Geology of the Dodgeville and Mineral Point Quadrangles Wisconsin

GEOLOGICAL SURVEY BULLETIN 1123-D

Prepared in cooperation with the Wisconsin Geological and Natural History Survey

Allingham—GEOLOGY OF DODGEVILLE AND MINERAL POINT QUADRANGLES, WISCONSIN—Geological Survey Bulletin 1123-D

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By JOHN W. ALLINGHAM

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GEOLOGY OF THE DODGEVILLE AND MINERAL POINT QUADRANGLES, WISCONSIN

By John W. Allingham

ABSTRACT

The Dodgeville and Mineral Point quadrangles comprise 110 square miles in the Driftless Area of southwest Wisconsin. The Galena-Platteville cuesta, the major physiographic feature, dips gently to the south.

Dolomite, limestone, and sandstone of Early and Middle Ordovician age are exposed and rocks of Early Ordovician and Late Cambrian age were penetrated in deep wells. The Prairie du Chien group of Early Ordovician age is about 250 feet thick, but only the upper 100 feet is exposed. Relief on the Prairie du Chien surface exceeds 100 feet and is thought to be the result of differential compaction of limy muds over rigid reef structures and solution of the carbonate rock in the interdome areas.

The St. Peter sandstone ranges in thickness from 45 to 210 feet, the result of compensating fill on the irregular Prairie du Chien surface. The St. Peter is a crossbedded friable sandstone and an important aquifer in the mining district.

The Platteville formation is 53 to 65 feet thick and comformably overlies the St. Peter sandstone. This formation is an important source of dimension stone and crushed rock. It includes in ascending order the Glenwood, Pecatonica, McGregor, and Quimbys Mill members. The Glenwood shale member consists of 0.5 to 3 feet of green arenaceous metabentonitic shale and dolomite sand lenses. The Pecatonica dolomite member consists of 19 to 22 feet of massive yellowish-brown to gray dolomite. The McGregor limestone member, uniformly about 30 feet thick, consists of 2 submembers of variable thickness, a lower unit of wavy thin-bedded light-gray fossiliferous limestone, and an upper unit of mottled buff calcareous dolomite. The Quimbys Mill member, light- to dark-brown sugary-textured magnesian limestone, thickens southward, from 10 feet at Dodgeville to 13 feet near Calamine.

The Decorah formation of Middle Ordovician age is about 35 feet thick and overlies the Platteville formation. This formation is the main host rock for zinc deposits. It includes in ascending order the Spechts Ferry, Guttenberg, and Ion members. The Spechts Ferry shale member consists of about 0.8 foot of green shale, shaly dolomite that contains phosphatic nodules, and a light-buff metabentonite. The Guttenberg limestone member consists of about 11 feet of thin-bedded nodular light-brown coquinoid limestone. The Ion dolomite

member is subdivided into blue beds of dark bluish-gray limestone and gray beds of greenish-gray argillaceous dolomitic limestone. Total thickness of the Ion member is 20 feet.

The Galena dolomite of Middle Ordovician age has a total thickness of about 225 feet. In the mining district, two units of about equal thickness are recognized within this formation by characteristic lithology and fauna: the lower cherty unit and the upper noncherty unit. The light yellowish-brown argillaceous dolomite of the cherty unit is subdivided into four zones. The distinctive caprock subunit is recognized in the noncherty unit.

The major structural features, the Mineral Point anticline and the monocline near Calamine, are superimposed on a southerly regional dip of about 15 feet per mile. The anticline and monocline are faulted on their flanks. Cross folds crenulate the large broad synclines or troughs between the major structural anticlines. Many small basins that have a structural relief of 10 to 20 feet and are believed to be tectonically controlled are the result of solution and subsidence of carbonate beds in the Decorah formation. The strata are well jointed. The dominant conjugate system of shear joints strikes N. 60° W. and N. 45° E. and is related to the Mineral Point anticline. In the Calamine area, the dominant joint set strikes N. 80° W. and is associated with echelon faulting and a broad monoclinal structure.

Mineral deposits are joint-controlled and pitch-and-flat types. Joint-controlled deposits are localized by the intersection of vertical fractures and certain stratigraphic units. Galena and minor amounts of smithsonite fill vertical fractures in the dolomite beds or partly replace the host rock. Some joint-controlled deposits are related to underlying pitch-and-flat deposits.

Pitch-and-flat deposits, more important commercially, contain sphalerite and galena in inclined veins (pitches) and horizontal veins (flats). These deposits are generally restricted to the Quimbys Mill member of the Platteville formation and to the Decorah formation. Small basins and inclined fractures associated with the pitch-and-flat deposits are the result of solution and subsidence of the Guttenberg member. Although pitches and flats are controlled by linear fractures in these quadrangles, they are partly the result of subsidence. A transition from deposits of flats to mainly deposits of pitches occurs between the towns of Dodgeville and Mineral Point.

Sphalerite occurs as banded or massive veins, open-space filling, disseminated crystals in shale, or characteristic masses in vugs and cavities. Galena is commonly intergrown with sphalerite. Pyrite and marcasite are widespread in the Mineral Point area. Copper, nickel, and cadmium minerals are associated with sphalerite. Strategraphic zoning and a crude internal vein zoning are recognized. During mineralization solutions selectively altered some stratigraphic units by solution, dolomitization, and silicification.

Hydrothermal and meteoric processes have been suggested for the origin of the ores, but present evidence favors the hydrothermal process.

The present inferred reserves of this area are estimated to be 1,500,000 tons of 4 percent zinc ore in pitch-and-flat deposits. The upland areas have not been fully prospected for zinc and lead. The amount of potential ore is estimated from favorable structure in the extensive upland areas.

A potential future source for ores of iron, copper, lead and zinc is inferred for the Upper Cambrian formations and the Precambrian basement rock underlying highly mineralized areas.

INTRODUCTION

LOCATION AND ACCESSIBILITY

The Dodgeville and Mineral Point quadrangles, in Iowa and Lafayette Counties in southwestern Wisconsin (fig. 25), cover 110 square miles of the Wisconsin-Illinois-Iowa zinc-lead district and lie wholly within the Driftless Area (Whitney, 1862a, p. 116–120). It is a moderately populated agricultural region and has excellent roads. Dodgeville and Mineral Point are the main trade centers for the area. Uplands consist of prairie, whereas valleys are generally bordered by small woodlots. Bedrock is exposed in streams, road cuts, and quarries. A mantle of soil, loess, silt, and residual fragments of rock, which averages 8 feet in thickness, is widespread but it is best exposed in vertical section in road cuts and small prospect pits that dot the ridges.

FIELDWORK

Detailed studies of the stratigraphy and structure of the rocks in small areas of extensive mining and their relation to the occurrence of ore in the zinc-lead district were started in 1942 by the U.S. Geological Survey as part of a strategic mineral investigation program. These geologic investigations have been made since 1945 in cooperation with the Wisconsin Geological and Natural History Survey. Mapping of the structure and ore deposits in the Dodgeville and Mineral Point quadrangles was begun in September 1951, and completed in August 1955, as part of a program of detailed geologic mapping of 7½ minute quadrangles.

Mapping was done on aerial photographs taken in 1940 by the U.S. Department of Agriculture and compiled on topographic base maps at a scale of 1:12,000. All available geologic data and drill-hole information from previous surveys were used in this compilation. The structure contours on the geologic maps are based on detailed stratigraphic studies of outcrops and of cuttings from exploratory drill holes, including supplementary churn drilling by the U.S. Geological Survey (Allingham, 1953). Altitudes of stratigraphic horizons and the local dip of beds were obtained by alidade surveys beginning at Geological Survey bench marks and established points of useful elevation. This information was reduced to a common datum, the top of the Platteville formation (pls. 12, 13).

ACKNOWLEDGMENTS

The writer acknowledges the cooperation of Mr. J. J. McDonald and Mr. William Singer of the Dodgeville Mining Co.; Mr. John Girman and Mr. Roger Ivey of Mineral Point; and officials of the Cuba Mining Co., the Eagle Picher Co., and the D. S. and H. Mining

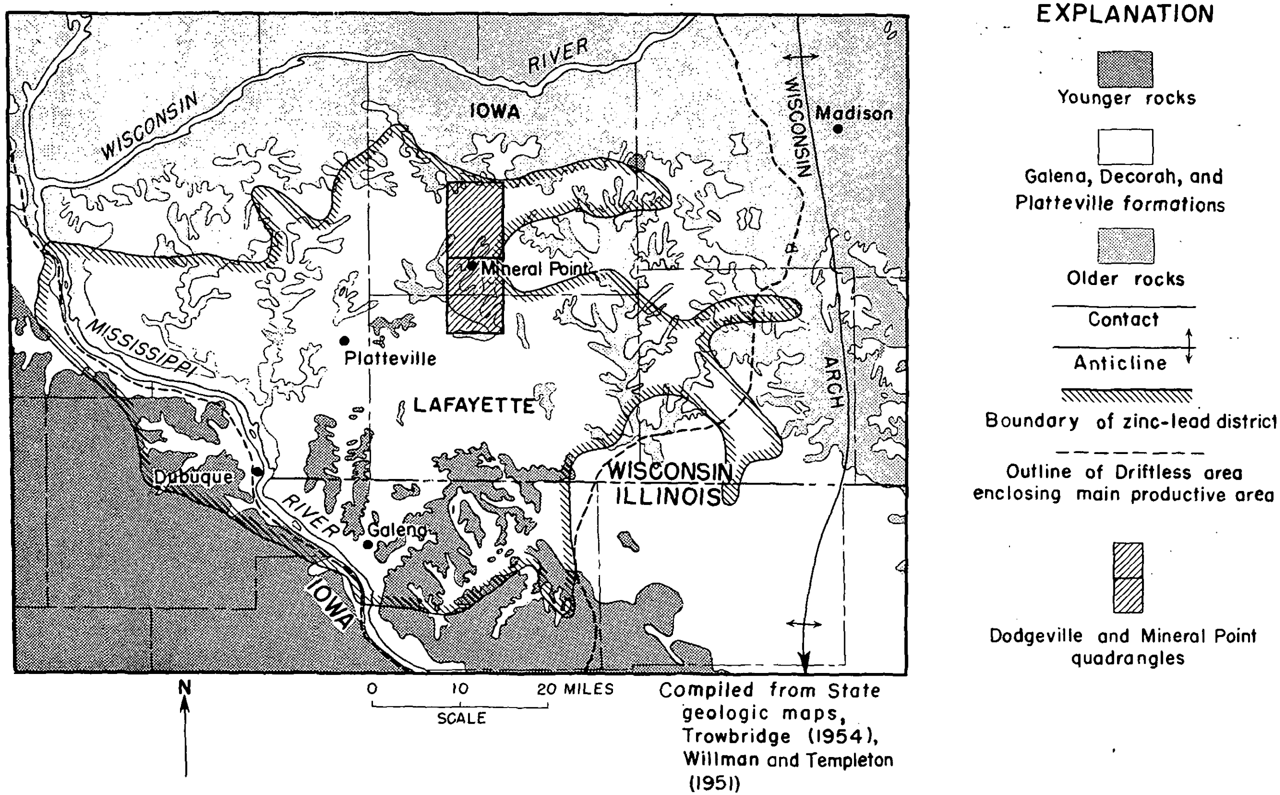

FIGURE 25.—Index map of Wisconsin-Illinois-Iowa zinc-lead district, showing the location of the Dodgeville and Mineral Point quadrangles, and outcrop area of productive rocks of the Galena, Decorah, and Platteville formations.

Co. who furnished data from exploration and mines. John E. Carlson assisted in mapping the rocks exposed in Pedler Creek and the mines at Dodgeville and Mineral Point. Loren Ziech, Mary Wheeler, and Ralph Chartraw assisted with the alidade surveying and mine mapping. Allen F. Agnew identified the fossils in the area.

PREVIOUS WORK

The first important geologic mapping was done by D. D. Owen (1840, 1848) in the 1830's during his evaluation of mineral-bearing Government lands. Galena was then the important mineral of this district. Daniels (1854) and Percival (1855, 1856) recognized the main stratigraphic features and mineral deposits of the district. Whitney (1858, 1862a), Strong (1877), and Chamberlin (1882) made important contributions to the theory of ore deposition in their studies of the lead deposits. As zinc mining was developed, studies relating to the deposition and origin of zinc ore were made by Jenny (1894), Blake (1894), Calvin and Bain (1900), and Van Hise (1900).

About 1900, the production of zinc became important and surface mining of lead had decreased. Studies by Grant (1903, 1906), Bain (1905, 1906), Grant and Burchard (1907), Hotchkiss and Steidmann (1909), and Cox (1911) of the zinc deposits and their relation to the stratigraphy and structure became a basis for recent investigations. Grant used detailed stratigraphy and structural mapping to determine the size and distribution of folds.

Spurr (1924), Emmons (1929), Behre (1935, 1937), and Bastin (1939) made additional contributions to our knowledge of the zinc deposits and their origin.

During World War II, interest in the zinc-lead district was renewed and detailed studies were made by Heyl and others (1945, 1948, 1955), Willman and Reynolds (1947), Agnew and others (1956).

A history of the district and much detailed information on the stratigraphy, structure, and ore deposits are contained in Professional Paper 309 by Heyl and others (1959).

PHYSIOGRAPHY

The dominant physiographic feature in the unglaciated area of southwestern Wisconsin is a cuesta. A mature dissected topography is developed on this feature.

TOPOGRAPHY

The gentle sloping cuesta surface and systematic stream pattern of the zinc-lead district in the Driftless Area differs markedly from the topography developed in the surrounding glaciated region (Whitney, 1862a, p. 101–127; Chamberlin and Salisbury, 1885, p. 205–322; Grant.

1903, p. 12–14; Martin, 1916, p. 63, 73–108; Trewartha and Smith, 1941, p. 42). This surface is bounded on the north by a poorly defined escarpment of Middle Ordovician rocks and on the south by an apron of Upper Ordovician shale and a ridge of Silurian dolomite. Weathering of the bedrock has produced a mantle of residual soil that is thickest on the upland areas. The residual soil is covered by thin deposits of interglacial loess on the ridges. Nearly flat lying strata are dissected on the dipslope by southward-flowing streams of dendritic pattern and gentle gradient, and are cut on the outcrop slope by northward-flowing streams with steep gradient. Military Ridge, a prominent topographic feature, is the divide between tributaries that drain northward into the Wisconsin River and streams that drain southward and enter the Pecatonica River. This cuesta ridge is characterized by a broad upland surface that dips gently southward about 8 feet per mile and by a northward-facing escarpment indented by deep dendritic valleys. Summits of the interfluves on the dipslope seem to be accordant.

In the areas of deep dissection, the St. Peter sandstone forms conspicuous cliffs and is capped by more resistant Platteville limestone. Pronounced widening and deepening of the valleys is typical in areas of massive, less resistant sandstone, but is lacking in areas underlain by the resistant dolomite and limestone. Valleys cut in limestone remain narrow and their slopes are gentle; whereas valleys in the sandstone tend to widen and the slopes tend to steepen into cliffs. Dissection of the mantle of loess and residual soil and the consequent exposure of mineralized beds aided early discovery of some areas that have been extensively mined.

From a uniform skyline, Bain (1905, p. 15; 1906, p. 13) postulated a peneplain, the Lancaster peneplain of Grant and Burchard (1907). The amplitude of the major flexures is too small to accurately disclose any possible beveling of structure by the upland surface; indeed, the upland erosion plain nearly parallels the strata. Any apparent local nonparallelism between the structure and the flat-topped ridges may be due to local differences in the rate of erosion caused by variations in lithology.[1] The large apparently entrenched meanders of the Pecatonica River and lower part of Pedler Creek are mainly controlled by shear zones or open fractures. Martin (1916, p. 55–70), Trowbridge (1921; 1954) and Thwaites (1958) discuss the criteria for local peneplanation or its absence. The upland surface may represent a partly dissected peneplain, but lacking evidence to the contrary, the surface is herein assumed to be of structural origin.

[1] Horberg (1946, p. 183) refutes a structural origin for the surface, however, and maintained that the Galena upland surface (Lancaster peneplain) is crossed by structure.

Altitudes in these quadrangles range from 820 feet on the Pecatonica River flats to 1,350 feet on a ridge 2 miles northwest of Dodgeville. The local relief is between 100 and 250 feet, and the topographic surface is in the erosional stage of early maturity.

DRAINAGE

The west one-third of the surface south of Military Ridge is drained by Pedler Creek, tributary to the East Pecatonica River. The east two-thirds of the surface is drained by the Mineral Point Branch, which joins the Pecatonica River near Slateford. Brewery Branch and Rock Creeks drain the northeastern part of the Mineral Point quadrangle and empty into the Pecatonica River through Furnace Creek. The Pecatonica River flows diagonally across the southern part of the Mineral Point quadrangle. Most of the headwater streams are fed by large springs at the contact between sandstone and dolomite or within the dolomite formations. Where the water flows over well-jointed dolomite, streams in the headwaters are generally intermittent during the dry seasons, but most large streams in the area are perennial.

Locally, the direction of stream channels is influenced by open parallel fractures and zones of shearing. The upper reaches of the Mineral Point Branch west of Dodgeville parallel the direction of major northeasterly open joints. South of Mineral Point, Furnace Creek, Rock Branch, Big Drain, and part of the Mineral Point Branch parallel the direction of northeastward-trending folds and major northeasterly open joints. Streams, as at the north edge of secs. 1 and 2, T. 4 N., R. 2 E., and sec. 9, T. 3 N., R. 3 E., parallel a major structure and may be partly controlled by westward-trending open fractures. Streams that are tributaries to the Mineral Point Branch reflect the trend of folds and joints and produce an asymmetric drainage basin, possibly owing to the open nature of the westward-trending joints with attendant ease of erosion on southwesterly tilted strata. The eastern tributaries closely parallel the northeasterly folds and joints, whereas the western tributaries parallel the northwestward-trending joints. In the Mineral Point area, many small tributary streams reflect the trend of northwestward-, northward-, and westward-trending fractures and folds. Hobbs (1905) noted a correspondence between the strike of major jointing and the direction of streams north of the Dodgeville area.

Rapid erosion of the soft sandstone resulted in wide flood plains on Mineral Point Branch, Furnace Creek, and the Pecatonica River. As a result of low gradient, the streams have developed meanders. Partly dissected terraces, in secs. 2, 10, 24, 25, 26, and 36, T. 4 N., R. 2 E., were cut on the sandstone adjacent to these flood planes.

Caves and sinks, as in sec. 10, T. 5 N., R. 3 E., sec. 33, T. 5 N., R. 3 E., and sec. 15, T. 4 N., R. 2 E., were developed by solution along major joints or zones of closely spaced fractures and generally show a persistent trend.

STRATIGRAPHY

Bedrock in the area covered by the Dodgeville and the Mineral Point quadrangles, as well as in most of the mineralized district, consists principally of Middle Ordovician carbonate sedimentary rocks of marine origin. Younger strata of Late Ordovician and Silurian age crop out toward the southwest as an irregular escarpment; Lower Ordovician and Cambrian strata ("older rocks" shown in fig. 25) are exposed to the north in the drainage basin of the Wisconsin River. The Ordovician beds comprise marine limestone, dolomite, sandstone, and shale; whereas the underlying Cambrian rocks are dominantly sandstone and siltstone. The Ordovician and Cambrian strata are more than 1,500 feet thick and lie on a complex of Precambrian crystalline rocks. This igneous and metamorphic complex of granite, gneiss, schist, volcanic rock, and quartzite forms the basement rocks upon which the overlying Paleozoic formations rest unconformably (Stark, 1932.) Although these Precambrian rocks are not exposed within the Dodgeville and Mineral Point quadrangles, they were penetrated elsewhere in the district in deep wells and their subsurface occurrence was described by Thwaites (1931).

The rocks exposed in the Dodgeville and Mineral Point quadrangles form the Prairie du Chien group of Early Ordovician age; the St. Peter sandstone, Platteville formation, Decorah formation, and Galena dolomite of Middle Ordovician age and aggregate about 385 feet in thickness. The lithology of only the upper part of the Prairie du Chien group is described. Although the Platteville formation is divided into four members and the Decorah formation into three members, these subdivisions are too thin to be differentiated on the maps. The Galena formation is divided into two lithic units, each of which is more than 100 feet thick, and these are easily differentiated on the maps.

