts of the interior: a species of Orthoceras sp., *Hyolithes parviusculus* Hall, *Liospira micula* Hall, *Pleurotomaria depauperata* Hall, *Cleidophorus neglectus* Hall, and *Ctenodonta fecunda* Hall. These are illustrated in Plate XIII, figures 1–8. Generally this horizon can be recognized with little difficulty.

Beds that lie at horizons in the upper part of the formation and that are more extensively exposed also contain fossils, at some places in great abundance. The thin plates of limestone and apparently also the intercalated shale are here and there highly magnesian, and the fauna they contain is altogether different from that found at the base of the formation. (See Pl. XIII, figs. 9–19.) The following species, collected near the tops of the mounds 3 to 5 miles northeast of Scales Mound, are characteristic of the upper beds:

Monotrypella quadrata.	Dinorthis subquadrata.
Monotrypa rectimuralis.	Platystrophia acutilirata var.
Heterotrypa singularis.	Rhynchotrema capax.
Plectambonites saxea.	Rhynchotrema perlamellosa.
Leptæna unicostata.	Rhynchotrema neenah.
Plectorthis whitfieldi.	

The fossils of the Maquoketa formation prove that its age is approximately that of the Richmond group of Ohio and Indiana and of the lower part of the Medina group (Queenston shale) of New York and Ontario.

Relations.—Conclusive evidence of stratigraphic unconformity or of a break representing an interval of erosion has not been observed at the base of the formation in the Galena-Elizabeth area, but there is some indication of such a break. The change from the dolomite of the Galena to the shale of the Maquoketa is abrupt, some of the fossils and pellets in the base of the shale seem to have been rolled and rounded, and the fauna of the Galena is very different from that of the Maquoketa, yet the sedimentation planes below and above the contact are parallel as far as seen. The occurrence of phosphate may itself be an indication of an unconformity.

The Maquoketa shale is unconformably overlain by the massive Niagara dolomite, the shale having been considerably eroded before the dolomite was deposited. Apparently the Maquoketa was originally more than 200 feet thick and in places where it is now thin its upper part was cut away before any of the Niagara beds were laid down. The best exposure of the strata above and below the contact at a locality where the Maquoketa is thin is at the Chicago Great Western Railroad tunnel 8 miles southeast of Galena, where the Maquoketa consists almost entirely of soft shale, 41 feet of which is well exposed at the east end of the tunnel. Borings near the middle of the tunnel showed 95 feet of soft material; a short distance to the east the formation appears to be 108 feet thick; on Pilot Knob, 4 miles to the northwest, it is 160 feet thick; in the vicinity of Hanover its thickness is more than 200 feet, and near Stockton it is 209 feet. The differences in lithologic character from district to district make it impossible to say positively that at some places certain beds were eroded away before the succeeding beds were laid down, for perhaps the upper beds were never deposited at those places, but there are strong indications of unconformity, not only in irregularities of thickness of the formation but in the absence, wherever the formation is thin, of some of the coarse-grained fossiliferous limestone beds that seem to be present wherever its thickness is 130 feet or more. Still another indication of unconformity is found in the character of the basal layers of the Niagara, described below.

SILURIAN SYSTEM.

NIAGARA DOLOMITE.

Distribution and thickness.—The Niagara dolomite occupies small areas in the northern part of each quadrangle, where it is found only at the tops of widely separated mounds and narrow ridges, and in a much larger area in the southern part, where it caps many narrow but irregular ridges and spurs.

The total original thickness of the formation is doubtless nowhere preserved in the quadrangles. The greatest thickness remaining, about 250 feet, is found in the southwestern part of the area, in secs. 26 and 27 of Rice Township. At many other places bodies of the rock more than 100 feet thick remain. Indeed, it is noteworthy that the Niagara in the quadrangles and the adjacent territory is generally about 150 feet thick in spite of local differences in the severity of erosion.

Large loose masses of the basal Niagara beds are strewn on all the Maquoketa shale slopes between the Niagara escarpment and the top of the Galena, particularly on the upper part of the slopes. They occur in trains that lie parallel to the ridges and exhibit all stages of weathering and of progress down the slopes, clearly illustrating the great extent to which the dolomite is displaced by the disintegration of its insecure foundation. Bodies of dolomite 50 feet or more thick and half a mile long that cap ridges or mounds may even in certain places have caused the underlying relatively plastic beds of the Maquoketa to flow out under their great weight, allowing the dolomite to settle down evenly without apparent displacement, for the base of the dolomite appears to be generally lower in the mounds than along the escarpments. It may be, however, that the thinness of the beds of Maquoketa shale at such places is due to pre-Niagaran erosion or the shale may originally have been thinner at those places.

The scarcity of exposures of the actual Niagara-Maquoketa contact and the frequent displacement of the dolomite beds, together with the irregularities due to pre-Niagaran erosion, has made the determination of the true position of the base of the Maquoketa shale difficult, and has heretofore caused slight inaccuracies in mapping and in the determination of the thickness of the formation, too great a thickness having been assigned at some places and too little at others. Another source of error has been the assumption that certain springs that seem to emerge at the top of the shale mark its true top. It is true that the base of the Niagara is a water-bearing horizon, but many springs appear below that horizon, especially in the plateau country, where the formations occupy their normal relations.

Character.—The Niagara is mainly a light-gray to light-buff fine to medium grained dolomite. It comprises both thick and thin beds and at certain horizons includes considerable chert in the form of nodules and layers of approximately uniform thickness. (See Pls. V and VI.) The following analysis of the rock from Sherrill Mound, northwest of Dubuque, Iowa, represents fairly well its chemical composition:

Analysis of Niagara dolomite from Sherrill Mound, Iowa.

[By J. B. Weems, Iowa Geol. Survey Ann. Rept. for 1899, vol. 10, p. 567, 1900.]

Water (H_2O)	0.05
Insoluble	3.24
Calcium oxide (CaO)	30.01
Magnesium oxide (MgO)	18.99
Carbon dioxide (CO_2)	44.91
Ferric oxide (Fe_2O_3)	.74
Phosphorus pentoxide (P_2O_5)	.52
Organic	1.34
	99.80

The following generalized sections show the character of the formation in several districts:

Section of Niagara dolomite exposed near Galena.

	Feet.
Dolomite, light buff to dark gray but light gray on weathered surface, massive	60
Dolomite, thin bedded, light gray, containing considerable chert	25
Dolomite, light gray, massive where fresh but weathering to beds 3 or 4 inches thick; weathered surface carious	25
Dolomite, compact, thick bedded, fine grained, buff, earthy, with a 1-inch laminated layer resembling sandstone at base in a belt running from Winston to Council Hill; maximum thickness about	70
	180

Section of Niagara dolomite exposed in southwest corner of Galena quadrangle.

	Feet.
Dolomite, thick bedded, gray, contains *Pentamerus oblongus*, Favosites, Halysites, and other fossils	160
Dolomite, thin bedded, very cherty	10
Dolomite, hard, massive, grayish, in thick layers, in places cherty, contains a few fossils	30
Dolomite, earthy, with a few impressions of *Leptæna rhomboidalis* and perhaps other fossils	16
Dolomite, bluish, weathers shaly	9
Dolomite, earthy, bluish where fresh, weathering brown or buff and finally to a sandy clay, contains some chert and a few indistinct fossils	23
Dolomite, earthy, weathering into thin chips	5
Dolomite, laminated, yellowish, sandy	1+
	254+

The lowermost five members of this section are found only at some places.

Section of Niagara dolomite exposed about Oak Ridge School.

	Feet.
Dolomite, cherty, thin bedded; chert in definite uniform layers	50±
Dolomite, massive, gray, hard, crystalline (a few calcite crystals,) bluff making, nonfossiliferous	20+
Dolomite, thin bedded, without much chert, lies directly on Maquoketa; rock ranges from white and crystalline to soft, yellowish, and argillaceous; beds average about an inch in thickness; generally not distinctly fossiliferous but contains *Atrypa marginalis* and *Orthis elegantula*	70– 80
	140–150

Section of Niagara dolomite exposed about Hanover.

	Ft.	in.
Concealed	100	0
Dolomite, cherty, thin bedded; beds 6 inches to 1 foot thick; chert in layers and lenses 1 inch to 6 inches thick; one-fourth of material is chert	20	0
Dolomite, thin beds, weathering to several beds to the inch; yellow, soft, earthy, with shale partings	7	0
Dolomite, thin beds, hard, white, containing much chert in irregular nodules; nonfossiliferous	12	0
Dolomite, soft, yellowish, argillaceous, earthy with shaly partings and dendritic markings; no chert, and nonfossiliferous	16	0
Concealed	7	0
Dolomite, hard, yellow, thin bedded, nonfossiliferous	3	0
Dolomite, yellow, earthy, sandy		4
Dolomite, hard, blue, nonfossiliferous	1	3
	166	7

Section of Niagara dolomite exposed in northern part of Elizabeth quadrangle.

	Feet.
Dolomite, hard, massive, with much chert, contains a few specimens of *Pentamerus oblongus*, weathers to a red cherty clay	40
Dolomite, gray, massive to thin bedded, not very resistant, contains a few silicified fossils; considerable chert occurs in irregular masses	60
Dolomite, light gray, in uneven thin layers with many interbedded layers of chert	30
Dolomite, thick bedded, compact, resistant, with considerable chert	20
Dolomite, light gray to buff, hard, fine grained	10
Dolomite, massive, nonresistant, earthy, largely concealed	(?)
	160+

Section of Niagara dolomite exposed near Stockton.

	Feet.
Dolomite, thin beds, interbedded with ten layers of chert ranging in thickness from $1\frac{1}{2}$ to $2\frac{1}{2}$ inches	11
Dolomite, thin bedded	3
Dolomite, thick bedded	2
Concealed	5
Dolomite, noncherty thin beds	3
Dolomite, massive beds averaging 1 foot 4 inches in thickness	5
Dolomite, thin beds with a little chert in discontinuous layers	4
Dolomite, thin beds	5
Dolomite, thick bedded, grading laterally into thin beds in a few feet	10
Dolomite, hard, compact, thin beds	5
	53

Section of Niagara dolomite exposed in southeast corner of Elizabeth quadrangle.

	Feet.
Dolomite, thin bedded, interbedded with seven layers of chert that average 2 inches in thickness; dolomite layers also contain a few nodules of chert	10
Concealed	24
Dolomite, 11 feet of massive beds averaging 1 foot in thickness overlain by 4 feet of thin beds containing a small amount of chert; rock buff to white	15
Concealed	2
Dolomite, thin bedded, yellowish, soft, grading into whiter, more crystalline dolomite in lower part; a little chert occurs in nodules; contains *Orthis elegantula*	18
	69

In places where the Maquoketa shale is thin the lower part of the Niagara dolomite has a distinctive appearance, differing both from other parts of the Niagara and from the Maquoketa. It is fine grained, earthy looking, and ranges from white and crystalline to yellowish and argillaceous. It contains very few fossils, though two or three specimens each of *Atrypa marginalis*, *Orthis elegantula*, and *Calymene niagarensis* have been found in it, and it weathers readily to a smooth surface. At the base there is usually a thin layer that looks like laminated sandstone but that in reality is composed of dolomite containing some grains of calcite. The character of this layer therefore suggests that the hollows in the Maquoketa surface had been submerged and filled before any deposits were made on the thicker parts of the Maquoketa formation, and there is some indication that these thicker parts were subjected to erosion during a part of the time when the hollows were being filled. In fact, as stated below, these basal beds may represent sediments of Medina age.

The lowest continuous beds of Niagara dolomite—the more typical beds—tend to split along lamination planes into relatively thin slabs, such as may be seen on the sides of the mound at Mount Pleasant School, but the cohesion of the layers is generally so strong that the rock is not separated into slabs until thick masses of it that have deep reentrants along the bedding planes have been broken off, tilted, or greatly displaced by the undermining and weathering of the softer Maquoketa shale.

