Geology of the Montfort and Linden Quadrangles Wisconsin

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Prepared in cooperation with the State of Wisconsin Geological and Natural History Survey

Carlson—GEOLOGY OF THE MONTFORT AND LINDEN QUADRANGLES, WISCONSIN—Geological Survey Bulletin 1123-B

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[Plates are in pocket]

GEOLOGY OF PARTS OF THE UPPER MISSISSIPPI VALLEY ZINC-LEAD DISTRICT

GEOLOGY OF THE MONTFORT AND LINDEN QUADRANGLES, WISCONSIN

By John E. Carlson

ABSTRACT

The adjacent Montfort and Linden quadrangles, in Grant and Iowa Counties in southwestern Wisconsin, cover 110 square miles in the upper Mississippi Valley zinc-lead district and are in the Driftless Area of southwestern Wisconsin. Maximum relief is 350 feet, and the altitude ranges from 880 to 1,230 feet. The major topographic feature is the Galena-Platteville cuesta that dips gently to the south.

The rocks exposed are dolomite, limestone, sandstone, and shale of Early and Middle Ordovician age. The oldest rocks exposed are cherty dolomite, sandstone, and shale of the Prairie du Chien group. These rocks are subdivided into three formations; however, subdivision in the mapped area is difficult owing to poor exposures. This unit is about 250 feet thick, but only the upper 100 feet is exposed. Relief on the upper Prairie du Chien surface exceeds 100 feet; this relief is thought to be the result of deposition of dolomite and sandstone over relatively incompressible reef structures. The overlying St. Peter sandstone is probably conformable on this undulating surface.

The St. Peter sandstone of Middle Ordovician age is 40 to 150 feet thick, a range in thickness that is a result of filling on the irregular surface of the Prairie du Chien. The St. Peter is a crossbedded buff to white friable fine- to coarse-grained quartz sandstone. The lower part of thick St. Peter sections contain interbedded shales but no interbedded carbonate rocks.

The Platteville formation of Middle Ordovician age is 50 to 62 feet thick and conformably overlies the St. Peter. It includes, in ascending order, the Glenwood, Pecatonica, McGregor, and Quimbys Mill members. The Glenwood consists of about 1½ feet of green arenaceous and dolomitic shale; the Pecatonica consists of 18 to 20 feet of thick-bedded buff to gray dolomite of sugary or medium granular texture; the McGregor consists of about 15 feet of wavy-bedded light-gray fossiliferous limestone in the lower part and about 15 feet of light-gray to light-yellowish-brown limestone and dolomite in the upper part; the Quimbys Mill is light- to dark-purplish-brown sublithographic limestone and dolomite. It thins uniformly from 11 feet along the east side of the area mapped to 1½ feet along the west side. No evidence for disconformities was noted at either the top or the base of the Quimbys Mill and the thinning is probably a depositional feature.

The Decorah formation of Middle Ordovician age is 35 feet thick and overlies the Platteville. It includes, in ascending order, the Spechts Ferry, Guttenberg, and Ion members. The Spechts Ferry consists of 1 foot to 5 feet of brown and green shale, light-gray limestone, and yellow bentonite; the Guttenberg consists

of 11 to 14 feet of thin-bedded light-pinkish-brown very fossiliferous, fine-grained limestone and dolomite; the Ion consists of about 20 feet of dark-bluish-gray to light-gray, coarsely to finely crystalline limestone and dolomite.

The Galena dolomite of late Middle Ordovician age has a total thickness of 215 to 230 feet, but only the lower 140 feet is preserved in the mapped area. In the mining district two units are recognized: a lower cherty unit and an upper noncherty unit. The cherty unit is about 105 feet thick and consists of light-yellowish-brown medium-bedded argillaceous dolomite and layers of chert. It is subdivided into four lithologic and faunal zones. The noncherty unit is about 35 feet thick in the mapped area; the upper part has been eroded. The lithologic character of the two units is similar except for presence or absence of chert.

The major structural feature is a southerly regional dip of the rocks of about 17 feet per mile. This southward dip is interrupted in the southern part of the area by two anticlines of about 100 feet amplitude and two faults of about 80-foot vertical displacement. The flank of one fold, interpreted as an anticline, possibly results from disturbance along the eastern extension of a fault. Many small basins of 10 to 30 feet depth are believed to be due to combined tectonism and thinning by solution.

Mineral deposits are gash-vein and "pitch-and-flat" types. Gash-vein deposits contain galena and smithsonite as wall-rock replacement and fracture filling along vertical joints in the Galena dolomite. Some gash veins may be related to pitch-and-flat deposits that contain mainly sphalerite.

Pitch-and-flat deposits are the commercially important type of occurrence; they contain sphalerite and minor galena in inclined veins (pitches) and horizontal veins (flats). These deposits are generally limited to about 90 feet of rock, which includes the Quimbys Mill member of the Platteville formation, the Decorah formation, and the lower 50 feet of the Galena dolomite. Many of the pitch-and-flat deposits are in basins, although the position of the deposit is probably due less to the specific type of tectonic structure than to fracturing and brecciation that accompanied folding. The basins are partly related to subsidence which results from solution of rock by mineralizing fluids; pitches and flats are fractures that are probably related to subsidence.

The first major mining operation in the mapped area began in 1833 at the Mason mine. The total tonnage of ore produced from pitch-and-flat deposits in the mapped area is estimated at 6 million tons of 3- to 6-percent combined metallic zinc and lead content. About 92 percent of the ore was shipped as zinc concentrates, and the rest was shipped as lead concentrates. The total production of lead from gash-vein deposits probably did not exceed 100,000 tons.

The mapped area has not been fully prospected for zinc and lead ore, and an estimated 3,000,000 tons of ore probably remains in pitch-and-flat deposits that might be discovered by more thorough prospecting. It is more difficult to discover gash-vein deposits than to find pitch-and-flat deposits, but at least as much ore probably remains in gash veins as has been mined. The probability of commercial deposits of lead and zinc in the Prairie du Chien group is remote.

INTRODUCTION

LOCATION, ACCESSIBILITY, AND RELIEF

The Linden and Montfort quadrangles, in Grant and Iowa Counties in southwestern Wisconsin (fig. 19), are bounded by longitudes

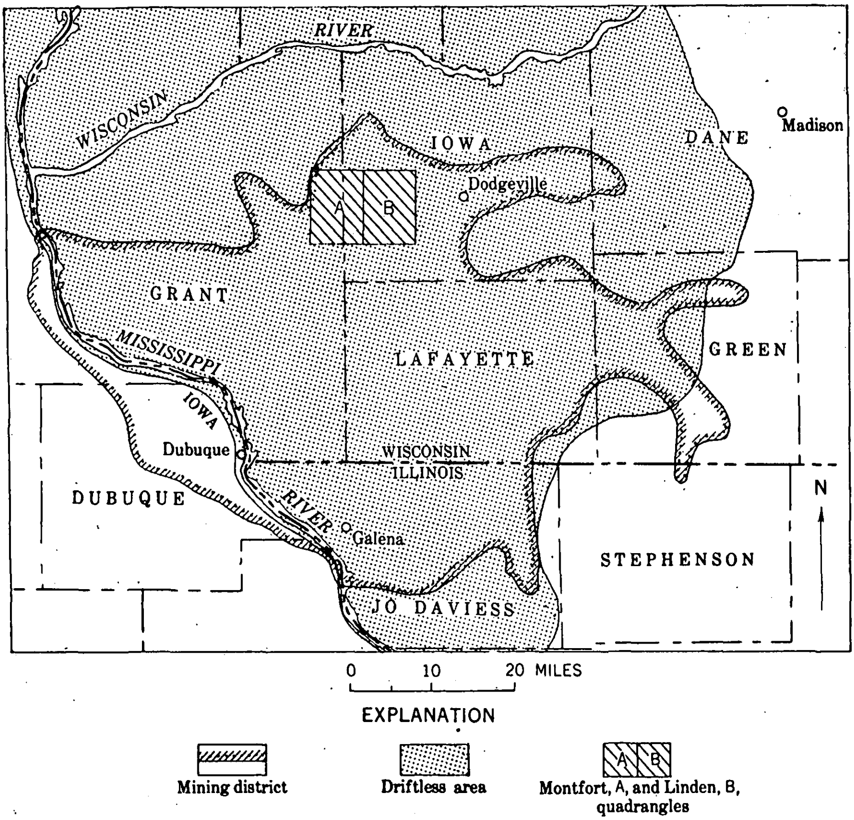

FIGURE 19.—Index map of southwest Wisconsin, northwest Illinois, and northeast Iowa showing outline of mining district, outline of Driftless Area, and location of Montfort and Linden quadrangles.

90°15′ W. and 90°30′ W., and latitudes 42°52′30″ N. and 43°00′00″ N. They cover 110 square miles in Illinois and Wisconsin and are in the north-central part of the upper Mississippi Valley zinc-lead district. Most parts of the area are easily accessible by all-weather roads.

Maximum relief is about 350 feet, and altitudes range between 880 and 1,230 feet.

Agriculture, mining, and cheese manufacturing are the only industries, and of these agriculture is by far the most important. Montfort, population 576, is the largest town, but Livingstone, Cobb, Linden, and Edmund also serve as trade centers for the farming population in the mapped area.

FIELDWORK AND ACKNOWLEDGMENTS

Mapping and geologic studies of the upper Mississippi Valley zinc-lead district were started in 1942 by the U.S. Geological Survey as part of a Strategic Minerals Investigations program. Since 1945, these geologic investigations in Wisconsin have continued in cooperation with the Wisconsin Geological and Natural History Survey. A program of detailed geologic mapping of 7½-minute quadrangles was started in 1951, using topographic maps prepared by the U.S. Geological Survey.

Field mapping of the Montfort and Linden quadrangles was done from 1951 to 1955 on aerial photographs at a scale of 1:7,920, and information was then compiled on topographic base maps at a scale of 1:12,000. Alidade surveys established the altitudes of formation boundaries, drill-hole collars, and other useful geologic control points; and the whole was reduced to a common structural datum. All available drill-hole data and previous work pertaining to the mapped area were evaluated and utilized.

The author is indebted for the help and courtesy shown him by the many landowners, mine operators, and drillers in the district. Officials of the Vinegar Hill Zinc Company, the New Jersey Zinc Company, the Calumet and Hecla Company, the Eagle-Picher Company, and the Mifflin Mining Company cooperated to the fullest extent in supplying drill-hole information. Mr. J. W. McDonald and Mr. William Singer of the Dodgeville Mining Company also assisted in supplying data.

PREVIOUS WORK

Many geologists have reported on the upper Mississippi Valley zinc-lead district during the past 130 years, and several of the more important studies are listed below.

Early geologic investigations began with surveys by Owen (1840, 1848), who did his fieldwork in the 1830's. Owen was followed by Daniels (1854), and by Percival (1855, 1856) who recognized the principal features of the district stratigraphy and mineral deposits. As the structure and distribution of the mineral deposits became better known, the literature increased rapidly in volume. Reports by J. D. Whitney (1858) and Hall and Whitney (1862, p. 140–193), White (1870), Shaw (1873), and Strong (1877) followed. Chamberlin (1882) did the next major work in the district, and his report was an important contribution to an understanding of the mineral deposits.