The lithology of the carbonate rocks is complicated by regional dolomitization and the effects of mineralizing fluids. The effects of these fluids are mainly local dolomitization, recrystallization, leaching and thinning of carbonate beds, and a blotchy staining by oxidized iron sulfide on weathered surfaces. The subdivision of rocks into units is described in terms of composition before alteration; the effects of rock alteration are described elsewhere.

The regional relations of strata of Middle Ordovician age have been described by Agnew and others (1956).

CAMBRIAN SYSTEM

Sandstone, siltstone, and dolomite of marine origin comprise the Upper Cambrian series of the upper Mississippi Valley. These strata were designated as St. Croixan by Walcott (1912, p. 257) and have become the reference area for the Upper Cambrian series in North America. Gradational boundaries and many facies changes are common in these rocks. Early classifications based on general lithic correlations and faunal studies resulted in disagreement and confusion. The present subdivisions are based on independent lithologic and faunal criteria and their relationship clarified by Nelson (1956), Bell and others (1956) and Berg (1954).

UPPER CAMBRIAN SERIES

Upper Cambrian strata have been observed in drill cuttings from wells at Dodgeville and Mineral Point (Dodgeville city well No. 3 and Mineral Point city well No. 3, table 1). The Mount Simon sandstone, the oldest Cambrian strata, rests upon the eroded Precambrian basement rock. It is estimated from data presented by Thwaites (1923) to be about 540 feet thick near Dodgeville and thickens southwestward to more than 600 feet. The Cambrian strata overlying the Mount Simon sandstone total about 460 feet in thickness. About 82 feet of dolomitic shale, sandstone, and siltstone of the Eau Claire sandstone, which conformably overlie the Mount Simon sandstone, was penetrated in Dodgeville city well No. 3. The gray Galesville sandstone and the greenish glauconitic Franconia sandstone together average 265 feet in thickness in wells at Dodgeville and Mineral Point and rest on the Eau Claire sandstone. Dolomite of the Trempealeau formation constitutes the remainder of the Cambrian system in southwestern Wisconsin. The Trempealeau formation, which consists of 45 to 125 feet of gray, sandy or silty dolomite, overlies the Franconia sandstone. Sandstone beds in the Franconia, Galesville, and Eau Claire formations are good aquifers. Water from these formations is abundant, free from iron contamination, and relatively soft. Local municipalities and milk-product plants have had deep wells drilled into these formations for their water supplies (table 1).

Cambrian strata are overlain with apparent conformity by dolomite of the Prairie du Chien group of Early Ordovician age through a gradational contact.

TABLE 1.—*Thickness of strata of Cambrian age in the Dodgeville and Mineral Point areas*

Location	Stratigraphic units	Thickness (feet)
Iowa Coop Dairy well sec. 27, T. 6 N., R. 3 E.	Trempealeau formation	105
	Franconia sandstone	95
	Galesville sandstone	152
Dodgeville city well No. 3 sec. 28, T. 6 N., R. 3 E.	Trempealeau formation	45
	Franconia sandstone	110
	Galesville sandstone	145
	Eau Claire sandstone	82
Dodgeville Pet Milk Plant sec. 27, T. 6 N., R. 3 E.	Trempealeau formation	75
	Franconia sandstone	90
Mineral Point city well No. 3 sec. 31, T. 5 N., R. 3 E.	Trempealeau formation	125
	Franconia sandstone	110
	Galesville sandstone	155
	Eau Claire sandstone	68

ORDOVICIAN SYSTEM

LOWER ORDOVICIAN SERIES

The Lower Ordovician series in southwestern Wisconsin is represented by the Prairie du Chien group. Three lithic units are recognized: a basal dolomite, a middle sandstone, and an upper dolomite. In many areas, separation of the dolomite sequence into lithologic or faunal units is difficult. Flint (1956), Kay (1954), Powers (1935), and Trowbridge and Atwater (1934) summarized the problem of correlating and subdividing Prairie du Chien rocks. Disagreement on the age and correlation, stratigraphic relations of the strata, the rank and validity of certain stratigraphic names result from the methods used in making the stratigraphic subdivisions, particularly in absence of the sandstone or in areas of poor exposures.

The lower beds of porous tan-gray dolomite are similar to those in the upper dolomite. In this area, the sandy facies are not well developed. The sandstone unit is only a few feet thick. The upper dolomite commonly contains oolitic chert. Algal structures and diverse lithology of the Shakopee dolomite indicate many irregularities in a shallow marine environment.

PRAIRIE DU CHIEN GROUP

The Oneota dolomite, the New Richmond sandstone, and the Shakopee dolomite constitute the Prairie du Chien group and are the earliest Ordovician rocks in this area. These rocks were named by H. F. Bain (1906, p. 18) for exposures near Prairie du Chien, Wis. Data from drilling (Heyl, Lyons, Agnew, 1951) indicate an extremely varied lithology for these units, which makes correlation difficult and uncertain. In the Dodgeville and Mineral Point quadrangles the only exposures of Prairie du Chien strata are outcrops of Shakopee dolomite in streams north of Military Ridge, in the southern part of the Mineral Point Branch, and in the valley of the Pecatonica River. In outcrop the gray, vuggy arenaceous dolomite of the Shakopee is characterized by large masses of chert, commonly oolitic. Discontinuous lenses of siltstone and sandstone and thin intercalated glauconitic shale separate beds of massive dolomite. Bedding is absent or obscure in areas of large reeflike structures in the dolomite. Locally, the top of the Shakopee dolomite is marked by an incompetent zone of green shale, siltstone, and sandstone. This shale and siltstone, where observed, are conformably overlain by sandstone. In places, where pyrite in the shale is oxidized, the shale is weathered to an ocherous clay resembling a fossil soil.

The upper surface of the Shakopee dolomite is irregular and undulating because of domelike reef structures, which have relatively flat tops and sides that dip as much as 15° (fig. 26). Siliceous rocks

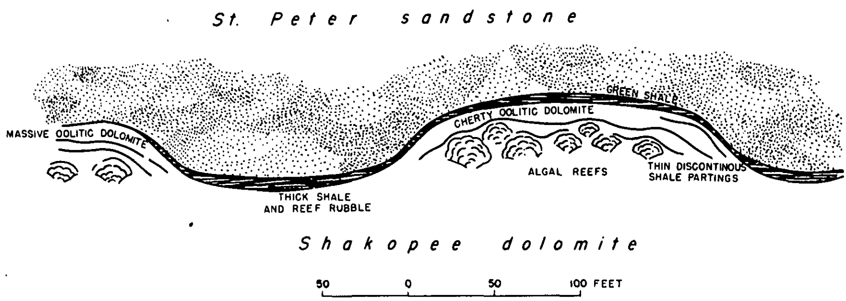

FIGURE 26.—Diagrammatic section showing the undulating surface of the Shakopee dolomite.

in these bioherms seem to resist the effects of solution and do not appear to be truncated or beveled. Contemporaneous doming or pre-Shakopee doming may have accentuated these structures (Andrews, 1955). The nature of the surface formed by these layered cryptozoon masses and algal structures has been discussed by Heyl, Lyons, and Agnew (1951) and Flint (1956). Many observers including Irving (1877), Strong (1877), Bain (1906, p. 19), Grant (1906, p. 29), Trowbridge (1917, p. 177–182), Dake (1921), Thwaites (1923, p. 541), and Stauffer and Thiel (1941) postulated an erosional unconformity at the top of the Prairie du Chien group, because of its irregular surface and stratigraphic relations with the overlying Platteville formation. Percival (1855), Hall and Whitney (1858), Chamberlin (1877, p. 138–140, 268–290), Calvin (1894), Sardeson (1916), and Flint (1956) attribute the irregular surface to depositional features. In his dis-

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cussion of the contact between the Shakopee dolomite and overlying St. Peter sandstone, Flint suggests that surface irregularities at this contact are caused by differential compaction of lime muds over relatively rigid reef structures and that the relief on this surface was accentuated by subsequent intrastratal solution and slumping in the interreef zones. Although this irregular surface has been described as an erosional unconformity, the writer believes the Prairie du Chien group is locally overlain with conformity by the St. Peter sandstone. Outside this area of investigation, Chamberlin (1877, p. 273) observed the Pecatonica dolomite member of the Platteville formation laying unconformably on the surface of the Shakopee dolomite. The contact of the St. Peter sandstone and the Shakopee dolomite is commonly obscured in outcrop by sand and soil, largely owing to slumping of the overlying friable sandstone. Their relations are commonly poorly defined.

MIDDLE ORDOVICIAN SERIES

Sandstone and carbonate rocks that have shaly partings comprise strata of the Middle Ordovician series. These sediments are all of shallow marine origin. Lithologic criteria were used to subdivide the carbonate strata in which convergence of beds and a lateral facies change from limestone to dolomite are evident. Four formations are exposed in these quadrangles.

The St. Peter sandstone varies in thickness largely due to sand fill on the uneven surface of the Prairie du Chien group. Rocks of the Platteville, Decorah and Galena formations, which have a northwesterly strike and southwesterly dip, overlie the sandstone and contain the productive ore deposits of the mining district.

The Platteville formation thins westward, owing to the wedging out of its upper member. The thin basal member grades into the St. Peter sandstone below and the dolomite member above. Limestone of the middle member becomes more dolomitic eastward. The upper member is mainly a dolomite in the mapped area.

The Decorah formation thins eastward over the Wisconsin arch. Its strata are divided into three members. The basal member wedges out eastward leaving only a bentonitic parting. Leaching and thinning of beds characterize the middle member. The greenish-gray beds of the upper member grade upward into the Galena dolomite.

The Galena dolomite has a remarkably uniform thickness. Bands of white chert distinguish the lower half of the Galena from its upper massive shaly beds.

ST. PETER SANDSTONE

Exposures of the St. Peter sandstone are continuous in the branches tributary to the Pecatonica River and in the deeply dissected areas north of Military Ridge. Here the sandstone erodes rapidly to form deep valleys and high bluffs. Crossbedding is displayed on some of the weathered surfaces of an otherwise massive sandstone. Whitney (1862a, p. 154) describes large-scale cross-stratification in the steep bluffs in the Mineral Point (Legate) Branch. Much of the upper part of the formation is well jointed. Some sandstone ledges near Mineral Point are sheared. Dolomite cement is common near the upper contact; however, in some places this zone is indurated to quartzitelike hardness by silica overgrowth of the sand grains. In the Mineral Point area tiny veinlets of iron sulfide occur in the upper part of the St. Peter sandstone and constitute its matrix near the top. Redistribution of the oxidized iron results in widespread cementing by iron oxide as well as sulfide. Commonly, a hard persistent ferruginous ledge crops out about 2 to 5 feet below the top of the sandstone (fig. 27).

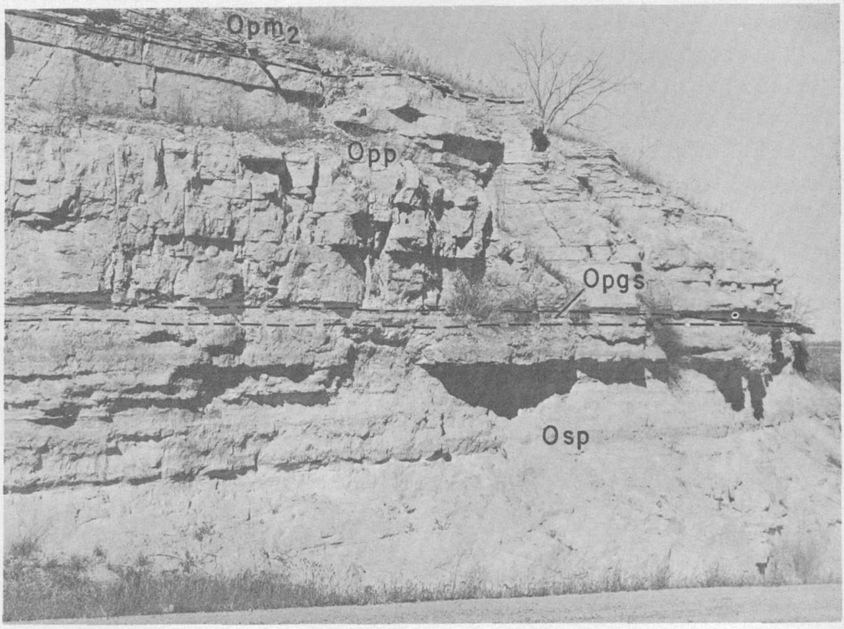

FIGURE 27.—Glenwood shale member, Opgs, Pecatonica dolomite member, Opp, and the Mifflin member of Bays, 1938, Opm_2, underlain by St. Peter sandstone, Osp. Road cut, U.S. Highway 151, at Mineral Point Branch of the Pecatonica River. Pecatonica member is about 20 feet thick.

The St. Peter sandstone is typically a buff to white, fine- to coarse-grained friable sandstone containing well-rounded and partly frosted quartz grains. Thiel (1935) summarizes the lithologic characteristics, distribution, and stratigraphic relations of the St. Peter sandstone in the upper Mississippi Valley. Over most of the mapped area, the normal thickness of the sandstone ranges from 45 to 65 feet and averages about 60 feet (fig. 28). The variation in thickness of the sandstone was first noted by Chamberlin (1877, p. 285; Strong, 1877, p. 677). This variation in thickness is partly due to the extreme relief on the surface of the Prairie du Chien group. Locally, the sandstone thickens to about 100 feet. Anomalous thicknesses of sandstone have been recorded in deep wells at Dodgeville and Mineral Point. The St. Peter sandstone is an important aquifer. In the vicinity of Mineral Point, however, the high iron content in the supper part of the sand seriously changes the quality of the water. Springs at the top of the sandstone provide a reliable source of water. Terry Springs on the Linden road northwest of Mineral Point, for example, is a historic landmark, a gathering point and watering stop for the early settlers. Locally the sand has been used for construction purposes; elsewhere it has been used for molding sand and the manufacture of glass.

The upper part of the sandstone yields a well sorted and well rounded mature suite of heavy minerals indicative of a regressing sea. The suite contains mainly zircon and tourmaline in a 1:1 ratio, and about 10 to 20 percent brown ilmenite. Zoned garnet, staurolite, and anatase also are present.[2] From his studies of heavy minerals, Tylor (1936, p. 75–79) concluded that deposition of the sandstone was partly in shallow water and partly aeolian and supplied by an intermediate sedimentary source, which was ultimately derived from a granitic terrane.

PLATTEVILLE FORMATION

The Platteville formation consists of four members known as the Glenwood shale, Pecatonica dolomite, McGregor limestone, and Quimbys Mill members, as now defined by Agnew and others (1956, p. 274). H. F. Bain (1905, p. 18–19) named the Platteville formation for outcrops along the Little Platte River near Platteville, Wis. Basal strata of the formation rest with apparent conformity on the St. Peter sandstone in the mapped area, although the Pecatonica dolomite member is reported disconformable with the sandstone elsewhere (William and Payne, 1942, p. 61–62; Chamberlin, 1877, p. 273). Rocks of the Platteville formation, as observed in many exposures and in cuttings from churn drill holes, have an average thickness of 64 feet. Only the upper members of the formation seem to be good host rocks for ore.

The lithologic characteristics of the carbonate rocks have been complicated by alteration, particularly dolomitization (Bain, 1906, p. 30).

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[2] Samples from sec. 15, T. 4 N, R. 2 E., and sec. 11, T. 3 N., R. 2 E.

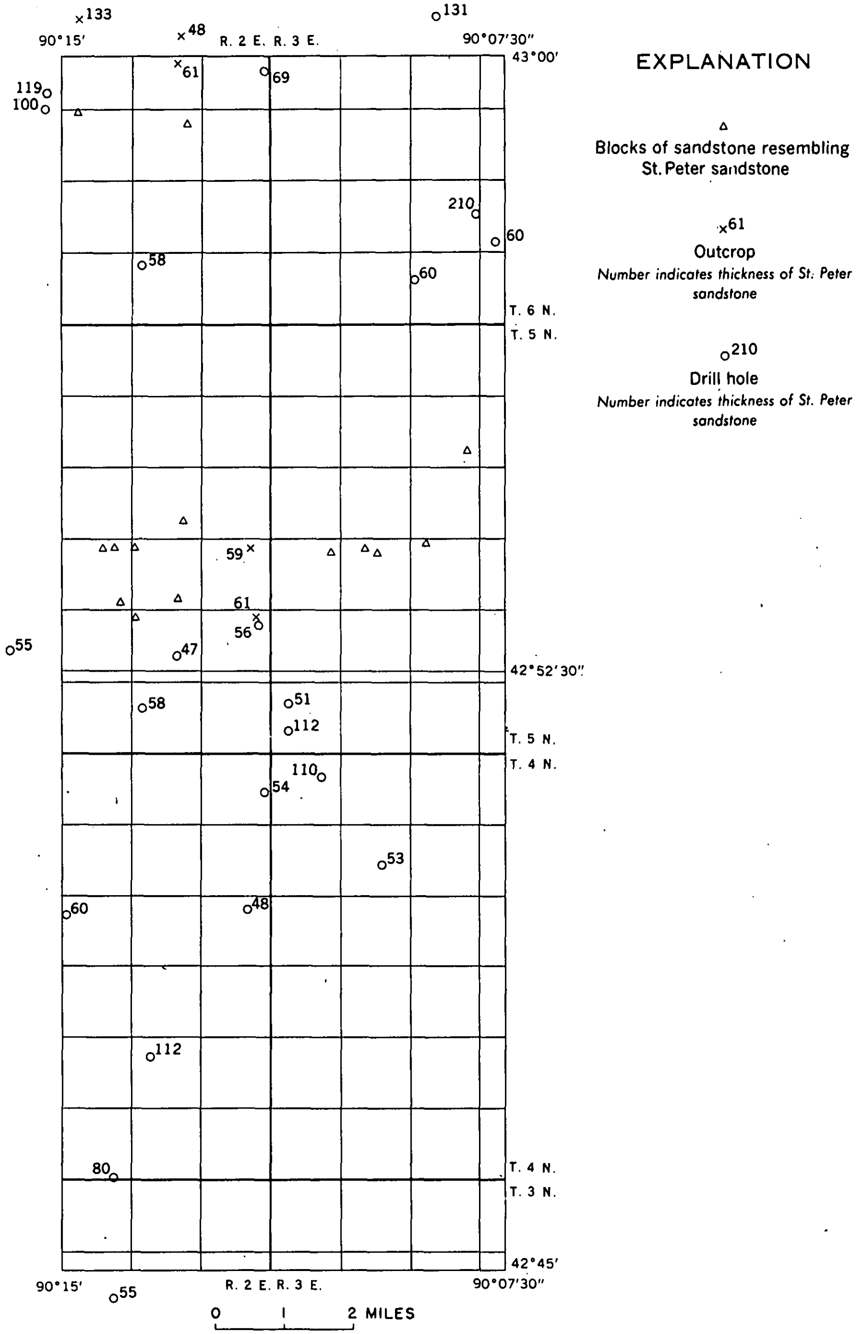

FIGURE 28.—Plat showing areas of anomalous blocks of sandstone and thickness of the St. Peter sandstone.

One type of dolomitization resulted in a widespread facies change from predominantly calcareous rock in the west to dolomitic rock near the crest of the Wisconsin arch. This dolomite is believed to have been formed diagenetically, although it may have been deposited as a primary dolomite. A more restricted type of dolomitization, related to mineralizing fluids, has locally changed the normally calcareous host rock to dolomite in ore-bearing zones, and produced irregularities in regional facies boundaries. These two types of dolomite are commonly indistinguishable. Units that were thinned by leaching as well as dolomitized complicate the interpretation of stratigraphic relations of beds in the Platteville and Decorah formations. Areas of isolated limestone within the dolomite facies are mainly restricted to the McGregor limestone and Quimbys Mill members of the Platteville formation and the Guttenberg limestone and Ion dolomite members of the overlying Decorah formation.

