Geology of the Dubuque North Quadrangle Iowa-Wisconsin-Illinois

GEOLOGICAL SURVEY BULLETIN 1123-C

Prepared in cooperation with the Iowa Geological Survey and the Wisconsin Geological and Natural History Survey

Whitlow and Brown—GEOLOGY OF THE DUBUQUE NORTH QUADRANGLE, IOWA-WISCONSIN-ILLINOIS—Geological Survey Bulletin 1123-C

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By JESSE W. WHITLOW *and* C. ERVIN BROWN

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

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C.

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[Plates are in pocket]

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

GEOLOGY OF THE DUBUQUE NORTH QUADRANGLE, IOWA-WISCONSIN-ILLINOIS

By JESSE W. WHITLOW and C. ERVIN BROWN

ABSTRACT

The Dubuque North quadrangle, which is near the west side of the Wisconsin-Illinois-Iowa zinc-lead district, is an area of about 37 square miles in Iowa, 17 square miles in Wisconsin, and half a square mile in Illinois. Topography is generally in the early maturity stage of erosion, and maximum relief is about 390 feet. The major physiographic feature is the steep-walled valley of the Mississippi River. The next most prominent feature is Couler Valley, the abandoned channel of the Little Maquoketa River which was captured by the Mississippi River.

Rocks exposed in the quadrangle are Middle and Late Ordovician in age. Drill cuttings from deep wells indicate that the entire quadrangle is underlain by rocks of Late Cambrian and Early Ordovician ages. Two wells penetrate biotite-rich granitic rocks of Precambrian age. The youngest deposits are till, loess, and alluvium of Quaternary age.

The St. Peter Sandstone is the oldest formation exposed in the quadrangle. It is generally 45 to 50 feet thick, but locally it is much thicker. This sandstone is composed of frosted white and clear coarse- to fine-grained quartz sand.

The Platteville Formation conformably overlies the St. Peter Sandstone and consists of limestone, dolomite, and shale and ranges in thickness from 52 to 61 feet in this quadrangle. It is divided into the following members, in ascending order: Glenwood Shale, Pecatonica Dolomite, McGregor Limestone, and Quimbys Mill.

The Decorah Formation apparently conformably overlies the Platteville Formation in the Dubuque North quadrangle and is divided as follows, in ascending order: Spechts Ferry Shale, Guttenberg Limestone, and Ion Dolomite. Locally the formation is limestone and shale. Normal thickness of the formation ranges from 45 to 48 feet, but local leaching of the carbonate and compaction of the insoluble residue have reduced it to 29 feet. Drill cuttings indicate that mineralized rock is commonly associated with thinned Decorah, but significantly mineralized rock was not observed in outcrops of the strata even where the formation is thin.

The Galena Dolomite conformably overlies the Decorah Formation. Normal thickness of the Galena ranges from 224 to 235 feet in this quadrangle; it is about equally divided into a lower cherty unit and an upper noncherty unit. Locally the Galena is a limestone stratigraphically as high as the base of the

noncherty unit. Leaching of the carbonate and compaction of the insoluble residue have locally reduced the thickness of the cherty unit to 88 feet.

The Maquoketa Shale of Late Ordovician age seems to conformably overlie the Galena Dolomite. This formation is as much as 243 feet thick in the Dubuque South quadrangle, but a thickness of about 110 feet is the maximum preserved in the Dubuque North quadrangle. The Maquoketa is divided into two units, on the basis of lithologic characteristics, as follows: the lower part is brown- to brownish-black medium-hard dolomitic shale called the brown shaly unit; the upper part is yellowish- to grayish-green and pale-blue unfossiliferous soft shale which is a correlative of the Brainard Member of the Maquoketa Shale.

Surficial deposits of Pleistocene age on hill tops and divides in much of the quadrangle are till and loess; either or both may be present. The unconsolidated deposits in the valleys are mainly glacial outwash of gravel, sand, and silt.

Strata in the western and southwestern part of the mining district have a regional southwestward dip of less than 1°. Superimposed on the regional dip in the Dubuque North quadrangle are low open folds whose strata have local dips of as much as 8°. Two systems of joints, three minor faults, and several clastic dikes are in the Dubuque North quadrangle.

Lead ore as galena was mined in the vicinity of Dubuque as early as 1690, and extensive mining began about 1788. Production increased steadily from 1833 until 1845 when the decline began and continued until the mines closed in 1910. The last attempt to mine galena was in 1952–53. Zinc ores, smithsonite and sphalerite, were first mined late in the 19th century. Mining of zinc ores continued until 1910 when the mines were closed, and no zinc ore has since been mined in Iowa.

Zinc and lead ores mined in Iowa were in gash-vein deposits in the Galena Dolomite. The deposits were principally along eastward-trending joints that were enlarged by solution of the wallrock at certain strata and at intersections with other joints. Most of the mining activity in this quadrangle was restricted to areas south of the Little Maquoketa River without a cover of Maquoketa Shale.

Many of the relatively large pitch-and-flat zinc-ore deposits in Wisconsin and Illinois are in the Decorah Formation and the lower part of the Galena Dolomite. Cuttings from churn-drill holes in the southwest quarter of the quadrangle indicate that these strata contain some zinc and lead minerals. This area may possibly contain pitch-and-flat deposits of zinc and lead ores.

INTRODUCTION

The Dubuque North quadrangle comprises about 37 square miles in Dubuque County, Iowa, 17 square miles in Grant County, Wis., and half a square mile in Jo Daviess County, Ill., a total area of about 55 square miles. The quadrangle is in the Wisconsin-Illinois-Iowa zinc-lead district, near the west boundary (fig. 22).

Maximum topographic relief is about 390 feet. The lowest altitude is 592 feet at the level of the Mississippi River at Dubuque and the highest altitude is over 980 feet in sec. 16, T. 89 N., R. 2 E., Iowa (pl. 10). Local relief is as much as 330 feet along the Mississippi River and as much as 250 feet along the Little Maquoketa and Platte Rivers. Relief along small tributary streams and Couler Valley is as much as 230 feet.