Most of these reports were written when the area was regarded primarily as a lead district, but as lead mining decreased and zinc mining increased, other studies were undertaken to determine conditions of origin and deposition of the ores. Jenny (1894), Blake (1894), and Calvin and Bain (1900) published reports on mineral deposits and district geology. Reports and structure maps by Grant (1903, 1906), Bain (1905, 1906), Grant and Burchard (1907), Hotchkiss and Steidtmann (1909), and Cox (1911) soon followed and became a basis for further work on structure, stratigraphy, and mineral deposits.

Spurr (1924), Emmons (1929), Behre (1935), Behre and others (1937), and Bastin and others (1939) reported on the nature and origin of the district structures and on the origin of the ores. Interest in the district later was renewed with important studies by Willman and Reynolds (1947), Heyl and others (1945, 1948, 1955, 1959), Agnew and others (1956), Flint (1956), J. W. Allingham (written communciation), and A. F. Agnew (writtten communication).

The report by Heyl and others (1959) contains detailed information on stratigraphy, composition and paragenesis of the ores, occurrence and structural control of mineral deposits, descriptions of the mines, and history of the district.

PHYSIOGRAPHY

The Montfort and Linden quadrangles are in the Driftless Area of Illinois, Wisconsin, Iowa, and Minnesota. The surface of the quadrangles is a broad, rolling upland dissected by streams of dendritic pattern (pl. 8). Many of the divides are flat or nearly so, but near the larger streams the divides are rounded spurs. This type of topography is characteristic of nonglaciated regions of moderate rainfall that are underlain by nearly horizontal beds of sedimentary rocks.

The basic land form in the mapped area is the Galena-Platteville cuesta (Martin, 1916, p. 63; Trewartha and Smith, 1941, p. 42). The escarpment or drainage divide of the cuesta, called Military Ridge, is followed by U.S. Highway 18 and extends eastward across the northern part of the quadrangles. Irregular dissection of the cuesta has obscured the escarpment form in many places. The surface slopes southward from the divide at a rate of 17 feet per mile (Heyl and others, 1955, p. 231).

The west one-third of the surface south of Military Ridge is drained by tributaries to the Platte River, which joins the Mississippi about 20 miles from the Montfort quadrangle. The eastern two-thirds of the surface is drained by branches of the Pecatonica River, a tributary of the Rock River, which joins the Mississippi about 100 miles from the Montfort quadrangle. North of Military Ridge the streams are tributary to the Wisconsin River and are both shorter and straighter than the streams south of the divide. Stream gradients are relatively low south of Military Ridge but approach 100 feet per mile on the north slope of this divide.

In much of the mapped area the valleys have sloping, rounded walls where they are cut in dolomite and limestone. In places where the streams have breached the St. Peter sandstone, the valley walls are nearly vertical and the valley floors are wider, owing to the more massive bedding and less competent nature of the sandstone.

Joints are of primary importance in controlling most stream courses within a simple dendritic pattern. However, the regional dip and homogeneous nature of the rocks have also been contributing factors in stream control. The East Pecatonica River in sections 6, 7, 8, 17, 21, and 29, T. 5 N., R. 2 E., of the Linden quadrangle is an excellent example of a joint-controlled stream.

The southward slope of the surface nearly parallels the dip of the rocks; thus, the present surface is due largely to structure, although some beveling has occurred across the two large anticlines in the southern part of the quadrangles.

STRATIGRAPHY

The rocks exposed in the mapped area are about 385 feet thick and consist of dolomite, limestone, sandstone, and small amounts of shale. These rocks form the Prairie du Chien group of Early Ordovician age and the St. Peter sandstone, Platteville formation, Decorah formation, and Galena dolomite of Middle Ordovician age. The Prairie du Chien group is generally divided into three formations, but these are not differentiated in this study because of poor exposures and varied lithology. The Platteville formation is divided into four members and the Decorah formation into three members. Members of these formations were not differentiated because they are too thin, but the members are described in detail below. The Galena dolomite is divided within the mining district into two units; each is more than 100 feet thick.

A typical stratigraphic section of rocks exposed in the Montfort and Linden quadrangle is shown in plate 9.

The study of the carbonate rocks in the mapped area is complicated by the presence of two stages of dolomite. The early stage is widespread and related to a facies change in which the proportion of dolomite to limestone in the upper two members of the Platteville and in the Decorah formation increases eastward across the quadrangles. The facies change forms an irregular front in the limestone beds below the Galena dolomite and above the Pecatonica dolomite member of the Platteville. Some limestone occurs as islands in the dolomite and indicates that the dolomite is probably replaced limestone.

The later stage of dolomite is related to the solutions that deposited lead, zinc, and iron sulfide minerals. This dolomite is local and is distinguishable from facies dolomite only when it occurs as islands in the limestone associated with known mineral deposits. These two stages of dolomite are not separable by field methods in areas where mineral deposits occur within the dolomitic facies or where dolomite within limestone is not known to be intimately associated with mineral deposits.

The stratigraphic units will be described in terms of composition before alteration, and the effects of mineralizing solutions will be noted later.

No attempt to describe the regional relationships of these rocks will be made in this report. The reader is referred to a recent study (Agnew and others, 1956) for regional relationships.

CAMBRIAN SYSTEM

UPPER CAMBRIAN SERIES

The uppermost Cambrian rocks are about 150 feet below the oldest rocks exposed in the mapped area. A full thickness of the Cambrian rocks has not been drilled in the mapped area, but information from adjoining areas indicates that about 1,200 feet of Cambrian rocks underlie the Montfort and Linden quadrangles. The descriptions below are from Thwaites (1923), who has studied the Cambrian rocks in detail in southwestern Wisconsin.

The oldest Cambrian formation is the Mount Simon sandstone, which rests upon the eroded Precambrian granitic basement. In ascending order above the Mount Simon are the Eau Claire sandstone, the Dresbach sandstone, the Franconia sandstone which contains glauconite as a distinguishing feature, and the Trempealeau formation. The Trempealeau consists of dolomite in the lower part and sandstone and siltstone in the upper part. The overlying Prairie du Chien group of Early Ordovician age is apparently conformable with the Trempealeau through a gradational contact. Thicknesses of these Cambrian formations differ from place to place, owing to regional depositional changes, and to the irregular contact with the Precambrian basement.

ORDOVICIAN SYSTEM

LOWER ORDOVICIAN SERIES

PRAIRIE DU CHIEN GROUP

The oldest rocks exposed in the Montfort and Linden quadrangles are dolomite, sandstone, and shale of the Prairie du Chien group of Early Ordovician age, named for the exposures near Prairie du Chien, Wis. These rocks crop out along the north boundary of the quadrangles and in a small area in the southwest corner of the Montfort quadrangle.

Rocks of the Prairie du Chien group are generally subdivided into three formations: the Oneota dolomite, New Richmond sandstone, and Shakopee dolomite, named in ascending order. However, these formations have not been recognized with certainty in the mapped area.

Where the Oneota dolomite and Shakopee dolomite are not separated by the New Richmond, division of the dolomites is difficult. Some sandstone lenses and stringers occur in the upper part of the Prairie du Chien but no rocks identifiable as New Richmond were observed, and the presence of this formation within the mapped area is in doubt. In addition to the stratigraphic difficulties, exposures of the Prairie du Chien are so poor that subdivision is impracticable. For these reasons, Prairie du Chien units are not described individually in this report.

The Prairie du Chien in the area is mainly gray to tan, medium-grained, cherty and siliceous dolomite, which contains thin intercalated tan to gray glauconitic shale and siltstone and buff sandstone. The dolomite may grade laterally to dolomite-cemented quartz sandstone within a short distance. This sandstone is buff to light gray, fine to medium grained, and it is similar to the underlying Trempealeau and to the overlying St. Peter. White to gray chert is abundant in the Prairie du Chien, and much of this chert is oolitic. Most of the chert occurs as nodules whose long dimensions parallel bedding planes; but some chert occurs as large masses as much as 5 feet in diameter which crosscut the bedding planes. Fossils are rare in the dolomite but are fairly common in the chert nodules. Locally, algal masses obscure bedding in the dolomite and give the rock a brecciated appearance. The dolomite weathers hackly, dark gray, and vuggy.

The top part of the Prairie du Chien commonly consists of 1 foot to 15 feet of thin-bedded green siltstone, green shale, and glauconite with some thin-bedded sandstone and arenaceous dolomite. The green shale and siltstone form an incompetent zone that, except in fresh road cuts, is covered by soil or slump blocks of the overlying St. Peter sandstone. The author was unable to find a natural exposure of this upper contact in either quadrangle.

The thickness of the Prairie du Chien is not constant in this area. Drill hole records indicate a range in thickness from 215 to 255 feet, but the minimum thickness may be less. This range in thickness is due mainly to a locally irregular contact of questionable conformity with the overlying St. Peter sandstone, as the basal contact is regular and gradational with the Trempealeau formation. Where the contact between the Prairie du Chien and St. Peter is not irregular, the Prairie du Chien is about 250 feet thick.

Examples of the range in thickness are shown by two groups of drill holes. About 2 miles north of the Montfort quadrangle (Agnew and others, 1953) the Prairie du Chien is 75 to 200 feet thick (fig. 20). Near the Crow Branch mine (Montfort quadrangle) the Prairie du Chien is 215 to 255 feet thick over a horizontal distance of 1,100 feet (Heyl and others, 1951, p. 7–8, 17–22). An inferred example of the irregular upper surface occurs along County Road I between sec. 13, T. 6 N., R. 1 W., and sec. 18, T. 6 N., R. 1 E., Monfort quadrangle, where the St. Peter sandstone is 130 feet thick above its contact with the Prairie du Chien. Drill holes and exposures near this place show the St. Peter to be about 50 feet thick and to have a regular and horizontal contact with the overlying Platteville. The irregularity is thus inferred along the contact of the Prairie du Chien with the St. Peter.

Irving (1877), Strong (1877), Trowbridge (1917, p. 177–182), Dake (1921), Thwaites (1923, p. 541), and Stauffer and Thiel (1941) argued that the irregular upper surface was an erosional unconformity at the top of the Prairie du Chien. None of the above workers, however, records a specific instance of truncated beds or a basal conglomerate.