In its general features the Niagara resembles the Galena, but it may be distinguished from that formation not only by its stratigraphic position and its fossils but by the following criteria: (1) The lithologic character of the strata composing the Niagara is not so persistent nor so homogeneous as that of the strata forming the Galena, for beds of the Niagara that seem to lie at the same stratigraphic horizon differ more or less at different localities; (2) the color of the Niagara inclines a trifle more to a straw shade than that of the Galena, which is prevailingly gray; (3) The Niagara strata are more thinly laminated and their weathered surfaces are not in general so carious or pitted as those of the Galena; (4) the chert in the Niagara is more abundant, occurs in larger masses, and is more highly fossiliferous than that in the Galena; it is also harder, of a finer grain, and at most places is of a lighter color; (5) dark-red clay and abundant chert are the characteristic products of the disintegration of the Niagara, whereas the Galena weathers to yellowish clay and magnesian sand.

Topographic expression.—In connection with the softer underlying shale the resistant dolomite and chert beds of the Niagara give to the region its dominant topographic features—the mounds (see Pls. IV and V) and the Niagara cuesta or escarpment, described under the heading "Geography" (p. 2). In fact, the distribution of the formation is so directly related to the topography that its presence may usually be recognized in a very casual survey of the landscape. The Niagara forms fewer cliffs than the Galena, because it lies high in the section, but in the area here considered it forms many small but picturesque towers and buttresses, some of which reach a height of 80 feet. On the level surfaces of the plateaus sink holes are of common occurrence. They are found along crevices in the rock, apparently in line with ravines that have been formed farther out toward the edges of the plateaus.

Fossils and correlation.—Fossils are not abundant in the Niagara formation, but three compound corals—*Halysites catenulatus* Linnæus, *Favosites favosus* Goldfuss, and *Favosites niagarensis* Hall—occur in it rather commonly, as well as many casts of the brachiopod *Pentamerus oblongus* Sowerby. These casts are found in the chert masses, which lie at a horizon higher than that of the corals, but they are also found at some places in the dolomite. These fossils belong to the true Niagara fauna. The earthy dolomite that constitutes the lowermost part of the formation contains very few fossils, *Leptæna rhomboidalis, Atrypa marginalis, Orthis elegantula,* and *Calymene niagarensis* being found sparingly. According to E. O. Ulrich these fossils, especially *Atrypa marginalis,* indicate a late Medina fauna, and it is therefore probable that the Niagara as mapped in this area includes at its base here and there some rock of late Medina age.

Relations.—As stated before, there is apparently a great unconformity at the base of the formation, and the basal beds found in the depressions in the Maquoketa shale seem to be absent from districts where that formation is thicker. There is also a faunal change suggesting a hiatus that probably represents at least a part of Medina time.

QUATERNARY SYSTEM.

Surficial deposits of Quaternary age cover most of the bedrock of the area to a thickness that varies from place to place and that measures along the bottom of the valley of the Mississippi more than 150 feet. Besides the residual clay, which immediately underlies the surface of more than half the area, these deposits comprise glacial drift, loess, dune sand, and terrace deposits of Pleistocene age and travertine and alluvium of Recent age. As the quadrangles lie almost wholly in the Driftless Area, glacial drift covers only a few square miles. Most of the drift is probably of Illinoian age, but a very little material believed to be Kansan or older is found on the west side of the Mississippi and in at least one place on the east side. The loess, terrace deposits, and alluvium together occupy less than half the surface.

PLEISTOCENE SERIES.

PRE-ILLINOIAN DRIFT.

Scattered over most of that part of the Galena quadrangle that lies in Iowa are bowlders and pebbles of granite, quartz, greenstone, and other igneous and metamorphic rocks, which indicate that an ice sheet once covered a part of the area here considered. Several quartzite bowlders are strewn along a small northern tributary of Pleasant Creek, in sec. 6, Washington Township, and greenstone bowlders are numerous in several ravines just north of Bellevue. A cubic yard or more of drift covers a spot on a low and rather narrow divide in sec. 12, a mile northwest of Bellevue. These materials may have belonged to either the Kansan or an older sheet of till. Only the most resistant materials now remain and they are much weathered. An excellent exposure of this drift in a railroad cut 15 miles southwest of the Galena quadrangle is shown in Plate II. The section shown is as follows:

Section exposed in Chicago, Milwaukee & St. Paul Railway cut near Delmar Junction, about 15 miles southwest of Galena quadrangle.

[By W. C. Alden.]

		Feet.
Post-Illinoian, pre-Wisconsin:		
	a. Buff loess, leached 10 feet or more	5–15
Kansan:		
b.	Till, red-brown to rusty buff; leached 6 to 7 feet	15–18
	Till, dense, dark gray, calcareous; rusty along joints	6+
Aftonian:		
	c. Gravel and sand, cross-bedded, partly clean gray, partly orange to brown; cemented with lime at top	3–10
Pre Kansan:		
	d. Till, dense, slate-colored, jointed, calcareous; upper 1 foot lighter gray; much included wood	8–12
e.	Gray sand and glacial gravel in part of the section	3
	Silt, slate-colored, fine, laminated, calcareous, much disturbed at top by overriding of glacier, includes much wood	2+

The lettered units in the above section correspond with those on Plate II. The horizontal bench shown in the plate is due to railroad grading and is not structural. Some of the adjacent cuts show an old soil in place of the Aftonian gravel, and at one point an old tree stump is still rooted in this soil.

In a ravine 1½ miles west-northwest of Hanover there are small masses of an apparently old drift.

HIGH TERRACE (?) DEPOSITS.

At several places on the bluffs along the valley of the Mississippi there are deposits of more or less washed and generally deeply iron-stained quartz gravel, consisting mostly of pebbles ranging in diameter from a quarter of an inch to an inch and lying at altitudes of 700 to 735 feet. They are of indefinite outline and have therefore not been mapped. The principal deposits are in secs. 11 and 14 of Tete de Mort Township, Iowa, 5 miles south of Galena. Some gravel on the east side of the river near Blanding and some about 4 miles southeast of Blanding lies at about the same altitude. The gravel is nowhere well exposed and is not sufficiently extensive to permit its definite interpretation, but its topographic position and degree of weathering suggests that it is a terrace deposit laid down at some time between the Kansan and Illinoian ice invasions. It may be equivalent to the gravel called by the Iowa geologists the Buchanan gravel.

ILLINOIAN (?) DRIFT.

In the eastern part of the Elizabeth quadrangle there is an area of unassorted material, of various thicknesses, deposited directly by glacial ice. The boundary of the drift-covered area enters the east side of the quadrangle 4 miles north of Stockton and runs thence irregularly southward to the ridge 1½ miles north of Stockton, where it bends southeastward and leaves the quadrangle half a mile southeast of the town. A few scattered bowlders and small bodies of drift lie outside the boundary, especially along stream courses that lead away from it. A body of till made up of unassorted material, including bowlders of shale, occupies a small area in sec. 34, T. 27 N., R. 4 E. Such bodies of drift, together with the scattered bowlders, indicate that, in some places at least, the ice extended a few miles beyond the boundary indicated.

Most of the drift in this area in the eastern part of the Elizabeth quadrangle consists of unassorted clay, sand, and rounded subangular or angular fragments of many kinds of rock, representing the various formations over which the ice passed before it reached the area. This drift contains abundant and generally well-rounded pebbles of quartz as well as bowlders of granite, diabase, greenstone, quartzite, sandstone, and chert. Most of these bowlders are subangular, some are waterworn, and a few are striated; all show deeply the effects of weathering since the ice disappeared, and only a few consist of rock that is easily disintegrated or dissolved.

In an old valley about 3½ miles north of Stockton the drift is 90 feet thick, completely filling the valley. Elsewhere in the Elizabeth quadrangle its thickness averages about 50 feet. There is no well-defined terminal moraine, but the drift thickens gradually toward the east and reaches its maximum thickness some distance east of the quadrangle.

The stones in the drift are so different from any that are found in place in the quadrangles that they can readily be distinguished from local material. A few have been carried out from the drift border by streams, but no extensive outwash deposits seem to have been made. Many foreign bowlders are found along Plum River but only a few along Apple River.

The evidence as to the age of this drift, though perhaps not regarded by all geologists as conclusive, seems strongly to favor its classification as Illinoian.

LOESS.

The uppermost unconsolidated material in a considerable part of the area is loess, a porous silt or very fine sand of light-buff color, which in places is claylike and difficult to distinguish from the residual clay. The loess in these quadrangles appears to be of eolian origin and seems to have been deposited as a thin layer over most of the area and subsequently to have been removed from places where erosion was most severe. At present it mantles the general surface, covering the broad upland areas and extending down the slopes. Thus it was probably deposited at a time when the topographic features of the district had reached nearly their present form, and it is regarded as of the same age as the loess mantle in Iowa, most of which is post-Illinoian and pre-Wisconsin in age, though a part of the loess here may be of other ages, a possibility suggested by the facts that the basal part of the deposit is here and there bluish or purplish and that at many places an indistinct boundary or parting lies a short distance below the top of the loess, suggesting that the uppermost part is of Wisconsin age.

The loess is exposed along roads and in many artificial excavations in the quadrangles. At some places it is rather sharply divided from the residual clay below; at others the plane of separation is indistinct. In general the residual clay is more compact and claylike and is locally reddish and contains angular fragments of chert. In thickness the loess ranges from 60 feet along the Mississippi bluffs to a few inches at points 30 or 40 miles from the river. On some of the uplands between Elizabeth and Stockton its thickness reaches 15 feet. In general the proportion of fine clayey material it contains increases with increasing distance from the river.

DUNE SAND.

In places along the Mississippi bluffs medium coarse sand that is heaped into dunes seems to be related to the uppermost part of the loess. Such dunes are common along both the bases and the tops of the bluffs in the southern part of the Galena quadrangle. Mixed sand and dust forms rather large hills just north of Blanding. A thick deposit of somewhat loesslike but rather sandy material whose bedding planes are nearly parallel to the slope of a hillside lies at the west end of the tunnel on the Chicago Great Western Railroad. It appears to be a valley-side wind deposit but may be a stream deposit laid down in slack water at the lower end of a tributary valley at the time that certain gravel deposits were being laid down at about the same altitude on the west side of the river.

LOW-TERRACE DEPOSITS.

The principal terraces of the area are of late Pleistocene age and are confined to the Mississippi gorge and the lower parts of the valleys of tributary streams. Many of them are only fragments of terraces, their missing parts having been cut away completely by recent erosion. The terraces in the valleys of tributary streams are horizontal and as a rule stand about 60 feet above the Mississippi flood plain, their height above the tributaries thus steadily decreasing upstream. The terrace along the Mississippi is built of stratified sand and some gravel, both of glacial origin and both probably deposited before Lake Agassiz was formed. The material has been traced up the river and some of its branches to the Wisconsin drift sheet in eastern Minnesota and northern and central Wisconsin and is regarded as of about the same age as that drift.

The material along the tributary streams consists of closely laminated purplish fine silt or clay, or, at some places, of sand, all of local derivation, and contains irregular concretionary masses of calcium carbonate. It seems to have been deposited as a result of the filling of the valley of the Mississippi. There is some reason for believing that the river is now filling its valley instead of cutting down. In Recent or possibly in late Pleistocene time erosion has removed much of this material, but remnants of it are well preserved along the sides of the valley at some places, as near Hanover and near Galena, as well as on Sinsinawa River, where the deposit is predominantly sandy and is irregularly cross-bedded in a way to show that it was deposited in a braided or anastomosing stream. (See Pl. X.)

The fossils listed below were collected about 2 miles from the mouth of Sinsinawa River:

Fossils collected in terrace deposit in the valley of Sinsinawa River, 2½ miles west of Galena.

1. Pyramidula cronkhitei Newc. var. shimeki Pils.
2. Vallonia costata Say.
3. Pupilla muscorum L.
4. Pupilla decora Gld.
5. Bifidaria cf. B. corticaria Say.
6. Sphyradium edentulum Drap. cf. var. alticola Mg.
7. Euconulus fulvus A.
8. Succinea campestris Say.
9. Succinea avara Say.
10. Lymnæa parva Lea.