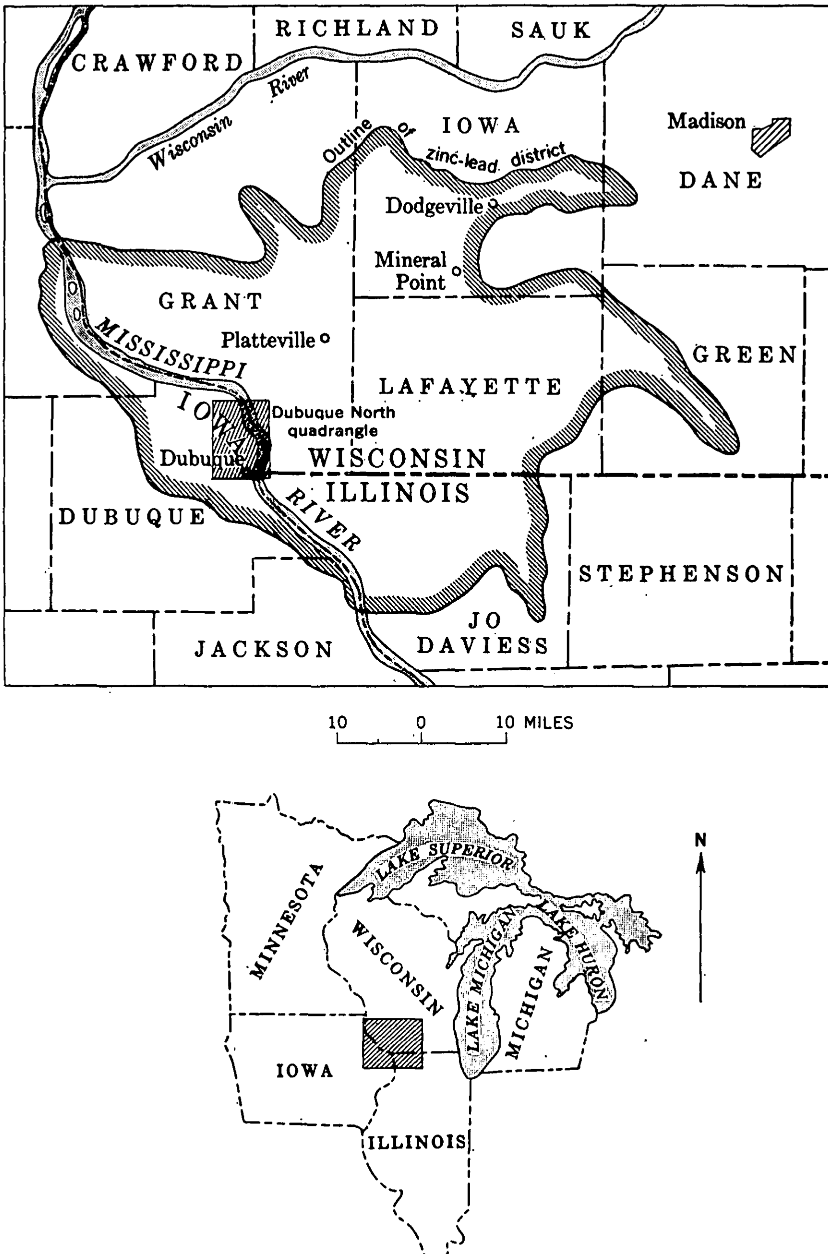

FIGURE 22.—Index maps showing the location of the Wisconsin-Illinois-Iowa zinc-lead district and the Dubuque North quadrangle.

The major topographic feature is the broad steep-walled Mississippi River valley (pl. 10). A prominent feature is Couler Valley which is the abandoned valley and channel of the Little Maquoketa River. The valleys of the Little Maquoketa and Platte Rivers and Couler Valley are similar in shape but different in size.

The transverse profile of valleys is closely controlled by bedrock lithology. Walls of valleys cut in shale are gently sloped; walls of valleys cut in dolomite or limestone are steep. Most of the rock exposed in the near-vertical bluffs in this quadrangle is Galena Dolomite.

The drainage pattern of the large streams cannot be determined in the quadrangle. However, locally the bluffs along the three rivers and Couler Valley indicate the possibility of some joint control. This is especially true of Couler Valley (pl. 10) which trends parallel to the strike of a prominent joint set in the area. The small streams have a dendritic pattern except locally where the pattern is joint controlled.

Well-developed joints probably aided the process of stream piracy as exhibited along the Little Maquoketa River and Bloody Run (pl. 10). Couler Valley is the result of capture of the Little Maquoketa River by the Mississippi River by breaching the divide in secs. 34 and 35, T. 90 N., R. 2 E., Iowa. This capture shortened the course of Little Maquoketa River several miles by changing its mouth from sec. 24, T. 89 N., R. 2 E. to sec. 35, T. 90 N., R. 2 E., Iowa. Piracy on a smaller scale occurred in sec. 28, T. 90 N., R. 2 E., Iowa.

Tops of divides and hills in the quadrangle are possibly remnants of an erosion surface which Trowbridge (1954, p. 801–802) called the Lancaster peneplain. Evidence of a peneplained surface was not recognized in the Dubuque North quadrangle because of extensive erosion near the Mississippi River.

The bedrock topography in the quadrangle is in the youthful stage of erosion except in the southwest corner where it is in the mature stage. The large stream valleys and much of the topography in the Dubuque North quadrangle are examples of an interrupted cycle of erosion and appear to be in an early mature stage of erosion; whereas the short tributary valleys are in the youthful stage (pl. 10). The seemingly mature erosion stage of the large streams is caused by valley fill of alluvium on which the streams now flow well above the bedrock bottoms of their valleys. This fill is over 300 feet thick (Brown and Whitlow, 1960, p. 63) and is discussed on page 157.

The latest geologic investigations by the U. S. Geological Survey in the Upper Mississippi Valley zinc-lead district of Wisconsin, Illinois, and Iowa were begun in 1942. This work has been in cooperation with the Wisconsin Geological and Natural History Survey since 1945, and was in cooperation with the Iowa Geological Survey from 1951 through 1957. Studies in Illinois were aided by the Illinois Geological Survey through interchange of data.

The authors appreciate the cooperation of Eldon Dietz, H. L. Landgraf, the Varner Well Drilling Co., Weber Well Drilling Co., and Hauser Well Drilling Co. for samples collected from wells and for data copied from their logs of holes drilled in and near the Dubuque North quadrangle. Geologic data from wells was also furnished by the following drillers: Kertels Brothers, Harry Ernster, Tony Beets, and Paul Gille.

The authors acknowledge the cooperation of the following people who aided in the work in many ways: H. G. Hershey, Director of the Iowa Geological Survey; M. A. Melcher, President of the Wisconsin Institute of Technology; Monroe Royce, a former lead miner; Elsie Datisman, librarian at the Dubuque Carnegie-Stout Public Library; the city and water engineers of Dubuque, Iowa; and James Bradbury of the Illinois Geological Survey.

About 18 square miles of the Dubuque North quadrangle was studied in detail and mapped before this quadrangle-mapping project began: Flint and Brown (1954), Brown and others (1955; 1957). (See pl. 10, index to geol. mapping.) Geologic data from these maps were adjusted to the 1955 topographic base map. This adjustment and geologic data collected since 1954 resulted in minor changes in configuration of formational boundaries and structure contours. The remainder of the quadrangle was studied and mapped in 1955 and 1956 in conjunction with mapping of the Dubuque South quadrangle (Brown and Whitlow, 1960) and completed in 1957.

The altitude of most structure control points was surveyed with planetable and telescopic alidade. The base altitudes used are bench marks and supplemental altitudes established by the U.S. Geological Survey.

Subsurface geologic data were obtained from well records in the files of the Iowa Geological Survey, from cuttings of holes drilled by the U.S. Geological Survey (Flint and Brown, 1956), from well logs of local well drillers, and from drill cuttings they collected for us.

GENERAL GEOLOGY

Rocks exposed in the Dubuque North quadrangle range from Middle to Late Ordovician in age (pl. 11). The unconsolidated materials are glacial till and loess of Pleistocene age and valley fill of Pleistocene and Recent age. Well data indicate that rocks of Late Cambrian and Early Ordovician ages underlie the entire quadrangle. The sequence of the formations in this quadrangle is conformable except for unconformities between rocks of Precambrian and Late Cambrian ages and possibly between the Prairie du Chien Group of Early Ordovician age and the St. Peter Sandstone of Middle Ordovician age. A more detailed discussion of the stratigraphy of the zinc-lead-district is given by Agnew and others (1956).

PRECAMBRIAN ROCKS

Rocks of Precambrian age were penetrated by Dubuque City wells 5 and 8 (SE¼ sec. 7, T. 89 N., R. 3 E., Iowa) at 1,165 and 1,180 feet below sea level, respectively. Cuttings of Precambrian material from well 8 are apparently from a biotite-rich granitic rock (Iowa Geol. Survey, written communication). A well at the Fisher Ice Co. (NW¼ sec. 30, T. 89 N., R. 3 E., Iowa) a quarter of a mile south of this quadrangle did not reach rock of Precambrian age at 1,350 feet below sea level. This information indicates that there is more relief on the Precambrian surface than can be accounted for by the regional dip alone. Therefore, the depth to the Precambrian can only be approximated in the Dubuque North quadrangle except at the two Dubuque City wells.