Percival (1855), Hall and Whitney (1862), Chamberlin (1877, p. 268–290 and 138–140), Calvin (1894), Sardeson (1916), and Flint

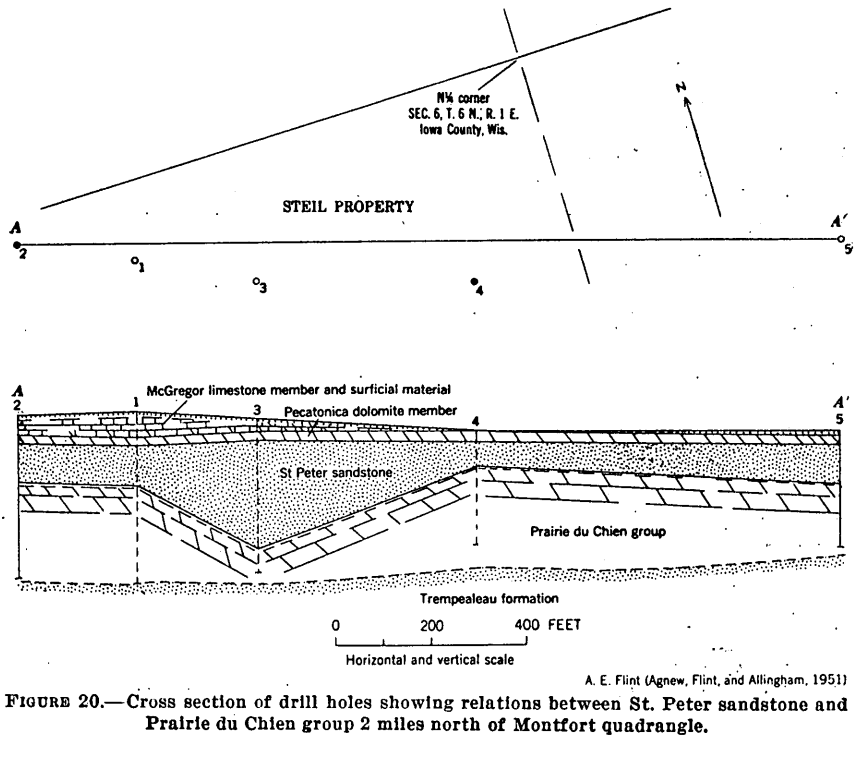

FIGURE 20.—Cross section of drill holes showing relations between St. Peter sandstone and Prairie du Chien group 2 miles north of Montfort quadrangle.

(1956) argued that the irregular upper surface was due to irregularities in deposition. Numerous outcrops and quarries north, west, and east of the mapped area were examined in detail by Flint (1956), who attributed relief on the contact of the Shakopee dolomite and the St. Peter sandstone to dome structures within the Prairie du Chien. No complete dome can be seen, but enough data can be found to establish the nature of the structure. Flint [1] also notes that:

The interior of the domes * * * display some of the characteristics of organic reefs, including alga structures, solution vugs, rehealed breccia, reef conglomerates, and quartz sand as a plaster in and around oblate cryptozoan masses.

Similar occurrences probably underlie the mapped area. The writer agrees with Flint that, in the mining district, the irregularity on the contact can be best explained by the compaction of lime muds over relatively incompressible reef structures.

MIDDLE ORDOVICIAN SERIES

ST. PETER SANDSTONE

The St. Peter sandstone of early Middle Ordovician age crops out in many of the deeper valleys and stands as well-jointed gray-weathering bluffs. This sandstone is named for exposures along the St. Peter River, now called the Minnesota River, in southern Minnesota. In the mapped area the St. Peter is a crossbedded, buff to white, friable, fine-grained to coarse-grained quartz sandstone. Individual grains are well rounded, and the larger grains are frosted. Sorting is poor in the upper few feet of the formation, but much of the lower strata is well sorted. Cement consists of calcite, dolomite, silica, or, where the rock is weathered, iron oxide. Where iron oxides are abundant, the sandstone is stained red or brown. Friability differs locally: some rocks can be crushed by hand; others are siliceous quartz sandstone. Case hardening gives durability to many natural outcrops and enables the St. Peter to form bluffs, but the sandstone is extremely friable in most recent manmade outcrops.

An iron-rich sandstone layer, several inches thick, occurs 3 to 5 feet below the top of the St. Peter. This layer crops out as a resistant ledge that serves as an excellent marker bed in many areas where exposures are poor. Green shale occurs in the upper few feet and reflects, in part, the gradational nature of the contact of the St. Peter with the Platteville. Green, maroon, or buff shales are found near the base, where the sandstone is abnormally thick (Agnew and others, 1956, p. 273).

[1] Flint, A. E., 1953, Stratigraphic relations of the St. Peter sandstone and Shakopee dolomite in southwestern Wisconsin: Ph. D. thesis, Chicago University.

Lead and zinc minerals have been reported in the St. Peter sandstone (Chamberlin, 1882, p. 417; Heyl and others, 1951, p. 5, 17), but none was seen in the course of the present work. Iron oxides are common, especially where the overlying Platteville, Decorah, and Galena formations contain lead and zinc deposits. The St. Peter is an important aquifer, because of its overall high permeability. It is also used as a pure sand for construction purposes.

The St. Peter is 40 to 65 feet thick and averages 55 feet thick in most outcrops and drill holes. Abnormally thick St. Peter sandstone, however, has been penetrated in drill holes in and near the mapped area (fig. 20), and approximately 130 feet of St. Peter sandstone is exposed along County Road I in sec. 13, T. 6 N., R. 1 W., and sec. 18, T. 6 N., R. 1 E., of the Montfort quadrangle. The increase in thickness is due to the irregular contact with the underlying Prairie du Chien.

Shale, in other than small amounts near the top, does not occur within the St. Peter where the formation is of normal thickness (40 to 65 feet), but varicolored shale in blebs, stringers, and lenses occurs in the basal part where the thickness of sandstone exceeds about 150 feet. To the St. Peter, the author assigns sandstone that is continuous with the main body of the St. Peter and that contains shale partings. Dolomite layers, below this sandstone, are properly assigned to the Prairie du Chien, as no bedded carbonate rock occurs in the St. Peter. Sandstone that underlies dolomite, whether similar to the St. Peter or not, should be considered as a sandstone in the Prairie du Chien or older formation. Differentiation of the St. Peter and the Prairie du Chien must be done by lithologic means, as fossil evidence is meager.

PLATTEVILLE FORMATION

H. F. Bain (1905) named the Platteville formation for exposures along the Little Platte River near Platteville, Wis., but he included in the Platteville some rocks now assigned to the Decorah formation. As now defined (Agnew and others, 1956, p. 274), the Platteville includes four members in southwest Wisconsin. These are, in ascending order, the Glenwood shale, the Pecatonica dolomite, the McGregor limestone, and the Quimbys Mill members. The Platteville is 50 to 62 feet thick in the Montfort and Linden quadrangles, and the range in thickness is due mainly to a regional east to west decrease in the thickness of the Quimbys Mill member. Generally within the mapped area, only the Quimbys Mill is ore bearing, although the upper few feet of the McGregor is of economic importance and in one place the entire Platteville contained ore.

GLENWOOD SHALE MEMBER

The Glenwood, lowermost member of the Platteville formation, was named by Calvin (1906) for exposures in Glenwood Township, Winneshiek County, Iowa. It is generally 1 foot to 1½ feet thick in the mapped area, although it is 4½ feet thick in a ravine in sec. 9, T. 5 N., R. 1 W., Montfort quadrangle. The Glenwood consists of green arenaceous and dolomitic shale with interbedded sandstone. Pyrite locally cements the sandstone and may also occur as disseminated crystals in the shale. The sand grains are well rounded, frosted, and similar to the sand grains in the St. Peter sandstone below.

At the type section in Glenwood Township, Iowa, the member is about 15 feet thick (Calvin, 1906, p. 74–75), and rests disconformably on the St. Peter sandstone. In the mapped area, however, the contact of the Glenwood with the St. Peter is transitional. No evidence suggesting a disconformity at this boundary is apparent in the many outcrops examined.

Smooth dull-black phosphatic pebbles and fossils occur near the top of the shale, and these, with the rounded quartz sand grains, continue into the lower 1 foot of the overlying Pecatonica dolomite member. These criteria indicate conformity between the upper Glenwood contact and the Pecatonica.

Good exposures of the Glenwood shale member are found in creeks of steep gradient and in small gullies where the shale makes a reentrant between the St. Peter sandstone and the Pecatonica dolomite member. Interstream areas, however, have few exposures. Springs commonly flow from open joints in the lower 1 foot to 4 feet of the Pecatonica, above the relatively impervious Glenwood. These springs and the boggy zones around them provide a fairly reliable means for locating the Glenwood shale member in covered areas.

PECATONICA DOLOMITE MEMBER

The Pecatonica member, referred to by earlier workers as the "quarry beds," was named by O. H. Hershey (1894) from exposures in northwestern Illinois. It consists of brown-weathering thick-bedded buff to gray dolomite of sugary or medium-granular texture. Individual beds average about 1 foot in thickness, although the upper 1 foot of the member is more thinly bedded. The Pecatonica maintains a thickness of 18 to 20 feet throughout the mapped area. Phosphatic nodules and pebbles and rounded quartz sand grains like those of St. Peter, and similar to those in the underlying Glenwood, occur in the basal 1 foot of the Pecatonica. Fossils, mostly gastropods, are common but poorly preserved. The thick beds in the Pecatonica contrast sharply with the thin-bedded gray limestone at the base of the overlying McGregor limestone member.

Many of the limestone and dolomite beds in the mining district were favorable hosts for the deposition of lead, zinc, and iron sulfide and were easily altered by the mineralizing solutions. These solutions had little effect on the Pecatonica, and the sulfide minerals were deposited only in trace amounts. Sulfide minerals are generally limited to relatively scarce iron sulfide that fills vugs; the only known exception in the mapped area is the Crow Branch mine (sec. 22, T. 5 N., R. 1 W.), where all the beds above the St. Peter sandstone contain lead, zinc, and iron sulfides.

M'GREGOR LIMESTONE MEMBER

The McGregor limestone member conformably overlies the Pecatonica member. It was named by Kay (1935, p. 286) for exposures near McGregor, Iowa, but in the mining district these beds are better known locally as the "Trenton lime." Within the mapped area the McGregor is 18 to 31 feet thick, and, with local exceptions, can be divided into two units, a lower limestone unit with subordinate amounts of dolomite and an upper limestone and dolomite unit. These are the Mifflin of Bays (1938) and the Magnolia of Bays and Raasch (1935, p. 298), named for exposures near Mifflin and Magnolia, Wis.

Typically, the lower part of the McGregor, or Mifflin of Bays, consists of 12 to 18 feet of dense limestone. It is light gray with red flecks, sublithographic, and very fossiliferous. Beds are generally 1 inch to 2 inches thick, characteristically wavy, and contain gray shale partings along the bedding planes. This unit weathers into thin, smooth, chalky-white plates and is partly or completely dolomitized locally; where it is dolomitized, it is brownish gray and coarser grained.

The upper part of the McGregor, or Magnolia of Bays and Raasch (1935), consists of 12 to 18 feet of thin-bedded dolomite and limestone. Variations in thickness of both units are complementary within the McGregor member. The upper part of the McGregor near the east side of the Linden quadrangle is mainly dolomite with minor limestone, whereas on the west side of the Montfort quadrangle the upper part is mainly limestone with minor dolomite. This change is progressive and represents a facies change instead of effects of mineralizing solutions. The limestone is light gray marked by darker gray mottling, fine to medium grained, and less fossiliferous than the lower unit. Dolomite in the upper part of the McGregor is light yellowish brown with green tinges and has a more sugary texture than limestone of the McGregor. The thin, brown-weathering dolomite beds are highly distinctive in outcrop. The uppermost 2 to 3 feet of the McGregor is locally sublithographic limestone or dolomite of greater density and more massive bedding than the beds below. Except for a difference in color and lack of carbonaceous shale partings, the upper 2 to 3 feet closely resemble beds in the overlying Quimbys Mill member.