GLENWOOD SHALE MEMBER

The Glenwood shale member, named by Calvin (1906, p. 60–61, 74–75) for exposures in Glenwood township, Iowa, is a green, sandy and dolomitic shale. It is exposed in streams of steep gradient; however, because of its friable character, it erodes from under the overlying dolomite and is concealed at most places. In areas of poor exposure, the shale zone is indicated by large springs. The green shale provides a distinctive stratigraphic marker in exploratory drilling, although this zone is seldom reached.

The Glenwood member has two notable features, the bentonitic character of its shale and high zircon content of its intercalated sand lenses. First, the composition and microstructures indicate a volcanic origin for the shale. The metabentonite is composed of abundant orthoclase, hydromica [3] that is probably an alteration product of montmorillonite, and a trace of quartz. It weathers to a white powder, a distinctive marker on soil-covered slopes. Secondly, sand lenses (fig. 27) between the layers of metabentonite contain floods of zircon and sparse tourmaline in a 7:1 ratio, in contrast to abundant dark tourmaline and zircon in a 1:1 ratio in the upper part of the St. Peter sandstone. Clear pink garnet is rare or absent in these sand lenses. In contrast, Thiel (1937) states that garnet is abundant in the upper third of the Glenwood but decreases toward its base, whereas the zircon content increases. Tourmaline is uniform in its distribution in the Glenwood member and in the St. Peter sandstone. Thiel observed well-rounded detrital grains of heavy minerals and orthoclase. He concluded that the shale was not bentonitic in origin. According to Allen (1929, p. 239) the

[3] X-ray film No. 8964 by F. A. Hillebrand, U.S. Geological Survey, 1956.

clay in this transition zone seems to be a normal Ordovician shale and gives no suggestion of volcanic origin, however, Kay (1935b, p. 238–239) noted a thin clay bed below the basal dolomite of the Platteville formation in Minnesota similar to characteristic metabentonite. Sardeson (1933, p. 83–84) argued that volcanic ash interrupted the deposition of sand and resulted in a bentonitic sand. In the mapped area, the Glenwood shale member is largely arenaceous instead of argillaceous. Elsewhere this member is mainly a shale that contains thin sand lenses.

Both stratigraphic boundaries of the Glenwood are gradational (fig. 29) in the Dodgeville and Mineral Point areas. Bevan (1926, p. 11) regards the Glenwood shale as transitional between the St. Peter sandstone and the Platteville formation. Stauffer (1935, p. 130) believes the basal Glenwood beds are St. Peter in age but the fossiliferous beds are Platteville in age (Mohawkian). The basal bed normally contains green arenaceous clay and oxidized pyrite. Near Calamine, this bed

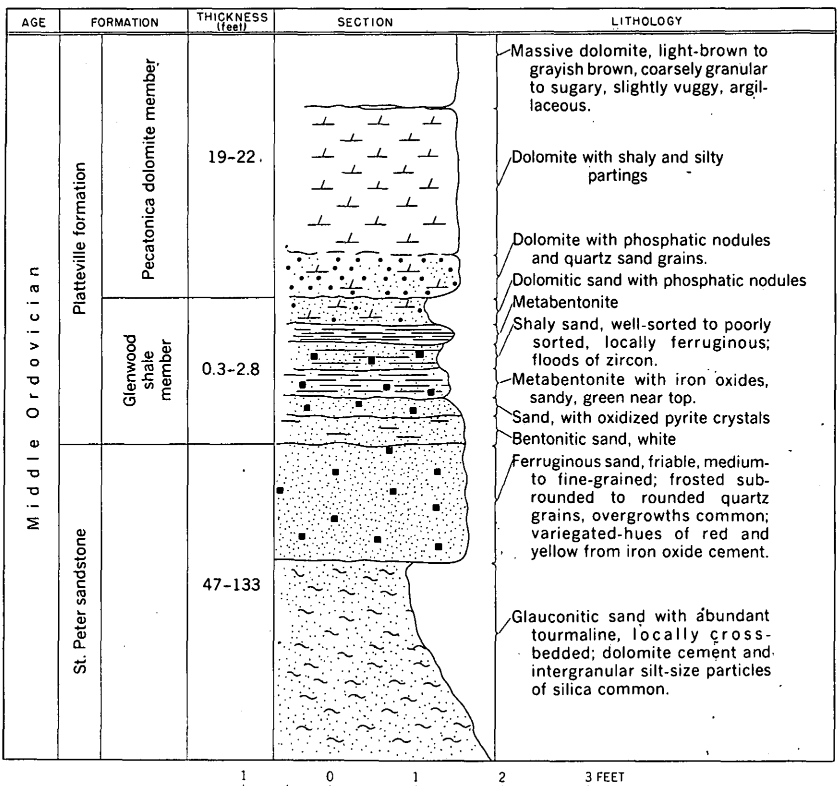

FIGURE 29.—Section showing lithology of the Glenwood shale member of the Platteville formation in the Dodgeville and Mineral Point quadrangles.

contains mainly granules and small pebbles. The uppermost bed of dolomitic sand contains phosphatic nodules and is similar to the basal bed of sandy dolomite of the overlying Pecatonica dolomite member. The wedging out of some beds and the interfingering of sparse shaly materials, commonly with relatively coarse clastics, indicate the fluctuating conditions of shallow marine deposition; variations in lithology and very thin beds may have resulted from the proximity of a nearby strandline on the flank of the Wisconsin arch.

PECATONICA DOLOMITE MEMBER

The Pecatonica dolomite member was named by Hershey (1894, p. 175) for exposures along the Pecatonica River in northern Illinois.

Massive, resistant dolomite of the Pecatonica member, which has a thickness of about 22 feet, is exposed in bluffs and in quarries where the rock was formerly broken for dimension stone. The uppermost bed in dense sublithographic limestone 6 inches thick and, locally, has a red, oxidized surface. An 8-foot zone near the top and a similar zone near the base are locally thin bedded. Abundant quartz sand and small phosphatic nodules occur in the basal 1-foot bed of the grayish-brown dolomite. Fossils are common although poorly preserved. Crystals of marcasite and pyrite are scattered sparsely through the dolomite. In some places the rock contains green argillaceous material and tiny red specks of oxidized iron or red clay.

MCGREGOR LIMESTONE MEMBER

The McGregor limestone member conformably overlies the Pecatonica dolomite member and was named by Kay (1935a, p. 286–287) for outcrops near McGregor, Iowa. The thin beds of the McGregor contrasts sharply with the generally massive Pecatonica below (fig. 30). Strata of the McGregor member locally comprise two units of contrasting lithology; the lower thin nodular beds of fossiliferous limestone are the Mifflin member of Bays (1938), and the upper massive dolomitic layers are the Magnolia member of Bays and Raasch (1935). Typically, the lower part of the McGregor member consist of 15 feet of wavy, thin-bedded, dense limestone. Bedding surfaces are separated by gray shale partings. On weathered surfaces the lower beds are characteristically nodular. Weathering locally produces an embayment near the top of the Mifflin member. The McGregor limestone member is almost entirely dolomite in the eastern half of the Dodgeville and Mineral Point quadrangles.

In the dolomite facies, these rocks are buff, mottled, sugary textured, more silty or shaly than the limestone facies of the western part of the district or isolated beds of limestone within the area of regional

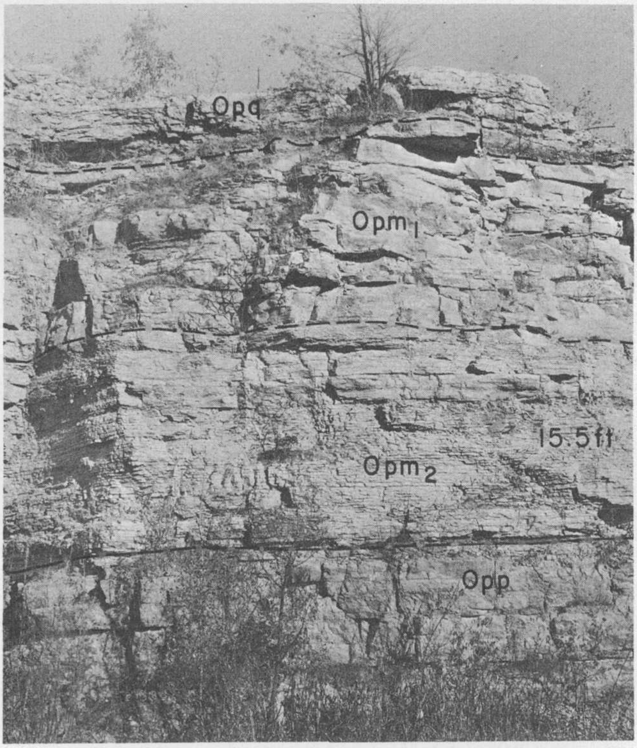

FIGURE 30.—McGregor limestone member (Magnolia member of Bays and Raasch, 1935, Opm₁, and Mifflin member of Bays, 1938, Opm₂) between the Pecatonica dolomite member, Opp, and the Quimbys Mill member, Opq, of the Platteville formation, in City quarry, Mineral Point, Wisconsin. Mifflin member of Bays (1938) is 15.5 feet thick.

dolomite. The normally gray intercalated shales of Bay's Mifflin member are locally brown, which is characteristic of incipient dolomitization related to ore deposition.

The contact between the Mifflin beds and the Magnolia beds is regarded as transitional by Agnew and others (1956, p. 281–282). Locally where the Mifflin is slightly thinner than 16 feet, the Magnolia is correspondingly thicker. In no place do the Mifflin beds exceed 16 feet.

In contrast to the dominantly calcareous and fossiliferous nature of the lower beds, the upper unit (the Magnolia beds) is more massive, generally dolomitic, coarsely granular, less fossiliferous, and more argillaceous. The upper beds contain more dispersed clay particles but have fewer shaly partings. A hard, rough, white concrete-like coquinoid limestone weathers out near the base of the Magnolia beds. A 1-foot transitional bed of light-gray sublithographic limestone, locally sugary textured and dolomitic, marks the top of the Magnolia. This dense, vitreous, mottled bed resembles the limestone of the overlying Quimbys Mill member except in color. Several vuggy bands containing *Streptelasma* sp. aff. *S. profundum* Conrad and *Leperditia* sp. aff. *L. fabulites* Conrad occur 1 to 3 feet below the base of this limestone unit in the Magnolia beds. The upper part of the McGregor strata is regarded as a potential host rock for zinc and lead minerals because ore is found in these strata in the Shullsburg area to the south.

QUIMBYS MILL MEMBER

The Quimbys Mill member was named for a quarry exposure at a millsite on the Galena River, west of Shullsburg, by Agnew and Heyl (1946). Beds of the limestone of the Quimbys Mill because of their resistant and blocky nature, crop out boldly in cut banks, watercourses, and on hillsides. Excellent sections have been exposed in quarries. This distinctive dolomitic limestone is locally known as glass rock, because of its dense, brittle vitreous character. The beds are generally the lowest zone for large zinc deposits in the mining district, and its basal beds have been most productive in mines at Dodgeville.

A persistent basal unit of thin dark-brown dolomitic shale, locally called calico rock, rests conformably on the McGregor. The uppermost bed of the Quimbys Mill member has a red, oxidized, slightly cupped surface that contains small pits and shale-filled tubular passages; its fucoidal surface appears to be locally eroded (Chamberlin, 1882, p. 413; Sardeson, 1898, p. 322; Ulrich, 1924, p. 96). This surface was probably produced under the oxidizing conditions of a shallow sea and represents mainly subaqueous erosion during a period of nondeposition in a changing environment on the flank of the Wisconsin arch. A second fucoidal layer is exposed about 0.6 of a foot below the top. The Quimbys Mill member has an average thickness of about 11 feet in the Dodgeville quadrangle, but thickens southwestward (fig. 31).

An increase in granularity is the most distinctive change in altered beds of the Quimbys Mill member. As a result of recrystallization of the dolomite or calcite cement, large skeletal rhombohedrons of dolomite or calcite as much as 3 centimeters across have formed in rocks of the dolomite facies. These large incomplete crystals contain inclusions of the matrix and impart a brilliant luster to parts of the rock. These crystals are very conspicuous in some areas that were altered by mineralizing fluids. Within a broad area of regionally dolomitized rock, beds in the lower 6 feet of the Quimbys Mill member locally consist of a dense, purplish-brown sublithographic lime-

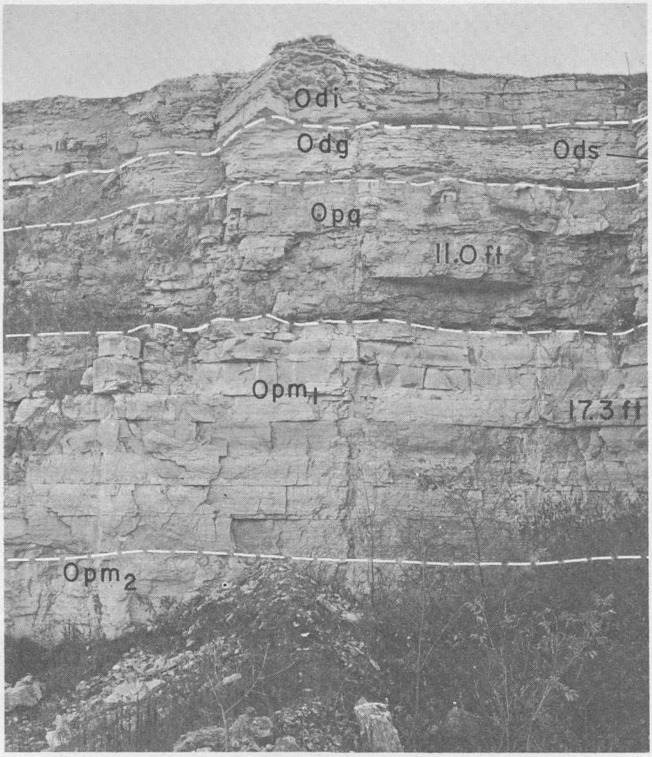

FIGURE 31.—Quimbys Mill member, Opq, and McGregor limestone member (Magnolia member of Bays and Raasch, 1935, Opm_1 Mifflin member of Bays, 1938, Opm_2 of the Platteville formation, Spechts Ferry shale member, Ods, and Guttenberg member, Odg of the Decorah formation, in quarry, south of Mineral Point, Wisconsin. Quimbys Mill member is 11 feet thick.

stone. These islands of limestone crop out in sections 24, and 34, T. 4 N., R. 2 E., sec. 22, T. 6 N., R. 2 E., sec. 22, T. 5 N., R. 2 E., and elsewhere (pl. 14). In most of the mapped area, the Quimbys Mill is a pale-brown dolomite or magnesian limestone.

Narrow elongate depositional structures, locally fossiliferous, are observed in the limestone of the Quimbys Mill member. The preferred orientation of these features was controlled by currents in shallow seas.

The contact between the Quimbys Mill and McGregor members forms an excellent aquifer as a result of extensive solution cavities at this horizon, especially in the Dodgeville and Mineral Points areas. Wells and springs in this aquifer provide an abundant reliable supply of water for local domestic use and stock. Increased argillaceous material near the base of the Quimbys Mill and shale partings at its basal contact permitted ground-water movement and leaching of the carbonate rock in this permeable zone.

DECORAH FORMATION

The Decorah formation was named by Calvin (1906, p. 60, 84) for exposures near Decorah, Iowa. Kay (1928, p. 16) divided the Decorah into three members, Spechts Ferry shale, Guttenberg limestone, and Ion dolomite. The lithology of each of these units is instrinsically uniform. The Decorah formation averages 30 feet in thickness in the area studied, but farther west its two lower members thicken.

The appearance of the limestone commonly has been altered by dolomitization and silicification. Removal of carbonate during mineralization and compaction of the shaly residue also have altered the character of these beds; the results are thinner beds, pseudobanding of concentrated argillaceous material; mottling due to scattered unaltered lenses of rock, and a rock of darker hue.

Agnew and Heyl (1946) showed the Platteville-Decorah boundary to be one of regional disconformity. In the mapped area, the nature and magnitude of the break is questioned as deposition seems to be continuous during Platteville and Decorah time.

SPECHTS FERRY SHALE MEMBER

Shale of the basal member of the Decorah formation overlies the red pitted surface of the Quimbys Mill member of the Platteville formation with apparent local conformity. Kay (1928) named the member from exposures at Spechts Ferry, Iowa. Although Kay (1935a, p. 286–287) later assigned the Spechts Ferry shale to the Platteville formation, Agnew (1950) reassigned the shale to the Decorah formation. Good sections of the Spechts Ferry shale member are exposed in quarries, road cuts, and streams of steep gradient, but elsewhere the soft shaly strata weather and erode easily and, thus, are not well exposed even though conspicuous in color and persistent throughout the quadrangle. Springs and marshes commonly disclose the trace of the shale at the surface. The shale is not always recognized in churn-drill cuttings because it is thin and tends to wash into the drilling mud.

Typically, the Spechts Ferry shale member consists of thin beds of green shale, tan limestone that contains specks of green shale, and buff to white metabentonite at the top. Shale is a distinctive but minor constituent of the lithology of this member. To the west, additional beds of shale and limestone increase the thickness of this unit (fig. 32). The limestone bed in the Spechts Ferry shale member

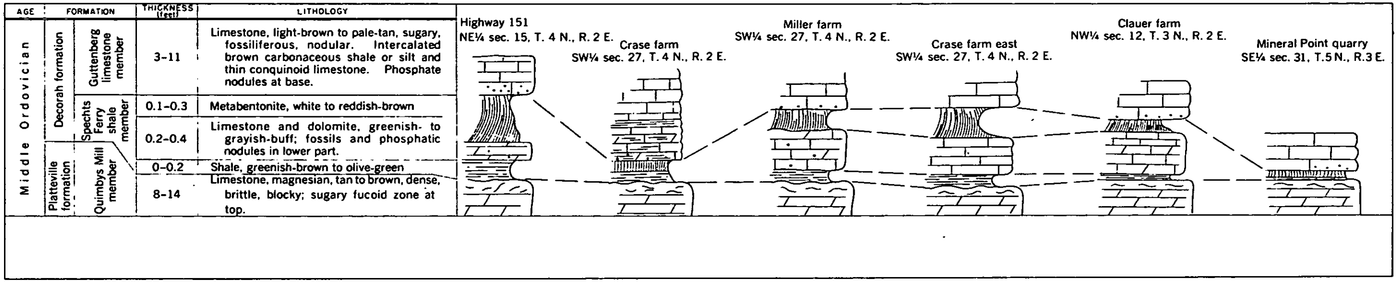

FIGURE 32.—Sections showing thickness and litholoigy of the Spechts Ferry shale member of the Decorah formation. Dots indicate phosphate nodules. Fucoid zone at top of Quimbys Mill member of the Platteville formation.

is transitional between the overlying Guttenberg and underlying Quimbys Mill members but shows closer affinities to the Guttenberg limestone member. The lower part of the fossiliferous limestone bed contains dark phosphatic nodules similar to those at the base of the Guttenberg member, as well as shale particles and shell fragments. This bed, in the mapped area, is mainly a light-brown calcareous dolomite and locally alters to a dark-brown banded shale. It is separated from the Quimbys Mill member by the thin green shale. Allen (1932) established the bentonitic character of the plastic clay in the Spechts Ferry shale member. The metabentonite at the Crase farm south of Mineral Point is composed of orthoclase and a montmorillonite-type mineral, probably a mixture of hydromica and montmorillonite.[4] Shard structures indicate a volcanic origin. Osmond [5] in his study of Ordovician bentonites concludes that volcanic ash was altered at the time of deposition on the sea floor to a randomly interstratified clay composed of illite and montmorillonite.

In altered zones the Spechts Ferry shale member crops out as a very thin bluish-green or yellow-green plastic clay, the pipe clay or clay bed of local usage. The Spechts Ferry rarely contains ore, but contains crystals of lead and zinc minerals that are commonly disseminated at the base of the limestone bed where it is altered.

The Spechts Ferry shale member, which is 0.8 foot thick, seems to rest conformably on the Quimbys Mill member in the mapped area, but Agnew and others (1956, p. 262, 286) report that farther east the Spechts Ferry shale member wedges out and the Guttenberg limestone member rests on the Quimbys Mill member. The Spechts Ferry thickens westward, whereas the Quimbys Mill member thins correspondingly. The white metabentonite, directly above the limestone or dolomite bed of the Spechts Ferry shale member, continues eastward from localities where the shale and limestone of the Spechts Ferry feather out on the east flank of the Wisconsin arch. This bentonitic clay could represent merely a break in sedimentation between the phosphatic limestone of the Spechts Ferry and the basal phosphatic limestone beds of the Guttenberg member. In the Dodgeville and Mineral Point quadrangles and westward, the limestone and shale of the Spechts Ferry member could then represent substantial facies of the underlying Quimbys Mill member. The Spechts Ferry member is overlain with apparent conformity by the Guttenberg limestone member.