UPPER CAMBRIAN SERIES

Rocks of Late Cambrian age unconformably overlie Precambrian rocks and include the following formations, in ascending order: the Mt. Simon Sandstone and Eau Claire Sandstone of the Dresbach Group, and the Franconia Sandstone, St. Lawrence Formation, and Jordan Sandstone. This series is dominantly sandstone but includes some siltstone and dolomite. Detailed descriptions are given by Heyl and others (1959, p. 6–9).

Cuttings from Upper Cambrian strata collected from deep wells near Dubuque and studied by the Iowa Geological Survey indicate that the thickness of the Upper Cambrian series ranges from 1,300 to 1,500 feet.

LOWER ORDOVICIAN SERIES

PRAIRIE DU CHIEN GROUP

The Prairie du Chien Group was named by H. F. Bain (1906, p. 18) for outcrops near Prairie du Chien, Wis. The Prairie du Chien, which was observed only as cuttings from deep wells in this quadrangle, is dominantly arenaceous dolomite and contains oolitic chert. The dolomite is fine grained to medium grained and, in terms of the "Rock-color chart" of Goddard and others (1948), appears grayish orange to yellowish orange; the chert is very pale orange to white. The thickness ranges from a reported 93 feet in Dubuque City well 5 (Norton, 1928, p. 185) in the SE¼ sec. 7, T. 89 N., R. 3 E., to possibly 330 feet at the John Deere tractor plant in the NE¼ sec. 35, T. 90 N., R. 2 E. The Prairie du Chien is 300 feet thick at the Trausch Bakery well (NE¼NE¼ sec. 25, T. 89 N., R. 2 E.) in the Dubuque South quadrangle. The uneven upper surface of this group is commonly interpreted as an erosional unconformity.

MIDDLE ORDOVICIAN SERIES

ST. PETER SANDSTONE

The St. Peter Sandstone is the oldest formation exposed in the Dubuque North quadrangle. It overlies the Prairie du Chien Group and is normally 45 to 50 feet thick. Locally the St. Peter is as much as 200 feet thick where it fills depressions in the top of the Prairie du Chien.

The St. Peter Sandstone was named by Owen (1847, p. 170) for outcrops along the St. Peter River which is now the Minnesota River in Minnesota. In outcrop, the St. Peter is a light-medium-gray to dark-gray massive and crossbedded sandstone. Wet fresh surfaces are pale grayish orange to yellowish gray. Locally it is stained brown and yellow from hydrous iron oxides. It is composed of frosted white and clear rounded coarse- to fine-grained quartz sand, a minor amount of interstitial argillaceous material, and a cement that is siliceous and locally ferruginous. Generally it is a poorly cemented rock; however well drillers in Southwestern Wisconsin report that locally the St. Peter is quartzitic. No quartzitic St. Peter Sandstone was observed or reported in the Dubuque North quadrangle. Outcrops indicate that a hard ferruginous bed is commonly at or near the top of the formation. This hard bed is stained shades of brown and red and cemented with limonite derived from oxidation of iron sulfides initially contained in the rock.

PLATTEVILLE FORMATION

The Platteville Formation was named by Bain (1905, p. 18–19) for outcrops near Platteville, Wis. It is divided into the following members, in ascending order: the Glenwood Shale, Pecatonica Dolomite, McGregor Limestone, and Quimbys Mill. Thickness of the Platteville Formation in the Dubuque North quadrangle ranges from 52 to 61 feet.

GLENWOOD SHALE MEMBER

The Glenwood Shale Member was named by Calvin (1906, p. 60–61, 75) for exposures in sec. 6, T. 98 N., R. 7 W., Glenwood Township, Iowa. The Glenwood overlies and is gradational to the St. Peter Sandstone. Maximum thickness of this shale member in the quadrangle is about 4 feet. The Glenwood in outcrop is a greenish- to yellowish-gray shaly sandstone at the bottom with the shale content increasing upward and becoming greenish-gray; it is stained dark yellowish brown to dusky red from oxidized iron sulfides. Near the top of the member is a dusky yellow-green to grayish-green shale 0.2 to 0.8 foot thick containing a small amount of quartz sand. A limonite-cemented sandy shale bed 0.2 to 0.5 foot thick marks the top of the Glenwood in outcrop. Churn-drill cuttings indicate that below the water table this bed is a sandy shale containing iron sulfide.

PECATONICA DOLOMITE MEMBER

The Pecatonica was named by Hershey (1894, pt. 2, p. 175) for exposures in the Pecatonica River valley in Wisconsin near the Wisconsin-Illinois State line. It overlies the Glenwood Shale Member and ranges from 20 to 26 feet in thickness. The Pecatonica Member is fine- to medium-grained fossiliferous dolomite that is generally thick to massive bedded. Outcrops of the basal part are yellowish-gray to light-olive-gray fine-grained argillaceous dolomite that has yellowish-brown streaks, and just above the contact with the Glenwood Shale Member contains sand similar to that in the St. Peter. Dark-gray to dusky-brown phosphatic fossils, fossil fragments, and phosphatic nodules are numerous at the base, but none are found more than 5 feet above the Glenwood-Pecatonica contact. The Pecatonica grades upward from the base into light-olive-gray fine- to medium-grained dolomite that contains medium-gray shale partings. The rock in the upper few feet is pale-yellowish-brown dolomite. Dark-yellowish-brown to dusky-red coatings which occur in fossil cavities and porous places give the Pecatonica a speckled appearance. These cavities and porous areas are commonly limy or contain calcite crystals. Locally part of the Pecatonica is limestone but no place is known in the quadrangle where the entire thickness of the member is limestone.

McGREGOR LIMESTONE MEMBER

The McGregor Limestone Member was named by Kay (1935, p. 286–287) for exposures near McGregor, Iowa. The McGregor locally known in the mining district as Trenton lime, conformably overlies the Pecatonica Member which has a 0.5-foot transition zone in its uppermost bed. Thickness of the McGregor in this quadrangle ranges from 28 to 32 feet. It is dominantly light-olive-gray to olive-gray and pale-yellowish-brown sublithographic to medium-grained fossiliferous limestone. Dolomitic limestone and dolomite occur locally in the upper part of the member. The limestone is argillaceous, thin wavy bedded, and has many shale partings in the lower part. The upper half of the McGregor grades upward into thicker beds and has fewer shale partings. The top 6 feet is thick bedded and contains less shale.

The thin- and thick-bedded parts of the McGregor correspond in general to the Mifflin and Magnolia units described in Bays and Raasch (1935, p. 298) and Bays (1938, p. 269) in an area about 20 miles northeast of the quadrangle. However, no division of the McGregor into two mappable, easily recognized units could be made in the Dubuque North quadrangle.

QUIMBYS MILL MEMBER

The Quimbys Mill Member, which is mainly limestone, was named for a quarry exposure at Quimbys Mill, Lafayette County, Wis. (Agnew and Heyl, 1946, p. 1585). It overlies the McGregor Limestone Member, and a dusky-brown shale or shaly layer less than 0.2 foot thick marks the base of the Quimbys Mill. Its thickness in the Dubuque North quadrangle ranges from 0.1 foot of shale in sec. 15, T. 90 N., R. 2 E., Iowa, to about 1.5 feet of limestone and shale in sec. 15, T. 1 N., R. 2 W., Wisconsin. The top surface is uneven where there is limestone, as if from wave action, and the thickness varies accordingly.