Many well-exposed sections of McGregor show a 1-inch bed of coquinoid limestone that separates the upper and lower parts of the McGregor. This limestone is dense and purplish gray but weathers white with a hackly surface.

Solution of limestone with attendant thinning and destruction of rock characters is common in the upper part of the McGregor in mineralized areas. In an exposure in a gully wall in the NW¼NW¼ sec. 20, T. 6 N., R. 1 E., 15 feet of limestone and dolomite was reduced to 4 feet of stiff ocherous clay. Mineralizing and dissolving solutions appear to favor the upper part of the McGregor to the nearly complete exclusion of the lower part in the mapped area.

QUIMBYS MILL MEMBER

The uppermost unit of the Platteville formation is the Quimbys Mill member, known locally as the "glass rock." It was named by Agnew and Heyl (1946, p. 1585) from an exposure at Quimbys Mill, near Shullsburg, Wis. Where the member is unaltered, it is probably the most distinctive unit in the district.

Typically, the Quimbys Mill is a light-brown to dark-purplish-brown, dense, brittle, sublithographic limestone that breaks with a conchoidal fracture. Fossils are common but not abundant. The Quimbys Mill contains brown argillaceous and carbonaceous material intimately combined with the carbonate, and thin brown shales along bedding planes. A dark-brown, thinly laminated carbonaceous shale, called "calico" in district terminology, is at the base. This shale marks the contact with the underlying McGregor, and it generally thickens from a normal one-half inch to several inches in zones of alteration. Where the Quimbys Mill is more than 5 feet thick, a thin chert layer may occur about one-half foot below the top. The bedding is regular and averages about 4 inches thick. Light-gray-weathering, subrounded blocks of Quimbys Mill form easily recognized float on hillsides and in streams below the Quimbys Mill.

Regionally, the Quimbys Mill thins to the west, and the member is reduced uniformly from 11 feet at the east border of the Linden quadrangle to 1½ feet at the west edge of the Montfort quadrangle. This westward thinning is probably a depositional feature.

The member is entirely a limestone along the west side of the mapped area, but it becomes progressively more dolomitic eastward, and along the east edge the dolomite to limestone ratio is approximately one to one. This increase in dolomite represents a change from a limestone to a dolomite facies. The dolomite of the Quimbys Mill is coarser in texture and locally lighter in color than limestone of this member.

The Quimbys Mill, because of its hard brittle character, fractures easily and thus provides access for mineralizing and dissolving solutions. These solutions partly or wholly dissolve the carbonate fraction and concentrate the shale and argillaceous material. The altered rock is thinner and darker brown than unaltered rock and is banded with blebs and stringers of brown shale. Oddly enough, a substantial thickness of Quimbys Mill always occurs in ore deposits, whereas in other areas, well removed from known ore deposits, the Quimbys Mill is reduced locally to a few inches of ocherous clay or brown shale. These extreme cases of solution-thinning are confined to elongate zones of unknown length and less than 100 feet wide that are probably related to joint systems that act as channels for solutions.

Agnew and others (1956) and Chamberlin (1882) report a regional disconformity at the contact of the Platteville and the Decorah. Evidence for this disconformity is a corrosion surface and small pits filled with material like that of the Decorah formation at the top of the Quimbys Mill. Within the mapped area, this surface is not confined to the upper bed; bedding planes within the Quimbys Mill may also show corrosion and pits. In the eastern part of the area, where the overlying Spechts Ferry shale member of the Decorah contains no limestone, a few inches of clay and shale lie on the Quimbys Mill. The base of the Spechts Ferry is a spring zone and commonly the clays and shales contain iron minerals or calcite. Consequently, a solution-pitted surface and a ferrous crust appear on the top bed of the Quimbys Mill. In the Montfort quadrangle, where limestone of the Spechts Ferry rests on the Quimbys Mill, the veneered upper surface was not observed although corrosion surfaces and pits exist along some bedding planes in the Quimbys Mill. As a result of these observations, the author believes that stronger criteria are needed to establish a disconformity at the top of the Platteville formation.

DECORAH FORMATION

The Decorah formation, named by Calvin (1906, p. 60, 84) from exposures in the city of Decorah, Iowa, includes three members. These are, in ascending order, the Spechts Ferry shale, the Guttenberg limestone, and the Ion dolomite members.

In this area the Decorah is 21 to 38 feet thick; much of this range is due to thinning by mineralizing solutions. Unaltered Decorah is 31 to 38 feet thick, and this range is due to regional changes in thickness in the three members.

SPECHTS FERRY SHALE MEMBER

The Spechts Ferry, basal member of the Decorah formation and known as the claybed in the mining district, overlies the Quimbys Mill member of the Platteville formation. The member is named from exposures at Spechts Ferry, Iowa (Kay, 1928), and, as originally defined, was included in the Decorah formation. Later, however (Kay, 1935, p. 286–287), the Spechts Ferry was transferred to the Platteville formation. Agnew [2] reassigned the Spechts Ferry to the Decorah formation.

The Spechts Ferry consists of thin beds of blocky brown and green shale, light-gray to light-purplish-brown limestone, and white to yellow bentonite, which aggregate 10 inches thick at the east edge of the area and 5 feet thick on the west border. Farther west, at Spechts Ferry, the member is 8½ feet thick. It thins to a featheredge a few miles east of the Linden quadrangle. This west to east thinning is opposite to the east to west thinning of the underlying Quimbys Mill.

The limestone-shale ratio is about 1 : 1 where the Spechts Ferry is thin (1 foot to 2 feet), but a limestone-shale ratio of about 4 : 1 is common where the member is 5 feet thick. In some mineralized areas the carbonate fraction is dissolved and only shale and bentonite remain. These places are usually spring zones for ground water following the course of former mineralizing and dissolving solutions.

A 4- to 6-inch bed of dense very fine grained light-bluish-gray limestone that resembles the Quimbys Mill in texture but resembles the limestone of the Spechts Ferry in color directly overlies the Quimbys Mill. This limestone thins from west to east in the mapped area and has been assigned to the Spechts Ferry (Agnew and others, 1956, p. 265) because it follows the convergence of the Spechts Ferry member. However, this bed may correlate with Weiss' Caramona member of the Platteville formation in Minnesota (Weiss and Bell, p. 62–63).

A plastic white to yellow clay in the Spechts Ferry was identified by Allen (1932) as bentonite or metabentonite that is probably derived from volcanic ash. The upper part of the Spechts Ferry

[2] Agnew, A. F., 1948, The Upper and Middle Ordovician strata of the upper Mississippi Valley, a restudy: Ph. D. thesis, Stanford University.

member contains a 1- to 6-inch bed of white to yellow bentonite that is continuous in the area.

The Spechts Ferry contains phosphatic nodules and fossils which can also be found in the lowermost one or two beds of the overlying Guttenberg member. Where the Spechts Ferry is relatively thick, the nodules occur very near the top; where it is thin, they may occur anywhere within the member. These nodules have been interpreted by Pettijohn (1926, p. 373) as residuum on a corrosion surface or diastemic plane as a result of submarine solution. The phosphatic limestone beds at the contact of Spechts Ferry and the Guttenberg do not have particular significance, in the author's opinion, to stratigraphic breaks within the area.

GUTTENBERG LIMESTONE MEMBER

The Guttenberg member of the Decorah formation, called "oil rock" by the miners, was named by Kay (1928, p. 16) for exposures near the town of Guttenberg, Iowa. It is typically a hard, thin-bedded, light-pinkish-brown, very fossiliferous limestone and dolomite of fine grain. Brown argillaceous material, disseminated in the limestone, and brown carbonaceous shales are present on bedding planes. It is 11 to 14 feet thick throughout the mapped area except in zones where solution and consequent thinning has occurred.

In the Montfort quadrangle the Guttenberg is limestone, but near the west edge of the Linden quadrangle a dolomite facies begins. The ratio of dolomite to limestone increases eastward until an approximate 1:1 ratio is reached at the east border of the Linden quadrangle. Silica locally replaces limestone and shale within ore bodies or marginal to ore bodies, and preserves all rock textures. Dolomite replacement obscures the original limestone textures and makes the rock granular or sugary.

The Guttenberg tends to be more poorly exposed than either the underlying Quimbys Mill or the overlying Ion member. It is generally best exposed in areas of rapid stream erosion or in recent roadcuts and is an easily recognizable unit. However, in isolated outcrops it is similar, in gross aspect, to the thin-bedded lower part of the McGregor limestone member.

The basal contact of the Guttenberg member is well defined by a sharp change from the greenish shale and limestone of the Spechts Ferry to the brown shale and limestone of the Guttenberg. The contact with the overlying Ion member is transitional, and in a 1- to 2-foot zone the rocks change from very fine grained pinkish-brown limestone of the Guttenberg to a coarsely crystalline gray-blue relatively massive dolomitic limestone or granular dolomite that contains stringers and blebs of gray-green shale.

In scattered and generally small areas throughout the mapped area, the Guttenberg member is thinned by dissolving solutions, but the extent of such areas is largely unknown because of poor exposures and lack of drilling data. The thinned zones are elongate and are probably related to fracture systems. The Guttenberg, in ore deposits seen by the author, is generally reduced to about 50 percent of its normal thickness. However, mineral deposits are not found in all places where the Guttenberg is thin.

The limestone in the Guttenberg is more susceptible to removal by solutions than other rocks in the mapped area. The solutions dissolved and removed the carbonate, but left the intercalated shale and argillaceous material contained in the limestone. As a result of removal by solution, the limestone beds become nodular and wavy, and, in advanced stages of solution thinning, the unit resembles a breccia. The shale becomes darker and softer as solution progresses. A 50-percent reduction in thickness is not uncommon; in a few places the entire carbonate fraction is absent, and the Guttenberg consists entirely of brown shale. This shale contains enough petroliferous material to ignite (when dry) with a match. The Quimbys Mill member of the Platteville formation is usually thinned in areas where the Guttenberg is thinned.

Some earlier observers (Bain, 1905, p. 21; Cox, 1911, p. 431) reported differences caused by solution of rock units as depositional irregularities or as a change from limestone to shale facies. This interpretation led to confusion in the stratigraphic relations between the Quimbys Mill, Spechts Ferry, and Guttenberg members.

ION DOLOMITE MEMBER

The Ion member was named and described by Kay (1929, p. 650) for exposures near Ion, Allamakee County, Iowa. Drilling data and outcrop studies show unaltered Ion to be from 18 to 22 feet thick in the mapped area.

In the mapped area, and generally within the mining district, the Ion can be divided into two units. The lower unit, locally called the "blue," is 6 to 8 feet thick and conformably overlies the Guttenberg member. It consists mainly of medium-bedded, dark-bluish-gray, mottled, coarsely to finely crystalline, fossiliferous dolomitic limestone. Finely disseminated green shale and interbedded gray-green to blue-green shales constitute about 10 percent of the unit. The base of the lower unit is a 1- to 2-foot zone in which the greenish shales and crystalline blue-gray dolomitic limestone of the lower part of the Ion grades into the brown shale and pinkish-brown limestone of the Guttenberg. Phosphatic nodules, quartz sand grains, and rarely, chert nodules are present near the base. Dolomite of diagenetic type replaces much of the lower part of the Ion in the eastern part of the area; and, where the unit is dolomitized, it is granular instead of crystalline.