All these species except the tenth are land animals and all but the first, fourth, and eighth live in the region to-day. Perhaps all may be found, though these three species have not yet been observed and reported. W. H. Dall, who identified the fossils, says that most of the individuals are immature.

Another lot of fossils, collected in a dark silty low-terrace clay near Bellevue, Iowa, contains the following species:

Fossils collected 2 miles west of Bellevue.

Goniobasis virginica Gmelin.	Planorbis bicarinatus Say.
Campeloma decisa Say.	Physa heterostropha Say.
Planorbis trivolvis Say.	Sphærium striatinum Lamarck.

RECENT SERIES.

RESIDUAL CLAY.

A residual clay overlies the bedrock throughout a large part of the area—perhaps more than half of it. It is generally of a light-buff color, but where it is overlain by drift or loess it is commonly dark reddish buff. It is formed by the decomposition in place of the underlying rocks, chiefly the Galena and Niagara formations, which have a greater lateral extent beneath the surficial deposits than any others in the area. Those two formations consist chiefly of dolomite—the double carbonate of magnesium and calcium—with which are mingled certain other substances, chiefly calcite, flint, iron oxide (and perhaps iron carbonate), and clay. The carbonates are dissolved and carried away by water, but most of the oxides and silicates remain. The mineral and chemical composition of the residual clay thus differs materially from that of the rock. The residual clay contains much silica, which was derived not only from the chert in the dolomite but also from the clay it contains.

The Galena dolomite contains nearly 96 per cent of soluble matter (calcium and magnesium carbonates), practically all of which is carried away by weathering, and only 4 per cent of other substances, most of which remain in the clay after the carbonates have been removed. The samples analyzed contained no nodules of chert, which are abundant in some parts of the dolomite, and no noticeable clayey laminæ, so the average rock of the formation probably contains much more silica and alumina than the analysis indicates.

An extended study of the residual clay of the Driftless Area was made by Chamberlin and Salisbury,[1] who found that the average thickness of the clay, as determined by 1,800 measurements, is 7.08 feet. It is thicker on the hilltops and in the valley bottoms and thinner on the slopes, and it is entirely absent from some places, such as the bare rocky ledges along the sides of some of the valleys. Its maximum thickness appeared to be about 70 feet. About 1,000 measurements on broad uplands gave an average thickness of 13.55 feet.

If the chemical composition of the original rock is compared with that of the residual clay and the thickness of the clay is considered it is readily seen that the amount of clay at any locality represents a great thickness of rock—just how great it is impossible to say without analyses, but the data at hand afford ground for a general estimate. The calcium and magnesium carbonates have practically disappeared from the clay, yet they made up probably 90 per cent of the original rock, and from some residual clays that have been carefully studied more than 97 per cent of the original limestone has been removed by solution. In other words, a present thickness of 3 feet of residual clay represents an original thickness of at least 100 feet of rock. As the numerous measurements already presented show that the clay has an average thickness of 13½ feet on the broad uplands, it is clear that a vertical thickness of at least 100 feet of rock has slowly disappeared from the area by weathering. It should also be borne in mind that the residual clay still remaining is likely to be but a fraction of the amount formed in the course of the long period of weathering, for ordinarily erosion nearly keeps pace with weathering on an area of uneven surface like that of these quadrangles.

TRAVERTINE.

Masses of calcareous tufa or travertine (so-called "Mexican onyx") are found at several places in the quadrangles, the largest lying 1½ miles northwest of the tunnel on the Chicago Great Western Railroad in sec. 10, T. 27 N., R. 1 E. The rock is grayish or buff, finely crystalline, and generally compact and clearly laminated. It was derived by solution from some layer or layers of limestone, the solvent being water containing carbon dioxide. It was deposited under conditions that permitted the liberation of the carbon dioxide. The presence of fresh-water algæ has been suggested as one such condition, and increasing temperature and evaporation of the water may have been another. The water of many of the springs of the district is very cold.

ALLUVIUM.

Along the permanent streams, and even along many of the intermittent streams, there are well-developed flood plains. The alluvium consists of fine clay, gravel, and, in places, of coarse fragments of rock. Some of it lies above the reach of high water and was evidently deposited before the streams reached their present levels. Such deposits do not constitute well-marked terraces, though at some places they have terrace-like forms. In general the alluvium becomes progressively finer from base to top, though there is a fairly sharp change about two-thirds of the way up.

STRUCTURE.

The strata in northwestern Illinois lie nearly level but slope gently southward at the rate of about 20 feet to the mile. Their slope is not regular but is interrupted here and there by domes, basins, anticlines, synclines, and minor irregularities.

[1] Chamberlin, T. C., and Salisbury, R. D., Preliminary paper on the Driftless Area: U. S. Geol. Survey Sixth Ann. Rept., pp. 199-322, 1885.

REPRESENTATION OF STRUCTURE.

METHODS.

Structure is commonly represented in two ways, by cross-sections and by contour lines. Cross sections are well adapted to show the structure of a region in which the rocks are sharply folded and faulted, not that of one in which the folds are low and there is little or no faulting, for the structure of such a region can be shown more clearly by contour lines.

STRUCTURE CONTOURS.

Delineation.—To delineate structure by contour lines a reference stratum is chosen which has extensive outcrops and is easily recognized. The altitude and dip of its surface are determined at as many points as possible, and points of equal altitude are connected by lines drawn on the map in the same manner that topographic contour lines are drawn.

In the Galena and Elizabeth quadrangles the reference surface shown by the contours on the structure-section sheet is the top of the Galena dolomite and the contour interval is 25 feet. At many places the altitude of this surface was determined directly from outcrops, wells, or mines by hand-level traverse carried from near-by bench marks; at other places it was calculated from observations of some other recognizable stratum, for the layers of rock in this region are approximately parallel and the average interval between any two may be easily determined. Thus where a bed known to lie a certain distance above the reference surface was found the altitude of the reference surface at that point was calculated by subtracting from the altitude of the higher bed the average distance or the nearest measured distance between the two beds. Where a recognizable bed known to lie a certain distance below the reference surface was found, the average distance between the two beds was added to get the approximate altitude at which the reference surface would lie if it were present at that locality. A point of intersection of a surface contour with a structure contour of the same altitude marks an outcrop of the top of the Galena dolomite.

Use of structure contours.—The structure map is of use not only for the study of broad structural problems and for conveying a general knowledge of the structure of the region, but is of service in locating and recognizing valuable beds and in giving data concerning the lay of those beds. In the Galena and Elizabeth quadrangles the beds lie nearly parallel and the average distance between them, as well as many local variations, was determined by geologic field work. Information concerning the spacing of the beds is given in the section on stratig-

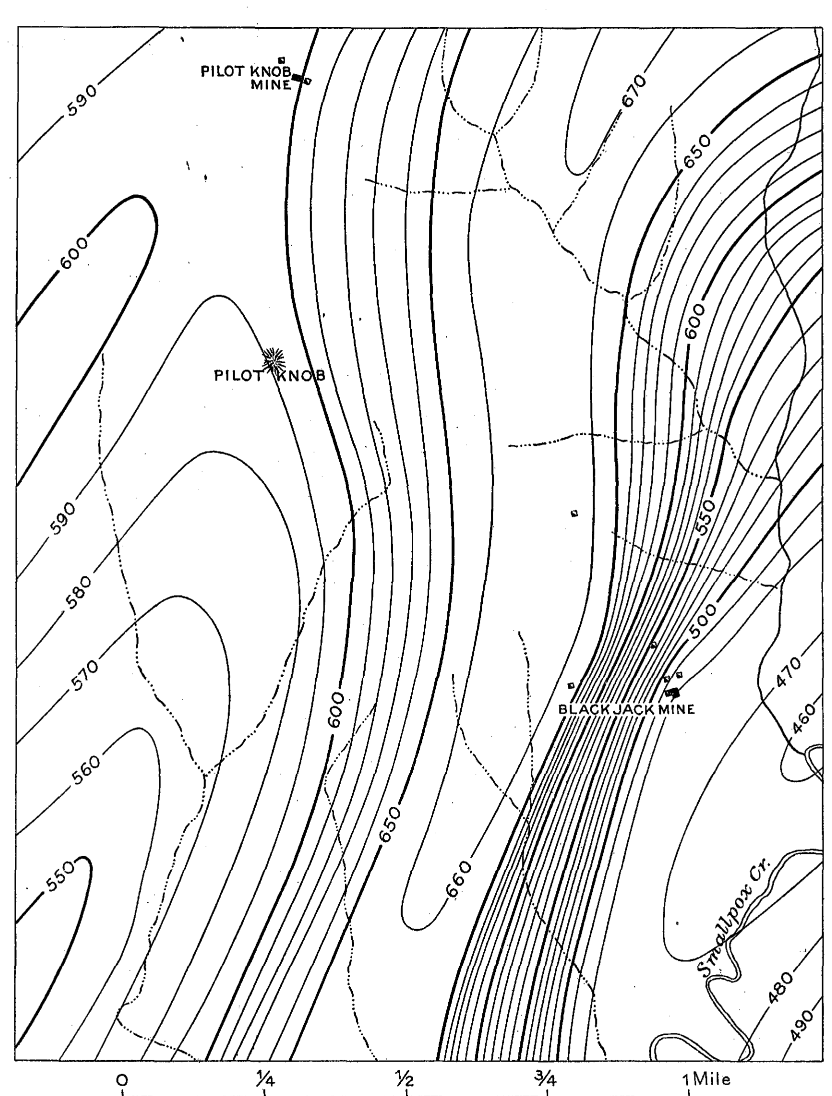


FIGURE 5.—Structural map of area around Pilot Knob, Ill., showing by contour lines the structure of the base of the Galena dolomite. (From Illinois Geol. Survey Bull. 21.)

Contour lines show elevation of the base of the Galena dolomite in feet above sea level.

raphy. The facts presented make it easy to calculate from the altitude of the reference surface or key rock, shown on the map, the approximate position of any bed at any point by adding or subtracting, according as the bed is above or below the key rock, the average distance between the two, allowance being made for local variations, as indicated in the text. The map may be used in this way for locating ore-bearing beds and other layers of economic value.

The structure map also shows the direction and amount of the dip of the beds, a knowledge of which is essential in all mining operations.

Reliability.—The reliability of the structure contours depends on three factors: (1) the accuracy of the altitudes obtained directly; (2) the difference between the actual and the assumed interval to the key rock; (3) the number and distribution of the observations. In the Galena and Elizabeth quadrangles the altitudes of many outcrops were obtained by hand level. Bench marks are numerous throughout most of the area and the determinations therefore involved only short horizontal distances and small possible errors.

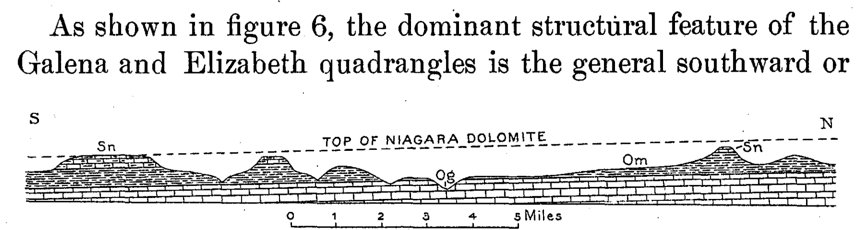
The second factor is more likely to lead to mistake, because the strata are not quite parallel. The most striking lack of parallelism is seen in the irregularity in the interval between the top of the Galena dolomite and the base of the Niagara dolomite. The intervals between most of the other strata in this area do not differ more than 20 feet. Another deviation from regularity is seen in an apparently abrupt thickening of the Galena dolomite in the vicinity of Pilot Knob, south of Galena. A comparison of the structure contours in figure 5 with those on the areal-geology map will make the abruptness of this thickening evident.

Inaccuracies classifiable under the third factor are thought to be small, for throughout both quadrangles the determined altitudes of recognizable strata, nearly half of which are of the reference surface itself, are numerous and comparatively evenly distributed. Allowing for all possibilities of error, it may be assumed that the structure lines are for the most part correct within a contour interval of 10 feet, though in some places the error may be considerably greater.