The Quimbys Mill Member comprises moderate- to dark-yellowish-brown sublithographic to medium-grained fossiliferous limestone having dusky brown shale at the base and top. It breaks with conchoidal fracture and rings when struck with a hammer. Locally, it is called glass rock.

The Quimbys Mill Member thickens toward the east and south. About 1 foot is recorded in a drill hole in the SW¼SE¼ sec. 5, T. 89 N., R. 2 E., Iowa; the member is 12 feet thick at the type section, which is 14 miles east of the Dubuque North quadrangle.

DECORAH FORMATION

The Decorah Formation was named by Calvin (1906, p. 60, 84) for exposures near Decorah, Iowa, where it is predominantly a green shale. The formation contains more carbonate rocks southeast of Decorah, and Kay (1928, p. 16) divided the Decorah into three members which are recognized in the Dubuque North quadrangle in outcrops and in cuttings from drill holes. They are, in ascending order: Spechts Ferry Shale, Guttenberg Limestone, and the Ion Dolomite. Normal thickness of the Decorah ranges from 45 to 48 feet. It consists of shale, shaly limestone, and dolomite and is locally altered by leaching of the carbonate, dolomitization of limestone, and silicification (fig. 23). Leaching of the carbonate and the resulting compaction of the insoluble residue is the most common alteration noted. This change can be seen in outcrop at Eagle Point, sec. 7, T. 89 N., R. 3 E., Iowa, and in sec. 29, T. 2 N., R. 2 W., Wisconsin (fig. 23). Leaching of the carbonate has reduced the Decorah to about 29 feet near the center sec. 5, T. 89 N., R. 2 E., Iowa. The Guttenberg Limestone Member in sec. 5, T. 89 N., R. 2 E., Iowa, has been dolomitized (Flint and Brown, 1956, p. 483–484). Silicification of the strata is the least common alteration in the mining district. It was not observed in this quadrangle.

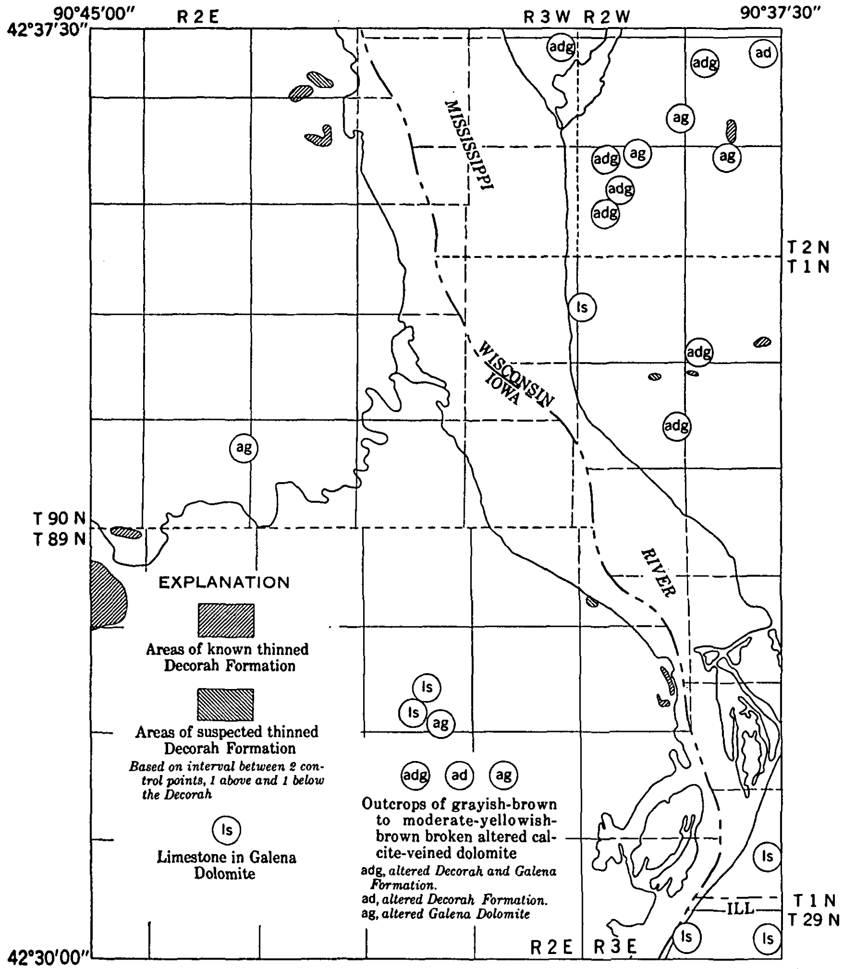

FIGURE 23.—Map showing location of some local lithologic changes in the Dubuque North quadrangle.

SPECHTS FERRY SHALE MEMBER

The Spechts Ferry Shale Member seems to overlie the Quimbys Mill Member conformably in the Dubuque North quadrangle. The Spechts Ferry Member was named by Kay (1928, p. 16) for an outcrop in a ravine at Spechts Ferry, Dubuque County, Iowa, about 1 mile north of the Dubuque North. At the type section this member comprises 8.8 feet of dark-greenish-gray medium-soft shale, and olive-gray, medium-gray, and medium-light-gray lenses and thin beds of dense fine-grained fossiliferous limestone. Local miners and drillers call it the clay bed.

The basal bed of the Spechts Ferry Shale Member is an olive-gray coarse-grained fossiliferous limestone. A layer of bentonite near the base of this member is light gray when first exposed to the atmosphere but oxidizes to pale yellowish orange when dry. This bentonite ranges from 0.1 to 0.3 foot in thickness. The amount and position of limestone near the middle of this shale member is variable. Phosphatic nodules ocur in an argillaceous limestone bed about 1 foot thick near the top of the member. The top bed of the Spechts Ferry is a dark-greenish-gray shale of variable thickness.

A thickness of 5 feet is reported for the Spechts Ferry in a drill hole in sec. 5, T. 89 N., R. 2 E., Iowa. This thickness is in an area of thinned Decorah Formation and is probably the result of solution and removal of the limestone in this member. The Spechts Ferry is 10 feet thick on the west side of sec. 6, T. 1 N., R. 2 W., Wisconsin.

GUTTENBERG LIMESTONE MEMBER

The Guttenberg Limestone Member conformably overlies the Spechts Ferry Member in the Dubuque North quadrangle. The abrupt change from the green shale of the Spechts Ferry to the overlying dark-yellowish-brown fine-grained limestone marks the base of the Guttenberg. It was named by Kay (1928, p. 16) for outcrops in the bluff northwest of Guttenberg, Iowa. The Guttenberg Member, locally called oil rock, comprises dark-yellowish-brown to light-olive-gray sublithographic to medium-grained argillaceous fossiliferous limestone containing many grayish-brown fossiliferous limy shale partings. Locally a discontinuous layer of chert nodules occurs about 6 feet below the top of the member. Unaltered Guttenberg ranges from 15 to 18 feet in thickness.

Solution leaching of the carbonate and compaction of the insoluble residue, and dolomitization of the limestone (Flint and Brown, 1956, p. 492–494) are the two forms of alteration noted in the Guttenberg in the quadrangle. Both forms of alteration reduce the thickness of the member, however the former generally thins the Guttenberg more than the latter. Solution-leached rock and dolomitized limestone occur together in some places and have locally reduced the Guttenberg in the quadrangle to a thickness of 5 feet in sec. 5, T. 89 N., R. 2 E., Iowa (Flint and Brown, 1956, p. 494). Generally the Guttenberg Member is thin in areas where the Decorah Formation is thin and (or) altered (fig. 23).