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[4] X-ray film Nos. 8968 and 11095 by F. A. Hillebrand, U.S. Geological Survey, 1956.

[5] Osmond, J. K., 1954, Radioactivity of bentonites: Unpublished Ph. D. thesis, Univ. of Wisconsin, 37 p.

A thin bentonite bed, about 2 feet above the base of the Guttenberg member, was described by Herbert [6] from exposures in Northern Ill. This bentonite may correlate with the clay bed included in the Spechts Ferry of the Mineral Point and Dodgeville areas.

GUTTENBERG LIMESTONE MEMBER

The Guttenberg member was named by Kay (1928, p. 16) for exposures near Guttenberg, Iowa. Normally the Guttenberg consists of thin wavy beds of light-brown argillaceous limestone, having brown shale partings on its bedding surfaces. The limestone facies of the Guttenberg member crops out in many localities north of Dodgeville, southwest of Mineral Point and elsewhere (pl. 14), but in areas of alteration it is well exposed only in quarries and road cuts. The highly fossiliferous character and uniform bedding of this thin nodular coquinoid limestone is characteristic of relatively shallow water deposits and is similar to Bay's Mifflin member in the Platteville formation. Fossils are commonly replaced by calcite or silica, and many are poorly preserved because of regional dolomitization and local alteration of the rock. Phosphatic nodules, similar to those in the dolomite bed of the underlying Spechts Ferry shale member, are common in the basal bed of the Guttenberg. Magnesian limestone near the base of the Guttenberg member shows close affinities to similar beds in the Quimbys Mill member of the Platteville formation. These limestone beds are dense, brittle, nodular and blocky, and are partly silicified in places. The upper beds locally are more shaly, granular, and vuggy than the magnesian limestone.

Brown carbonaceous shales of altered beds in the dolomite facies are called oil rock or brown rock by the miners. Beds of the Guttenberg member are predominantly limy dolomite and shale in the mapped area. Bleached dolomitic limestone of the Guttenberg in mineralized areas resembles altered beds of Bay's Mifflin member. The Guttenberg member is ore bearing in the Mineral Point area and normally averages about 10 feet in thickness, except in large mineralized areas where it thins to a few feet of dark-brown dolomitic shale (fig. 33).

ION DOLOMITE MEMBER

The Ion dolomite member was named by Kay (1929, p. 650) for exposures near Ion, Allamakee County, Iowa. The bluish-gray to brownish-gray dolomite of the Ion is clearly exposed in streambanks and in quarries, which are locally an important source of road metal. In the mining district, the Ion dolomite member can be divided into

[6] Herbert, Paul, Jr., 1949, Stratigraphy of the Decorah formation in western Illinois: Unpubl. Ph. D. thesis, Chicago Univ., Chicago, Ill.

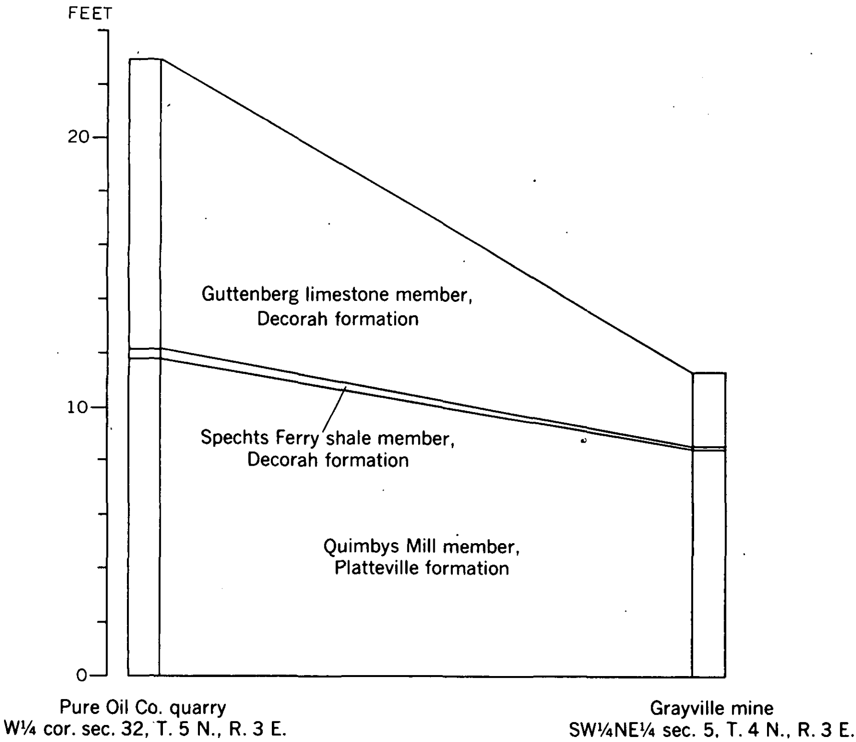

FIGURE 33.—The effect of mineralizing solutions on the thicknesses of the Guttenberg limestone and Spechts Ferry shale members of the Decorah formation, and Quimbys Mill member of the Platteville formation at Mineral Point, Wis.

two units. The lower 6 feet of bluish-gray dolomitic limestone, commonly known as the blue beds, is more fossiliferous, shaly and granular than the overlying 12 to 14 feet of light-gray dolomite, locally called the gray beds. The contact between the Guttenberg member and the overlying Ion dolomite member is gradational. A 1- to 3-foot interval contains brown limestone and shale of the Guttenberg and granular clots of gray fossiliferous dolomitic limestone and flecks of bluish-green shale of the lower part of the Ion.

The basal limestone of the blue beds contains dark sand-size phosphate grains, scattered clear quartz sand, and blue-green dolomitic shale. A few isolated nodules of chert are scattered along bedding surfaces near the base of the blue beds. Shale and siltstone constitute about one-fifth of this lower unit. The contact between the blue and gray beds in the mineralized areas is marked by a bright dark-red ferruginous shale.

Thin coquinoid strata, increased granularity, and sparse argillaceous material locally distinguish the lower half of the gray beds from the upper; both units of this dolomitic limestone contain green shaly partings. The Ion dolomite member has a uniform thickness of about 20 feet. At the top of the Ion dolomite is a zone of bryozoa *Prasopora insularis* Ulrich in a 1-inch layer of green shale, which separates the Ion member from the overlying Galena dolomite.

GALENA DOLOMITE

The Galena dolomite was named by Hall (1851, p. 146) from exposures near Galena, Ill. The Galena dolomite makes up three-fifths of the exposed rock in the mapped area. It crops out in small bluffs and is commonly seen in road cuts and quarries. It is widely used for agricultural lime and road metal. This light-brown porous granular dolomite has a remarkably uniform thickness of about 225 feet in the mining district (Allingham, and others, 1955; Agnew, 1956, p. 259). The lower half of the Galena dolomite contains chert nodules as bands parallel to its bedding. The surface of weathered outcrops of Galena dolomite is pitted and contains numerous small vugs produced by selective solution of the intergranular calcareous cement. As the residual dolomite grains are carried away the vugs are enlarged. Large skeletal rhombohedrons of calcite or dolomite have formed in beds of the Galena by recrystallization of its calcareous cement and are similar to the skeletal crystals in parts of the dolomitic limestones of the Quimbys Mill and Guttenberg members. The Galena dolomite is commonly separated mainly on faunal criteria into three members: the cherty Prosser member of Ulrich (1911a, p. 257); the massive Stewartville member of Ulrich (1911b, pl. 27); and the Dubuque member of Sardeson (1907, p. 193). Agnew and others (1956, p. 259, 267) subdivided the Galena by lithologic criteria, because fossils, destroyed by local rock alteration and churn drilling, are not observed in mines and cuttings. He divided the dolomite into two easily recognizable lithologic units of about equal thickness: a lower cherty unit, which is a favorable host for ores of lead and zinc; and an upper noncherty unit, which contains only lead minerals. This division is equally useful for subsurface and outcrop studies.

CHERTY UNIT

The cherty unit was subdivided by Agnew and others (1956, p. 296–297) into four distinctive lithologic and faunal subunits. The presence of chert bands not only affords a means of distinguishing the cherty unit from the overlying massive noncherty beds, but differences in the amount of chert also provide a basis for subdivision of the thin-bedded grayish-brown cherty dolomite. Differences in

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bedding, smooth hard layers, shaly or vuggy beds, the presence of specimens of *Receptaculites oweni* Hall, and other minor variations are also used for differentiating subdivisions of the cherty unit (pl. 12 and 13).

The lithology of the lowermost subunit, Zone D (lower buff zone), is transitional between the Ion dolomite member of the Decorah formation and the overlying cherty subunit, Zone C (lower cherty zone). In some highly altered areas the Ion dolomite member may be indistinguishable from the basal beds of the Galena dolomite. The shaly or silty partings and green argillaceous streaks in the basal 3 to 4 feet of Zone D are commonly brown in mineralized areas. Zone C (lower cherty zone) contains the lowermost widespread chert bands in the cherty unit. Beds of Zone B (lower *Receptaculites* zone) rest on Zone C and contain only a few scattered chert nodules; however, the upper part of this 12- to 14-foot zone contains 2 bands of *Receptaculites* and, less commonly, hard resistant fucoidal beds. The overlying subunit, Zone A, contains several distinctive noncherty intervals. The most important noncherty interval is about 20 feet below the top of Zone A; its base is indicated by 2 bands of chert containing *Receptaculites*. The normal thickness of the cherty unit is 103 feet; alteration has thinned this unit locally to 90 feet or less.

NONCHERTY UNIT

The noncherty unit includes the upper part of the Prosser cherty member and all of the Stewartville massive and Dubuque shaly members. The base of the noncherty unit is a well defined lithologic break and is locally well exposed. In contrast, the boundary between the Prosser and Stewartville members is the base of a vague, poorly defined *Maclurea* zone, which becomes indistinguishable in altered areas, mines, and drill cuttings. This faunal contact between the Prosser and Stewartville members of the Galena dolomite is neither easily recognized nor well exposed in the mapped area. For the mining district the Prosser member should be redefined to include only the cherty dolomite beds and the lower 10 feet of the present cherty unit. The Stewartville member should also be redefined to include 30 feet of noncherty beds, the upper part of the present Prosser member, as its basal beds. The boundary between the Prosser and the Stewartville members is then indicated by the uppermost band of chert in the Galena dolomite. Weiss and Bell (1956) compare certain stratigraphic classifications of the Galena dolomite and other Middle Ordovician rocks and conclude that a single classification is not satisfactory for the entire upper Mississippi Valley.

The Prosser member contains many noncherty zones; the upper 30 feet of this member is noncherty. Strata equivalent to that of the Stewartville member are commonly thin bedded in deeply weathered rock. The writer recommends that the terms "cherty" and "massive" be discontinued in the normal nomenclature. The more massive, light-brown dolomite of the lower beds in the noncherty unit generally can be distinguished from the thin-bedded, yellow-orange shaly dolomite of the upper beds of this unit, the Dubuque member.

The abundant silty shale partings and thin beds of dolomite are the most distinctive lithic features of the Dubuque. Sardeson (1907, p. 193) described the basal Dubuque as those beds containing the lowermost *Lingula iowensis*. Willman and Reynolds (1947, p. 9), from their work in northern Illinois, and Brown and Whitlow (1960, p. 22), from their mapping in the Dubuque area, designated the lowermost shale bed as the base of the Dubuque member. A white feldspathic metabentonite separates the more massive Stewartville member from the overlying thin bedded and shaly Dubuque member in the Johnson quarry, SE 1/4 NE 1/4 sec. 19, T. 6 N., R. 3 E. (fig. 34). Specimens of *Lingula iowensis* are oriented vertically in the Dubuque member about 1 foot above this bentonite. Bentonite in the Dubuque and Stewartville members have been described by Weiss (1954) from southeastern Minnesota. Most of the shale partings in the Dubuque member contain clay-size muscovite, quartz, and adularia. The recurrence of layers of metabentonite are probably the result of volcanic activity in the southern Appalachians (Nelson, 1922).

A resistant ledge, about 3.3 feet above the bentonite in the Johnson quarry (fig. 34), is equivalent to the caprock unit of Flint and Brown (1955), which is a conspicuous sequence of dolomite beds 3.4 feet above the basal shale of the Dubuque member. This competent unit consists of three beds of dense resistant dolomite separated by shale partings. In outcrop, weathering produces a re-entrant in the less resistant silty dolomite below the caprock unit. The consistent thickness of the caprock unit throughout the mining district (Allingham, Flint, Agnew, 1955; Brown and Whitlow, 1960, p. 22) indicates uniform conditions of quiet-water deposition of carbonate sediments in this area, although its thickness may also indicate a nearby strandline southwestward.

POST-GALENA DEPOSITS

Thin deposits of clay, chert, loess, and anomalous boulders of sandstone lie mainly on the uplands of Galena dolomite. A reddish-brown clay of various thicknesses that contains fragments of white chert and dolomite lies directly on the Galena dolomite. This clay zone and cherty residuum was derived mainly from the parental Galena dolo-

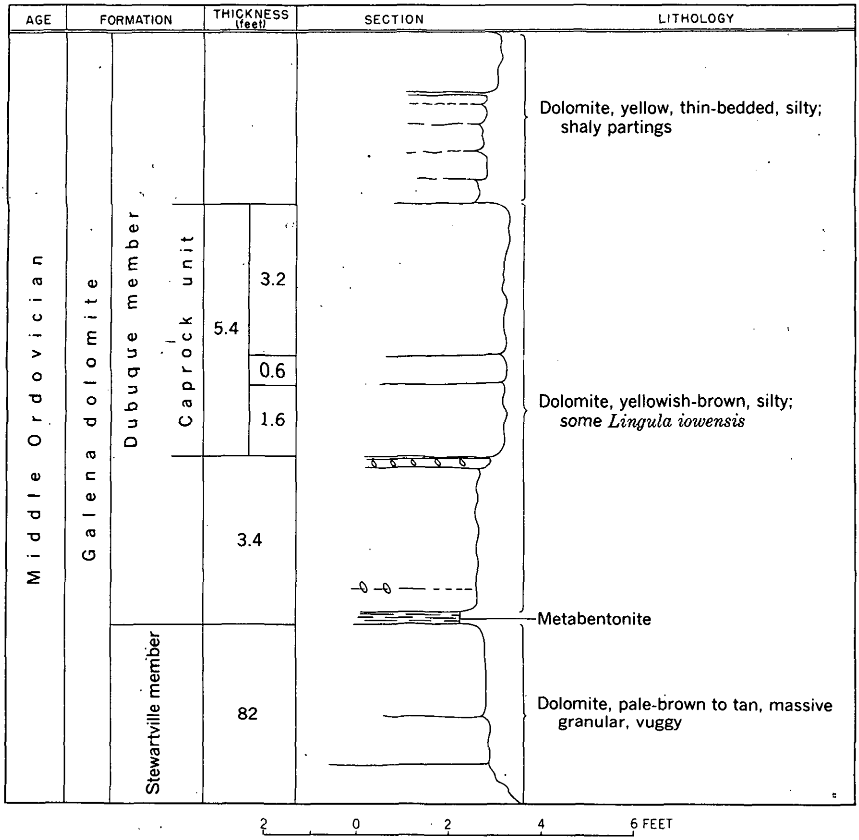

FIGURE 34.—Section at the contact between the Stewartville and Dubuque members of the Galena dolomite, Johnson quarry, Dodgeville, Wis.

mite and dolomite of Silurian age (Whitney, 1862a, p. 121–122). The upland surface, south and southwest of Mineral Point, is covered by several feet of loess (Bain, 1906, p. 34; Grant, 1906, p. 19-20). This windblown silt probably originated from the flood plains of the Mississippi River (Hole and others, 1952). Recent alluvium and stream gravels fill the larger valleys.

Anomalous boulders of quartz sandstone have been found in outcrop areas of the Galena, Decorah, and Platteville formations (Whitney, 1862a, p. 137; Strong, 1877, p. 667; Grant, 1906) along the crest of the Mineral Point anticline and the flanks of small flexures (fig. 28). These boulders lie at altitudes between 1,030 and 1,250 feet. The sand is well sorted and is very similar in lithology to the St. Peter sandstone. Calcite and iron oxide commonly cement the outer quartz grains of the blocks; however, the interior sand is very friable. The sandstone contains numerous fragments of chert and casts of rock fragments, which may have come from Silurian dolomite, the Galena dolomite, or from cherty beds of the Decorah and Platteville formations. Some of the fine-grained chert was preferentially dissolved from the coarse-grained sand and iron oxide cement. The alinement of these large blocks of sandstone conforms to the direction of tension joints in the major anticlinal areas; they commonly trend N. 5° E. to N. 5° W. or N. 85° W. to S. 85° W. Whitlow and Brown (1963) have observed sandstone dikes in the Galena formation in the Dubuque area.

Sandstone boulders are believed to be erosional remnants of sandstone dikes originating from the St. Peter formation. During folding, brittle carbonate rocks on the flanks of large anticlinal structures ruptured under tension and formed open joints. Under hydrostatic and compressional forces, unconsolidated, water-saturated sand from the St. Peter was rapidly injected laterally and upward into dilatant fractured dolomite. Cherty dolomite and post-Galena sandstone caved from above into these open joints. Broken rock from formations above was incorporated into the loose sand. The blocks were probably derived from subsequent erosion of lithified sandstone dikes. Boulders of hematite and quartz sand of the same common origin, that of sandstone dikes, lie on the south flank of the Mineral Point anticline where iron mineralization is widespread. The dike rock, source of these anomalous iron-cemented blocks, was probably derived from the ferruginous layer of sand at the top of the St. Peter.

STRUCTURE

The zinc-lead mining district is on the west limb of the Wisconsin arch (fig. 25), the southward continuation of a broad uplift known as the Wisconsin dome. The arch, formed during Precambrian time (Ekblaw, 1938), has a structural relief of 200 to 300 feet in 30 miles and is the dominant structure in south-central Wisconsin.

The sedimentary rocks on the flanks of the arch dip gently southwestward into the Forest City basin and southward into the Illinois basin. The strata in the entire mining district have a regional dip of 18 feet per mile southwestward; although within the mapped area, the average dip is about 12 feet per mile in the same direction. The Cambrian rocks strike northwestward and generally thicken southwestward. The Ordovician rocks also have a northwesterly strike.

The layered brittle carbonate rocks in the Dodgeville and Mineral Point quadrangles have been tilted, folded into broad and shallow synclines and anticlines, and fractured. The strata were deposited in broad shallow basins, which were formed during the warping that accompanied uplift of the Wisconsin arch. Uplift of the arch is indicated by the change in thickness of sediments of Ordovician age southwestward from its axis. The initial northwest trend of the basins was controlled by their position on the arch. Their shape and elongate direction was later modified to a westerly trend, probably by faults in the basement. The carbonate rocks were folded mainly by fracturing, bending, and adjustment of segmented beds along vertical fractures and horizontal bedding surfaces. The major folds trend nearly westward across the mining district and have as much as 200 feet of structural relief (Bain, 1906, p. 38; Heyl and others, 1955, pl. 1). Minor folds, that are several miles long and have 50 to 75 feet of structural relief, are superimposed on the larger structures. These folds trend northwestward, northeastward, or may parallel the larger structures. Cross folding, preferential leaching of the strata in zones of fractured rock, or underlying sedimentary and structural features have resulted in a complex of small domes and depressions. Faulting is local. Major faults and fractures that control mineral deposition are mainly restricted to minor depressions or the flanks of small folds. The Ordovician rocks were sheared principally in an easterly direction in the southern part of the area; elsewhere, shearing is northwestward and northeastward. Northwestward and northeastward-trending fractures localized some formerly important deposits of lead. Tension joints related to major folds have a northerly trend.