STRUCTURE OF THE GALENA AND ELIZABETH QUADRANGLE

FOLDS.

As shown in figure 6, the dominant structural feature of the Galena and Elizabeth quadrangles is the general southward or



Vertical scale 20 times horizontal.

FIGURE 6.—Ideal structure section from south to north across the Elizabeth quadrangle, showing the general southward dip of the rocks.

The Niagara dolomite, now remaining only on the hilltops, was formerly continuous across the area, as indicated by the line showing the former position of the top of the formation. Sn, Niagara dolomite; Om, Maquoketa shale; Og, Galena dolomite.

south-southwestward dip of the beds, but, as before noted, this dip is interrupted by many minor irregularities and is really broken into a complex system of slight folds, some of which are important because of their relation to mineral deposits. Many of the folds are, however, not large enough to be shown except on large-scale structure maps with small contour intervals, and generally the possibilities of error are too great to permit such maps to be made except for areas where there has been considerable underground exploration.

Along the west side of the area the dip is, on the whole, to the southwest, though it ranges from south at a point west of Galena to west about 6 miles southwest of that town. Immediately west of Galena there is a broad but short shallow syncline, and immediately east of it there is a rather high but irregular anticline, which extends from near Millbrig southeastward to the Republic lead mill, beyond which it is low and indistinct for 2 or 3 miles but seems to swing to the south. From Horseshoe Mound to Pilot Knob it is high and prominent, and beyond Pilot Knob it swings to the southwest and becomes broader. It affects the strata as far as the southwest corner of the area.

Just east of this anticline is a shallow syncline, which extends from Independence School southward to a point where the Mississippi leaves the area. In the area farther east the structure is irregular, but at Hanover there is a fairly well developed syncline flanked on the east and west by low anticlines. At Elizabeth there is a syncline of medium size, which extends northeastward to Warren. On the east of this syncline there is an anticline, which is most pronounced in the northern half of the area. Other irregularities, most of them consisting of variations in direction and amount of dip, occur throughout the area. The strata are nowhere sharply bent, and their slight waviness may be due largely to irregularity in the sea floor upon which the beds were deposited.

Many of the lead and zinc deposits of these quadrangles lie in small basins or synclines. Such basins may have originated in at least four different ways: (1) They may be due to original inequalities that existed on the sea bottom when the sediments were deposited, for such inequalities were present at the beginning of Galena time, as has been noted in the description of the basal layers of the Galena dolomite; (2) they may be due to irregularities of deposition, a lack of sediment in some areas causing slight local depressions, although in this district such a cause is not probable, for the areas that exhibit lack of sediments are really anticlinal; (3) vertical compression and consequent slumping of the beds may have produced such basins, and as they occur in areas containing thick deposits of oil rock—a carbonaceous deposit which, in the manner of coal beds, has undoubtedly decreased much in thickness—this means of producing such basins has certainly been important;

(4) actual mechanical depression of the rocks by lateral pressure may have and undoubtedly has taken place, especially in some of the more marked and steeper folds.

It is probable that no one of these causes alone has produced all the basins, but that two or more have worked together, for while the lower beds of the Galena were being deposited small basins were already in existence, and in them the thicker deposits of oil rock were made. The shape of the basins themselves and the later compression and shrinking of the oil rock would produce initial dips, which would very likely be steepened by any lateral compression to which the beds were subjected.

JOINTS.

All the hard-rock formations in the district except the Maquoketa shale show distinct systems of joints, which are especially well developed in the massive beds of the Galena dolomite and have played an important part in the deposition of the ores. The principal joints are practically vertical but trend in several directions. Among the miners those trending nearly north and south are spoken of as "north and south," those trending northwest-southeast are called "ten o'clocks," and those trending northeast-southwest are called "two o'clocks."

At many places there are other joints, most of them having the same trend as those that are vertical, with hades ranging from 30° to 70°. They occur in the minor synclines in which the mines are located and dip outward from the axes of the basins. They are especially important in some of the mines, for they contain the ore deposits known as "pitches." They are thought to be due either to the slumping or settling of the beds on account of the shrinkage of the underlying oil rock or to actual lateral compression. At some places both causes may have acted together to produce them. Most of them occur in the lower 50 feet of the Galena dolomite.

Recent careful field work has failed to discover clear evidence of notable faulting, so it is believed that the area is practically without faults.

GEOLOGIC HISTORY.

PRE-CAMBRIAN TIME.

The geologic history of the Galena and Elizabeth quadrangles during pre-Cambrian time is not known but was presumably much like that of central and northern Wisconsin, where pre-Cambrian rocks are exposed and whose pre-Cambrian history in its general features is known. Great lava streams were poured out; thick series of strata, now metamorphosed and deformed, were laid down; and internal earth movements, causing local uplift and consequent surface erosion, at times interrupted sedimentation, as is shown by profound unconformities between the successive series.

PALEOZOIC ERA.

CAMBRIAN PERIOD.

Throughout early and middle Cambrian time the region seems to have been above sea level and to have been subjected to erosion. About the end of middle Cambrian time the sea spread over the region, probably advancing from the south, and on its bottom was deposited a considerable thickness of alternating beds of sand and mud, now constituting the Cambrian formations, which are widely exposed in Wisconsin, Iowa, and Minnesota. Deposition seems to have been interrupted several times. Near the close of the Cambrian period some calcareous mud, now the St. Lawrence formation, was deposited, and afterward more sand, now the Jordan sandstone.

ORDOVICIAN PERIOD.

Prairie du Chien epoch.—Upon the Jordan sandstone a considerable thickness of calcareous mud, now forming the Oneota dolomite, was deposited, in a body of quieter and possibly deeper water, which was part of a great inland sea that covered the Mississippi basin and much of the Appalachian province. The extent of this sea is shown by the wide distribution of the remains of the peculiar fauna of the time.

Oneota deposition was succeeded by sea invasions or by other changing conditions, indicated by the irregular alternation of sandstone and magnesian limestone that constitute the Shakopee dolomite. The arenaceous beds of this formation may be in part reworked and redeposited Cambrian sandstone. This period of deposition was followed by a period of uplift, during which the surface was gently warped and unevenly eroded.

St. Peter epoch.—The period of uplift and erosion last mentioned was succeeded by a period of depression when the water was shallow and when a thin layer of sand, now the St. Peter sandstone, was deposited over a large part of the Mississippi basin. Much of this material was doubtless a product of the disintegration of older sandstones. The St. Peter sand seems to have been deposited by a northward transgressing sea. The thorough rounding of the sand grains and the development of frosted surfaces on them suggest that they were wind worn. As the sea advanced northward the former shore line, at least in Missouri and west-central Illinois, was covered by calcareous mud, now the Joachim limestone, which becomes thicker toward the south.

Platteville and Decorah epochs.—In Decorah time the water was muddy and deposited some clayey material, but it soon became clearer and deposited relatively pure calcareous sediment, now represented in the area by the Platteville limestone, which contains abundant remains of marine animals, to which it owes much of its calcareous composition. While the middle part of the Platteville was being deposited the epicontinental sea laid down a uniformly fine grained sheet of limestone over a large part of the United States east of the one-hundredth meridian. This sea was limited on the east by the Appalachian highlands but spread northward into Ontario.

After this widespread deposition of limestone a gradual shoaling, marked by alternate thin beds of limestone and shale, occurred in the Galena and Elizabeth area, a part of which at least appears to have been above sea level for a time. In northern Iowa, Minnesota, and western Wisconsin, however, considerable beds of mud, now forming the Decorah shale, were laid down at this time.

Galena epoch.—The Galena epoch began with general submergence and deposition. The oldest stratum referred to the Galena formation in the quadrangles is the "oil rock," which consists in part of clayey material but contains a large amount of carbonaceous matter. This rock is believed to be composed largely of the remains of floating plants, which accumulated in great quantities on the bottoms of shallow basins early in the epoch.

In the early part of the Galena epoch the surface in this region probably oscillated considerably, being at one time above sea level and at another time below, but later the water became somewhat deeper and the conditions more stable, favoring the formation of limestone. The water was no doubt clear and may have been rather deep. Deposition seems to have gone on continuously until enough material to form 150 feet of dolomite had accumulated. Near the end of the epoch another change, which may have included emergence, seems to have checked deposition, but afterward more calcareous material was laid down. The uppermost part of the formation is irregular in thickness, but how much of the irregularity is due to inequalities in deposition and how much to erosion is not known. The whole formation, 235 feet or more thick, includes only a few beds of shale, which represent a little clay that was carried into the sea and deposited with the calcareous material.

Maquoketa epoch.—After the uppermost beds of the Galena had been deposited the surface in this region seems to have emerged once more, at least for a time, after which it again sank beneath the sea and upon it there was laid down the deposits of mud and clay that now form the Maquoketa shale. The deposition of this formation seems to have continued without interruption, though changes in conditions from time to time permitted the accumulation of material that formed shale, dolomite, or limestone, the character of the rock formed depending, of course, upon that of the material deposited. Some of these beds contain few well-preserved fossils but others contain great numbers. During the Maquoketa epoch the sea seems to have been shallow and vast quantities of clay were brought into it from land that lay north of this region. At the close of the epoch the surface seems again to have emerged and been subjected to erosion. In at least some places the Maquoketa formation appears to have been cut into by streams to a depth of 100 feet.

SILURIAN PERIOD.

Niagara epoch.—The Niagara epoch began with a southward advance of the sea, which occupied first the hollows in the surface of the Maquoketa formation—the places which presumably had been most deeply eroded. These hollows probably formed small embayments of the shore line, and deposition seems to have begun in them while erosion continued on the unsubmerged parts of the surface. The first materials laid down in the hollows consisted of grains of dolomite, probably derived from the reworking of dolomitic material in the Maquoketa, which, like that of the other formations, weathers characteristically to dolomitic sand. Upon this was laid down a deposit of dolomitic or calcareous material mixed with considerable clay, which to-day forms an earthy, fine-grained dolomite that, with the overlying deposit, fills the hollows in the old Maquoketa surface.

At that time the species of brachiopod known as *Atrypa marginalis* was living in the region, although it appears not to have lived there at any earlier or later time. This species is regarded as characteristic of the late Medina in America, and as it is found in these quadrangles only in material deposited in the hollows of the Maquoketa surface some part of the beds here assigned to the Niagara may have been formed in late Medina time.

No evidence has been found that the region emerged from the sea before the higher and more continuous beds of the Niagara were laid down, but a break in sedimentation is suggested by the absence of beds representing the Clinton epoch of New York. After this probable break the conditions were again favorable to the deposition of calcareous material which either was magnesian at the time it was deposited or became so later and which accumulated until it reached a thickness of 200 feet or more.

LATER PALEOZOIC TIME.

The history of the sedimentation and erosion in the district from late Silurian time until the Cenozoic era is almost unknown. There is nothing to show how long the Paleozoic sea existed in the region after the Niagara dolomite had been deposited. Devonian sediments may have been laid down and eroded, but during the Devonian period the region was probably land that lay near sea level and that was undergoing erosion.

So far as known, no record of Carboniferous time remains in the district, but Carboniferous strata were deposited less than 20 miles away, both on the south and on the west, and, in view of the amount of erosion to which the region has been subjected, it seems quite possible and rather probable that deposits were formed in the district in Carboniferous time and were afterward eroded away. The nearest Carboniferous strata consist of shale and sandstone and thin beds of coal, all presumably laid down in extensive marshes that lay not far from sea level.

MESOZOIC ERA.

No record of Triassic or Jurassic time is preserved in the quadrangles or in any area that is near enough to afford information as to the events of those periods. The district probably lay a little above sea level and the surrounding region was probably nowhere high, so that there was neither extensive erosion nor extensive deposition.

During the Cretaceous period the sea advanced from the west and in it sediments that now form sandstone, shale, and limestone were deposited in western Iowa and Minnesota, but there is no evidence that the Cretaceous sea covered northern Illinois. So far as can be made out, no Cretaceous events are recorded in this area either in deposits or in surface features. All land forms developed during the period seem to have been destroyed by erosion. The general fine grain of the Cretaceous rocks to the west and south indicates that the region lay at a low altitude and was nearly level.