Solution-thinned Guttenberg crops out in sec. 7, T. 89 N., R. 3. E. and sec. 15, T. 90 N., R. 2 E., Iowa, and in sec. 29, T. 2 N., R. 2 W., Wisconsin. Commonly, dusky-brown shale is the only recognizable Guttenberg lithology remaining in outcrops where the entire member has been leached of carbonate. Thinning is also probable in gullies containing much rubble, few outcrops, and no visible Guttenberg outcrop or float where Guttenberg bedrock should be.

Dolomite and dolomitic limestone in the Guttenberg Member was penetrated in the Dubuque North quadrangle in two drill holes in sec. 5, T. 89 N., R. 2 E., Iowa (Flint and Brown, 1956, p. 492–494). Also, a well penetrated dolomite of the Guttenberg in the NW¼SE¼ sec. 3, T. 89 N., R. 2 E., Iowa. Several drill holes in areas west of the quadrangle penetrated dolomite and dolomitic limestone of this member (Flint and Brown, 1956, p. 487–498).

ION DOLOMITE MEMBER

The Ion Member was named by Kay (1928, p. 16) for 16 feet of calcareous and argillaceous limestone which is the upper part of the Decorah Formation exposed near Ion, Allamakee County, Iowa. It conformably overlies and is transitional from the Guttenberg Limestone Member in this quadrangle. The transition is from the typical dark-yellowish-brown fine-grained limestone of the Guttenberg Member to the medium-dark-gray to light-olive-gray coarse-grained limestone or dolomite of the Ion Member. This transition zone is thin where the basal part of the Ion is dolomite and thick where it is limestone. The Ion crops out in the river bluffs in this quadrangle from Eagle Point, Iowa, to the north side of the quadrangle.

Normal thickness ranges from 20 to 23 feet, but solution thinning is indicated by cuttings from churn-drill holes in secs. 5, 8, and 16, T. 89 N., R. 2 E., Iowa. A twofold division of the Ion can be recognized in exposures and in drill cuttings. Local drillers have given the name blue to the lower 7 to 11 feet and the name gray to the upper 11 to 14 feet.

The lower unit of the Ion Dolomite Member is shaly limestone and dolomite. Outcrops of limestone at the base commonly grade upward through dolomitic limestone to limy dolomite and dolomite at the top of the unit; however, the entire unit is limestone at some places. The lower unit is medium dark gray to light olive gray, fine to coarse grained, crystalline, fossiliferous, and argillaceous. Beds range from less than 0.1 to about 1.2 feet in thickness and have many pale-blue-green to grayish-green shale partings. Normal thickness ranges from 7 to 11 feet, and where the unit is less than 7 feet thick, it is considered to have been solution thinned. Solution leaching and compaction have reduced this unit to a thickness of 3 feet in drill holes in sec. 5, T. 89 N., R. 2 E., Iowa. A transition zone of variable thickness forms the top of the lower unit and the base of the upper unit of the Ion Member.

The upper unit of the Ion Dolomite Member is thick bedded, moderate-yellowish-brown and yellowish-orange, medium- to fine-grained, crystalline fossiliferous dolomite containing pale-blue-green to yellowish-green shale partings. Locally this unit is limestone and generally at the same places the lower unit of the Ion is limestone. This unit is predominantly dolomite in the bluffs along the Mississippi River; however, limestone is more common than dolomite in the upper part of the Ion in drill holes in sec. 5, T. 89 N., R. 2 E., Iowa. Locally solution and alteration have reduced this unit to a thickness of 8 feet in drill holes in sec. 5, T. 89 N., R. 2 E., Iowa. Lithology of the upper 2 feet of the Ion is transitional to the overlying Galena Dolomite. The highest common occurrence of the pale-blue-green shale partings and a thin zone of *Prasopora*, a bryozoan fossil, mark the top of the Ion Member.

GALENA DOLOMITE

The Galena Dolomite conformably overlies the Decorah Formation in the Dubuque North quadrangle. It was named by Hall (1851, p. 146) for exposures near Galena, Ill. Thickness ranges from 224 to 235 feet in the quadrangle. The Galena is divided into three members, in ascending order, as follows: the Prosser (Ulrich, 1911, p. 480), Stewartville (Ulrich, 1911, p. 488), and the Dubuque (Sardeson, 1907, p. 193). The Prosser extends from the top of the Decorah Formation upward to the base of the upper *Receptaculites* zone (pl. 11). The Prosser-Stewartville contact is not useful in the mining district. The top of the cherty section, however, is distinct and is a natural lithologic division in the Dubuque North quadrangle. The terms "cherty unit" and "noncherty unit" of Agnew and others (1956, p. 259) are used in this report. The detailed description of the Galena Dolomite in the Dubuque South quadrangle (Brown and Whitlow, 1960, p. 16–22) is, with minor variations, applicable to this quadrangle.

CHERTY UNIT

The cherty unit comprises the lower 109 to 117 feet of the Galena Dolomite (pl. 11) in the Dubuque North quadrangle. Normally it is a pale-yellowish-brown to light-olive-gray and grayish-orange fine- to medium-grained vuggy fossiliferous dolomite containing abundant chert as nodules and nearly continuous layers in certain strata. Some outcrops of the cherty unit are partly light-olive-gray to pale-yellowish-brown fine- to coarse-grained crystalline fossiliferous limestone (fig. 23). Generally where the Galena is composed of limestone the underlying Ion Member of the Decorah is also limestone. A transition zone, of moderate- to grayish-brown and dark-yellowish-brown fine- to coarse-grained limestone and dolomitic limestone containing much calcite, occurs at the contact between limestone and dolomite regardless of stratigraphic position in the Galena. A similar transition zone was noted in the Dubuque South quadrangle (Brown and Whitlow, 1960, p. 18). The occurrences of limestone in the Galena Dolomite in the Dubuque North quadrangle have no apparent relation to structure or to mineralized areas but are possibly at the fringe of the limestone facies that occurs to the northwest in Iowa (Agnew, 1955, p. 1720).

Chert in the cherty unit is nodular and distributed parallel to the bedding. It grades from yellowish gray to pale yellowish brown and contains fossil molds and brownish-gray fossil markings that give the chert a mottled appearance. Chert near mineralized zones is selectively mineralized with disseminated microscopic grains of iron sulfide that colors it bluish gray. A powdery white secondary tripoli from alteration of chert generally occurs as a rind on nodules in dolomite and is common on nodules in limestone. However, chert at some places in limestone grades into the limestone without any change in color or texture, and a hardness or acid test is necessary to distinguish chert from limestone in a hand specimen.

The cherty unit is normally 109 to 117 feet thick in this quadrangle, but locally it is thinned by partial leaching of the carbonate and compaction of the residuum. Also, locally as much as 30 feet of the basal beds are intensely fractured and altered to a moderate-brown and grayish-brown argillaceous dolomite. Caving rock in the cherty unit is reported from several drill holes in sec. 5, T. 89 N., R. 2 E., Iowa. The reported thickness of the cherty unit in one drill hole is 97 feet. Flint and Brown (1956, p. 484) report that the unit is 88 feet thick in sec. 11, T. 89 N., R. 1 E., Iowa, about 2 2/3 miles west of the quadrangle.

The top of the cherty unit is marked by two discontinuous layers of chert nodules separated from the main cherty unit by 4 to 5 feet of dolomite in the south half of the Dubuque North quadrangle. This interval increases to about 6 feet near the northwest corner and to as much as 9 feet near the northeast corner of the quadrangle. The highest chert is not always found in cuttings from drill holes, and the highest reported occurrence may be as much as 9 feet below the actual top of this unit.