The significant structures that control the position of zinc and lead deposits are vertical fractures of negligible displacement and basins of small amplitude. These zones of fracture and associated small flexures or depressions were locally modified by rock alteration, largely leaching. The basins were also modified by lithologic variations and irregularities in underlying rocks. Leaching related to mineralization accentuated local structures of tectonic origin by (a) widening joints, (b) producing solution cavities along bedding planes, and (c) increasing the amplitude of small folds by reducing the thickness of strata in troughs.

The Mineral Point anticline, which trends nearly eastward, is the main structure of the central part of the mapped area (fig. 35). A quarry on the north flank of this anticline has exposed one of the few normal faults in this area. A reverse fault on the south limb of the anticline near Calamine is exposed in several road cuts and streambanks.

Geologic structure of the Dodgeville and Mineral Point quadrangles is shown in plates 12 and 13 by structure contours on the top of the Platteville formation, mainly on the basis of control points distributed throughout this formation (table 2). The top of the Platteville formation was chosen as a datum, because structural features, based

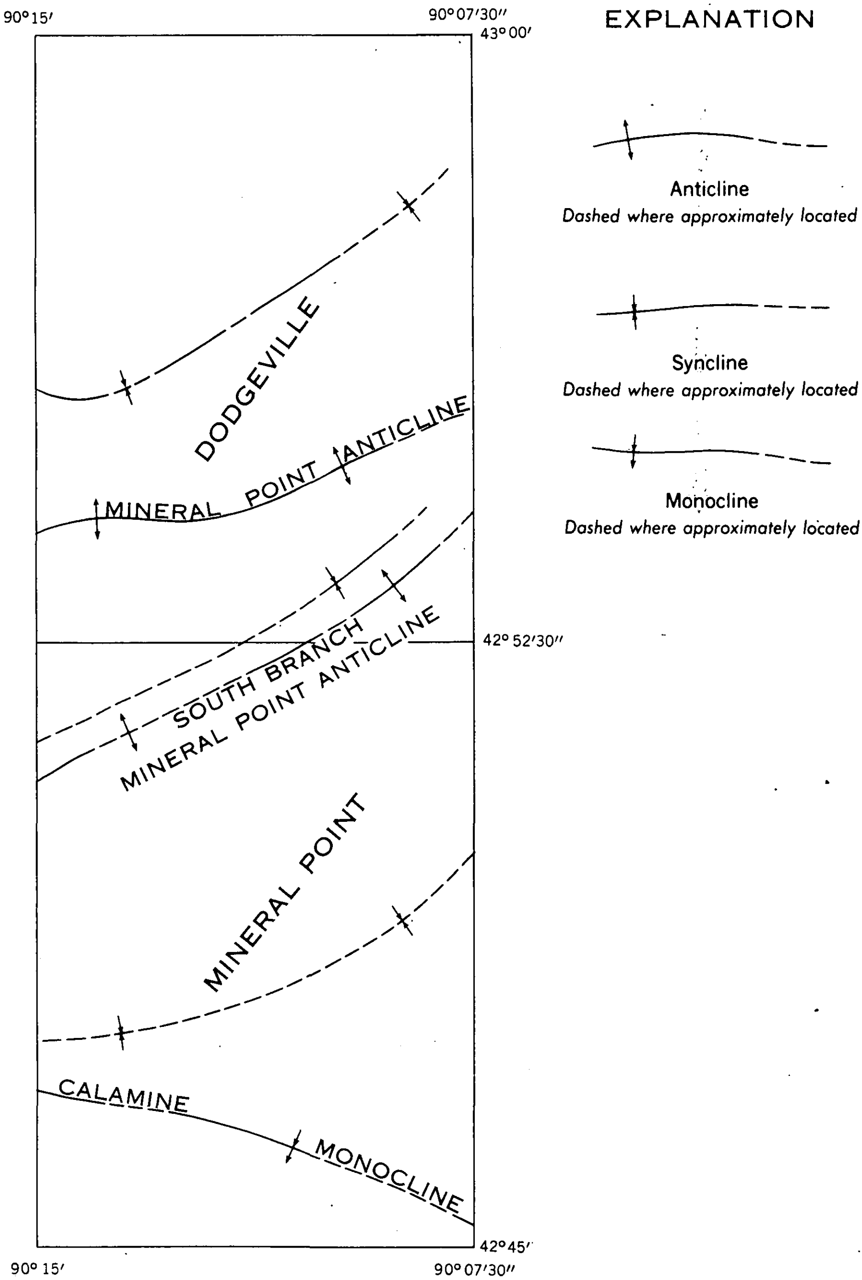

FIGURE 35.—Major structures in the Dodgeville and Mineral Point quadrangles, Wisconsin.

TABLE 2.—*Horizons and thickness of strata used for structural control in the Dodgeville and Mineral Point quadrangles*

[Datum is the top of the Platteville formation]

Lithologic unit	Interval between the top of Platteville formation and top of the lithologic unit		Average thickness of the unit		Range	Number of points used for control[1]	Percent of total control points[1]
	Dodgeville quadrangle	Mineral Point quadrangle	Dodgeville quadrangle	Mineral Point quadrangle			
Galena dolomite, noncherty unit							
Dubuque member							
Caprock unit	224						
Stewartville member	215		82				
Prosser member	163		134				
Cherty unit	131		102		87–103	5	0.3
Zone A	131		68				
Zone B (lower *Receptaculites*)	61	65	12	14	11–15	24	1.4
Zone C (lower cherty)	49	51	10	10		33	1.9
Zone D (lower buff)	39	41	10	10	9–11	62	3.5
Decorah formation			29	31			
Ion dolomite member	29	31	19	20			
Gray beds	29	31	12	14	8–14	66	3.8
Upper gray beds	29	31	6	8			
Lower gray beds	23	23	6	6			
Blue beds	17	17	7	6	4–7	44	2.5
Guttenberg limestone member	10	11	9	10	3–13	50	2.8
Spechts Ferry shale member	.8	.8	.8	.6	.1–1.0	21	1.2
Platteville formation			65	64			
Quimbys Mill member	0	0	11	12	8–14	148	8.4
McGregor limestone member	11	12	30	30		169	9.6
Magnolia member of Bays and Roasch, 1935	11	12	15	16	14–17		
Mifflin member of Bays, 1938	26	28	15	14	12–16	32	1.8
Pecatonica dolomite member	41	42	22	21	19–22	170	9.7
Glenwood shale member	63	63	2	1	.3–2.8	690	39.3
St. Peter sandstone	65	64				242	13.8

[1] Exclusive of drill-hole or mine data.

on this horizon and control points below, are mainly tectonic in the area of investigation. Beds of the Platteville are rarely thinned. Sand of the St. Peter formation has filled irregularities on the surface of the Prairie du Chien group, so that these irregularities are not reflected in the overlying strata. Eighty-three percent of the outcrop control is below the Decorah formation. All churn drill holes used for structural control reached the top of the Platteville formation. In the Mineral Point quadrangle, 62 percent of the outcrop control points are at the base of the Platteville formation. The top of the Pecatonica dolomite member accounts for an additional 10 percent of the structural control; the thickness of this member has not been changed by leaching. Two-thirds of the control points, mostly near Mineral Point and near the base of the Platteville formation, not only indicate tectonic features but may also include some irregularities in sedimentation. Although leaching has not thinned beds of the McGregor member in this area, these strata are thinned in some mineralized areas in the southern part of the mining district (A. E. Broughton and T. E. Mullens, oral communication, 1957). Beds in the Decorah and Galena formations may be thinned locally by mineral-bearing solutions. Some small folds in these formations may result from the effects of thinning as well as tectonic activity. The contrast between the simple structure shown in the upland areas and the complex structure shown in the dissected areas is probably largely a result of unequal distribution of outcrop data—sparse in the uplands and abundant in the dissected areas. Some flexures of very low relief due to cross folding, fracturing, or leaching and thinning are indicated only as slight bends in the contours, although they were perceptible and measurable during the survey.

FOLDS

Percival (1855, p. 23) recognized the eastward-trending Mineral Point anticline as "a point of extraordinary elevation" of rocks northwest of Mineral Point where the anticline is a prominent symmetrical feature having a maximum structural relief of 70 feet. Northeast of Mineral Point the anticline separates into broad folds. The anticline plunges westward and terminates by faulting in the Mifflin quadrangle (Carlson, 1961, p. 117). The south branch of this anticline extends southwestward from the Barreltown area, parallel to the Mineral Point branch. It terminates near the east edge of the Mifflin quadrangle (Taylor, 1963). A broad crenulated basin lies parallel to the north flank of the Mineral Point anticline; no well-defined basin is present on its south bank (fig. 34). Chamberlin (1882, p. 420) postulated a sedimentary origin for the large basin, later modified by a deforming force. In addition, Bain (1906, p. 38) believed the basins partly formed by compaction during consolidation of the sedimentary rocks. Grant (1906, p. 53) believed that some of the folds resulted from inequalities in deposition and were later accentuated by tectonic folding.

Near the confluence of Furnace Creek with the Pecatonica River, ledges of the St. Peter sandstone dip continuously southward. This westward-trending structure is mainly monoclinal. Near Calamine, the monocline has a northwesterly trend. The monocline lies south of the Mineral Point anticline and the arch at Arthur (Taylor, 1963). It has a maximum structural relief of about 50 feet. A broad crenulated basin lies between this structure and the south branch of the Mineral Point anticline to the north. Grant (1906, p. 54) recognized monoclinal features near Mifflin and south of Meeker's Grove.

Minor folds are numerous and show variations in trend in different parts of the mapped area (pl. 14). Minor folds of northwesterly and northeasterly trends produce a rhombic pattern of plunging cross folds on the flank of the Wisconsin arch. In the Dodgeville quadrangle the most continuous of these minor folds, which are those with a northeasterly trend, parallel part of the Mineral Point anticline. These small folds are, in general, closely spaced, ellipsoidal and have amplitudes not exceeding 30 or 40 feet. The trend of the fold axes north of the Mineral Point anticline is dominantly N. 60° E. The direction of the folds on the south flank of the Mineral Point anticline shifts from N. 30° W. in the western part of the area to about N. 60° W. in the eastern part. The trend of the fold axes in the Mineral Point area is dominantly N. 30° E. and N. 60° W. South of the monocline near Calamine, the trend of the folds is about N. 55° E. and N. 45° W.

In the northern part of the Dodgeville quadrangle, a complex of small elliptical basins and domes with closures of 10 to 20 feet is the result of transverse folding, fracturing, and solution. Some basins and domes at the top of the St. Peter sandstone may partly result from undulations on the surface of the Prairie du Chien group. The amplitude of small folds may have been diminished (anticlines) or accentuated (basins) elsewhere by thinning of certain beds in the Decorah and Galena formations and, to a lesser extent, in the Platteville formation in zones of fracture by mineralizing solutions. A similar complex of small elliptical basins and domes, south and southeast of Mineral Point, is apparently the result of thinned strata at the intersection of zones of closely spaced fractures or shear zones. The rhombic pattern of basins and domes is indistinguishable from cross folds in this area.

As a primary structure, the Mineral Point anticline interrupts the continuity of the minor folds, basins and domes, of northwesterly trend parallel part of the south flank of the anticline. The apparent cross folding or alinement of basins and domes postdates this anticline and did not change its form. Minor folds crossing the monocline near Calamine predate this structure and changed its geometry. This monocline may be related to faulting in the basement or large sedimentary structures in the underlying beds of Cambrian and Early Ordovician age.

FRACTURES

Three types of fractures are distinguished in this area. Fractures showing appreciable movement are described as faults. Widely spaced fractures a few feet apart that have no perceptible vertical displacement of bedding, are called joints. Joints are distinguished from faults by an absence of offset or by apparently negligible movement. Groups of closely spaced fractures within inches of each other, generally inclined and showing very small vertical movement, are called shear zones. These zones may parallel a nearby set of joints. Most fractures are related to very gentle structures—broad, shallow folds or flexures. Shear zones in mineralized areas are commonly indicated by vuggy rock, fractures filled with calcite and oxidized minerals, or large springs.

An apparent absence of faulting in the mining district was noted by Whitney (1862b), Strong (1877), and Chamberlin (1882). Faulting reported by Jenney (1894) and Blake (1894) was later refuted by Calvin and Bain (1900, p. 519) and Bain (1906, p. 43). Recent detailed mapping has disclosed faults (Behre, 1937, p. 526–527, Heyl and others, 1959), but faults with displacement of more than 20 feet are rare. Unless the trace of a fault was observed stratigraphic evidence of a dislocation of the bedding is assumed to indicate a sharp flexure. Several well-exposed faults are recognized. The north flank of the Mineral Point anticline, S½ secs. 14 and 15, T. 5 N., R. 2 E., is partly faulted. The surface trace of the fault is marked by a narrow zone of brecciated dolomite and iron oxide. Drag of the bedding along its steeply dipping fault zone is exposed in a small quarry (fig. 36). Here the displacement is about 22 feet, with beds of the Lower Cherty zone of the Galena dolomite faulted against the gray beds of the Ion dolomite member of the Decorah formation. The fault dips southward in the direction of the downthrown side. North of Bonner Branch a series of reverse faults parallel the monocline near Calamine. The southward-dipping fault zone is marked locally by numerous closely spaced fractures, drag along the bedding, and claylike gouge. The vertical displacement is about 18 feet and the beds of the Guttenberg member are faulted against the gray beds of the Ion member of the Decorah formation. Faults seem to be related to a sharp flexure extending downward into the St. Peter sandstone, as shown in streams tributary to Bonner Branch.

A minor fault in the NW¼ of sec. 6, T. 5 N., R. 3 E., although not well exposed, has a minimum vertical displacement of 10 feet and strikes about N. 60° E., parallel to the direction of folding. Here beds of the Ion dolomite member are faulted against the lower buff zone of the Galena dolomite.

Normal and reverse faults are clearly exposed in a road cut in sec. 22, T. 4 N ., R. 2 E. These westward-trending faults bound 3 small grabens with vertical displacements of 2 to 4 feet. The relations of the faults are complicated by the removal of soluble carbonate rocks. The residual shale is folded and contorted. These faults coincide with a flexure in beds of the Decorah and Platteville formations. The

FIGURE 36.—Normal fault with displacement of 22 feet, beds of lower cherty zone of the Galena dolomite, Ogl, against gray beds of the Ion dolomite member, Odi, of the Decorah formation, in quarry, on Linden Road, 4.3 miles northwest of Mineral Point, Wis.

faults were initiated by folding and were exaggerated by local solution of the fractured beds and underlying rock.

Many of the major westward-trending open fractures have a vertical displacement ranging from 0.2 to 2 feet with the downthrown side to the south. These fractures can be seen in quarries in sec. 31, T. 5 N., R. 3 E., secs. 12 and 27, T. 4 N., R. 2 E. Their trace in the soil and quarry floor is marked by red clay, iron oxides, and calcite crystals. Miners commonly refer to these fractures as crevices. The pattern of minor southward adjustments in the strata by these fractures, particularly south of Mineral Point, is related to southward-dipping monoclinal flexures of westerly trend. The brittle rocks ruptured during flexing, and resulted in shearing with minimum movement.

The dominant trend of joints due to shear is northeastward and northwestward; shearing in a true northerly and easterly direction is negligible. In the southern third of the Dodgeville quadrangle and in the area of the Mineral Point anticline, two sets of joints in the dominant system are conjugate and strike N. 60° W. and N. 45° E. (figs. 35, 37). A second system of conjugate joints strike N. 75–80° W. and N. 20–25° E. This system of joints probably is genetically related

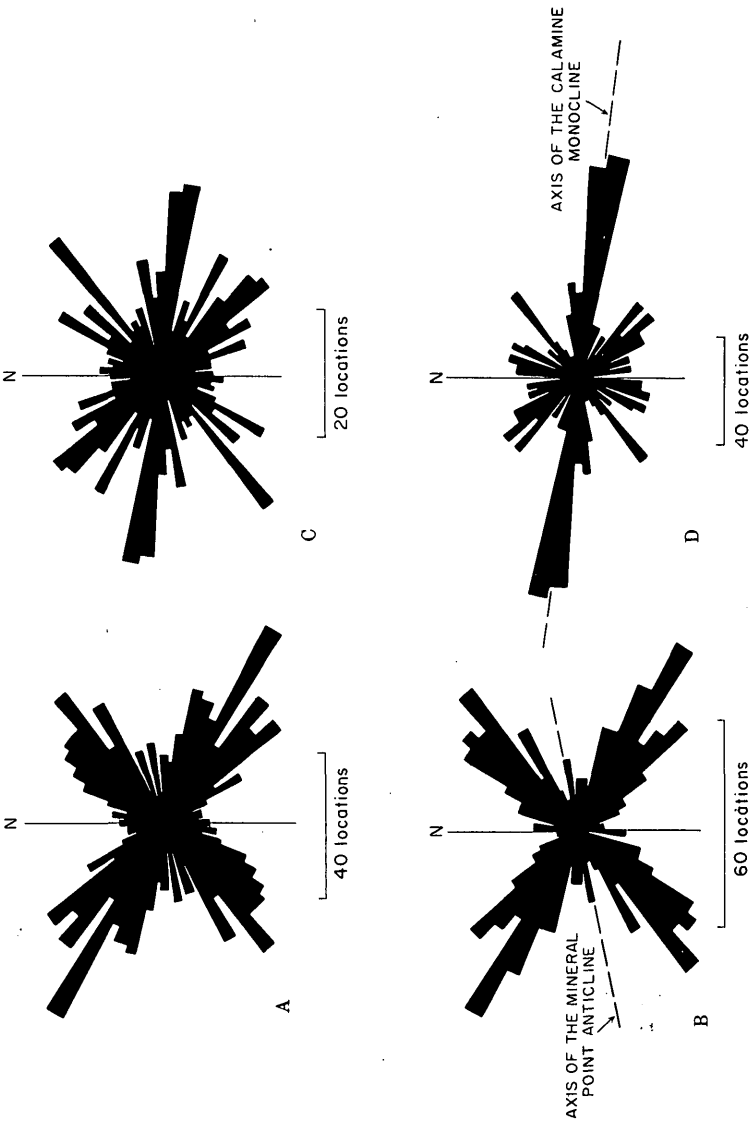

FIGURE 37.—Diagrams showing strikes of joints in rocks of Ordovician age in the Dodgeville and Mineral Point quadrangles.

to the northeastward-trending folds. A set of northward-trending joints, together with minor westward-trending joints are conjugate and seem to form a shear pair related to the elongate folds of northwesterly trend.

The northward- and westward-trending fractures throughout the mapped area are well developed only in areas of major folds. Near the Mineral Point anticline, joints that have a northerly trend are open vertical fractures along which sand was emplaced. These joints, transverse to the anticline, are believed to result from tensional stress.

In the southern third of the Mineral Point quadrangle, the dominant trend of the fractures is N. 80° W. These joints roughly parallel the Calamine monocline and the reverse faults in the Bonner Branch area (pl. 13; fig. 35). The dominant westward-trending joints in this area are related to small nearby zones of faulting and shearing. A minor set of tension joints trends N. 10° E. A minor system of joints trends N. 40–50° W. and N. 50° E.

Open fractures in the Mineral Point area and in the North Survey area (pl. 14), those which have been enlarged locally by solution of the calcareous rocks, are dominantly westward trending. Many of these fractures are mineralized. They are equally notable for their persistent parallelism and direction of strike as observed by Percival (1855).

Although tectonic deformation initiated regional structures and controlled many small flexures and fractures, a few local structural features including the control of ore deposits may be caused by leaching, compaction, folding, or fracturing of underlying strata. These structural controls may be the result of (a) earlier depositional features such as reeflike domes at the top of the Shakopee dolomite, which were accentuated by differential compaction of muds and removal of soluble carbonate rocks of the interdome areas or by pre-Shakopee doming (Andrews, 1955), or (b) leaching that produced thinning of strata or open cavities along vertical joints and bedding surfaces, or (c) diverse variations in density and crystallinity of the rocks.

The unique inclined and flat fractures associated with the zinc mines are described in the section on structural control of the ore deposits. Flat fractures or horizontal breaks in beds are mainly along shaly or silty partings at bedding surfaces or along planes of weakness due to the planar orientation of argillaceous specks, natural sedimentary features. In some places, minute movement at these surfaces produced slickensides during flexing of the strata. These striated surfaces are observed in mines. The flat fractures or open bedding surfaces and the inclined irregular fractures related to shear zones are partly due to leaching and subsidence of soluble brittle strata in mineralized areas.