CENOZOIC ERA.

TERTIARY PERIOD.

The record of the Tertiary period is almost as scanty as that of late Paleozoic and Mesozoic time, but it appears to show that near the beginning of the period the region was uplifted and tilted southward. In the following cycle of erosion much material was removed from the area and a new surface, approximately a plain—a peneplain—was formed. Remnants of this plain are believed to be still present in the area, for the tops of many of the highest hills stand at concordant altitudes and the better preserved of these hills are flat-topped and bear about 200 feet of the Niagara dolomite. The remnants of this old surface seem to increase in altitude from heights of 900 to 1,000 feet above sea level in the southern part of the area to a height of 1,200 feet in the northern part. In southern Wisconsin isolated hills reaching heights of 1,700 feet are capped with the same rocks that cap the highest hills 30 miles to the south, whose tops are 500 feet lower. It also cuts across formations. For example, it has been traced across all formations from the Niagara dolomite to the Platteville limestone between Dubuque and Church, Iowa. It is believed to be the same plain as that which bears high-level gravels at Waukon, Iowa, and Devils Lake, Wis. The age of the plain indicated by these hilltops is not known and can be estimated only by comparing the area, as regards its features and the amount of erosion, with districts whose history is similar and with districts in which the amount of post-Tertiary erosion is known. Estimates so made, though uncertain, indicate that the plain marked by the tops of the hills capped with Niagara dolomite were in existence in Tertiary time, though perhaps its dissection began as early as the middle of the period. This plain, whose formation no doubt occupied a long time, was probably not the product of long erosion and was probably not constructional, yet it is inconceivable that during Mesozoic and early Tertiary time there was practically no erosion and no deposition. If it were a plain of deposition it must represent the surface of deposits laid down in middle Paleozoic time—in other words, an uplifted and dissected coastal plain of pre-Devonian age—which remained almost unmodified until late Cretaceous time, and this is extremely improbable.

A later and lower plain covers much of the northern part of the area and also much territory in southern Wisconsin. This surface may date from late Tertiary time, when a similar peneplain was being formed in other parts of the Mississippi basin. It could not be called smooth, and it was probably so rough that it could barely be called a plain, for it was broken in places by remnants of the older plain, or monadnocks, which, though now somewhat reduced in size, still stand as the hills—commonly called mounds—capped by the Niagara dolomite.

However, the surface was so nearly a plain that even after later uplift and erosion it is still recognizable.

Probably near the end of the Tertiary period the region was again uplifted to form a new plain in which narrow valleys several hundred feet deep were cut. The rock bottom of the Mississippi gorge is about 500 feet below the near-by upland, and some geologists believe that it was cut to that depth before the end of the Tertiary period, for certain material from the bottom of it seems to them to be of earliest Quaternary age, and the bottoms of the valleys of tributaries of the Mississippi are somewhat concordant in position with the bottom of the gorge. Others, including the writers, suspect that in late Tertiary time a divide, from which small streams flowed northward and southward, lay just north of the area, and that the deep, partly filled Mississippi gorge and other deep, narrow valleys in the region were formed largely in the earliest part of Quaternary time. That the plain into which the valleys are cut was in existence in early Pleistocene time is indicated by the fact that in Iowa it bears a cover of till which may be Nebraskan.

QUATERNARY PERIOD.

PLEISTOCENE EPOCH.

The events of the Pleistocene epoch, which profoundly and widely affected much of North America, affected only indirectly most of the Galena and Elizabeth quadrangles, where the Pleistocene record is short and incomplete. Of pre-Illinoian time the only record is found in the remnants of till in the southwest corner of the area and in part of the residual clay. Both the pre-Kansan or Nebraskan and the Kansan ice sheet approached at least within 15 miles of the area. Possibly the thin edges of both sheets covered the part of the district that lies in Iowa, and one of these glaciers seems to have crossed the river and advanced to the vicinity of Hanover.

A long interglacial stage (the Yarmouth) succeeded the Kansan stage and was followed by the Illinoian ice invasion. The earlier ice sheets had approached the area from the west or northwest, but the Illinoian ice advanced from the east, though its general movement was southward. It covered several square miles along the eastern side of the area and brought

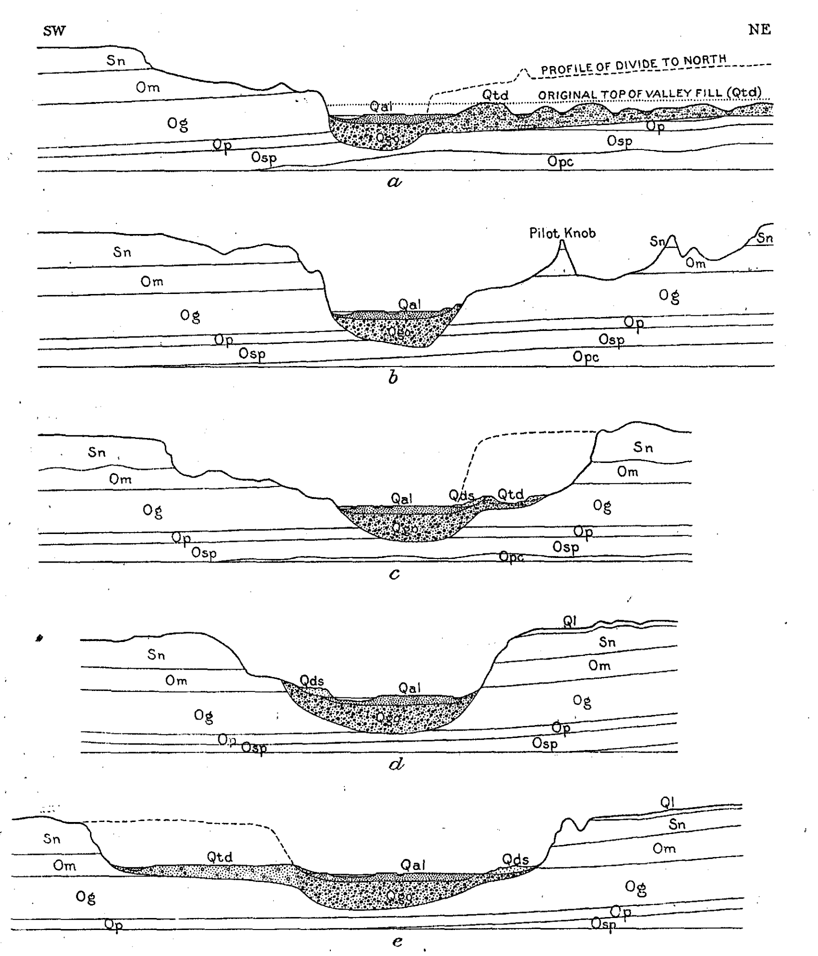


Figure 7.—Cross sections of the Mississippi gorge, showing profiles of the old valley cut in the hard rocks, the valley fill, and the bordering terraces.

Section *a*. at mouth of Galena River; *b*. opposite Pilot Knob; *c*, at Yeager Creek; *d*, below Spruce Creek; *e*, at Bellevue.

Qal, alluvium; Qds, dune sand; Qtd, local stream terrace deposit and valley fill; Qgo, glacial outwash deposits; Ql, thick loess; Sn, Niagara dolomite; Om, Maquoketa shale; Og, Galena dolomite; Op, Platteville limestone and Decorah shale; Osp, St. Peter sandstone; Opc, Prairie du Chien group.

Horizontal scale: 1 inch = about 2 miles; vertical scale, 10 times horizontal.

large quantities of stones, more or less finely ground, and clay. Northeast of Stockton the ice and its deposits filled the valley of a stream which may originally have drained southeastward into Stephenson County along the course of Yellow Creek. The headwaters of the stream were here dammed and held until the lake formed by the dam rose high enough to overflow a low place in a divide south of Millville, which separated the valley of the stream from what was then the head of Apple River valley. The water flowing across the divide gradually carved a trench, and the drainage basin of Apple River was thus extensively and permanently enlarged. This trench, which connects the old Apple River valley with the new valleys in the vicinity of Apple River and Warren, is one of the most striking topographic features in the area. (See Pl. XI.) The Pecatonica Valley, northeast of these quadrangles, was also dammed, and probably its water overflowed into Apple River, but no traces of its channel have been found in the area under discussion. Indeed, there is surprisingly little foreign gravel along Apple River.

After the Illinoian ice sheet had disappeared there was another time of genial climate, during which the loess was deposited. The origin of the loess has been much discussed and the consensus of opinion now seems to be that most of the material which has received that name was deposited by wind, although possibly a small part was deposited by water. Perhaps it would be well to restrict the use of the name loess to the wind-deposited part of the material. The fossils which it contains are the shells of air-breathing gastropods such as now inhabit forests in climates not very different from that of the region to-day.

The Wisconsin ice sheet occupied the valley of the Mississippi no farther south than a short distance below St. Paul, but while the ice margin lay there the valley was probably flooded and the water was loaded with detritus. The valley was filled to a depth of 125 feet or more, possibly by this material alone, but possibly in part by material brought in after the ice melted, by streams which cut new valleys in the drift. The arrangement of the drainage systems during Wisconsin time seems to have been essentially the same as now. Flooding and filling of the Mississippi channel caused back water in the tributaries—to a greater degree, of course, than at present—and their lower courses were accordingly filled with closely laminated fine silt or clay of local derivation. Figure 7 shows the amount of valley filling and the form of the glacial gorge.

RECENT EPOCH.

The recorded events of the Recent epoch consist of the further development of the mantle of partly decayed rock that covers the surface, the deposition of the travertine and of the alluvium in the stream bottoms, and the clearing out by the Mississippi as well as by its tributaries, at their lower ends, of part of the deposits formed in the Pleistocene time. In their middle and upper parts most of the tributaries are now, as heretofore, working away on hard rock, undisturbed by the far-reaching events that have affected their lower courses and the master stream.

Most of the streams, whether on the whole building up or cutting down, have continually formed deposits along their banks. Each stream swings back and forth across its valley, depositing on one bank and cutting on the other. This work is done mainly at times of high water, when the streams spread over their flood plains, dropping the finer materials where the land surface is high and the water is shallow, and the coarser where the water is deeper.

The wind has here and there perhaps formed fresh deposits of dust or loess and has shifted somewhat the positions of the deposits already made, but the principal products of its work in Recent time are sand dunes along the edges of the river valleys. (See Pl. VIII.)

ECONOMIC GEOLOGY.

The geologic resources of the Galena and Elizabeth quadrangles include ores of lead and zinc, sulphur, building stone, clay, cement materials, lime, sand, road materials, water, and soils.

LEAD AND ZINC ORES.

OCCURRENCE.

The quadrangles lie within the area which has been called the Upper Mississippi Valley lead and zinc district and which has long been known as a producer of lead and zinc ores. Small amounts of the ores have been found in all the Paleozoic formations of the quadrangles, but the productive ore-bodies are confined to the Galena dolomite and the Decorah shale.

The deposits occur in all the divisions of the Galena, but the most valuable ones—that is, the peculiar "flats and pitches" and the disseminated deposits—lie at or near the base of the formation. Some of the crevice deposits, rarely in the form of flats and pitches, reach as high as the upper half of the Galena and a few lie even close to the top of the formation. A little mining for zinc ore has been done in the Maquoketa shale northeast of Scales Mound, but apparently with no very encouraging result.

ORE MINERALS.

The ores consist of several minerals containing lead or zinc, with which are associated other minerals that must be separated from these in the concentration of the ores.

Galenite or lead sulphide (PbS; lead, 86.6 per cent; sulphur, 13.4 per cent; sp. gr., 7.4 to 7.6), known also as galena, and by the miners as "mineral," is the only commercially valuable lead ore found in the district. It generally occurs in crystals, either cubes or, less commonly, octahedrons. At some places combinations of the two forms are seen. Some of the large crystals are several inches or a foot across and are called "cog mineral" by the miners. Galena commonly occurs in crystals disseminated through the rock in such a way that on crushing the rock and concentrating the mineral it is recovered in small cubes. Galena in this form is called "dice mineral." It also occurs in peculiar reticulated forms having treelike branches. It was the original lead ore of the district and from it have been derived other minor ores. The galena of this district, unlike that of most Rocky Mountain mining districts, contains practically no silver.