Persistent cherty and noncherty zones in the cherty unit were used extensively for stratigraphic control in the quadrangle. Agnew and others (1956, p. 296) made a zonal subdivision of the cherty unit on the basis of presence or absence of chert and the fossil *Receptaculites oweni*. However, the division used in the Dubuque South quadrangle by Brown and Whitlow (1960, p. 17–18) is used in this quadrangle. This is a more detailed division than was used by Agnew and others; especially for their zone A. Zones B, C, and D are about as described by Agnew and others (1956, p. 296) but differ in thickness.

NONCHERTY UNIT

The noncherty unit includes all of the Galena Dolomite above the cherty unit and comprises part of the Prosser Member and all of the Stewartville and Dubuque Members. It ranges in thickness from 115 to 120 feet. The noncherty part of the Prosser Member and Stewartville Members are thick to massive bedded and make up the lower 75 to 79 feet of the noncherty unit. These beds are overlain by the even-bedded shaly Dubuque Member.

The Stewartville Member was named by Ulrich (1911, p. 488) for exposures near Stewartville, Minn. Both the noncherty Prosser and Stewartville are pale-yellowish-brown to yellowish- and grayish-orange fine-grained crystalline porous fossiliferous dolomite. *Receptaculites oweni* is common in the upper *Receptaculites* zone.

The Dubuque Shaly Member was named by Sardeson (1907, p. 193) for exposures on the campus of Loras Academy in Dubuque, Iowa. Willman and Reynolds (1947, p. 9) named the lowermost shale bed above the massive beds of the Stewartville as the base of the member. This definition, which is accepted by us, makes the Dubuque Member about 40 feet thick in the report area. The Dubuque Member consists of moderate-yellowish-brown, yellowish-gray, and dusky yellow, fine-grained fossiliferous finely porous even-bedded dolomite interlayered with light-olive-gray, blackish-red, and dusky yellowish-brown, silty fossiliferous dolomitic shales as much as 0.4 foot thick.

The basal shale bed is less than 0.2 foot thick. This shale and the others in the Dubuque Member erode faster than the dolomite and form distinct reentrants in outcrops. The lower 9 feet of the member is thick to massive bedded. The beds 3.4 to 9 feet above the base form the caprock unit according to Flint and Brown (1956). The caprock unit and a bed 2 feet thick from 2 to 4 feet above it form prominent outcrops that are useful in mapping. Shale beds are more common above the caprock unit. The upper 15 to 20 feet of this member is nodular, wavy bedded, vuggy, and more argillaceous than the underlying even-bedded strata.

Drill cuttings from unoxidized Dubuque below the water table are grayer than those from the same strata above it.

UPPER ORDOVICIAN SERIES

MAQUOKETA SHALE

The Upper Ordovician series is represented in the mining district by the Maquoketa Shale, which was named by White (1870, p. 180–182) for outcrops along the Little Maquoketa River 7 miles west of the southwest corner of the Dubuque North quadrangle. White described the shales as "bluish and brownish shales, which weather into a tenaceous clay." Calvin (1906, p. 94–109) named and described four formations in the Maquoketa Shale Group in Winneshiek County, Iowa. These formations are, in ascending order: Elgin Shaly Limestone, Clermont Shale, Fort Atkinson Limestone, and Brainard Shale. The name Elgin has been abandoned by the U.S.

Geological Survey. H. S. Ladd (1929, p. 329–349) reported that from the type locality of the formation the carbonate rock increases to the northwest and argillaceous material increases to the southeast. He recognized the units described by Calvin (1906) northwest of the type locality but called them members and called the Maquoketa Shale a formation instead of a group.

Correlatives of the Elgin Shaly Limestone, called the brown shaly unit in the Dubuque South quadrangle (Brown and Whitlow, 1960, p. 25), and part of the Brainard Member are recognized in this quadrangle. However, the Clermont Shale and the Fort Atkinson Limestone of Calvin (1906, p. 94–109) are not recognized either in drill cuttings or outcrops.

The Maquoketa Shale was observed only in that part of the Dubuque North quadrangle west of the Mississippi River. It caps a small area in secs. 29 and 32, T. 90 N., R. 2 E., Iowa, and much of the area south of the Little Maquoketa River and west of Couler Valley (pl. 10). Because of the few outcrops, the boundary of the Maquoketa Shale on the geologic map was calculated from the structure contours and the topography by assuming the topographic surface to closely represent the bedrock. This assumption is valid except where surficial deposits are thick.

The maximum thickness of Maquoketa Shale preserved in this quadrangle is 110 feet that was penetrated by a churn drill in the SE¼SE¼ sec. 17, T. 89 N., R. 2 E., Iowa. The nearest places where complete thicknesses of the formation exist are at Lore and at Sherrill Mound; it is more than 177 feet thick 2 miles west of this quadrangle. The shale at both places is capped by rocks of Silurian age.

BROWN SHALY UNIT

The brown shaly unit of the Maquoketa Shale apparently conformably overlies the Galena Dolomite in the Dubuque North quadrangle, but the base of the unit has some features that indicate a disconformable relation. The features are: (1) a distinct lithologic change from dolomite to shale; (2) a distinct faunal change from the dolomite to the shale, and (3) the occurrence of abundant phosphatic nodules, pellets, and fossils in the lower beds of the brown shaly unit. Ladd (1929, p. 345–349) states that an erosional unconformity is beneath the Maquoketa Shale in Missouri and Illinois; however, there is little or no evidence of an erosional unconformity in the upper Mississippi Valley. In this quadrangle the change is abrupt from yellowish-gray to dusky yellow fine-grained dolomite of the Dubuque Member of the Galena, to generally a ferruginous bed as much as 0.1 foot thick that is overlain by a light to medium dark gray phosphatic bed as much as 0.8 foot thick. The ferruginous bed is not always present, and it is a limonite bed in outcrops and an iron sulfide-rich bed, which may contain some limonite, when it occurs below the water table. The phosphatic bed is always present and contains normal-sized fossils. Dark-yellowish-brown or brownish-black to dusky-yellowish-brown shale containing small fossils overlies the phosphatic bed.

The brown shaly unit comprises brownish-black to dusky-yellowish-brown fossiliferous shale containing black specks and interlayered dusky yellowish-brown and grayish-brown siltstone, and fine- to coarse-grained granular crystalline argillaceous fossiliferous limy dolomite. Iron sulfide is common in both the shale and dolomite. The rocks are abundantly fossiliferous in the lower 10 to 15 feet and contain a varied phosphatic depauperate fauna which Ladd (1929, p. 371–375) described as a zone of universal smallness. The depauperate zone is well exposed in a streambank near the northwest corner of sec. 16, T. 89 N., R. 2 E., Iowa. The shale also contains abundant carbon films of graptolites.

The brown shaly unit can be identified in cuttings from drill holes, and according to drillers' logs, ranges in thickness from 35 to 60 feet in this quadrangle.

BRAINARD MEMBER

The Brainard Member was named by Calvin (1906, p. 60, 97) for outcrops near Brainard, Fayette County, Iowa, and is the top unit of the Maquoketa Shale remaining in the Dubuque North quadrangle. It is covered by surficial deposits but was seen, in excavations and drill sludge to be yellowish- to grayish-green and pale-blue unfossiliferous soft shale that is sticky and plastic when wet. The maximum thickness in this quadrangle is not known because it is difficult to distinguish the soft shale from loess in drill sludge or in excavations.