Large anticlines in the sedimentary rocks of Cambrian and Ordovician age are believed to be caused by faulting in the Precambrian basement complex, especially the postulated gravity faults transverse to the Wisconsin arch. Several broad anticlines and synclines pitch westward to southwestward from the axis of the arch (Bieber, 1948, p. 244–245; Heyl and others, 1955, pl. 25). An abrupt break in the structure of the strata over the Wisconsin arch (Bieber, 1948) suggests faulting or a sharp flexure parallel to major transverse faults (King and others, 1944). Tectonic folding and fracturing accentuated these large structures.

Broad reef structures resulting in the undulating upper surface of the Shakopee dolomite are reflected to the top of the St. Peter sandstone and the Pecatonica dolomite member of the Platteville formation despite the smoothing effect of sand deposition and rigidity of the massive dolomite beds in the overlying Pecatonica member. Small basins on the upper surface of the St. Peter, contoured from data in the Mineral Point quadrangle (table 1), arise from irregularities in the surface of the Prairie du Chien group.

Broad basins resulted from widespread solution-thinned beds of the upper part of the Platteville and Decorah formations and lower cherty unit. These basins are reflected to the top of the cherty unit despite the competency of massive beds in the Galena dolomite.

TECTONICS

According to Heyl and others (1959), the eastward-trending folds have been formed by compressional forces directed northward from the deforming Illinois basin and the northwestward-trending folds by a northeast compression or holding force from the Forest City basin. The writer's views differ from this concept. Some of the westward-trending structures are, however, probably compressional features produced by a more westerly directed gravitational force during uplift of the Wisconsin arch, with the dome to the north and the basin to the south providing holding forces.

The forces operating in the relatively stable buried Precambrian shield of the upper Mississippi Valley are vertical—that of renewed uplift of the Wisconsin arch and contemporaneous depression of the basin areas—presumably owing to a delicate isostatic adjustment of large crustal blocks in the basement. Uplift of the Wisconsin arch which caused tilting of the strata was followed by transverse faulting and fracturing in the basement rock. The transverse faulting of dominantly westerly trend in the basement rocks caused parallel initial warping and fracturing of the overlying sedimentary rocks. Parallel zones of shearing were also caused by this faulting. Uplift of the dome provided sufficient relief for the thin strata to slide imperceptibly along bedding surfaces from the crest of the arch under the influence of gravity and exert a lateral component of force in a south to southwesterly direction. By this mechanism the major westward-trending folds were developed in areas of initial faulting and related folding.

Major systems of conjugate joints that form a shear pair and strike N. 60° W. and N. 45° E. are related to this folding, as are similarly minor tension joints that strike northward and westward. Minor cross folds of northwesterly trend and related shearing in a westerly direction parallel to the major preexisting fractures were developed in some areas between the major folds. Tension and compression joints related to the minor cross folds that strike northwest and northeast cannot be distinguished from joints produced during the major folding.

During post-Silurian uplift (Pirtle, 1932, p. 146–148; Eardley, 1951, p. 28) and regional tilting of the strata, renewed faulting in the basement complex probably accentuated the major overlying structural features. This later period of deformation provided a favorable structural environment for subsequent ore deposition by additional flexing of the strata, reopening of fractures, and locally opening bedding surfaces. Mineralizing solutions later widened many fractures and thinned certain beds by selective removal of soluble carbonate. Small basins and domes coincident with the major rhombic pattern of fractures resulted from leaching of these strata.

MINERAL DEPOSITS

Much of the early mining of lead and zinc in the upper Mississippi Valley district centered around Dodgeville and Mineral Point and dates from about 1827, when the initial discoveries of lead were made in these areas. Mining ceased about 1910 and was revived only recently.

Deposits of zinc, lead, and copper are structurally and stratigraphically controlled. Two related types are recognized: joint-controlled deposits related to a regional fracture system, and pitch-and-flat deposits, controlled by small basins as well as the fracture system and a related leaching and thinning of the host rock. Sphalerite and galena occur as replacements and open-space fillings in the carbonate strata. Generally pyrite and marcasite, and less commonly chalcopyrite, barite, and calcite are closely associated with these ore minerals. Above the water table, in the oxidized zone, the sulfide minerals are coated or completely replaced by smithsonite, cerussite, hematite, goethite, and less commonly by chalcocite, covellite, psilomelane, and pyromorphite. Coatings of greenockite and erythrite are common in the mines near Mineral Point.

JOINT-CONTROLLED DEPOSITS

Lead ore was generally mined from veins in long vertical or steeply inclined solution-widened fractures, locally called crevices, and closely spaced parallel crevices called ranges (Percival, 1855, p. 34–35). Whitney (1862a, p. 225) called these lead deposits "gash veins" in order to distinguish thin continuous sheets of galena of limited stratigraphic extent from common fissure veins (pl. 15).

Many of the joint-controlled deposits have been mined in groups called "sheet lots" because of their narrow width and close spacing. Such a "sheet lot," the Koop lot in the South Survey area, SW¼ sec. 7, T. 5 N., R. 3 E., is composed of many closely spaced parallel sheets of galena (Whitney, 1862a, p. 238). In addition, joint-controlled deposits locally have an echelon arrangement (pl. 14). At the junction of two or more crevices, lead minerals are commonly localized in irregular vertical shoots. In general, fractures trending N. 25° W. to N. 30° E. have little open space and contain thin sheets of galena in contrast to relatively open fractures trending N. 70° W. to S. 80° W., which commonly contain large masses of galena (Phillips, 1854). Beds adjacent to many solution-widened fractures of westerly trend show as much as 1.5 feet of vertical displacement. The areal extent and open character of these fractures result from repeated movement as evidenced by small offsets in bedding and recemented blocks or breccias in many of the fractures. The apparent vertical displacement of beds may result from an undetermined amount of strike-slip movement because of shear stress in warped or slightly folded strata. The displacement of northward trending vertical fractures is generally negligible. Deposits of galena are stratigraphically as well as structurally controlled.

The podlike cavity or spongelike zone formed in a solution-widened vertical or steeply inclined fracture at a single bed or restricted set of soluble strata is called an "opening" (Whitney, 1862a, p. 239). In contrast to the more continuous sheetlike deposits in "gash veins", deposits in openings are restricted to definite stratigraphic zones (pl. 15). Owen (1940, p. 27) noted that the lead deposits were mainly limited to the middle and lower part of the Galena dolomite. An opening may be as much as several hundred feet long, oriented parallel to the strike of the joint as at the Joestegan lead mine (sec. 7 and 18, T. 5 N., R. 3 E.). The height of an opening is generally several feet (pl. 16).

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Locally, galena-filled fractures may parallel small folds as tensional or compressional features (Barreltown area) or cross the major folds diagonally, parallel to conjugate joints or shear pair (North Survey and South Survey areas). In addition to their apparent relation to folds many galena-filled fractures are locally associated with sphalerite at depth. The relation between lead and zinc deposits and small basins was observed by Whitney (1862a). In the Barreltown area (pls. 14, 16), as well as in the Mineral Point area lead-bearing crevices strike parallel to linear zinc ore bodies and are a part of the same system of fractures that control these underlying zinc deposits.

Galena occurs within openings as cementing matrix in solution-breccias and porous zones; crystals or small aggregates of crystals in the clay-filling ("cog lead" of local usage); encrustations coating the walls; and large, discontinuous, loose lenticular masses ("chunk lead" of the miners) embedded in the residual clay and dolomite sand. In crystalline form, galena commonly assumes the shape of cubes, rarely cubo-octahedrons, and in complex networks, a reticulate form. Sphalerite, pyrite, marcasite, and chalcopyrite accompany galena and are locally abundant in joint-controlled deposits, as at the Conley, Spensley, and Bennett ranges, southwest of Barreltown, and the Beach and Walsley copper ranges, east of Mineral Point. Some joint-controlled deposits contain only a single mineral, or, at the most, two minerals, such as galena, or pyrite, or chalcopyrite, or combinations of these minerals. Marcasite and, less commonly, pyrite encrust the walls of some open joints and fill the open space at bedding surfaces adjacent to these joints. These iron sulfides are usually partly oxidized. The order of mineral deposition follows this sequence: pyrite, chalcopyrite, marcasite, and galena. Some overlap was noted. A late stage of marcasite generally follows the deposition of galena. Common gangue minerals, such as calcite and barite, fill the remaining open space in many of the veins. Barite is a common gangue mineral in the Spensley, Bennett, and Lanyon deposits north of Mineral Point.

Solutions moving through the massive galena dolomite have preferentially removed the more soluble intergranular line from the dolomite rock and produced tumbled breccias, accumulations of dolomite sand, porous honeycombed structures in the fractured rock, and large residuum of red clay (Chamberlin, 1882, p. 451–468). The decomposition of sulfides in the zone of oxidization acidifies circulating ground water, which greatly aids the process of disintegration in limy dolomite. Some clay, silt, and sand that fill some open joints may have been carried down from the soil zone. The soluble calcareous materials are commonly deposited in the upper parts of open joints as travertine (SE¼SW¼ sec. 14, T. 6 N., R. 3. E.). In some joints iron oxides are mixed with the residual clays to form an ocherous mass suitable for pigment.

Residual concentrations of galena at shallow depth near the contact of bedrock with soil have resulted from weathering and erosion of lead-bearing fractures (pl. 15). These partly exposed deposits were easily discovered. The trace of mineralized joints from which lead ore was mined is commonly indicated on the surface by an alinement of shallow pits, mine shafts, mine dumps, or by reddish streaks in the darker contrasting soil. Owen (1840, p. 18–41) cited the alinement of vegetation, sinkholes, elongate depressions, calcite or ocher in the soil, and altered limestone as indicating the location and orientation of crevices or open joints.

PITCH-AND-FLAT DEPOSITS

The main zinc production in the Dodgeville and Mineral Point areas is from pitch-and-flat deposits (pls. 15, 16 and 17). Zinc ore, predominantly sphalerite, is mined from inclined veins locally called pitches and from horizontal veins along bedding surfaces called flats (Percival, 1855, p. 53–54; Whitney, 1862a, p. 230). Pitches, well developed in the Mineral Point area, dip steeply at angles of 45°–60° (pl. 17). Beds adjacent to these veins have negligible displacement. The deposits generally contain several pitches with opposed dips. Several parallel pitches generally make up an economic zone as much as 50 feet wide (pl. 17). Many pitches show refracturing of the veins and continued deposition of sphalerite or calcite to reheal the mineral breccia. The broken and brecciated rock in the footwall of these pitches is called core ground. Pitches are associated with flats in the Mineral Point area but are unimportant and almost entirely absent in the Dodgeville area. The most important deposits in the Dodgeville area are flats, or horizontal veins in open spaces produced by flexing and solution enlargement along bedding surfaces (pl. 18).

STRUCTURAL AND STRATIGRAPHIC RELATIONS

The pitch-and-flat deposits may be divided into two general types: linear and arcuate. Linear ore bodies are parallel to the flanks of narrow, elongate basins and are related to groups of fractures in parts of the structure where the dip of the bedding is nearly at a maximum. An individual mineralized fracture may have a sinuous trend, but the aggregate zone of pitches is a linear feature and is closely related to a zone of parallel joints. Pitch-and-flat ore deposits of arcuate form occur at intersections of cross folds where these fractures appear to bend around the nose of the resulting small plunging flexure. Vertical or slightly inclined transverse tension fractures are closely spaced at the extremities of these plunging structural features and tend to follow their outline. Structural controls such as inclined fractures commonly dip away from the synclinal areas, and, like the bedding-plane fractures or silty partings, have apparently negligible displacement. These fractures generally flatten or terminate downward along less competent plastic shaly beds and continue upward as a single fracture (pl. 17).

Pitch-and-flat deposits in the Mineral Point area are mostly restricted to the lower part of the cherty unit of the Galena dolomite, the Decorah formation, and the Quimbys Mill member of the Platteville formation. South of the Mineral Point anticline, the main ore zones are in the Decorah formation, particularly in blue beds of the Ion dolomite member and in shaly beds of the Guttenberg limestone member. North of the Mineral Point anticline where mineralization has been widespread, much of the ore has come from the basal part of the Quimbys Mill member, as a Dodgeville, North Survey, and in the vicinity of Pedler Creek.

Behre (1935) and Heyl and others (1959) believe that the fracture that control's the pitch in these deposits is a small reverse fault of tectonic origin originating as a bedding plane fault in the shaly Decorah formation. The fault is deflected upward through the overlying rock and dies out on a bedding surface or in a vertical joint. Later, solution-thinned rock in the core ground permitted subsidence, that resulted in development of open spaces at the small fault and between bedding surfaces. In addition, they believe these small basins are chiefly of tectonic original and control the location of pitch-and-flat deposits.

Another hypothesis for the origin of pitch-and-flat deposits was advanced by Chamberlin (1882, p. 380–398), Bain (1906, p. 44), and by Willman and Reynolds (1947). From his studies of the ore deposits, Chamberlin postulated that circulating ground water produced horizontal openings into which the overlying rocks sagged, and resulted in a structural environment for later mineral deposition. Bain refined these ideas to show that pitches resulted from subsidence. Willman and Reynolds believe that solution of the host rock due to mineralizing fluids removed support for the overlying rocks which consequently collapsed along an irregular domelike fracture system, leaving a series of inclined fractures and openings along bedding surfaces. The general theories of ground movement and subsidence are summarized by Royce (1941, p. 10–520 to 10–525). Mullens (1963) presents extensive data from the Shullsburg-New Diggings area to support a subsidence origin for structural control of pitch-and-flat deposits.

The writer believes that zones of shearing or closely spaced fractures are a major structural control of pitch-and-flat deposits in this area. These fractures are related to the major folds and, in part, parallel the minor cross folds (fig. 37). The westward-, northeastward-, and northwestward-trending fractures provided a permeable zone for the upward and lateral movement of solutions, particularly along bedding surfaces, near the contacts between the Quimbys Mill, Guttenberg, and Ion members. The structural control was modified by the lithology. Solution of the rocks preceded mineralization and provided part of the structural environment for ore deposition. Pitch-and-flat deposits developed in stratigraphic zones susceptible to leaching, near more permeable contacts. Clastic, silty, argillaceous partings in the rock units also provided permeable zones for movement of solutions. Flat openings or natural subterranean watercourses formed by leaching at the contacts, such as those at the base and top of the Quimbys Mill member. These permeable zones served as channelways for mineralizing fluids and removal of soluble materials as well as convenient areas for initial deposition and later redistribution of minerals and continued preferential leaching. This selective leaching of carbonate rocks partly removed support from the overlying beds. In addition, local support by hydrostatic pressure was decreased or absent during periods when solutions moved elsewhere due to natural drainage effects. Lack of structural support permitted beds of the overlying Ion member to sag over the thinned strata of the leached Guttenberg limestone member, breaking the rock in a stairstep pattern (pls. 16 and 17). Fracturing and brecciation were followed by collapse of the rock. The argillaceous residuum of the leached strata was compacted by the subsiding beds. The stairstep fractures and brecciated rock are localized in zones where the leached rock is very thin, such as near Mineral Point (fig. 33). Homogeneity and strength of the rock partly determined the pattern of fracture. The strong brittle rocks fractured in nearly vertical and horizontal breaks of the fracture system. Dilatant areas were the loci for final deposition of the ore. An arching reverse fault of small displacement formed in some places where leaching of thick beds achieved maximum thinning. The sag is less apparent in the massive beds of the Galena dolomite because of its rigidity and partial support of the underlying broken rock. The height of the pitches is controlled by the amount of thinning in beds of the McGregor, Quimbys Mill, and Guttenberg members and the strength of the Ion and Galena strata. Local brecciation, small offset of the veins, and repeated opening of the veins indicate continued solution and adjustment of the beds during and after mineralization.

Linear deposits such as the Richards mine (pl. 16) and the Grayville mine (pl. 17) are primarily controlled by northwest shearing. Here the pitch fractures and associated small basins of low structural relief are produced mainly by subsidence, a result of solution of the Guttenberg limestone member. The regional fracture pattern and open space at the contact between the soluble strata of the Quimbys Mill and McGregor members controlled the distribution and configuration of zones most susceptible to solution. Lithology partly controlled the areal extent of deposition and the type of deposition, mainly the disseminated minerals. The organic character as well as the argillaceous content of the lower part of the Quimbys Mill, Guttenberg and Ion members may have controlled deposition. Compaction of insoluble residue, widespread subsidence, and adjustment of these zones of leached rock around small basins produced curved fractures of the arcuate ore bodies. The intensity of collapse fracturing and the amount of open space are mainly determined by the extent of thinning, amount of soluble material removed, and the final thickness of the residual altered beds. Strata of the Guttenberg and Ion members in the Dodgeville and North Survey areas are more dense, less argillaceous, less permeable, and less subject to leaching than similar beds near Mineral Point (fig. 33). Lithologic differences may partly account for the transition of pitch-and-flat deposits in the Mineral Point area to the flat veins or absence of pitches in the mines of the Dodgeville area.

MINERALOGY

Zinc minerals commonly occur as: (a) symmetrical or asymmetric banded or massive veins in fractures and between bedding surfaces mainly in the Ion member of the Decorah formation; (b) open-space filling along bedding surfaces and in shear zones or solution breccias peculiar to the brittle rocks of the Quimbys Mill member of the Platteville formation and cherty unit of the Galena dolomite; (c) disseminated crystals that replace carbonate rock or are emplaced in the brown shaly partings commonly found in the solution-thinned Guttenberg member; (d) crystals or masses, which are characteristically reniform, colloform, nodular, stalagtitic, or botryoidal, and encrust podlike, elongate vugs and cavities. Brecciated ore is locally referred to as honeycomb or brangle ore.

Lead minerals are commonly intergrown with the zinc minerals. Small cubes of galena and crystals of sphalerite are disseminated in the shaly beds of most zinc deposits. Thick, complex sheets of reticulated galena and rosettes of sphalerite constitute some of the flat veins in the Dodgeville mine.

Iron sulfide is widespread near Mineral Point, where pyrite in the upper part of the St. Peter sandstone is abundant and conspicuous over the Mineral Point anticline. Iron minerals, common along the crest of the Mineral Point anticline, are also associated with structures bearing lead and zinc minerals on the flanks of the anticline. The pyrite occurs in partly oxidized veinlets and as cementing matrix of thin layers of sand. In many ore bodies, pyrite coats all the fractures. It was deposited as disseminated crystals in the adjacent wallrock. Pyrite is found most commonly as irregular, rounded nodules surrounded by small crystals of marcasite and, more rarely, is intergrown with chalcopyrite. Pyrite less commonly assumes the form of cubes or elongate octahedrons. Two forms of marcasite are easily recognized: by dull, grayish green sooty reniform masses or irregular amorphous powdery masses that readily oxidize, and by a bright brassy bladed cockscomb type or tetrahedrons coating other minerals. An undeveloped deposit of pyrite and marcasite lies on the flank of a small dome at the Williams sulfur mine (SW¼, sec. 2, T. 5 N., R. 2 E.). Elsewhere, deposits of iron sulfides are closely related to zinc ore bodies but have not been mined separately, nor has marcasite been separated from the zinc minerals for commercial use except at the acid plant at Mineral Point, now abandoned. Grant (1906, p. 61) recognized pyrite in marcasite at the Western mine northwest of Mineral Point. Large quantities of marcasite were mined with zinc ore from beds in the Quimbys Mill and Guttenberg members at the Tripoli and Western mines in the Diamond Grove area (sec. 26, T. 5 N., R. 2 E.) and roasted for separation (Bain, 1906, p. 107). Similarly, ores of the nearby P.M. and Victoria mines contain much iron sulfide in the blue beds of the Ion member.

Chalcopyrite is intimately intergrown with pyrite or occurs as discrete crystals in the surrounding dolomite. Nickel-rich erythrite, together with some copper minerals, occurs with sphalerite in the Richards, Grayville, Simpson, and Rabbits Foot mines near Mineral Point.

Barite fills the central part of veins as bladed crystals, and as coatings or encrustations on the sulfide minerals. It also replaces the wallrock adjacent to vein minerals as large tabular masses.