Cerusite or lead carbonate ($PbCO_3$; carbon dioxide, 16.5 per cent; lead oxide, 83.5 per cent; lead, 77. 5 per cent; sp. gr., 6.46 to 6.57), known also as white lead ore, occurs at some places in minute, colorless crystals on the surface of the larger crystals of galena, but more commonly it forms a white to yellowish powder-like coating on crystals of altered galena. It is a secondary mineral derived from the alteration of galena in the zone of weathering. It is not found in large quantity and is not mined as a source of lead.

Anglesite or lead sulphate ($PbSO_4$; sulphur trioxide, 26.4 per cent; lead oxide, 73.6 per cent; lead, 68.3 per cent; sp. gr., 6.3), which has been mentioned in some of the earlier reports on the district, is of rare occurrence. The so-called anglesite seems to be selenite or gypsum, and, in fact, it may be questioned whether true anglesite has been found in northwestern Illinois, although no reason is known why it may not occur there.

Sphalerite or zinc sulphide (ZnS; zinc, 67.15 per cent; sulphur, 32.85 per cent; sp. gr., 3.9 to 4.1), known also as zinc blende and by the miners as "black jack," or simply as "jack," is the original zinc mineral and is by far the most valuable ore of the district. As it usually lies below the level of ground water it was not discovered in the early explorations of the district and was not utilized for some years after its discovery. It ranges in color from light straw-yellow through brown to jet-black, the black color being due to impurities, especially iron. It occurs most commonly in sheets that line the sides of crevices. On free surfaces it occurs in small and rather poorly formed crystals. At some places small nodules of sphalerite, an inch or less in diameter, are embedded in clay, especially in the clay bed that marks the base of the Galena dolomite. This form of sphalerite is frequently spoken of as "strawberry jack." The other zinc minerals of the district have been formed by the alteration of sphalerite.

Smithsonite or zinc carbonate ($ZnCO_3$; carbon dioxide, 35.2 per cent; zinc oxide, 64.8 per cent; metallic zinc, 52.06 per cent; sp. gr., 4.3 to 4.4), is known by the miners as carbonate, or more commonly as "dry bone," a name suggested by its light, porous structure, which roughly resembles the inside of a bone. It generally occurs in brownish or yellowish porous masses which have a decidedly earthy appearance. It is also found, though less commonly, in more compact and irregular masses, most of which are white. Next to sphalerite it is the most valuable zinc mineral in the region. It generally occurs above the level of ground water, but at some places extends a short distance below that level. In the early lead mining in the district it was neglected, and in the early period of zinc mining it was about the only ore of zinc mined, sphalerite not being then used, but it is now produced in considerably less amounts than formerly and in decidedly smaller amounts than sphalerite. Most of the smithsonite now mined is burned into zinc white at Mineral Point, Wis.

Hydrozincite (a basic hydrous carbonate of zinc; sp. gr., 3.58 to 3.8) is known also as zinc bloom. Pure hydrozincite contains 60 per cent of metallic zinc. It is generally associated with smithsonite and is difficult to distinguish from that mineral in the field. In fact, it is rarely recognized in the district and no definite statements can be made as to its occurrence.

Calamine or zinc silicate (H_2ZnSiO_5; silica, 25 per cent; zinc oxide, 67.5 per cent; water, 7.5 cent; metallic zinc, 54.23 per cent; sp. gr., 3.4 to 3.5) is common in some districts, but has not been certainly recognized in the upper Mississippi Valley. In one of its forms it closely resembles the massive, nonporous variety of smithsonite and may therefore possibly have been overlooked.

MINERALS ASSOCIATED WITH THE ORES.

Marcasite and *pyrite* (FeS_2; iron, 45.78 per cent; sulphur, 54.22 per cent; sp. gr., 4.67 to 5.2) are intimately associated with sphalerite and galena, especially sphalerite. Marcasite, or white iron pyrites, crystallizes in the orthorhombic system, whereas pyrite crystallizes in the isometric system and ordinarily in cubes, pentagonal dodecahedrons, or octahedrons. Marcasite is the most common form of iron sulphide in the district, and in the following descriptions it is assumed that all the iron sulphide is in the form of marcasite. Pyrite is much less common, though it is found at some places, as, for instance, near Pilot Knob, where the two minerals occur side by side. Marcasite is associated with sphalerite and is a detriment to the ore, because the two are hard to separate in milling. Above the level of ground water marcasite is generally altered to limonite.

Psilomelane (a hydrous oxide of manganese; sp. gr., 3 to 4.7) occurs as an amorphous black substance known as wad. It is widely distributed in small quantities, generally in the form of a fine black powder.

Calcite or calcium carbonate ($CaCO_3$; carbon dioxide, 44 per cent; lime, 56 per cent; sp. gr., 2.7), is widely known as calc spar or simply as spar, and the miners usually call it "tiff." It is the most common mineral in the district, and is almost everywhere associated with the lead and zinc ores. At many places it lines the interior of the crevices, having been deposited after the metallic sulphides already mentioned. It occurs also in veins or in any kind of cavity in the dolomite and limestone of the quadrangles, especially in the Galena and Platteville formations.

Dolomite ($MgCaCO_3$; carbon dioxide, 47.9 per cent; lime, 30.4 per cent; magnesia, 21.7 per cent; sp. gr., 2.8 to 2.9), though the principal constituent of most of the Galena formation, rarely occurs in large crystals and does not seem to have been deposited in the crevices.

Selenite or hydrous calcium sulphate ($CaSO_4 2H_2O$; sulphur trioxide, 46.6 per cent; lime, 32.5 per cent; water, 20.9 per cent; sp. gr., 2.3), occurs in small crystals, but is not very common. It undoubtedly owes its origin to certain chemical reactions that take place between the calcium carbonate of the rocks and the sulphuric acid produced by the breaking down of the marcasite or other sulphides.

Barite or barium sulphate ($BaSO_4$; sulphur trioxide, 34.3 per cent; baryta, 65.7 per cent; sp. gr., 4.3 to 4.6), commonly known as heavy spar, is found at some places near the oil rock, but also lines cavities, being the last mineral deposited. It is not common in the district, though in some of the mines it is abundant. It is highly undesirable commercially because its specific gravity is so nearly that of sphalerite that the two minerals are very difficult to separate during concentration.

Sulphur (S; sp. gr., 2), though not abundant, occurs here and there in the lead region in a pulverulent or minutely crystalline form in crevices or small cavities in the mines. It is undoubtedly produced by the decomposition of the iron sulphides, marcasite and pyrite. It is nowhere found in sufficient abundance to be economically important.

Quartz (SiO_2; oxygen, 53.3 per cent; silicon, 46.7 per cent; sp. gr., 2.6) occurs chiefly in the form of chert, which is abundant in parts of the Galena dolomite. Notwithstanding the large amount of silica in the ore-bearing rocks it is rarely found in crystalline form.

FORMS OF DEPOSITS.

Classification.—The lead and zinc ores are at many places associated, and both occur in the same kinds of formations and at the same horizons. The deposits may be grouped into two divisions based upon their form, those that occur in cracks or crevices in the rocks, including both vertical crevices and the flats and pitches described below, and those that are disseminated in small particles throughout the rock.

Crevice deposits.—The deposits in cracks or fissures and along joint planes, many of which have been enlarged by solution before the ore was deposited, were formed in open cavities, and not by replacement.

Most of the crevices trend from east to west or from a little north of west to south of east and are essentially vertical. They are crossed by many other crevices, the main series of which runs a little east of north and west of south, about at right angles to the major set. To the first series of crevices the miners apply the term "east and wests," and to the second, "north and souths." In addition there are smaller fissures, called quartering crevices, that cross the main fissures at various angles, and to these the names "two o'clocks," "ten o'clocks," etc., have been applied by the miners, as their direction coincides with that of the shadow cast by the sun at 2 o'clock or 10 o'clock, or at other times. Most of the ore mined has come from the east-west crevices, but particularly rich deposits occur at the intersections of crevices.

The general term "range" is applied by the miners of the Upper Mississippi Valley district to an ore-bearing crevice or to a series of such crevices that lie parallel and close together. Some of the ranges can be traced for several hundred feet, and some, apparently, for a few miles.

The ore deposits in the vertical crevices at some places impregnate adjacent beds laterally for short distances, where solution of the dolomite has occurred. Irregular cavities that are more or less filled with ore have thus been formed, and to these cavities the term "openings" has been applied. Most of the openings are in the upper part of the Galena dolomite, and most of the flats and pitches are in its lower part.

In the lower part of the Galena dolomite, especially in bed 2 of the generalized section, many of the vertical joints are replaced by a series of joints that dip away on either side of a main vertical crevice. These dipping joints, which contain ore, are connected with horizontal openings that run along the bedding, which also contain ore. It is these peculiar forms of deposits that miners call flats and pitches, the flats being the horizontal parts of the deposit, the pitches the inclined parts. (See fig. 8.)

Many of the flats and pitches are connected with vertical east-west crevices. The crevices as a rule do not extend below the horizon of the oil rock, although at some places the main glass-rock beds contain numerous fractures filled with ore. A series of flats and pitches may be 100 feet to 200 feet across, and in a flat that runs back from a pitch into the foot wall there may be a considerable mass of mineralized rock, which extends from one pitch to the other, and which can be mined out. In general the pitches in any one mine are approximately parallel with one another and also parallel with a vertical crevice, but at some places there are secondary pitches which contain ore and which trend in a direction very different from that of the main system of pitches.

Associated with the crevice deposits are others to which the name "honeycomb" deposits has been applied, but these are not genetically different from the ordinary crevice deposits. They occur in connection with the crevice deposits at places where the rock has been brecciated, semibrecciated, or strained,

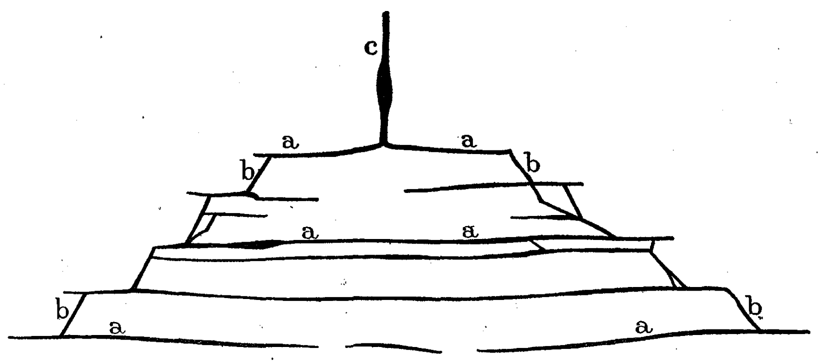


FIGURE 8.—Diagrammatic cross section of the ore-bearing flats and pitches in the Galena dolomite.
a, Flats along bedding planes; b, pitches; c, vertical crevice.

and where it has therefore been more subject to solution. In the solution cavities that have been made along the zones of brecciation ore has been deposited. Deposits of this kind, which grade directly into the crevice deposits, occur at many places.

As before stated, many of the vertical crevices that are filled with ore are not connected with flats or pitches. Flats also occur without pitches. Most of these are found at or just above the horizon of the oil rock. In some places, however, flats occur just below the main glass-rock beds, where there is also another thin bed of oil rock. The ore in some of these flats has been deposited in open cavities made by solution, but that in others seems to be a replacement deposit, and thus to grade directly into the next class, called disseminated deposits.

Disseminated deposits.—At certain horizons the rock has been more or less permeated or impregnated by ore-bearing solutions and in such places crystals of sphalerite and of Galena occur in abundance. The disseminated deposits can not be sharply separated from the flats that occur in connection with the oil rock just mentioned. Most of them are found in thin beds of limestone or dolomite that immediately overlie the oil rock, in the oil rock itself, in the clay bed that immediately underlies the oil rock in some of the mines, or at the base of the main glass-rock beds, associated with some thin layers of oil rock.