The upper unit, called the "gray," generally is 12 to 14 feet of medium-thick to massive-bedded dolomite and dolomitic limestone, although one exposure in the Montfort quadrangle (sec. 10, T. 5 N., R. 1 W.) contains dark-pinkish-gray, finely crystalline, thinly bedded limestone. The "gray" is light- to medium-gray, contains few fossils, and is coarsely crystalline. Gray-green shale inclusions appear as blebs and stringers throughout the upper unit but are particularly numerous in the top 1 foot to 2 feet. Interbedded shales, however, are a minor component of the "gray." The upper part of the Ion grades into the overlying Galena dolomite without a suggestion of disconformity.

The Ion member is commonly thinned by solution and locally is reduced to one-half its normal thickness. This thinning takes place mainly in limestone and dolomitic limestone; the lower unit, which contains more limestone than the upper unit, may be reduced to 2 or 3 feet of gray-blue clay, whereas the upper unit is relatively unaffected by solution thinning.

GALENA DOLOMITE

The Galena dolomite was named by Hall (1851, p. 146) from exposures near Galena, Jo Daviess County, Ill. The Galena has a full thickness of between 215 and 230 feet in the mining district, but erosion has removed all but the lower 125 to 140 feet in the Montfort and Linden quadrangles. West of the mapped area the Galena contains both limestone and dolomite, but in the mapped area the Galena contains only dolomite.

The Galena is divided into three members, which, in ascending order, are the Prosser cherty member (Ulrich, 1911a, p. 257), the Stewartville massive member (Ulrich, 1911b, pl. 27), and the Dubuque shaly member (Sardeson, 1907, p. 193). The Prosser member is at least 140 feet thick; but only the lower 100 to 105 feet contains chert and is the cherty unit described below. The Stewartville and Dubuque members are absent in the mapped area. The members are separated mainly on the basis of faunal criteria, but this subdivision of the Galena is not practicable in the mining district because of the difficulty in recognizing faunal zones in drill cuttings and in outcrops. Agnew and others (1956, p. 266–267) divided the Galena into two lithologic units: a lower cherty unit about 105 feet thick, which contains dolomite and chert; and an upper noncherty unit about 120 feet thick, which contains only dolomite. This two-fold division is reliable and easy recognized, both in drill cuttings and in outcrops.

Cherty unit

The cherty unit has been subdivided by Agnew and others (1956, p. 296–297) into four lithologic and faunal subunits, which are consistent in the mining district. These subunits are of great value in outcrop study but of considerably less value in the study of churn drill cuttings because of chert salting and destruction of fossil criteria. Drill-hole data show that the cherty unit is consistently 100 to 105 feet thick.

The lower subunit, called zone D, conformably overlies the Ion member of the Decorah formation. It is a light-brown dolomite, medium crystalline to coarsely granular, medium thick bedded, and argillaceous. Green shale blebs, stringers, and partings are common only in the lower 2 feet, but the entire unit may locally have a greenish tinge. The brownish color, in addition to the more massive bedding and vuggy weathering, distinguishes it from the light-gray Ion beneath. This unit is 8 to 10 feet thick and does not contain chert. The top of zone D is marked by the lowest chert layer in the Galena dolomite.

Zone C consists of 12 to 15 feet of medium-crystalline, grayish-brown dolomite and interbedded chert. It is similar to zone D except for its color and its chert content. The chert occurs mainly as mottled gray and white cryptocrystalline nodules from 2 to 12 inches in diameter and from 1 inch to 3 inches thick. Layers of nodules lie along, or parallel to, bedding planes at ½- to 1-foot intervals in the lower half of zone C but are more widely spaced in the upper part. In some exposures the chert forms continuous layers, from 1 inch to 3 inches thick, as well as nodules. Where the dolomite is mineralized with lead, zinc, or iron sulfides, the chert contains disseminated iron sulfides. Where the iron sulfides are oxidized, the chert is light- to dark-yellowish-brown; but, where the disseminated iron sulfides are not oxidized, as in ore bodies or drill cuttings below the water table, the chert is dark blue gray.

The chert has been removed from zone C by solutions in a quarry in the NE¼SE¼ sec. 21, T. 6 N., R. 2 E., Linden quadrangle, and only a few thumbnail-size pieces of friable white "cotton rock" remain. However, absence of chert in this zone is a local phenomenon and examples of dissolved silica are rare in the mining district. The rock in this quarry was pervasively mineralized by iron-rich solutions, and these solutions possibly dissolved the chert. *Receptaculites oweni* Hall may be present, but are rare in zone C.

Zone B, which overlies zone C, is marked by abundant *Receptaculites* and scarce chert layers. It is 10 to 15 feet thick and, except for a general absence of chert, is similar to zone C. This unit is also known as the lower *Receptaculites* zone. The contact between zone B and zone C is not sharp because both chert and *Receptaculites* occur through a few feet of the contact region. However, this boundary is one of the most useful markers in the Galena.

Zone A consists of 70 to 75 feet of thinly to massively bedded dolomite and is nearly identical with the three lower zones. It is poorly exposed in the mapped area, and few drill holes passed through the complete thickness, as the surface of much of the area is cut in this zone. The upper 5 to 7 feet of zone A contains sparse chert, above which chert is absent and below which chert is abundant. The top of this sparse chert zone, locally called the "thin top of chert," is the true top of the cherty unit, although it is often overlooked in drill cuttings owing to the scarcity of chert. Agnew and others (1956, p. 296–297) subdivided zone A into four general units to assist in identification and correlation as follows:

Subdivisions of zone A of cherty unit of Galena dolomite	*Thickness (feet)*
Unit 1. Dolomite, light-buff, massive above to thin-bedded below; many chert bands; thin shale or shaly zone, locally with bentonite, at base	32
2. Dolomite, thin-bedded, as above; chert rare, *Receptaculites* and *Ischadites* sparse	6
3. Dolomite as above, chert common	6
4. Dolomite, light-gray to drab, thick-bedded, sparsely cherty near top but chert common near base; *Receptaculites* and *Ischadites* present sparsely in a thin zone near middle	26
Total, zone A	70

The bentonite in unit 1 was not seen in the mapped area.

Noncherty unit

The noncherty unit is 115 to 125 feet thick, caps the highest parts of the area, and includes the upper, noncherty part of the Prosser cherty member (zone P), the Stewartville massive member, and the Dubuque shaly member in ascending order (Agnew and others, 1956, p. 297–298). The upper two subdivisions are absent owing to erosion, and a possible 40 feet of the noncherty unit remains. However, the maximum thickness is probably less than 30 feet as 12 to 20 feet of residual soil and loess tops the area underlain by this unit.

Zone P is 35 to 40 feet thick and consists of light-yellowish-brown medium-coarse to coarse-grained crystalline to granular noncherty dolomite in thin to massive beds. In weathered outcrops in adjoining quadrangles the rocks are brown with a vuggy, deeply pitted surface that masks the bedding planes and gives the effect of greater massiveness. Outcrops of the noncherty unit are rare in the mapped area and are restricted to a few square feet of exposure in the headwater areas of creeks.

POST-GALENA DEPOSITS

The upland surface of the area is covered by 2 to 4 feet of calcareous silt called loess that was blown onto the uplands from the Mississippi River bottom probably during Pleistocene time (Hole and others, 1952). Loess was also deposited on the steeper slopes but has been mostly removed by erosion.

Beneath the loess, the subsoil, commonly from 2 to 5 feet thick, consists of reddish-brown clay and dolomite, limestone, and chert fragments. This subsoil is as much as 20 feet thick in places where mineralizing solutions have accelerated rock decomposition. The chert fragments are white to dark gray or reddish brown. The white to dark-gray chert was derived mainly from the cherty unit of the Galena dolomite and the reddish-brown chert was derived mainly from cherty dolomite of Silurian age. The reddish-brown clay is argillaceous material that remains when the carbonate part of the bed rock is dissolved by ground water. The color is due to iron oxides that occur in most rocks in the mining district.

STRUCTURE

The major structural features influencing the zinc-lead district are the Wisconsin dome to the north, the Wisconsin arch to the east, the Forrest City basin to the west, and the Savannah anticline in northwestern Illinois (Heyl and others, 1959). These structural features outline a roughly rectangular basin of about 9,000 square miles in which rocks are only slightly warped.

Geologic structure of the Montfort and Linden quadrangles is shown in plate 8 by structure contours at the top of the Platteville formation. The points on which the structure is based are shown by drill-hole symbols and by small crosses at exposures; all outcrop data is shown, but only the drill holes used in structural interpretation appear on the maps. Vertical control for outcrop data and drill-hole collars is accurate to ± 1 foot. Differences in altitude along a contact are assumed to represent folds unless fault relations can be clearly established. This assumption is necessary because of poor or scarce exposures, but it is probably valid.

Structure contours at the top of the St. Peter sandstone and on members of the Platteville formation are similar to those drawn at the top of the Platteville. The structure is interpreted as tectonic, although other causes are possible, such as initial dip or irregularities on the Precambrian surface. Structure shown by the Decorah and Galena formations may not reflect the structure at the top of the Platteville because the Decorah and Galena are locally thinned by mineralizing solutions whereas thinning is uncommon in beds older than the Quimbys Mill in the mapped area. Synclines or basins on the order of 10 to 24 feet of relief and less than a mile long possibly reflect solution, or tectonics, or a combination of the two.

The dominant structural feature in the Montfort and Linden quadrangles is a southward dip of the strata at 15 to 17 feet per mile, although this dip is interrupted by two large anticlines near the south boundary of the area and by secondary folds. The large folds, in conjunction with the southward-dipping rocks, form a broad irregular trough that includes the Linden and part of the Mifflin mining areas. The simple configuration of structure contours in this trough, as shown by dashed lines, is due more to a paucity of data than to an actual flat-lying attitude of the rocks.

FOLDS

The largest and best defined folds are in the south one-half of the mapped area. The fold shown in the southwest corner of the Montfort quadrangle has 110 feet of structural relief. The strike of this fold changes from N. 45° W. at the south border of the Montfort quadrangle to due west at the west border of the Montfort quadrangle. This fold, part of the Mineral Point anticline (Heyl and others, 1959), is asymmetric and dips more steeply on the north flank than on the south flank.

An anticline that plunges west-southwestward and has a maximum of 100 feet of structural relief on the north flank, trends east-northeastward and is 1 to 2 miles north of the south border of the Linden quadrangle. The west end of the fold is interrupted by faults, and the east end extends past the east border of the mapped area. Northeastward-trending secondary folds occur south of this anticline but are eastward-trending on the north side and essentially parallel to the strike of the anticline.

Folds of 10- to 30-foot amplitude and diverse trend interrupt the southerly regional dip in the north one-half of the area. Some of these folds form elliptical basins and domes, but the exact shapes and sizes of most of these structures are not known as outcrops and drill holes are too widely spaced to do more than indicate scattered high and low points. The relation of the basins and domes to the minor folds is not known.