QUATERNARY SYSTEM

PLEISTOCENE AND RECENT

All of the Dubuque North quadrangle was included in the Driftless Area by Chamberlin (1883, p. 28, 31, 35). However, he later recognized till in the quadrangle and revised the limit of the Driftless Area so that the area west of the Mississippi River was in the attenuated pebble drift zone (Chamberlin and Salisbury, 1885, p. 275).

A. J. Williams[1] studied glacial till in eastern Dubuque County. He concluded that the till is of Nebraskan age because it remains only on the divides, which indicates that present valleys were cut after the Nebraskan till was deposited. Trowbridge (1921, p. 123–125; 1954, p. 801–804) agrees with this conclusion, and he believes the Nebraskan till was deposited on the Lancaster peneplain. Trow-

[1] Williams, A. J., 1923, Physiography of the "Driftless area" of Iowa: unpublished Ph. D. thesis, Iowa Univ., Iowa City, 116 p.

bridge (1954, p. 801–804) also believes that the present course of the Mississippi River is the approximate ice border of the Nebraskan glacier, and the present valleys were cut during the interglacial intervals. Kansan till in western Dubuque County occurs on hills and in valleys.

Glacial till was seen at only a few outcrops in the quadrangle, and glacial erratics are uncommon. A ditch dug for a water main on Pennsylvania Avenue in Dubuque at the middle of the north edge of sec. 27, T. 89 N., R. 2 E. exposed till at least 14 feet thick. A few drillers' logs report sandy and gravelly yellow clay just above the normal gray and green clay of the soft Maquoketa Shale. This sandy and gravelly clay is commonly listed as surficial deposits or clay and has been reported by drillers to be as thick as 70 feet. Glacial debris was seen in the NE¼ sec. 8, T. 90 N., R. 2 E., Iowa. Pebbles of quartz, chert, and iron-formation and igneous rock as large as three quarters of an inch in diameter occur in streams and gullies in Wisconsin from the E½NE¼ sec. 17, T. 1 N., R. 2 W. south to the Illinois State line. Martin (1916, p. 100) reported similar material in the same area. These pebbles may represent stream deposits or till; but no outcrop of such material was observed east of the Mississippi River.

Loess of varying thickness covers most of the upland of this quadrangle, and erosion has removed the loess from only a few ridges. Exposures in gullies show loess as much as 25 feet thick.

Loess and till are not shown on the geologic map because they are poorly exposed and consequently little is known about their distribution in the quadrangle.

ALLUVIUM

The alluvium in the Dubuque North quadrangle is valley fill that is predominantly glacial outwash material of late Wisconsin age (Trowbridge, 1954, p. 803) and a minor amount of debris of Recent age from local rock and till. The glacial-outwash material is restricted to the valleys of the Mississippi and Little Maquoketa Rivers and Couler Valley in this quadrangle. The Platte River valley contains no outwash material except at its mouth because its drainage basin is in the Driftless Area and has no source of glacial debris. The smaller streams in the Dubuque North quadrangle in Iowa contain alluvial material from local rocks and till, and the smaller streams in the part of the quadrangle in Wisconsin contain debris from local rocks except south of sec. 17, T. 1 N., R. 2 W. as mentioned above.

The glacial outwash material comprises gravel, sand, and silt that is predominantly debris from metamorphic and igneous rocks of the Lake Superior region. Chalcedony and iron-bearing fragments are common, and fragments of agate are present but not common. The fine fraction of the outwash contains much magnetitic material, considerable black and brown nonmagnetitic debris, fine quartz, garnet, and zircon, a trace of rutile, a rare trace of gold, and many other minerals that were not identified. Commonly the coarse outwash material is covered by very pale orange to grayish-yellow sand and silt that contains little other than quartz sand. This may be outwash, but it is probably a mixture of alluvium and loess where it occurs in the valleys. The relation of sand and silt over coarse outwash debris is not well exposed in the quadrangle, but an excellent example is in a large sand and gravel pit north of Bellevue, Iowa; about 20 miles southeast of Dubuque.

The maximum thickness of fill in the valleys is unknown, but it was probably close to 400 feet thick in the Mississippi River valley and thinner in the valleys of the Little Maquoketa and Platte Rivers. According to Trowbridge (1954, p. 803) the bedrock bottom of Couler Valley is 224 feet above the bedrock bottom of the Mississippi River valley. Fill in the Mississippi River valley is 337 feet thick (Brown and Whitlow, 1960, p. 63). A well at the John Deere Tractor plant (NE¼NE¼ sec. 34, T. 90 N., R. 2 E., Iowa) penetrated 165 feet of fill. As much as 95 feet of sand and gravel is in Couler Valley in the SE¼SW¼ sec. 2, T. 89 N., R. 2 E., Iowa. A well in the SE¼NW¼ sec. 34, T. 90 N., R. 2 E., Iowa, penetrated 121 feet of fill in the Little Maquoketa River valley. Depth of fill in the Platte River valley and other streams in the quadrangle east of the Mississippi River is not known. The valley fill is over 60 feet above normal pool elevation upstream from Lock and Dam 11 (pl. 10). The coarse outwash debris is as much as 25 feet above the river level and is overlain by sand and silt.

ALLUVIAL TERRACES

Remnants of two alluvial terraces are in the river valleys in the Dubuque North quadrangle (pl. 10). The terraces are best preserved in Peru Bottoms in sec. 35, T. 90 N., R. 2 E., Iowa. According to Trowbridge (1954, p. 803), the terraces are younger than late Wisconsin glaciation.

The upper or older terrace has an altitude from 650 to more than 660 feet above sea level or about 50 to 60 feet above the normal pool elevation upstream from Lock and Dam 11 (pl. 10). Remnants of this terrace are well preserved along the Mississippi River and its tributary streams in the Dubuque North quadrangle. The upper 20 to 30 feet is generally sand and silt underlain by coarser glacial outwash material.

The lower terrace is about 630 to 640 feet above sea level or about 20 feet lower than the upper terrace. This terrace is better preserved along the Mississippi River than along the tributary streams. Part of the city of Dubuque is built on this terrace; however, it is generally indistinct because it is beveled to the river flood plain by a gentle slope. Coarse outwash material is near the top of this terrace in secs. 35 and 36, T. 90 N., R. 2 E., Iowa.

CLASTIC DIKES

Several clastic dikes were noted in the Dubuque North quadrangle within the city of Dubuque. The thickness of the dikes ranges from less than 1 to 36 inches. The thickest dike noted is at the north side of the Eagle Point quarry in the SE¼ sec. 7, T. 89 N., R. 3 E., Iowa (pl. 10). The remainder of the clastic dikes, observed in three other places in the quadrangle, are seldom more than a few inches thick.

The dikes range in composition from a dolomite and chert breccia that contains no quartz sand to a quartz sandstone that may or may not contain dolomite and chert fragments. Dolomite is the cement in all the dikes and is similar to the enclosing rock except for lack of stratification. The thickest dike is a dolomite and chert breccia and contains no quartz sand. A dolomite-cemented sandstone dike 6 inches thick in the N½NW¼ sec. 24, T. 89 N., R. 2 E., Iowa, contains a small amount of galena and sphalerite. The remainder of the clastic dikes observed in the quadrangle contain dolomite and chert fragments and quartz sand.

The strike of all clastic dikes observed except one is N. 75° W. to S. 75°W. A dike in the quarry in the N½NW¼ sec. 24, T. 89 N., R. 2 E., has a northward strike. The westward-striking dike in this quarry can be traced for 100 feet along the strike; the northward-striking dike can be traced less than 30 feet.