Most of the flats and pitches and the vertical crevices contain notable amounts of marcasite, which at some places occurs in great abundance. As a general rule less marcasite is found in the disseminated deposits than in the flats and pitches or the vertical crevices.

RELATIONS OF THE ORES.

Order of deposition.—As has been already stated, the ore in the crevices was deposited in the open fissures. The usual order of deposition of the minerals, from the wall to the center of the vein, is as follows: (1) marcasite, (2) sphalerite, at some places containing galena, (3) galena, (4) calcite, (5) barite. Each of these minerals appears in a characteristic band, but all five of these bands are not observable in every deposit. Practically everywhere, however, the wall rock is coated by a layer of marcasite, either thin or thick, and outside of this lies sphalerite, which may or may not contain a little galena and which may or may not have galena outside of it. The richest ore of the district, an ore that is very plentiful in the flats and pitches in some of the larger mines, is this second layer, which is made up essentially of sphalerite with here and there a little galena. At some places the layer of ore on each side of the open crevice is 3 to 6 inches thick.

Although the order of deposition given above for the ores is that generally noted throughout the district, a second period of deposition of marcasite has occurred at some places, and at a few other places all the metallic sulphides are mingled together.

Downward change of ores.—The ore minerals are not only arranged in layers or bands from the wall rock out toward the centers of the crevices, but exhibit a significant arrangement in a vertical direction, from the earth's surface down to and below the level of the ground water—that is, the level below which the rocks are saturated with water. Three distinct horizontal zones occur in this vertical succession. At the top, in many places near the surface of the ground, there is a zone containing galena in large crystals and masses. It is, of course, above the level of ground water, and it is being continually lowered by erosion. Below this is a second zone, in which smithsonite is the principal ore, and which extends down to the level of ground water and in some places a few feet lower. The third zone, which is below ground-water level, is essentially a zone of sphalerite.

In the Galena and Elizabeth quadrangles the level of ground water ranges from 10 feet or less below the surface in the valleys to 100 feet below the surface on the broad interstream areas.

Although each of the three zones is characterized by its own peculiar mineral, galena extends from the first down into the second zone, which contains principally smithsonite, and some galena is found also in the zone of sphalerite, especially near its top. At many places in the lower zone crystals of galena have been deposited on sphalerite in the open centers of the cavities, but just below the top of this zone these crystals of galena are much less numerous, and in its lower part galena is intimately mingled with sphalerite.

The smithsonite of the district is a product of the alteration of the original sphalerite, an alteration which has taken place everywhere in the zone above the level of ground water, and which at some places extends a few feet below that level. The lower part of the second zone yields specimens showing all stages of alteration from sphalerite to smithsonite.

Relation of ore deposits to structure.—Attention has already been called to the fact that the crevice deposits occur in joints, and more commonly in joints that have been enlarged by solution. These joints bear a more or less close relation to the warping that the rocks in the district have undergone, the principal joints running nearly parallel to the main axes of warping.

Recent detailed work in the Upper Mississippi lead and zinc district has shown that many of the lead and zinc deposits of the region lie at or near the bottoms of synclinal basins, especially the disseminated deposits, the flats associated with the main oil rock, and the thin beds of oil rock that lie just below the glass rock of the Decorah shale. Many and perhaps all of the deposits in the flats and pitches also lie in synclinal basins, but sufficient data are not at hand to show positively that all of them occur in such basins.

The general character and the origin of the synclinal basins have been discussed in the description of the structural geology, under the heading "Folds" (pp. 8–9).

ORIGIN OF THE ORE DEPOSITS.

It is now commonly believed by geologists that the ore deposits of the district were derived entirely from the country rock, and mainly from the Galena dolomite. The views here set forth are in accord with those of Chamberlin and Bain. There is no evidence that the ores or the ore-bearing solutions were here brought up from great depths, as they were in many metalliferous deposits elsewhere. In fact, it is doubtful whether such solutions could have passed through the Decorah shale, which underlies the dolomite. The ore-forming substances might have come from above the present ore bodies, but they could scarcely have been carried down through the Maquoketa shale, and if they were carried down over its eroded surface they must have been deposited in Pleistocene time. More probably, however, they were brought in solution from the crystalline rocks that lay farther north and were precipitated by some means, possibly by the agency of plants, in the Ordovician and Silurian seas, as a part of rocks that were afterward uplifted. The ore bodies as they exist to-day were derived from these rocks and deposited by water that circulated in the Ordovician rocks. The waters dissolved the minute particles of the ore materials that were scattered through the rocks and redeposited them in the main ore bodies at the base of the Galena dolomite and in the scattered particles of ore in the upper part of this formation and in other formations. The percentage of lead and zinc in the country rock required to form valuable ore deposits is very small indeed. I. M. Buell, at the suggestion of T. C. Chamberlin, made an estimate of the degree or amount of metallic impregnation of the rock that would exist if the entire quantity of ore taken from the Potosi district, in the Lancaster quadrangle (in Wisconsin, Iowa, and Illinois) were uniformly distributed through the adjacent rock. In determining the limits of the district, a margin outside the outermost crevices was allowed equal to half the average distance between the crevices—that is, the outer crevice was supposed to draw only as much ore-forming mineral from the territory outside of it as from the territory between it and the neighboring crevice. As the basin occupied by the district is large this is a reasonable assumption. Furthermore, it was assumed that, in the deposition of the ores, the rock had been leached to a depth of only 100 feet, although probably twice that amount of rock originally lay above the base of the deposit. The estimate showed that the lead and zinc content of the rock under this hypothesis would amount to $\frac{1}{1400}$ of 1 per cent of the mass of the rock.

It has already been stated that many of the ore deposits seem to lie in structural basins. These basins, or at least such of them as occur in the Galena dolomite, are floored with practically impervious layers—that is, by the oil rock and Decorah shale—and are now generally above the ground-water level. It is therefore thought by some investigators that these basins have acted as channels for water that descended to the impervious floors and then flowed down the pitching synclines forming the basins. The disseminated deposits and those in the lowest part of the flats and pitches suggest that the organic matter found in the oil rock was among the agencies of the precipitation of the metallic substances held in solution by the circulating water, and that the volatile materials given off from the oil rock may reasonably be supposed to have aided materially in precipitating the ore in crevices higher up in the formation.

There is evidence that the ore minerals are continually migrating downward along the crevices to become arranged in the horizontal zones already described. Sphalerite, which is readily altered to smithsonite, is dissolved and carried downward to be precipitated close to the water level as smithsonite, or carried still farther down and reprecipitated as sphalerite. Galena is not so easily dissolved and does not travel downward so rapidly. A large part of the galena lies close to the surface and travels downward about as fast as the surface is lowered by erosion. The lead ore that is dissolved and carried downward is commonly reprecipitated near the level of ground water, and this precipitation gives rise to the large crystals of galena that line the veins in the upper part of the lower ore zone at many places.

MINES AND PRODUCTION.

The most productive mines are grouped in certain rather small districts, known as the Galena, the Sand Prairie, and the Elizabeth districts. The principal mines near Galena are the Waters, Little Corporal, Weber & Cring, Vinegar Hill, Fox River Valley, Oldenburg, Northwestern, and Stacy; those in the Sand Prairie district are the California, the Pittsburg, and the Peru or Black Jack; and those around Elizabeth are the Wishon, Apple River, Skene, and Queen. Two shafts have been sunk near Scales Mound (the Vista Grande and the Glanville prospects), and several smaller prospects have been opened at other places.

The Elizabeth district is sharply defined, being separated from other producing areas by a wide belt of barren territory. Many of the mines in the district were a few years ago abandoned but have since been reopened.

Most of the mines are 100 to 200 feet deep, but the extreme range in depth is 50 to 300 feet. The production of lead concentrates in 1914 was 646 short tons, valued at $28,778, and that of zinc concentrates was 16,725 short tons, valued at $320,012. The maximum production of lead was reached between 1840 and 1850 and that of zinc between 1900 and 1914. The total amount of the ore of each metal produced is about 500,000 tons, the lead having been sold for about $50,000,000 and the zinc for about $10,000,000. The early prices of zinc ore were very low and practically no ore was mined before 1860. The relation of surface to underground workings is well shown in figure 9, redrawn from a report of the Illinois Geological Survey by G. H. Cox.

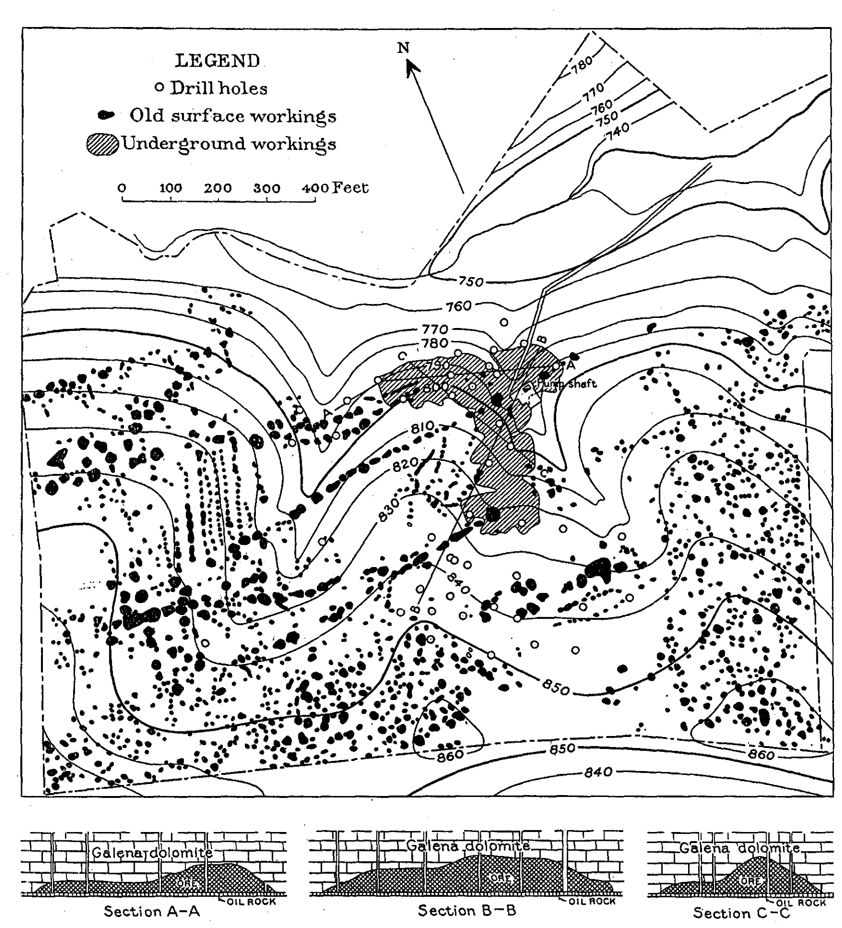


FIGURE 9.—Map showing the old surface workings and the extent of deep mining at Vinegar Hill, Ill., in September, 1910.

(Redrawn from Illinois Geol. Survey Bull. 21.)

The surface workings were in small ore pockets in the upper part of the Galena dolomite. The deep mines are in ore at the base of the Galena. The shape of the ore body as determined by drilling and mining is shown in the cross sections below the map, which represent sections along the lines A-A, B-B, and C-C on the map.

PROSPECTING.

The ranges and the districts that in early days produced lead or lead and zinc in large quantities close to the surface are, other things being equal, the most favorable locations for prospecting. The chances are that a range which has borne considerable quantities of rich ore in its upper part will bear large quantities in its lower part, the main difference being that below the level of ground water there will be less lead, practically no smithsonite, and probably more sphalerite. In prospecting, however, only those areas should be selected in which there is below the level of ground water a considerable thickness of the Galena dolomite—that is, a considerable thickness of rock that may carry ore—for the deposits are in most places limited by the base of the Galena and in practically all places are limited by the oil rock. It should be added that a range or a series of ranges or a district that lies in a synclinal basin is a more favorable place for prospecting than one not so situated.