Although widespread and common in areas of major deformation, iron minerals are generally concentrated at the margins of ore deposits as veins or disseminated crystals in the shaly residuum at the toe of a pitch and as halos of disseminated mineral over zinc depoits. Iron sulfide generally fills vertical fractures extending upward from the deposits and extends laterally in the shaly partings of the bedding adjacent to these fractures. Chalcopyrite is locally intergrown with pyrite.

A marginal mineralized zone, consisting of iron sulfide in veinlets and as disseminated crystals, generally overlies zinc deposits at Mineral Point and extends beyond the sphalerite at the extremities of these bodies. The bottom of a zinc deposit is indicated in places by a dark zone of dense microscopic marcasite crystals as shown in the Dodgeville mines.

Although intimately associated with the sphalerite, galena fills fractures that directly overlie zinc ore bodies and is disseminated in the shaly Guttenberg member at the margins of these deposits along with pyrite and marcasite.

Some veins are crudely zoned (pl. 18). The core of the vein is generally sphalerite, but tabular masses of barite or calcite also can occupy this position. An intergrowth of sphalerite and galena lies between the core and the next successive band, generally pyrite and marcasite. Barite can also occur between the vein and the host rock. Calcite coats the sulfide minerals and barite. A widely dispersed halo of finely divided iron and zinc sulfides extends upward and laterally over the ore body.

In contrast to the upper part of the Galena dolomite where galena occurs with minor amounts of sphalerite, marcasite, and barite, the Decorah formation and the upper part of the Platteville formation contain abundant sphalerite, and subordinate amounts of pyrite, marcasite, and galena. Marcasite and pyrite in the underlying St. Peter sandstone complete the vertical stratigraphic zoning of important mineralized strata.

Weathering of sulfide bodies near the surface has partly oxidized the primary minerals to secondary sulfide, carbonate, and silicate minerals. Sphalerite is largely altered to a porous, cellular form of smithsonite called "dry bone" by the miners. Smithsonite forms dull, light-brown to pale gray tabular sheets, thin coatings, and replacements after late minerals such as rhombohedral calcite. Locally, in the Guttenberg member, where silica has partly replaced limestone or dolomite, smithsonite is coated with hemimorphite, a zinc silicate. Galena is protectively coated by the carbonate, cerussite. The interior of coated galena commonly remains unaltered. Chalcopyrite, intimately associated with marcasite and pyrite, overlies some of the small zinc deposits, and alters to a variety of supergene copper oxide, sulfide, and carbonate minerals. The copper sulfides, covellite and chalcocite, are carried downward by percolating ground water and coat the sulfides of lead and zinc. In the Galena dolomite, chalcopyrite, commonly alters to malachite, a hydrous carbonate. The manganese and iron released by the oxidation of sulfide minerals are redeposited in deeper zones as wad, psilomelane, pyrolusite, pyromorphite, hematite, and goethite; these minerals are commonly associated with the joint-controlled deposits.

The sequence of deposition in the pitch-and-flat deposits is very similar to that in the joint-controlled deposits. The relationship of the minerals in open veins and in mineral-lined cavities indicates early deposition of pyrite. Pyrrhotite, in rounded nodules of pyrite and marcasite, has been identified in the Grayville mine.[7] The association of pyrite and pyrrhotite indicates that the early ore-bearing solution was rich in sulfur. The main deposition of pyrite was accompanied by marcasite and a very dark, iron-rich sphalerite. The deposition of marcasite continued to the end of the sulfide deposition; however, most of the marcasite was deposited after the deposition of sphalerite ceased. Sphalerite immediately followed early marcasite and was the first of the two ore minerals to be deposited. The early sphalerite is very dark in color and has a relatively high iron content, whereas late stages of sphalerite are very light in color and contain little or no iron.

Deposition of galena seems to have been concurrent with the early sphalerite stage and reached a maximum rate at the end of sphalerite deposition. In open cavities, large cubes of galena are perched on banded nodules of sphalerite.

Barite was deposited after the sulfide stage, concurrently with calcite, and appears to overlap the deposition of the late marcasite. Heyl and others (1959) recognized four substages of calcite deposition. The earliest substage of calcite appears as a pointed scalenohedron, commonly called dog-tooth spar. The first three substages of scalenohedrons appear as "ghosts" within the final rhombohedral substage of calcite. Early calcite crystals may be colored by inclusions of clay and iron oxide, clouded by bubbles or silt, and coated with fine crystals of marcasite. The final substage of calcite is generally free from included matter. Calcite and less commonly barite are gangue minerals in the area near Mineral Point.

ROCK ALTERATION

Mineralizing solutions have selectively altered certain beds by the common processes of solution, dolomitization, and silicification. Solution alteration has created minor structures or has modified existing structures. Dolomitization of two types has been recognized. The first type is a widespread regional dolomitization apparently controlled by the Wisconsin arch, whereas the second type is locally operative and related to mineralization. Silicification is less common and not easily recognized. In some areas, altered beds cannot be readily separated by normal lithologic criteria. Chertification and dolomitization related to the Wisconsin arch was noted by Agnew

[7] X-ray film Nos. 10000 and 10001 by Marie Lindberg, U.S. Geological Survey, 1955. Pyrrhotite is present in the more magnetic fractions from a Franz separator.

and others (1956, p. 257, 284–286) and Willman and Payne (1942, p. 64–65). Several early observers, Bain (1905, p. 21; 1906, p. 22–25), Ellis (1905, p. 313), and Cox (1911, p. 431), considered alteration of Platteville and Decorah beds by ore-bearing fluids as a sedimentary facies change. This interpretation confused the stratigraphic relations between the Quimbys' Mill member of the Platteville formation, and Spechts Ferry, and Guttenberg members of the Decorah formation.

The mapped area has been affected by regional dolomitization, except for limestone west of the Slateford area, in the Eden area, and north of Dodgeville (pl. 14). The northern and western facies of limestone in the upper part of the Platteville and Decorah formations crop out in these areas. Strata in the limestone facies are commonly sublithographic or exceedingly fine grained and represent an interfingering of limestone with a few beds of dolomite. In the dolomite facies these strata are generally recrystallized magnesian limestone or dolomite with a calcareous matrix. The facies boundary between dolomite and limestone is irregular and transitional. Laterally in the transition zone, clots or lenses of dolomite occur in the more permeable silty, fossiliferous parts of the limestone. Near the dolomite facies, the amount of dolomite is sufficiently large so that limestone is isolated as blobs in a matrix or dolomite. Vertically the transition between facies consists of alternating beds of limestone and magnesian limestone.

The effects of regional dolomitization are observed best in the McGregor member, where the limestone changes laterally eastward becoming more dolomitic. Beds in the Quimbys Mill and Ion members show widespread uniform recrystallization, evidence of a primary regional dolomitization. Eastward, these beds are more coarsely crystalline. In the eastern part of the area a few chert bands, believed to indicate regional silicification, occur in the upper part of the Quimbys Mill member and in the lower part of the Ion member. Here the Guttenberg and McGregor members are finely recrystallized and have a uniform color. Strata dolomitized during mineralization may be distinguished from regional dolomite by the effects of leaching, local thinning, content of insoluble argillaceous or silty material, color, granularity, and sparsely disseminated sulfide minerals, mainly iron. Stain from weathered or oxidized iron sulfide and diverse granularity commonly give the rock a blotchy appearance. The regional dolomite is probably diagenetic or a primary deposit controlled by a favorable shallow environment over the Wisconsin arch.

Solution of the carbonate rocks is partly controlled by stratigraphy. Dense argillaceous limestone is generally more completely leached than dolomite. Mineral-bearing solutions have locally thinned 30 feet of McGregor limestone member to about 20 feet of gray dolomite and dolomitic clay. Similarly a normal 13 feet of dolomitic limestone of the Quimbys Mill member has been leached, especially at its base, and reduced to 8 feet of dark-brown banded shale and dolomite (pl. 17), as observed from drill-hole data. In mineralized zones, the limestone bed of the Spechts Ferry shale member is leached and forms an insoluble residue of plastic clay. Kay (1939, p. 27) observed that leaching of limestone resulted in a concentration of brown argillaceous material in the Guttenberg member. Removal of soluble carbonate commonly reduced the Guttenberg limestone member to a few feet of dark-brown carbonaceous shale and thin discontinuous lenses of granular dolomite (fig. 33 and pl. 17). Residual beds of dolomitic shale instead of shaly partings are present where strata of the Ion dolomite member are leached. The contact between the Ion member and Galena dolomite is also more sharply defined, as the basal Galena has little shale, and leaching is less effective in this unit.

Solution in the Galena dolomite is mainly intergranular. The more porous calcareous beds in the dolomite adjacent to vertical fractures have been leached preferentially. Leaching of the more soluble carbonate in the Galena took place at bedding surfaces with increased concentration of argillaceous residuum, formation of the irregular cavities, and reduction of massive beds to porous cellular masses of very coarse dolomitic sand or granules. In the Mineral Point area the effects of solution are widespread vertically and laterally, but elsewhere these effects are limited to elongate narrow zones, largely in the Decorah formation. Roadside exposures on State Route 29 in Mineral Point and on U.S. Highway 151 north of Mineral Point branch show extreme alteration of strata in the Decorah formation. Solution of calcareous rocks of the Decorah and Platteville formations, commonly within or near mineralized zones, is accompaned by a relative increase in the magnesium content of these rocks.

Dolomitization that accompanied mineralization was more complete within ore zones. It notably affected the Quimbys Mill member as well as other rocks, and resulted in a more sugary texture and in the growth of large incomplete dolomite crystals in a granular matrix of fine-grained carbonates, with subordinate clay and silica. Limestone beds of the Spechts Ferry and Guttenberg members not only developed a sugary texture in some mineralized areas, but also were bleached or otherwise changed in color. This bleached rock is difficult to distinguish from altered beds of Bay's Mifflin member. In some places dolomitization and leaching of the relatively more soluble intergranular carbonate altered the calcareous beds of the Quimbys Mill, Guttenberg, and Ion members to porous friable layers of shaly dolomite sand without noticeably decreasing their thickness. Although the rocks in the mapped area have been regionally dolomitized, much lateral variation may be found in the completeness of the dolomitization in the rocks of the McGregor, Quimbys Mill, and Guttenberg members depending upon their proximity to mineralized zones, for example, those rocks near Mineral Point and Dodgeville, or barren zones, "limestone islands" in secs. 15 and 16, T. 6 N., R. 3 E., or sec. 27, T. 4 N., R. 2 E.

Silification that accompanied mineralization, although a less common type of alteration, has affected parts of the Quimbys Mill and Guttenberg members. Replacement by silica has extended outward from the microscopic fractures and zones of shearing, has preserved the original texture of limestone and is easily detected by increased hardness of the rock. Early silicification probably reduced the permeability of the rocks as silica filled the fractures and intergranular pore space; fracturing of the competent silicified rock provided local access for later mineral deposition. Regionally, beds in the Quimbys Mill member become cherty in the southeastern part of the mapped area. Silica of the rock matrix is microscopically indistinguishable from that of chert nodules in the lower part of these beds in mineralized zones. Fossils in the Guttenberg limestone member are locally replaced by silica in mineral-bearing zones. Near Mineral Point, the upper part of the Prairie du Chien group has been affected by widespread silicification in which replacement of the oolitic limestone results in large masses of chert.

ORIGIN OF THE ORE

Early investigators, Owen (1847, p. 160–173) and Percival (1855, p. 100; 1856, p. 63) believed that the ores originated from below, but the genesis of the zinc and lead deposits in the mining district became a controversial topic when Whitney (1862a, p. 380–406; 1882, p. 152–155) suggested that the zinc and lead were deposited from downward circulating meteoric waters by reconcentration and redeposition of sulfides originally deposited during the precipitation of the carbonate strata. His ideas were refined later by Chamberlain (1882, p. 522–553), and restated by Bain (1906, p. 124–142). Chamberlin postulated a source of ore in the Precambrian rocks to the north and preliminary concentration in the sea by eddies and currents. Van Hise (1900) believed that the ore originated by lateral secretion with secondary enrichment by surface waters. Two major hypotheses for the origin of ore had been postulated by these observers: a hydrothermal hypothesis and a meteoric hypothesis. For about 75 years the meteoric hypothesis was supported by most of the workers in the upper Mississippi Valley district.

Spurr (1924, p. 246–250, 287–292) in his discussion of ore magmas reaffirmed the magmatic hypothesis for origin of the ore. Investigations by Emmons (1929), Newhouse (1933), Graton and Harcourt (1935), Garrels (1941), and Hemley (1953), indicate a probable low-temperature hydrothermal origin for these deposits from a postulated deep-seated source beneath the district. Newhouse (1932, p. 435) believes that sodium chloride concentration in solutions found in galena and sphalerite from Mississippi Valley ores excludes the possibility of their formation by descending meteoric waters. Sphalerite in pitch-and-flat deposits formed at temperatures ranging from 121° to 75° C. according to Bailey and Cameron (1951). Heyl and others (1951) from their observations in the mining district, conclude that the ores are of telethermal origin. In this writer's opinion a study of trace-element liquid inclusions or a study of an isotope of the ores may partly resolve this controversy. The deposits of lead and zinc probably originated from a hydrothermal source as present information indicates; although some aspects of the vein development in ore bodies show characteristic oxidation, movement, and redeposition by meteoric waters and thereby suggest a dual origin for some of the ore minerals.

HISTORY AND PRODUCTION

Early deposits of lead were readily found because of their exposure in streams, surface expression, linear patterns, and stratigraphic position above the water table. Mines that previously produced galena are not economic presently. Joint-controlled deposits are not mined because of a low-production rate and the lack of adaptability of modern mining methods to their geometry. The present production of lead is incidental to the large and more easily mined deposits of zinc.

EARLY PRODUCTION

Early lead mines were operated as groups of shallow pits and shafts, locally known as diggings, on the upland slopes that border the main drainage system (Owens, 1840; Percival, 1855; Whitney, 1862a; and Strong, 1877). However, ancient artifacts from pits in sec. 21, T. 5 N., R. 3 E. indicate that the presence of lead minerals was known to Indians before territorial settlement. Deposits of galena were discovered in 1827 and shortly thereafter Governor Dodge erected a lead furnace nearby; up to 1839 this cupola had produced 375 tons of lead metal. From 1830 to 1871, the mining district was the most important lead-producing area in the United States, but production steadily declined after 1850. During this period mining was commonly sporadic and the mines were operated in widely separated areas; however, a single group of diggings during its peak production commonly yielded several hundred tons of ore annually.

Between 1862 and 1876 about 9,600 tons of lead ore was smelted from mines in the Dodgeville-North Survey areas. About 15,000 tons of lead ore was produced in the Mineral Point district during the same period.

In 1875, for example, 500 tons of lead ore was produced from the Sinapee diggings south of Barreltown, SE¼, sec. 30, T. 5 N., R. 3 E., and about 300 tons was produced from the Lamby range at Dodgeville. Previously, several ranges near the Lamby range yielded as much as 2,500 tons within a mined distance of 400 yards. Before 1860, as much as 100 tons of lead ore was mined from each of closely spaced parallel mine workings on the Dreadnaught, Martins, and Scantling ranges northeast and southwest of Barreltown, secs. 20 and 30, T. 5 N., R. 3 E. Some galena was mined from the widespread opening at the base of the Quimbys Mill member, especially from the ranges west of Dodgeville, the diggings along Pedler Creek, and ranges near Mineral Point. Large amounts of disseminated galena were mined from shaly zones in the Decorah formation at diggings south and east of Mineral Point. About 1840, O'Neill's furnace 2 miles south of Mineral Point produced 2½ tons of lead per day according to Hodge (1842, p. 42). Much lead ore was produced from the opening at the top of the Ion member and a similar opening in Zone B of the Galena dolomite, in particular, the Duke Smith range in the South Survey area, the Van Metre range in the North Survey area, and the Gray and Joseph ranges near Mineral Point.

Zinc ores were mined intermittently in small tonnages beginning in 1860 (Chamberlin, 1882, p. 490). In 1874, diggings in the Diamond Grove area (fig. 28) yielded 90 tons of smithsonite; during the same period the Sinapee diggings produced 50 tons of zinc ore and the nearby Ashbank range produced about 125 tons of mixed ore. An estimated 100,000 tons of zinc ore was shipped from the Mineral Point area between 1860 and 1876. The production of zinc carbonate ore declined at this time and was exceeded by that of sphalerite after 1873; however, mines south and west of Barreltown produced large quantities of zinc carbonate from 1910 to 1915.

The lead production by 1900 was largely a byproduct of zinc mining operations. In the Dodgeville area, the annual production from 1900 to 1905 was 300 tons of zinc ore and about 150 tons of lead ore (Ellis, 1905).

According to Chamberlin (1877, p. 741) copper was first discovered near Mineral Point in 1837 and traced for more than one-third of a mile. It is reported that about 500 tons of copper, of 25 to 30 percent grade, was mined from these workings. From 1841 to 1846 about 110 tons of 95 percent copper was shipped from the furnace of Kendell and Co. at Mineral Point (Hodge, 1842, p. 38–41). The last serious attempt to mine copper was made between 1873 and 1875, when about 200 tons of copper ore was produced from the mines near Mineral Point.

The production of iron sulfide is unknown.

RECENT PRODUCTION

From 1940 to 1946, more than 230,000 tons of ore of 4 percent zinc was produced from the Dodgeville mine No. 1 (secs. 27 and 34, T. 6 N., R. 3 E.); an additional 100,000 tons of zinc ore was mined from the same ore body through adjoining mines. Dodgeville mines No. 2 and 3 (sec. 34, T. 6 N., R. 3 E.) and the Simpson mine yielded about 325,000 tons averaging about 4 percent zinc from 1946 to 1952. In 1948, the Dodgeville Mining Co., then the largest zinc producer in Wisconsin, mined and concentrated 49,000 tons of ore from mine No. 2, produced 1,900 tons of sphalerite concentrate averaging 61.8 percent zinc and 375 tons of galena concentrate averaging 62.9 percent lead (Gustavson, 1950, p. 1482). During 1954 the Rabbits Foot mine and the Richards mine in the Barreltown area produced small tonnages of zinc ore, but mining was temporarily curtailed because of a decline in the price of zinc. About 40,000 tons of ore of about 5 percent zinc was shipped from the Grayville mine at Mineral Point during 1956 and 1957. The price of zinc did not warrant further production and mining was temporarily suspended.

POTENTIAL PRODUCTION

With the present methods of exploration and mining, economic production from the narrow, vertical, joint-controlled deposits is not possible. These deposits may assume some economic importance in the future if a successful method of exploration can be devised to locate these deposits in upland areas.

The possibility of developing mineral deposits of economic importance below the presently mined strata, for example below the Platteville formation, is remote because lead and zinc deposits in the Prairie du Chien group have been very small and low in grade (Agnew and others, 1953). Dolomite of the Prairie du Chien is believed by many to be a poor host rock for large deposits of lead and zinc. In addition to the probability of finding deposits of small size and low grade in the Prairie du Chien group the factors of depth and close proximity of underground workings to an excellent aquifer, the St. Peter sandstone, generally rule out the possibility of developing commercial deposits in this group.

Recent developments of rapid geophysical methods of prospecting, the airborne magnetometer, portable, sensitive electromagnetic equipment, and the stable light-weight Worden gravimeter, demand serious consideration for exploration for mineral deposits in the Precambrian basement complex and overlying Cambrian formations. The potential for the development of hidden or blind ore bodies under intensely mineralized areas is increasingly great, particularly in view of recent discoveries of iron-ore bodies in the buried Precambrian rock of southeast Missouri by the airborne magnetometer. The assemblage of minerals in the upper Mississippi Valley district indicates a potential not only for lead and zinc but also for iron, copper, nickel, and cobalt in the Cambrian formations and Precambrian granitic basement rocks.

The area between Dodgeville and Calamine is estimated to contain 1½ million tons of potential zinc and lead ore of about 4 percent grade in undiscovered deposits. On the basis of ore deposits previously mined, an estimate of the size of the potential ore deposits ranges from about 25,000 to 150,000 tons. The estimate of potential ore tonnage is based mainly on the areal extent of uplands which lacks systematic prospecting. Knowledge of much of the structure comparable to pitch-and-flat deposits in the upland area remains to be developed through a successful exploration program.