Several of the basins are in areas where rocks are known to be thinned by mineralizing solutions, but some basins have more structural relief than can be accounted for by solution alone. The well-defined basin of about 30-foot closure in secs. 15 and 16, T. 6 N., R. 1 E., Linden quadrangle, shows beds dipping at 5° toward the center of the structure. This structure is thought to be primarily tectonic but deepened by thinning by solution. The smaller basins, of from 10- to 15-foot closure and of differing degree of thinning by solution are regarded as scaled-down versions of the above example. The low domes are regarded as high points isolated on the axes of anticlines by obscure cross folding. So far as is known, these domes do not overlie thinned strata.

The author believes that the larger folds are probably a surface reflection of premineralization faults in the Precambrian basement complex; and the smaller folds are related in part to these large folds, and in part to thinning by solution of rock units. However, both primary and secondary folds are thought by Heyl and others (1959) to have been formed by compressional forces acting from the south and southwest, and to a lesser extent from the east, during one general period of folding. The steeper north flanks of the larger folds are also believed to have resulted from northward-directed deformational forces.

FAULTS

The two large faults in the south-central part of the Montfort and Linden quadrangles and three minor faults in secs. 19 and 30, T. 6 N., R. 1 E., sec. 22, T. 6 N., R. 1 E., and sec. 22, T. 5 N., R. 1 W., are the only faults of more than a few feet displacement observed in the mapped area.

The north fault in the south-central part of the area has been named the Mifflin fault (Heyl and others, 1959) for the village of Mifflin, a mile to the south. It has a maximum vertical displacement of about 80 feet, strikes about N. 50° W., and judging from vertical joints nearby, the fault plane is approximately vertical. No evidence of horizontal offset is apparent in outcrops or drill holes along the strike. The fault plane is not exposed, but the trace is determined by outcrops along the bank of the Pecatonica River in the SE¼ sec. 22, T. 5 N., R. 1 E. Zone C of the cherty unit of the Galena dolomite is at the same altitude as the upper part of the McGregor limestone member of the Platteville formation. These two outcrops are about 80 feet apart. The trace can also be approximately located from closely spaced exposures of the Decorah formation along the Pecatonica River in the northern part of sec. 21, T. 5 N., R. 1 E.

The south fault has a vertical displacement of 70 to 80 feet, an inferred vertical dip and strikes east. The trace of the fault can be approximately located along the Pecatonica River between secs. 27 and 28, T. 5 N., R. 1 E. Here zone C of the Galena crops out at flood-plain level north of the river, and the McGregor member of the Platteville is exposed at a higher elevation in a road ditch 800 feet to the south. The attitude of nearby rocks is essentially horizontal. The west end of the fault was located from records of drilling near the Coker mine. The east half of the block between the faults is interpreted as a synclinally folded graben, although outcrops and drill holes are so scattered that other interpretations are possible. There is no evidence of horizontal movement along this fault.

Heyl and other (1959) suggest that the Mifflin fault extends farther to the southeast, beyond the Okay mine, but the author does not believe that such an interpretation can be supported by field evidence. The south fault, however, may extend as much as 3 miles farther east along the north flank of the large anticline in the Linden quadrangle. About 30 feet of relief on this structure is based upon widely spaced drill holes and outcrops, and it is possible that the fault passes between control points.

The small fault in secs. 19 and 30, T. 6 N., R. 1 E. (pl. 8), is near the headwater of Badger Hollow Creek and strikes through a group of early lead diggings. Exposures of the Platteville and Decorah formations show that the fault has a maximum displacement of about 15 feet. The degree and direction of dip of the fault plane is unknown. A vertical fault of 6- to 8-foot displacement in the lower beds of the McGregor is exposed in a creek bank in sec. 22, T. 6 N., R. 1 E. The third minor fault is assumed to strike parallel to the trend of the Mineral Point anticline in sec. 22, T. 5 N., R. 1 W. It offsets upper beds of the Platteville and lower beds of the Decorah about 10 feet vertically; and, like the fault in Badger Hollow, it strikes through a group of early lead and zinc diggings in a heavily mineralized zone.

A few faults of 5 to 20 feet displacement without gouge, drag folding, or surface expression were observed in limestone quarries and in outcrops in areas adjacent to the quadrangles. Covered areas within the mapped area probably conceal similar faults that, for lack of evidence, were interpreted as folds.

No faults that could be attributed to tectonic causes were observed in the few zinc mines accessible to the author in the mapped area. Faults of a few inches displacement were observed, but the author believes that they are due to sagging and breaking of strata after thinning by solution. Many of these breaks are confined within the mine workings, and both ends of the breaks can be seen where they are cut off by unaltered beds. Heyl and others (1959), however, believe most of the small faults associated with zinc ore bodies are tectonic but later opened in places as a result of solution sag.

JOINTS

Vertical joints in the Montfort and Linden quadrangles form two major sets. Joints in one set strike between N. 20° E. and N. 20° W., and joints in the other set strike between N. 80° E. and S. 80° E. A fewer number of joints in the mapped area strike N. 45° to 55° W., and N. 45° to 55° E. The northward- and eastward-trending joints, where they occur in the Galena dolomite, are more likely to contain lead ore than those of different strike. The occurrence of lead ore in these joints is probably due to slight brecciation in the joint that provided access for solutions.

Some of the vertical joints near the large anticline in the Linden quadrangle strike at approximately 45° to the fold axis and are interpreted as conjugate joint sets. Some of the joints near the Mineral Point anticline may also form conjugate sets. However, many of the mapped joints do not appear to be related to the folds shown on the maps.

Inclined joints are not common in the Linden and Montfort quadrangles and where found cannot be easily related to folding. They are nearly always tight and are probably the result of shear forces. Many of the joints shown to be vertical on the maps were seen in plan only on creek bottoms or in small exposures. Some of these are probably inclined joints.

AGE OF DEFORMATION

Silurian rocks are the youngest rocks in the mining district, and they are structurally similar to the underlying Ordovician rocks. Thus, the age of the deformation can be given only as post-Silurian. Heyl and others (1959), who studied the regional structures of the mining district, believe that the deformation in the mining district may be related to the closing phase of the Appalachian orogeny during the late Paleozoic time.

MINERAL DEPOSITS

The mineral deposits in the Montfort and Linden quadrangles consist of two separate types. Gash-vein deposits (Hall and Whitney, 1858, p. 437–438) contain mainly lead ore and occur in vertical joints. Pitch-and-flat deposits contain mainly zinc ore and occur in inclined veins and veins parallel to the bedding. Figure 21 shows an idealized cross section of the types of deposits.

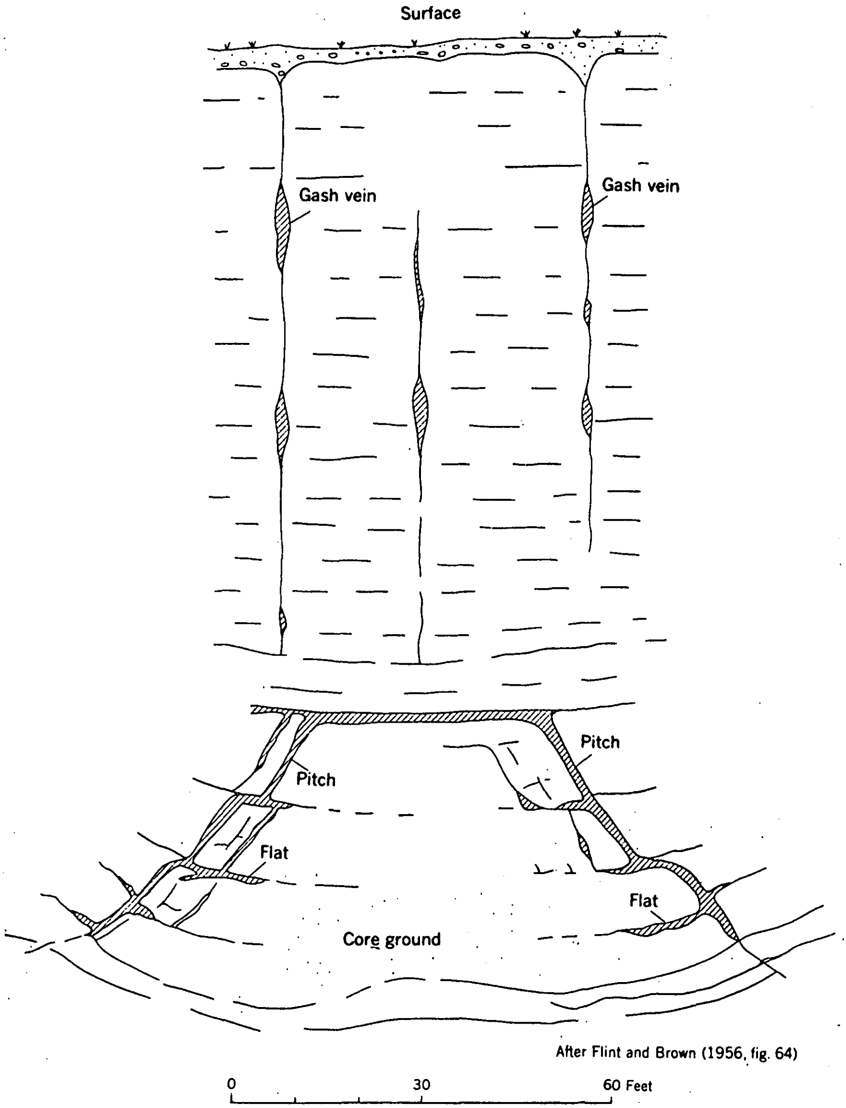

FIGURE 21.—Diagram showing idealized cross section of gash-vein and pitch-and-flat deposits.

GASH-VEIN DEPOSITS

DESCRIPTION

Gash-vein deposits are numerous in the mapped area and generally consist of irregular podlike masses of galena and subordinate amounts of smithsonite, spaced along vertical joints in the Galena dolomite. The large masses are connected by a more or less continuous film of ore minerals along a single joint. A number of closely spaced parallel joints containing ore is known as a "range." Particularly rich deposits may occur at intersections of joints where, owing to increased area exposed to solution, large openings are formed.

Galena forms discrete crystals and large crystalline masses weighing as much as one ton. Cubic galena is the common form, but locally octahedral galena grows on cubic crystals. In places the crystals form aggregates that contain individual crystals as much as 8 inches on a side. The galena occurs as replacement crystals in porous rock along joints or "openings," as filling or cement in brecciated zones, and as loose galena in residual clay and dolomite sand which fills some "openings."

Galena also occurs in residual deposits that are closely related to gash-vein deposits. Galena is heavy and resistant to weathering, and it is selectively concentrated on bedrock as rock containing gash veins is removed by erosion.

Smithsonite, an oxidation product of sphalerite, occurs in gash-vein deposits above the water table; below the water table the sphalerite is unaltered. Smithsonite may occur as dull light-yellowish-brown cellular masses containing residual sphalerite and segregations of dolomite wall rock; as a thin coating on galena crystals; or as pseudomorphs after calcite. Smithsonite also occurs as a variety known as rock bone in fractures or openings, and so closely resembles the enclosing Galena dolomite that it can be distinguished from it only by its greater weight and hardness.