SULPHUR ORES.

The metallic sulphides—galenite, sphalerite, and marcasite—are sources of sulphur. Sphalerite ores of low grade that are burned for zinc oxide are first roasted, and the resulting sulphur is used for making sulphuric acid. In a few of the mines marcasite is so abundant that it is possible to sell it to manufacturers of sulphuric acid.

BUILDING STONE.

The thinner beds of the Galena dolomite, especially those in the upper member of the formation, furnish good building stone, and at Dubuque, Iowa, stone from some of the massive beds lower down in the formation has been used in constructing large buildings and in bridge and railroad work. West of Dubuque the lower part of the Niagara dolomite includes about 20 feet of good building stone, which has been quarried at some places for use near by.

The district contains plenty of building stone for all local uses, and even a good supply for shipment to outside points, but it probably will not be shipped in large quantities, for much of the surrounding country is almost equally well supplied.

CLAY.

The clays of these quadrangles, though widespread and of excellent quality, have not yet been extensively utilized. Most of those that have been used were derived from three sources—(1) loess and alluvium, (2) residual clay, and (3) clays in the Maquoketa shale, all being suitable for making ordinary bricks. Alluvium and sandy loess taken at low levels are used at Dubuque for making common building bricks, and such bricks are also manufactured in a few small kilns in the Galena and Elizabeth quadrangles. The demand for brick and other clay products, however, is slight, for an abundant supply of ordinary building stone is everywhere available.

The Maquoketa formation contains, near its base, much shale and clay that can probably be used for making clay ware, including pressed brick and tile. None of this material is now used in the area. An analysis of shale from Kidder, Iowa, near Lattners, just west of the Galena quadrangle, is given below:

Analysis of Maquoketa shale from Kidder, Iowa.

[J. B. Weems, analyst, Iowa Geol. Survey Ann. Rept. for 1899, vol. 10, p. 606, 1900]

Silica (SiO_2)	42.53
Ferric oxide (Fe_2O_3)	5.66
Alumina (Al_2O_3)	16.83
Calcium oxide (CaO)	5.66
Magnesium oxide (MgO)	4.82
Potassium oxide (K_2O)	3.70
Sodium oxide (Na_2O)	4.10
Combined water	15.76
Undetermined	.94
	100.00

Transportation for the plastic clays of the Maquoketa can be had at some places along the Chicago Great Western Railroad, and as the shale lies rather high above the railroad track the material could be loaded on the cars by gravity.

LIME.

The ruins of kilns that once furnished local supplies of lime may be seen here and there throughout the district. A few kilns are still in operation, but most of the lime used in the district is made from purer limestones found in other areas. The rock most extensively burned was taken from the central part of the Niagara dolomite, but rock from the Galena dolomite has been burned at a few places.

SAND.

Large deposits of clean sand are found at some places along the Mississippi, where it has been blown into dunes. The principal deposits are shown on the map, but there are also others too small to be shown.

ROAD MATERIALS.

The rough topography of the Driftless Area and the steep grades near the Mississippi and the larger streams have necessitated the general improvement of the roads in the quadrangles. Fortunately the region is well supplied with material suitable for use as road metal. Dolomite, limestone, and chert are the rocks commonly so used. The rock is hand broken and spread over a graded and rolled surface and may be covered with a layer of gravel or finer crushed rock. The flood plains of the larger streams become almost impassable at times of high water, especially the streams that lie along the lower courses of the tributaries of the Mississippi, and it has therefore been necessary to build substantial roads across the valleys to a height of 4 or 5 feet above the bottom land.

OIL OR GAS ROCK.

The oil rock closely resembles the torbanite of Scotland, central France, and New South Wales. These foreign deposits are a source of certain illuminating gases—particularly of gases desirable for train service and other uses requiring compression — and of oil for enriching ordinary gas. Some experiments intended to discover whether the oil rock of the upper Mississippi district can be used as a source of gas have been made, but the work is not yet completed.

WATER RESOURCES.

SPRINGS.

In these quadrangles there are numerous springs, many of which issue at the base of the Galena or, particularly, at the base of the Niagara dolomite. Springs issue at other horizons, such as those above shaly layers in the Galena as well as from the layers of limestone in the Maquoketa shale, but they are not large or numerous. The oil rock at the base of the Galena is generally underlain by one or more thin strata of practically impervious bluish clay or shale, which turn much of the water that soaks down through the porous dolomite above. There are several springs at this horizon in the northwestern part of the area at places where the horizon is above the drainageways.

Many springs are the sources of permanent streams and are of great value to farmers, as they furnish supplies of excellent water for domestic use and for cooling and thus determine the location of farmhouses.

WELLS TO GROUND WATER.

The position of the top of ground water in this area ranges from the surface to a depth 10 feet below the surface in the valleys and reaches a depth of 100 feet or more on some of the high interstream areas. At most places it lies so far below the surface as to make the sinking of open dug wells inexpedient, so that wells are generally sunk by the churn drill, especially on the broad uplands. The Galena dolomite is sufficiently porous to furnish adequate domestic supplies to wells sunk a few feet below ground-water level. At some places the water is "let out" of the rock through crevices, and it is necessary to drill beyond the ordinary depth. The water of wells in the Galena is somewhat hard but is of excellent quality for domestic use.

DEEP WELLS.

The deep wells in the quadrangles derive their supplies from two water-bearing formations—the Cambrian strata and the St. Peter sandstone—one or both of which lie beneath the whole area. The sandstone in the upper part of the Prairie du Chien group is also commonly water-bearing, though it carries no water in places where it is not separated from the St. Peter by beds of limestone. At Dubuque, where it lies about 435 feet below the level of the Mississippi, it yields an artesian flow.

Wells sunk to the St. Peter sandstone furnish abundant supplies of water that is softer than that derived from the dolomite. At Stockton two wells about 1,500 feet deep have been drilled and the water in them stands about 125 feet below the surface.

The quality of the water is shown below:

Analyses of water from deep wells in the Galena and Elizabeth quadrangles.

[Parts per million.]

	A	B	C	D	E
SiO_2	6.8	6.1	3.7	8.0	10
Fe	.7	.9	1.5	1.2	....
Al	1.4	.6	.4	1.0	....
Ca	106	46	116	84	103
Mg	32	68	47	45	47
Na	15	16	7.0	7.3	182
K	1.1	4.0	6.6	1.6	
HCO_3	436	355	528	428	326
SO_4	1.1	24	63	13	425
Cl	.6	36	8.0	16	83
NO_3	.5	88	.6	41	....
Solid residue	329	534	496	429	978

A. From 1,500-foot well of J. M. Sharp, at Stockton, Jo Daviess County; collected Oct. 11, 1898. Water from sandstone.

B. From 100-foot well of B. W. Hicks, at Warren, Jo Daviess County; collected May 9, 1899. Water from limestone.

C. From 130-foot well of E. Hermon, at Woodbine, Jo Daviess County; collected Apr. 2, 1900. Water from limestone.

D. From 137-foot well of E. Hermon, at Woodbine, Jo Daviess County; collected Apr. 2, 1900. Water from limestone.

Analyses A-D by Illinois State Water Survey; R. W. Stark, analyst; published in Illinois Univ. Bull., vol. 6, No. 3, 1908.

E. Average of ten samples from Clinton County, Iowa, of which the analyses are published in U. S. Geol. Survey Water-Supply Paper 293, 1912.

STREAMS AND WATER POWER.

The annual rainfall in the district is about 35 inches, the streams are numerous, and irrigation is not necessary. The smaller streams have rather steep gradients, at some places as much as 60 feet to the mile, but the average fall of the large streams in their lower parts does not exceed 10 feet to the mile. Many of the streams that have a fall of 10 to 40 feet to the mile are large enough to furnish power for small gristmills. Abandoned mills and millraces testify to the use of these water powers before the large mills in the Northwest were built. The Mississippi is the only navigable stream in the area.

SOIL.

The fertility of a soil depends on many factors, among which are geologic processes, for the texture and the physical and chemical composition of a soil are determined in part by the character of the rock or rocks from which it has been derived.

That part of the soil of these quadrangles that was derived from the formations which outcrop at the surface shows at any locality a character corresponding to that of the underlying rock or deposit, though it may be modified somewhat by surface wash.

The soil on the Galena and Niagara dolomites is generally fine grained, compact, and dark gray, but at some places, particularly on the Niagara platform, it is reddish or even bright red, and at other places, especially where it is old and contains some calcareous wash, it is very black. The dolomite generally weathers first to a more or less cherty material having a remarkable sandy texture.

The soil that lies upon the Maquoketa shale is generally very fine grained and uniform, though the Maquoketa contains so much dolomite that the soil derived from it does not differ greatly from the soil on the Galena and Niagara dolomites except that it is rarely either reddish or deep black.

The loess soil varies with the character of the underlying loess, being most porous along the river bluffs and most fine grained and impervious at places farthest from the river. Both the physical and the chemical nature of the loess soil tend to make it very fertile. It is composed of a great variety of more or less decomposed minerals and a goodly supply of organic matter. Its consistency is that of a soil made of dust particles somewhat modified by weathering. It is comparatively open and porous and consists of very fine sand or silt with which more or less clay is mixed.

The soil developed by the weathering of glacial till differs from the soils described above principally in being somewhat gravelly. It is more compact than the soil in the loess areas, and more heterogeneous in composition than the soil on the hard rocks. It covers only small areas on the eastern and western sides of the area.

The alluvial soil contains much sand and gravel derived from the chert in the dolomites and is deep black, porous, and fertile. Along the borders of the alluvial tracts are irregular belts of colluvial soil consisting of material that has crept or been washed from the adjacent slopes. It is somewhat similar to the alluvial soil but is generally deeper and blacker and less washed.

On the whole, the soils contain less deep, black alluvial material than is found in the soils of the surrounding glaciated area, yet they yield abundant and diversified crops, including corn, oats, and hay.

December, 1914.

FOSSILS SHOWN IN PLATES XII AND XIII OF ILLUSTRATION SHEET.

Plate XII.

Figures 1, 2. *Receptaculites oweni.* The most characteristic fossil of the Galena dolomite. This supposed sponge is radiate in structure and is popularly called "sunflower coral." It is most commonly seen in the rock in section, as shown in figure 2. Figure 1 is a surface view. Two zones in the Galena formation, in which these forms are abundant, are known as the "upper Receptaculites zone" and the "lower Receptaculites" zone.

3. *Triptoceras lambi.* From the upper part of the Galena formation. A few segments of a large cephalopod now extinct but related to the chambered nautilus of to-day.

4, 5. *Dalmanella minneapolis* (N. H. Winchell). Two valves of large specimens abundant in the Decorah shale. Closely resemble *D. subæquata* of the Platteville limestone.

6. *Platystrophia biforata* var. From the upper thin beds of the Galena dolomite. The species occurs also in the Maquoketa shale.

7. *Lingula iowensis.* Characteristic of the uppermost Galena beds. This is a more primitive brachiopod than the others, as is indicated by its flatness, its lack of plications, and its lack of an articulate hinge between the valves of the shell.

Plate XIII.

Figure 1. *Pleurotomaria depauperata.*
2. *Liospira micula.*
3. *Cleidophorus neglectus.*
4. *Cleidophorus neglectus.* Cast of inside of shell.
5. *Ctenodonta obliqua.*
6. Zygospira sp.?
7. *Dalmanella* sp.? allied to *D. testudinaria.*
8. Orthoceras sp.? A small undetermined species.
9. *Plectambonites saxea.*
10. *Platystrophia acutilirata* var.
11. *Orthis whitfieldi.* Dorsal valve.
12. *Rhynchotrema capax.*
13. *Rhynchotrema perlamellosa.*
14. *Hebertella insculpta.* Dorsal valve.
15. Hebertella aff. *H. occidentalis.* Ventral valve.
16. Rafinesquina. A common but undescribed species.
17. Isotelus n. sp. Imperfect pygidium of a trilobite.
18. *Monotrypa rectimuralis.* A "biscuit" bryozoan.
19. *Heterotrypa singularis.* A bryozoan.