Areas favorable to the extension of known ore bodies and most likely to yield new deposits are those adjacent to Mineral Point and Dodgeville. Other favorable areas for finding ore deposits are described as follows (pl. 14): The mineralized upland area between Dodgeville and South Survey, east of the Mineral Point Branch; a trough area northeast from sec. 10, T. 5 N., R. 2 E. through the Bloomfield area to sec. 31, T. 5 N., R. 3 E.; an area south of Military Ridge through secs. 34, 35, 36, T. 4 N., R. 2 E. for the possible extension of the Linden ranges; an area west of Dodgeville parallel to the ranges in secs. 28, 31, and 32, T. 6 N., R. 3 E.; the north flank of the Mineral Point anticline in secs. 13, 14, S½ sec. 15, T. 5 N., R. 2 E.; south flank of the Mineral Point anticline in the N½ sec. 26 and sec. 27, T. 5 N., R. 2 E.; the upland area in the vicinity of Barreltown; the upland area south and east of Mineral Point on the north and south side of Rock Branch; the upland area northwest of Willow Spring Church; the upland area northeast of Slateford and northwest of Seven Oaks School; the upland area between Mineral Point Branch and the Pecatonica River; the upland area on the south flank of the Calamine anticline near Bonner Branch.

GUIDES TO ORE

Exploration for joint-controlled deposits can be limited to certain permeable zones in the Galena dolomite, because the vertical occurrence of ore is largely controlled by strata that favor solution-widened openings along fractures and localize small lead deposits (pl. 15). Exploration for the extensions of known mineralized zones in the upland areas can be advantageous in discovering new deposits. These projections are indicated by an alinement of prospect pits and shafts. Exploration beneath the water table should be considered in areas where mineralized rock occurs at a high topographic position. Early mining was limited to shallow workings because of water. Sinks and solution-cavities, such as in sec. 3, T. 5 N., R. 3 E., indicate zones of shearing or fracture systems (Owen, 1840, p. 31) that may be related to underlying mineralized structures.

In contrast to the widespread distribution of lead deposits, the discovery of zinc deposits has been limited generally to less obvious structures in more highly mineralized and dissected areas. Areas favorable for future exploration for zinc-lead deposits can be distinguished from less favorable areas in the Dodgeville and Mineral Point quadrangles as a result of this study. Willman, Reynolds, and Herbert (1946) and Agnew (1956) summarize many useful guides for the exploration of zinc deposits in the southern part of the mining district. Exploration for pitch-and-flat zinc deposits can be profitably limited to upland areas that may locally appear to be barren but are relatively unprospected. Areas of tightly folded and sheared rocks in the immediate vicinity of small, structurally controlled basins should be explored as these areas may contain economic zinc deposits. Not all strata, however, are good host rocks for ore, and not all highly fractured rock or small basins are ore bearing. Altered and mineralized zones of shearing at sharp flexures in favorable host rocks, as exposed in Pedler Creek in the NE¼ SE¼ sec. 3, T. 5 N., R. 3 E., may, however, indicate a nearby ore body. Mineralized fractures parallel and adjacent to the northwestward- and northeastward-trending folds may have localized sufficient zinc to produce an economic deposit. These areas should be explored by drilling through the upper strata of the Platteville formation. Although large anticlinal areas, such as the Mineral Point anticline, localized only iron minerals along their crests, their flanks should be prospected for zinc deposits.

A widely spaced grid pattern can be used to ascertain the general structure in upland areas, to determine the proximity to nearby ore bodies, and to correlate mineral-bearing zones. As much as one-half of the potential area can be eliminated by widely spaced drilling. Mineralized ground in an area considered favorable by structural and stratigraphic criteria may be prospected by several lines of drill holes. The spacing of drill holes as well as the orientation of lines are governed by the width of the expected ore bodies in the trend of the structures. A maximum spacing of 100 feet between drill holes can be used for exploration of zinc deposits, such as those at Dodgeville, but for linear structures, such as those in the Barreltown area, a maximum spacing of 50 feet is desirable. In the Dodgeville area the depth to the lowest productive zone is about 100 to 150 feet, whereas in structurally high areas north of Mineral Point, the depth of the drill holes through productive zones is 60 feet or less (table 3).

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TABLE 3.—*Thickness of strata in surface exposure and in drill holes in the Dodgeville and Mineral Point areas*

Location	Stratigraphic unit														
	Cherty unit of Galena (undivided) dolomite	Cherty unit of Galena dolomite			Ion dolomite member of Decorah formation	Guttenberg limestone member of Decorah formation	Spechts Ferry shale member of Decorah formation	Quimbys Mill member of Platteville formation	McGregor limestone member of Platteville formation	Magnolia member of Bays and Roesch (1935) of Platteville formation)	Mifflin member of Bay's (1938) of Platteville formation	Pecatonica dolomite member of Platteville formation	Glenwood shale member of Platteville formation	St. Peter sandstone	Prairie du Chien group
		Zone B	Zone C	Zone D											
Bonner Branch road cut, sec. 11 T. 3 N., R. 2 E.							0.55	11.8	28.4	14.8	13.6	19.4	1.2		
New quarry, Mineral Point, sec. 5, T. 4, N., R. 3 E.							.5	10.9		17.3					
Old City quarry, Mineral Pt. sec. 31 T. 5 N., R. 3 E.							.3			17.5	15.5				
Quarry, Gulf Oil storage, sec. 32, T. 5 N., R. 3 E.						10.8	.6	11.8		16.2					
Bluff exposure, Calvert farm, sec. 24, T. 4 N., R. 2 E.												19.6			
Stream exposure, Crase farm, sec. 27, T. 4 N., R. 2 E.						12.8	1.0	12.2					.6		
Roadcut, sec. 13, T. 6 N., R. 2 E.		15.2	9.4	9.7	14.7	7.0					14.4	16.09			
DH Rock farm, sec. 1, T. 5 N., R. 2 E.					16	4½	½	8½							
DH Mitchell farm, sec. 4, T. 5 N., R. 3 E.	89				15½	7	1	6½							
DH Meudt farm, sec. 9, T. 5 N., R. 3 E.				10½	18½	5½	1	10½							
DH Martin farm, sec. 10, T. 5 N., R. 3 E.					19	9½	1	10½							
DH Murrish farm, sec. 16, T. 5 N., R. 3 E.					15	4½	½	7½							
DH Dalles farm, sec. 17, T. 5 N., R. 3 E.					17	6	1	10							
DH Phillips farm, sec. 22, T. 5 N., R. 3 E.					17	9	1	11½							
DH Sullivan farm, sec. 22, T. 5 N., R. 3 E.					21	7	1	13½	30			21	1½		
DH Richards farm, sec. 29, T. 5 N., R. 3 E.					16	4	Tr.	11							
DH Harris farm, sec. 31, T. 5 N., R. 3 E.						5½	1½	14	31			19	3	51	204
DH Day farm, sec. 26, T. 6 N., R. 2 E.					19	8	½	10							
DH Biddick farm, sec. 25, T. 6 N., R. 2 E.					20	7½	½	13							
DH Maso farm, sec. 27, T. 6 N., R. 2 E.					16½	6½	Tr.	11							
DH Iowa County Home, sec. 35, T. 6 N., R. 2 E.					16	12	1	11	32			18	±4	58	

DH Humbert farm, sec. 35, T. 6 N., R. 2 E	----	----	----	----	17	8½	½	10	----	----	----	----	----	----	----
DH Wonn farm, sec. 36, T. 6 N., R. 2 E	----	----	----	----	22	4½	½	10	----	----	----	----	----	----	----
DH Stoldt farm, sec. 20, T. 6 N., R. 3 E	----	----	----	----	19	9	1	12	----	----	----	----	----	----	----
El Rancho Motel, sec. 22, T. 6 N., R. 3 E	----	----	----	----	19	10	1	----	----	----	----	----	----	----	----
DH Metcalf farm, sec. 27, T. 6 N., R. 3 E	----	----	----	----	18	10	----	13	----	----	----	----	----	----	----
DH Brue farm, sec. 29, T. 6 N., R. 3 E	93	----	----	----	18½	11	½	12½	----	----	----	----	----	----	----
DH Prideaux farm, sec. 29, T. 6 N., R. 3 E	----	----	----	----	20½	8½	½	14	----	----	----	----	----	----	----
DH Wonn farm, sec. 30, T. 6 N., R. 3 E	----	----	----	----	21	9½	1	11½	----	----	----	----	----	----	----
DH Campbell farm, sec. 33, T. 6 N., R. 3 E	----	----	----	----	16	7	½	12½	31	----	----	22	3	----	----
DH Hannah property, sec. 21, T. 5 N., R. 3 E	----	----	----	----	17	9	½	10	----	----	----	----	----	----	----
DH Weinbrenner farm, sec. 34, T. 5 N., R. 3 E	----	----	----	----	17	7	----	12	29	----	----	19	----	----	----
DH Tonkin farm, sec. 26, T. 5 N., R. 2 E	----	----	----	----	----	----	----	10	30	----	----	20	----	44	----
DH Powell farm, sec. 28, T. 6 N., R. 3 E	----	----	----	----	18½	9	----	12	----	----	----	----	----	----	----
DH Peterson farm, sec. 12, T. 6 N., R. 3 E	----	----	----	----	----	----	----	10	32	----	----	22	±4	53	----
DH Mineral Point RR, sec. 6, T. 4 N., R. 3 E	----	----	----	----	----	----	----	----	----	----	----	----	----	110	260
DH Carey Bros. stockyard, sec. 29, T. 5 N., R. 3 E	----	----	----	----	19	9	----	12	----	----	----	----	----	----	----
DH Wendtlant farm, sec. 1, T. 4 N., R. 2 E	----	----	----	----	21	9	½	10½	----	----	----	----	----	----	----
DH Frontz farm, sec. 26, T. 4 N., R. 2 E	----	----	----	----	----	----	----	----	----	----	----	22	1½	112	----
DH Jensen farm, sec. 3, T. 3 N., R. 2 E	----	----	----	----	20	10	1	13½	30½	15½	15	----	----	----	----

The extension of beds of the Decorah formation, thinned by solution beyond the limits of ore-bearing ground, is particularly useful in exploration. The dolomite facies of these beds is useless as a guide to ore in the Mineral Point and Dodgeville areas, because of regional dolomitization near the Wisconsin arch. Rocks in areas thinned by solution, notably the Guttenberg limestone member, may contain economic quantities of zinc and lead, although not all strata in these thin zones are ore bearing.

In oxidized ground, ore minerals and associated iron sulfides are partly or completely altered. Oxidation of the iron sulfide halo and the resultant ocherous rock may be a possible guide to ore. In oxidized ground, dolomite is commonly soft and sandy, because the intergranular cement has been partly leached by mineralizing solutions; thus, soft porous iron-stained drill cuttings may indicate the proximity of mineral-bearing rock.

Minute specks of iron sulfide in nodules of chert in the Galena dolomite may be used as a guide to mineralized ground. Near some zinc deposits, the normally white to pale gray chert changes to a bluish gray. The darker chert generally contains more iron sulfide.

At Dodgeville, geochemical tests made of the heavy-metals in the residual soil zone at the top of the weathered parental dolomite successfully indicated the underlying northwestward-trending ore bodies (pl. 18).[8] The anomalous zinc content of the soil gave the best correlation with the underlying zinc and lead deposit. Samples were taken with a power-driven auger to a depth of 3 to 7 feet in the residual clay, a safe distance below an interfering cover of loess at the surface. Kennedy (1956, p. 201–202) reported that rocks in zones of mineral-bearing fractures with northwesterly trend similarly gave high geochemical anomalies. Widespread, diffuse trace quantities of zinc and lead minerals in thin zones at the base and top of the Guttenberg member and the gray beds of the Ion member, also near the top of the cherty unit of the Galena dolomite, decrease outward from the ore deposits. These zones provide convenient control by geochemical methods for testing exploration drill cuttings for their proximity to an ore deposit.

DESCRIPTIONS OF MINES

Mines near Dodgeville have been developed within a broad synclinal trough, first recognized by Grant (1906, p. 76, pl. 4), in which arcuate ore bodies bend around ends of gently plunging eastward-trending minor synclines and anticlines. They show maximum structural relief of about 15 feet. The horseshoe form of these deposits

[8] Analyses by H. E. Crowe and A. P. Marranzino, U.S. Geological Survey.

was noted by Chamberlin (1882, p. 440). Heyl and others (1959) have an excellent detailed description of Dodgeville mine No. 1 and its arcuate form. Linear zinc deposits parallel to the overlying lead-bearing fractures trend N. 17° W. and connect the limbs of the arcute ore bodies. Major faults are absent; breccia and zones of shearing are present, however, in the northwest segments of linear ore bodies. Movement of unknown displacement is indicated by striae on the shaly bedding surfaces. Evidence of vertical dislocation in the beds is absent in Dodgeville mine No. 3 (pl. 18), although minor reverse faults were reported in other Dodgeville mines. The northwestward trending part of the ore body of Dodgeville mine No. 3 lies in a shallow structural trough. Local subsidence in the Quimbys Mill member caused the trough. Solution produced an opening at the intersection of vertical fractures (crevices) and the contact between the Quimbys Mill and McGregor members. Adjustment on the vertical fractures allowed the beds to subside partly in the opening.

Elongate, canoe-shaped structures, called rolls, are displayed in the mine back, about 4 to 6 feet above the base of the Quimbys Mill member. As viewed in the mine workings, the ends of these narrow troughs plunge upward into the back. The orientation of the long axis is consistent throughout the mine. These roll structures are depositional in origin; their orientation was controlled by currents in shallow seas. Brown (written communication, 1958) observed large *Orthoceras* in narrow troughs in the Quimbys Mill member, in a section on the flank of the Meekers Grove anticline along the bluffs of the Mississippi River. Here the Quimbys Mill member is only a few feet thick.

The aggregate thickness of the Quimbys Mill, Guttenberg, and Ion members is about 37 feet near the ore deposit. The thickness of the Guttenberg member is about 10 feet. Lead and zinc minerals in beds of the Guttenberg and Ion are insignificant or absent. These strata maintain their normal thickness. Lack of solution-thinned beds and absence of subsidence failed to produce a structural environment for pitches. The upper few feet of the McGregor member contain finely disseminated sphalerite and pyrite. These beds are altered to a crumbly granular gray shaly dolomite. Solution-thinned beds of the upper strata of the McGregor may have opened their contact with the Quimbys Mill member.

The ore consists of a single flat vein of sphalerite and galena at or near the base of the Quimbys Mill member and above bands of disseminated marcasite in the basal carbonaceous shale. The ore minerals commonly form complex intergrowths within a vein, ranging in thick-

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ness from 4 to 12 inches and in width from 50 to 100 feet. A microscopic examination of the banded sphalerite failed to show wurtzite, a common zinc sulfide that is found in the banded ores of Europe. Some breccia filling or brangle ore also occurs above the basal shale in the Quimbys Mill member. Sphalerite was deposited as euhedral crystals or in alternating light and dark bands. This banding was probably caused by a variation in intergranular pore space as well as in the iron held in the sphalerite lattice. Ellis (1905, p. 311–315) described mining in the Quimbys Mill member (glass rock) east of Dodgeville, where the ore was mainly smithsonite.

As mining progressed westward at Dodgeville mine No. 2, the ratio of zinc to lead decreased from 5:1 to 4:1 whereas in Dodgeville mine No. 3 the ratio remained about 7:1. The grade of lead ore also decreased appreciably southward.

In the North Survey mine high-grade ore was mined from a 1- to 2-foot flat of sphalerite at the base of the Quimbys Mill member. This mine, developed in a local northeastward-trending syncline, was apparently controlled by a northward- to northwestward-trending zone of fracture.

In the Barreltown area, the Richards mine (pl. 16) is a typical pitch-and-flat deposit developed in the Ion member. This linear deposit is controlled by a northwestward-trending fracture related to the shear system of the Mineral Point anticline. Beds of the Guttenberg limestone member have been thinned by solution and subsidence from a normal thickness of about 10 feet to about 3 feet. This reduction in the thickness of the Guttenberg and blue beds of the Ion member is sufficient to account for the structural relief of the small basin adjacent to this ore body. In addition to dark sphalerite, locally coated by covellite, veins contain the minor amounts of galena. Some chalcopyrite has partly replaced pyrite veinlets in the wallrock. A pink bloom of erythrite, $(Co, Ni)_3As_2O_8.8H_2O$,[9] coats some of the disseminated sphalerite crystals in the shaly beds of the Ion dolomite member. In the east workings of this mine, the inclined vein of sphalerite terminates in the vertical fracture filled with galena, which is coated with a minor amount of chalcocite, covellite, and malachite. Similarly, the Ashbank mine near Barreltown is also typical of a northwestward-trending linear ore body having well-developed pitches that dip northward and southward. Production was mainly smithsonite and cerrusite-coated galena from the Ion dolomite member. Barite and calcite are the common gangue minerals. Disseminated sphalerite in the Guttenberg member was discarded with waste rock, and only galena was shipped to a local smelter.

[9] X-ray film No. 10034 by R. A. Bailey, U.S. Geological Survey, 1955. Erythite and pyrite compared with erythite from Table Mountain district, Nevada, X-ray film No. 1284–A.

The Hazel Patch mine (near the center of sec. 26, T. 5 N., R. 2 E.) is a typical westward-trending linear ore body. It was mined from 1905 to 1908 on two levels, one at the top of the Guttenberg member and the other at the base of the Quimbys Mill member. Many of the mines of similar trend near Mineral Point were first worked for sheet or gash-vein lead ore in the upper part of the cherty unit, but later produced large quantities of smithsonite. Grant (1906, pl. 6) mapped the broad structures and the early mines such as the Hazel Patch (Western) mine, near Mineral Point.

The Grayville mine (pl. 17) south of the town of Mineral Point, is an excellent example of a series of northwestward-trending deposits controlled by closely spaced fractures parallel to the ore body. A series of small basins is associated with the westernmost ore body. The Guttenberg has thinned from a normal thickness of 11 feet to about 3 feet. The ore occupies a series of opposed pitches developed in the blue beds of the Ion member and is disseminated in the dark brown shale of the Guttenberg member as crystals of sphalerite and galena. The zinc minerals are coated with covellite and chalcocite, where copper-bearing fractures of easterly trend intersect the pitches. These copper-bearing fractures are the westernmost extensions of the Walsley and Beach copper ranges. A sample of ore from a 2-foot cut in a development drill hole assayed 5.6 percent copper. Greenockite (yellow) and erythrite (pink) locally coat the ore minerals and their host rock. At least one-third of the iron sulfide in the Grayville mine was identified by X-ray [10] and polished sections as a dull greenish gray form of pyrite. This mineral forms the core of nodules and sheetlike encrustations of marcasite.

NONMETALLIC DEPOSITS

DOLOMITE AND LIMESTONE

Rock quarried locally from the Platteville and Decorah formations and the Galena dolomite is used for dimension stone, road metal, railroad ballast, and agriculture lime. The rolling terrain and thin cover of soil and loess afford many convenient quarry sites.

Dimension stone was quarried in the vicinity of Mineral Point from about 1830, largely from the massive dolomite and limestone beds of the Platteville formation. Large flags were quarried from beds in the Pecatonica member for structural arches and bridge abutments. Hard vitreous beds in the upper part of the Platteville provide excellent stone facings, but its blocky nature limits the size of building stone. Many of these quarries are now important sources of crushed stone.

[10] X-ray film Nos. 11018–11019 by F. A. Hillebrand, U.S. Geological Survey, 1956.

Quarries opened in rock throughout the entire exposed stratigraphic section provide ample and varied road-building materials. Crushed dolomite contains sufficient bonding material to make a hard, durable well-drained topping for many secondary roads in this region. Although coarse tailings or rock waste from zinc concentrators provide an inexpensive source of uniform, clean road material, it lacks the natural bonding qualities of freshly quarried stone. Open quarries serve as a storage for crushed stone.

Weathered and partly disintegrated noncherty Galena dolomite in the upland areas is quarried, crushed, and screened for agricultural purposes. The magnesium content of the dolomite is not sufficiently excessive as to be detrimental.

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