"Openings" in the mining district range from small brecciated zones along a joint to large caverns. In the Montfort and Linden quadrangles, openings are of the following types: a zone along a joint where the wall rock has been made soft and spongy by mineralizing solutions or ground water; or a zone along a joint from which the original rock has been entirely dissolved and which is filled by rock breccia, dolomite sand, and ocherous clay. These zones are usually 1 to 10 feet wide, 1 to 10 feet high and several hundred feet long; however, they may be as much as 30 feet wide, 40 feet high and 1,000 feet long. In rare cases, openings are empty, but generally they are filled either with softened wall rock or with rock debris and clay. They may or may not contain ore.

Breccia along joints is of both tectonic and solution type. Tectonic breccia probably formed first owing to slight shearing along the joint. This fracturing gave the joint a favored position with regard to later solution and deposition of sulfide minerals. Solution breccias were formed both before, during, and after mineralization. Premineralization solution breccia consists of dolomite wall rock that has been eroded along joints and cross fractures by ground water. The voids and channels thus formed were further dissolved and filled with sulfides by ore solutions. Breccia of this type resembles tectonic breccia in appearance but differs from tectonic breccia in its spatial relation within the joint. Postmineralization solution breccia consists of intermixed residual clay, dolomite fragments, dolomite sand, and locally, galena. These collect on the floor of openings as ground water dissolves wall rock along joints.

The openings are in stratigraphically favorable zones and several may occur, one below the other, along a joint. The author was unable to establish the exact stratigraphic position of the most favored zones in the mapped area. However, in gash-vein deposits in adjacent areas the most favored zones are near the top of zone A of the cherty unit of the Galena dolomite, near the middle of zone A, and in zone B of the cherty unit. These openings probably are due to subtle differences in chemical composition or porosity of some beds.

Gash-vein deposits in the area were mined from 1830 to 1900, but since 1900, few attempts have been made to locate and mine new deposits. The ore was mined by digging small pits, which intersected concentrations at the base of the soil in residual deposits or by closely spaced shafts, which penetrated bedrock containing the gash veins. These shafts were connected by short drifts along the joint. The extent of these early workings varied considerably; some gash veins or ranges were followed more than a mile and contained ore the entire distance. Other joints were mined for less than 100 feet. All the early mine workings were above the water table, as the primitive pumps used could not cope with the heavy flow of water in cavernous dolomite.

Areas where lead pits and shafts can be seen in the field are shown by dots on the maps. Other areas where lead was mined, however, have been reconverted to farm use, and no trace of the old lead pits can be seen.

STRUCTURAL RELATIONS

Gash-vein deposits are controlled by joints in the Galena dolomite and in the mapped area mainly trend eastward or northward, although some deposits are in joints that strike northwest or northeast. Ore is more likely to occur in joints that contain breccia than in those with smooth walls.

Gash-vein deposits, so far as can be determined, are most common in areas of slight deformation. The relation of the small, tectonic folds to the gash-vein deposits is not known; however, the flanks of these folds dip 3° at most, and quite possibly, there is no relationship. Extensive northward-trending lead ranges along the Pecatonica River in secs. 5, 6, 7, and 8, T. 5 N., R. 2 E., Linden quadrangle, are not influenced by the eastward-trending structure.

A few gash-vein deposits near Linden outline underlying zinc deposits, although such a relationship is probably not valid in other parts of the mapped area. The relationship of gash veins to zinc deposits can be illustrated by the Mason mine at Linden. When this deposit was first opened, galena was mined from a range that consisted of three parallel gash veins in the cherty unit of the Galena dolomite. At depth, probably near the top of the Decorah formation, these gash veins joined a common flat. From this flat, pitches extended downward to the Quimbys Mill member, where they joined a second large flat. The ratio of lead to zinc in the upper part of the mine was 7 to 1; in the lower part the ratio was 1 to 24 (Chamberlin, 1882, p. 473). Other pitch-and-flat deposits in the Linden area were discovered in a similar manner (Bain, 1906, p. 105, 109).

PITCH-AND-FLAT DEPOSITS

DESCRIPTION

The largest deposits in the mapped area contain mainly zinc ore in inclined veins and in veins parallel to the bedding and are known as pitch-and-flat deposits. They are 6 to 50 feet thick, 10 to 200 feet wide, and as much as 2 miles long. In plan the deposits are linear, sinuous, or arcuate. Veins of zinc, lead, and iron sulfides along inclined fractures are called pitches. They are a fraction of an inch to several inches in thickness and their angles of inclination range from nearly vertical to 30° from the horizontal. Pitches generally occur in a zone that contains several pitches of various size, and the zone may be as much as 50 feet wide and 2 miles long. In some mines ore grade material is continuous vertically along the pitch zone, but in other mines it occurs only where the pitch zone crosses certain beds. Veins of sulfide minerals connected to the pitches but lying along horizontal bedding planes are called flats. They are generally between half an inch and 8 inches thick, but locally the thickness may be greater. In some mines most ore is from pitches, but in other mines most ore is from flats. Commonly the deposits contain two pitch zones with opposed dips and parallel strikes and are known as double-pitch ore bodies (fig. 21). These zones are discontinuously connected by flats that dip at small angles toward the axis of the pitch zones and make a pattern similar to that in sagging masonry. In other deposits, however, only one set of pitches is of economic importance; the opposing set has been poorly formed or eroded away. These are known as single-pitch ore bodies.

The footwall rock between opposing pitches in a double-pitch ore body, or the footwall rock near the pitch in a single-pitch ore body, is called core ground and may be as much as 200 feet wide. It contains most of the flats, usually some disseminated lead and zinc minerals, and generally more iron sulfides than pitch zones. The ore in the core ground may be rich, or the flats may be poorly formed and the disseminated minerals too lean to mine. The ore is mined along the pitches, and the footwall rock (core ground) is taken up if profitable.

Disseminated ore consists of euhedral replacement crystals of sphalerite and subordinate galena one-sixteenth to three-fourths of an inch in diameter, chiefly distributed throughout the Guttenberg member and blue beds of the Decorah formation. Bain (1906, p. 66) thought that the organic material in the Guttenberg probably reduced zinc and lead sulfate solutions to sulfides. However, disseminated ore occurs in the lower part of the Ion dolomite member of the Decorah formation and in the Galena and Platteville formations, which contain little organic material. These strata also contain pitches and flats, but where shale has been concentrated by removal of carbonate, disseminated ore is more common.

Pitch-and-flat deposits in the mapped area are generally limited stratigraphically to about 90 feet of rock, which includes the Quimbys Mill member, the Decorah formation, and lower 50 feet of the Galena dolomite; however, parts of individual ore bodies differ in stratigraphic range. Pitches are not as common as flats in the Quimbys Mill, and in many places it contains breccia, or brangle, ore that was formed when the fractures in these easily brecciated beds were filled with sulfides. Most deposits of economic importance are either in or above the Quimbys Mill; but minor amounts of ore also occur in the upper few feet of the McGregor member. At the Crow Branch mine ore occurs in the Pecatonica member of the Platteville formation and extends upward through nearly 100 feet of beds. However, no part of the mine contains this aggregate thickness of ore-bearing rock.

Generally, the pitch-and-flat deposits contain about 10 times as much zinc as lead, although this ratio may differ greatly from one deposit to another. In one mine, the Robarts near Linden, more lead than zinc was produced from a pitch-and-flat deposit.

Sphalerite in the pitches and flats fills fractures, forms small replacement veins, and is disseminated in rock near the pitches. Galena occurs as irregular masses, ingrown with sphalerite and iron sulfides in veins, but unlike sphalerite, it is not continuous along the pitch or flat.

Principal gangue minerals are calcite, dolomite, chert, barite, and iron sulfides and oxides. Silica, as replaced host rock in the Decorah formation, is a less common gangue mineral. These gangue minerals occur in pitches and flats and are disseminated in the core ground.

Minute quantities of millerite, chalcopyrite, malachite, cerrusite, chalcocite, and melanterite occur in some deposits. Native sulphur is common on some old mine dumps, where it forms as marcasite decomposes.

STRUCTURAL RELATIONS

Pitches and flats are probably related to subsidence due to solution and removal of rock, although the areal position of the deposit is probably controlled by tectonic fracturing that preceded solution. Compressional or shear forces fractured the Quimbys Mill, Guttenberg, and Ion members, and the Galena dolomite and provided a permeable zone for solutions. Parts of these rocks were dissolved, and the rocks sagged where excessive voids were formed. Bedding planes were opened, and a stairstep pattern of outward-dipping fractures spread upward. The height of the inclined fractures is mainly dependent upon the amount of rock solution, the width of the fracture zone and, where the ore body contains opposing pitch zones, upon the distance between them at their lower ends. Tectonic fracturing, alternating rock solution and collapse, and mineralization that continued throughout the solution and collapse stages, are probably the order of ore body emplacement. The author believes that the mechanics of formation of a pitch-and-flat ore body are exactly those of fractures in a masonry wall when its foundation is lowered.

Displacement and offset along inclined fractures and bedding planes are limited to a few inches in the mines in the mapped area. Locally brecciated ore and slight offset of some veinlets in the pitches and flats indicate postmineralization movement that is probably caused by continued rock solution and readjustment.

Many of the known pitch-and-flat deposits in the area are in, or on the flanks of, basins or synclines. Other deposits apparently are not limited to these structures; they are normal to, parallel to, or overlap any structure. The pitch-and-flat deposits probably are not related as closely to the specific type of fold structure as to the amount of fracturing and brecciation caused by folding.

The Ion member of the Decorah formation and the cherty unit of the Galena dolomite contain basins of 5 to 20 feet closure above some, but not above all pitch-and-flat deposits. However, the basins were formed before or during ore emplacement by solution thinning of rock units and the subsequent formation of collapse fractures; thus, the basins probably did not control the ore deposit but were caused by the same solutions that deposited the ore. The Mason mine in Linden (pl. 8) is an example of an arcuate ore body in a basin that is interpreted from shaft depths, outcrop data, and descriptions by early writers as being of solution type.

Heyl and others (1959) believe that the pitches are tectonic reverse faults and that some of the flats are bedding-plane faults. They further believe that the small basins are chiefly tectonic features and that the basins control the location of pitch-and-flat deposits.

PARAGENESIS

The author did not attempt a detailed study of the paragenetic sequence of the ore and gangue minerals as this is described by the authors of the professional paper on the district (Heyl and others, 1959). However, the sequence in the mapped area was observed to follow closely the district sequence as reported in that paper, which is, from early to late: silica, dolomite, pyrite, sphalerite, galena, barite and calcite.

Silica is not a common gangue mineral in the Linden and Montfort quadrangles and, where present, it was the first mineral introduced into a zone that became either an ore body or an altered zone. The silica locally replaces limestone or dolomite in the Guttenberg member, but other strata in the mapped area apparently were not silicified. Introduced silica is present only in pitch-and-flat deposits; it is absent in gash-vein deposits. No crystalline or drusy quartz associated with mineral deposits was observed.

Dolomite of known secondary origin occurs as small pink crystals lining vugs or filling fractures, and as replacement dolomite that is similar to facies dolomite in the Platteville, Decorah and Galena formations. It is limited to ore bodies or nearby rocks and is always older than the first sulfides. The patchy distribution of dolomite due to ore solutions and the undetermined boundaries of facies dolomite detract from the value of local dolomite as a guide to mineral deposits.

Pyrite was the first sulfide introduced, and it occurs as thin films on the walls of fractures and as disseminated crystals in the wall rock bordering fractures. This form of iron sulfide is much less common than marcasite, particularly in pitch-and-flat deposits.

Marcasite immediately followed pyrite, continued nearly to the end of sulfide deposition, and was deposited mainly after the formation of sphalerite ceased. Marcasite occurs as bladed, reniform, or botryoidal masses intimately associated with ore and gangue minerals in most mines, although a few ore bodies contain very little marcasite or pyrite.

Sphalerite was the first of the two ore minerals deposited and is generally the most abundant mineral in symmetrically banded veins. The center space in the vein is filled with calcite, marcasite, and in some mines, barite. The euhedral crystals disseminated in the core ground are assumed to be the same age as sphalerite in veins.

Crystallization of galena began early in the sphalerite stage of deposition and reached a maximum at the end of that stage. Both cubic and octahedral forms occur, but cubic galena was deposited first.

Barite occurs in massive form or as globular and botryoidal masses with marcasite in the central part of veins. Relations to deposition of other minerals are not entirely clear, and overlap with sulfides is common.

Calcite was nearly always the latest formed mineral, although some calcite was deposited with sulfides. Four substages of calcite are recognized (Heyl and others, 1959). Calcite of the first three substages is scalenohedral, and calcite of the final substage is rhombohedral. Early-formed calcite is cloudy and some is colored, but in the final substage it is clear and colorless. Calcite is the most common gangue mineral in the mining district and occurs throughout the Platteville, Decorah, and Galena formations as veinlets, replacement clots and masses, and as cavity lining. Most calcite is in or near ore bodies, but calcite-filled fractures that contain no sulfides are common in the mapped area.

ORIGIN OF THE ORE

The origin of the ore in the Upper Mississippi Valley zinc-lead district has been a matter of dispute for many years. Since 1848, two major theories of ore deposition, the magmatic and the meteoric (or a combination of both), have been postulated by many geologists, but neither theory has been proved conclusively. From 1848 to 1924 the meteoric hypothesis was supported by most workers, but a paper by Spurr (1924, p. 246–250, 287–292) renewed interest in the magmatic hypothesis. Investigators from 1924 to the present strongly favor a magmatic origin from a postulated igneous source at some undetermined depth beneath the district. Heyl and others (1959) have given an excellent review of the literature, and they conclude that the weight of evidence points to a hydrothermal origin. The author believes that the ores of the district will eventually prove to be hydrothermal, although no new evidence supporting this hypothesis was found during the course of the present fieldwork.

MINING HISTORY AND PRODUCTION

PITCH-AND-FLAT DEPOSITS

Most of the major producing areas of the mining district were discovered by 1830. The first major ore body opened in the mapped area was at the Mason mine in 1833, although gash-vein deposits had been mined for several years previously.

An estimated 6,000,000 tons of zinc and lead ore of 3- to 6-percent grade (combined metallic lead and zinc content) has been mined from pitch-and-flat deposits in the mapped area. Ninety-two percent of the total tonnage of concentrates shipped from these mines between 1900 and 1931 was sphalerite concentrates; the other 8 percent was galena concentrate. Figures given by Behre (1935, p. 382) for tons of metal produced between 1906 and 1933 from southwest Wisconsin show the same zinc-lead ratio. Two-thirds of the total ore was from two large deposits (Coker mines) and from two small, unrelated deposits (Crow Branch and O. P. David mines) in the Montfort quardrangle. The other one-third was mostly from three deposits in the Linden quadrangle: the Linden Range, the Stevens-Gillman group, and the Okay-Squirrel group.

The Mason mine produced zinc and lead ores with some interruptions from 1833 until it was closed in 1909. Twenty-three thousand tons of lead ore was produced before 1866 (Strong, 1877, p. 726); 21,000 tons of zinc ore was produced by 1882 (Chamberlin, 1882, p. 473). However, the zinc and lead ores referred to in these early reports were hand-sorted concentrates which probably contained 60 to 80 percent lead and more than 20 percent zinc. The Optimo No. 2 and Depot mines which were worked in conjunction with the Mason after 1900, closed about 1915. The Mason and the Optimo No. 2 are the southernmost mines on the Linden Range. The total production of these three mines is estimated at 200,000 tons of zinc and lead ore of 3- to 6-percent grade.

The South Rule, Optimo No. 4, North Rule, and Prairie mines are all on the same mineral deposit, which is 11,000 feet long. The Prairie mine is the northermost mine on the Linden Range. These mines operated between 1923 and 1932. Production is estimated at between 600,000 and 800,000 tons of lead and zinc ore of 3- to 5-percent grade.

The Dark Horse mine, reopened briefly in 1954, and Trio mines operated between 1905 and 1912 and produced an estimated 50,000 tons of lead and zinc ore of about 3-percent grade.

Several small mines of low grade and tonnage were opened and operated in the Linden area in the early 1900's. These are the Rajah, Wicks, Weigel, Spargo, and Spring Hill mines. The Vial mine was operated in the 1930's. Most of the ore in these mines was disseminated inasmuch as pitches and flats were not well formed. The total production of all these mines probably did not exceed 50,000 tons of low-grade ore.

The Crow Branch mine (southwest corner Montfort quadrangle) was opened in the 1830's and produced until the 1880's. According to Heyl and others (1959), this mine probably contains zinc ore, for earlier investigators (Percival, 1856, and Hall and Whitney, 1862) reported considerable sphalerite, but only lead ore was mined. Total production is not recorded, but by 1859 production ranging between 2,000 and 2,500 tons of lead concentrates was produced. Total production is estimated at 100,000 tons of lead ore of between 6- and 10-percent grade.

The Robarts mine on the Linden Range was also mined in the 1830's and was operated intermittently under many owners and various names until 1916. It was reopened in 1954 and the east end, called the Kickapoo mine, was being worked for zinc and lead ores in 1957. Total production is estimated at 200,000 tons of lead and zinc ore of about 5-percent grade.

The west Glanville mine on the Linden Range was opened in the 1840's and was operated until 1917. It produced an estimated 100,000 tons of lead and zinc ores of 3- to 6-percent grade.

The Optimo No. 3 mine was operated between 1918 and 1921. Total production is estimated at 150,000 tons of lead and zinc ore of 3- to 6-percent grade.

The Okay, Slack, Peacock, and Lucky Six mines are probably on the same mineral deposit, although one-quarter of a mile separates the Okay and Slack and nearly 1,000 feet separates the Slack and the Peacock. The Squirrel mine, farther east, lies on the same trend. These mines operated from 1889 to 1918. The Okay was reopened in 1943 but shut down 1 year later, and the Slack was reopened briefly in 1951. An estimated 400,000 to 500,000 tons of zinc and lead ore of 4- to 6-percent grade was produced.

The Ross, Stevens, east Glanville, and Gribble mines were opened and operated in the early 1900's. The Gillman was operated at intervals between 1916 and 1933. This group of mines produced an estimated 150,000 to 200,000 tons of zinc and lead ores of 5- to 8-percent grade.

The Coker No. 1 and Biddick mines are in the same ore body which was discovered when prospectors deepened an old lead shaft in 1901. The east end of the Coker mine is accessible by an adit and some ore was mined in 1956. The two mines have produced more than 2,000,000 tons of zinc and lead ores of an average 3-percent grade.

The Coker No. 2, Sunrise, Sunset, Ellsworth, Rundell, and Yewdall mines are on the same mineral deposit, and 80 percent of the workings in these mines lie within the Montfort quadrangle. These mines contain 12,000 feet of workings, and an estimated 2,000,000 tons of zinc and lead ore was removed. The east end was worked for lead ore in the 19th century and reopened for zinc ore in 1900. It was shut down in 1926. The part within the Montfort quadrangle produced an estimated 1,700,000 tons of zinc and lead ore of about 3-percent grade.

The Defense mine, only part of which is in the Linden quadrangle, and the New Defense mine were operated from 1942 to 1945 and contained low-grade ore.

The Argall mine in the southeast corner of the Linden quadrangle was operated around 1905 to reclaim zinc ore left in the old lead stopes. Production and grade are unknown.

The only mine of importance in the Montfort area is the O.P. David. It was opened in 1907 and operated until about 1912. Production was an estimated 100,000 to 120,000 tons of zinc-lead ore of 3- to 6-percent grade. The Montfort mine produced mainly marcasite that was used in manufacturing sulphuric acid, but a small amount of sphalerite was also produced. The United and Nagle mines were not successful, and there was no production.

GASH-VEIN DEPOSITS

The production of lead and zinc from gash-vein and residual deposits throughout the mapped area probably does not exceed 75,000 to 100,000 tons of metal. About 95 percent of this amount is lead, and the remainder is zinc. Most of these lead deposits were discovered where dissection had cut to bedrock and washed out float galena or uncovered openings. Some deposits were discovered by farmers who plowed up float lead or noted that the oxidized iron sulfides in mineralized joints made reddish-brown streaks in the black soil. The deposits were mined by many individuals who generally did not keep records or make mine maps. Therefore, no reliable figures for production and no reliable method of making a closer estimate exists.

POTENTIAL PRODUCTION

PITCH-AND-FLAT DEPOSITS

About 3,000,000 tons of potential zinc and lead ore of approximately 3-percent grade is estimated by the writer to be in undiscovered pitch-and-flat deposits in the mapped area. This estimate is made on the basis of indicated structure and on the extent of stratigraphically favorable areas in which no systematic prospecting has been done.

Areas in which unmined ore deposits are most likely to be found can be briefly described as follows: the north flank of the large anticline in the Linden quadrangle along which a possible fault zone may occur, specifically in secs. 23 and 24, T. 5 N., R. 1 E., and sec. 19, T. 5 N., R. 2 E.; the upland area north and west of the Linden Range that includes Military Ridge and extends to the west edge of the mapped area; the area bounded by the north flank of the Mineral Point anticline, County Road E, State Route 80, the south edge of the Montfort quadrangle, and including sec. 19, T. 5 N., R. 1 E., and sec. 25, T. 5 N., R. 1 W.; and the area between and immediately east of the two basins shown in the northwest corner of the Linden quadrangle. The area in and around Montfort was drilled during a prospecting boom in the early 1900's. The O. P. David ore body was discovered by this drilling, but the drilling was not systematic, and many possibilities were overlooked.

GASH-VEIN DEPOSITS

At least as many gash-vein and residual deposits remain in the slightly dissected upland areas as have been removed thus far. However, it is difficult to find these deposits, and at present they are not of economic importance for that reason. The vertical churn drilling used in the mining district is not adaptable to gash-vein prospecting owing to the narrow width, vertical orientation, and soft interiors of these deposits. Gash-veins will be of economic importance in the future if a different method of drilling or geophysical prospecting can be devised to locate these deposits beneath the thick soil cover of the uplands.

POTENTIAL PRODUCTION FROM THE PRAIRIE DU CHIEN GROUP

Lead and zinc deposits occur in the Prairie du Chien group a few miles north and east of the mapped area, and lead and zinc minerals were observed in drill cuttings in these rocks in the area. However, the probability of commercial deposits of lead and zinc in the Prairie du Chien within the area is remote, in the author's opinion. This opinion is due to the generally small size of the known deposits, the excessive depth, and probable low grade. In addition, workings through the St. Peter sandstone would create serious water and collapse problems.

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