The stratigraphically lowest dike observed is 4 feet below the top of the Pecatonica Dolomite Member of the Platteville Formation near the center of the NW¼ sec. 5, T. 90 N., R. 2 E., Iowa, about 1¼ miles north of this quadrangle. The stratigraphically highest dike observed is in the lower part of the noncherty unit of the Galena Dolomite in a quarry near the center of the north edge of NW¼ sec. 18, T. 89 N., R. 3 E., Iowa. However, all clastic dikes seen in the Dubuque North quadrangle are in the Decorah Formation and the Galena Dolomite, and all sandstone dikes observed in the quadrangle are in the Galena Dolomite. Probably many more clastic dikes occur in the quadrangle than were observed.

Quartz sandstone boulders in an abnormal geologic position are in a gully in the SW¼SW¼ sec. 35, T. 90 N., R. 2 E., Iowa. These boulders may have been ice rafted into their present position, but it is more likely that they are residual boulders from a clastic dike. Several places where quartz sandstone occur in an abnormal stratigraphic position have been reported in Wisconsin (Heyl and others, 1959, p. 46).

The quartz sand grains and heavy-mineral grains from the dikes and sandstone boulders are similar to those in the St. Peter Sandstone. It is proposed that the sand in the dikes was emplaced during earthquakes. Fractures which now contain the dikes were opened during these disturbances, and weakly cemented sand of the St. Peter, along with much water, was forced upward into the cracks in the overlying formations by differential hydrostatic pressure.

The dolomite and chert fragments in these dikes are of wallrock that has been crushed by recurring tectonic adjustments along the fractures. This material generally has moved downward as is shown in the dike at the north side of the Eagle Point quarry where chert fragments from the Galena Dolomite occur stratigraphically lower than the lowest chert layer in the Galena.

The presence of small galena and sphalerite crystals in the sandstone dikes indicates that dike emplacement antedates or is concurrent with the mineralization.

STRUCTURE

The dominant structural feature in the western part of the Wisconsin-Illinois-Iowa zinc-lead district is a southwestward dip of 15 to 20 feet per mile, less than 1°. Superimposed on the regional dip in the Dubuque North quadrangle is a major anticline, possibly part of a major syncline, and several small anticlines, synclines, domes, and basins (pl. 10).

Two different systems of joints are in the quadrangle, one in the south half and the other in the north half (fig. 24, *A*, *B*). No major faults are known, but three small faults are shown in the mapped area (pl. 10).

Maximum structural relief for the top of the Decorah Formation is about 240 feet. The average dip of the strata in the south half of the quadrangle is southwestward about 16 feet per mile. The Meekers Grove anticline masks the regional dip in the north half of the quadrangle.

Selection of a datum surface to contour involves the consideration of several variables. First, a surface is needed that will most nearly show the structure of the rocks in the mineralized zone, because some mineral deposits are related to folding (Heyl and others, 1955, p. 235). Second, a datum surface is required that involves the least amount of extrapolation through strata of locally unknown thicknesses such as might be caused by local alteration and thinning of the Decorah Formation.

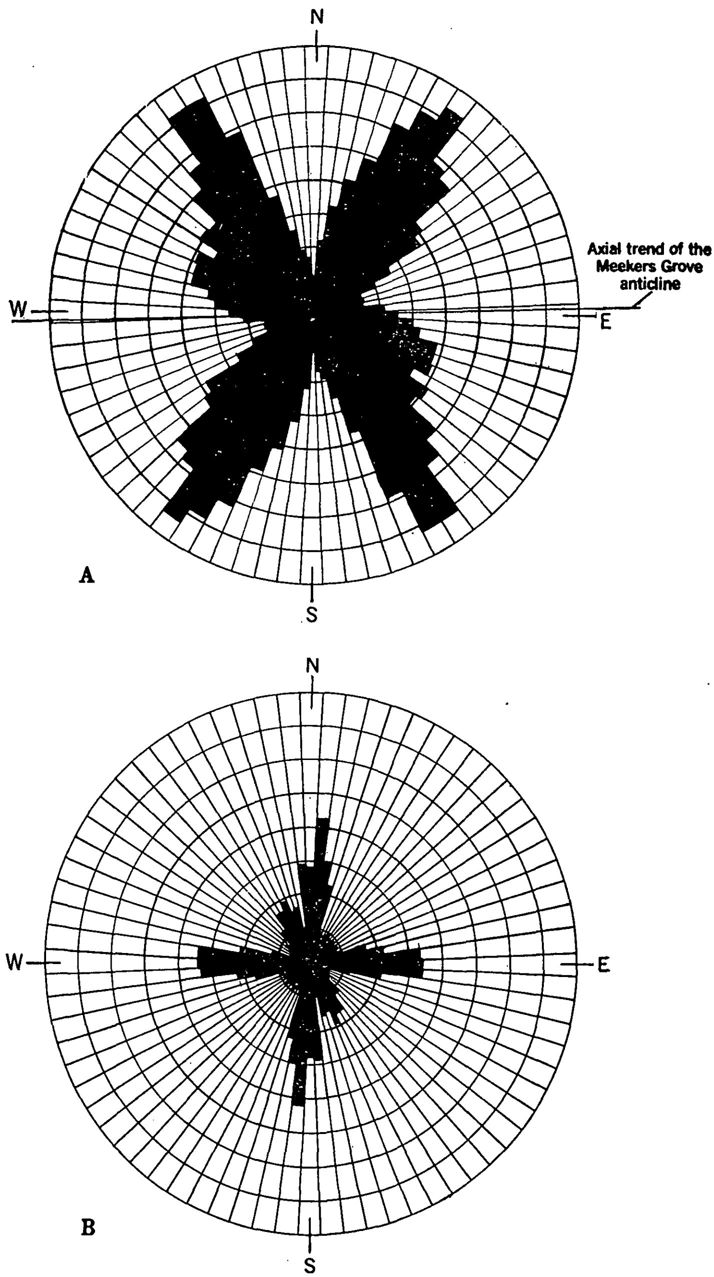

FIGURE 24.—Diagrams showing strikes of joints. *A* shows 694 steeply dipping to vertical joints in the north half of Dubuque North quadrangle and axial trend of the Meekers Grove anticline. *B* shows 288 steeply dipping to vertical joints in the south half of the Dubuque North quadrangle. Each 5° segment represents the average of the number of joint readings in that segment and the adjacent segments. Each circle equals five joints.

Most of the control points in the Dubuque North quadrangle are in the cherty unit of the Galena Dolomite and on the top of the Decorah Formation, therefore the structure contours are drawn on top of the Decorah Formation. Contours that are drawn from control points extrapolated from within the Galena Dolomite will show folds that are partly solution effects because of collapse of rocks over areas of solution-thinned Decorah. Contours drawn from control points extrapolated upward will not show the structure on top of the Decorah in areas where the Decorah is thinned. All geologic information was carefully considered to minimize this source of error.

FOLDS

The Meekers Grove anticline (Heyl and others, 1955, pl. 25) is in the northern part of the Dubuque North quadrangle, striking west from secs. 29 and 32, T. 2 N., R. 2 W., Wisconsin, into sec. 17, T. 90 N., R. 2 E., Iowa. This anticline can be traced about 18 miles eastward. It is asymmetrical in the quadrangle and has structural relief of as much as 100 feet within 1 mile of the fold axis on the north limb and less than 60 feet of relief within 1 mile of the axis on the south limb. Much of the Decorah Formation and the lower half of the Galena Dolomite that are exposed on the north limb are broken and highly altered, but no lead or zinc minerals were seen on this limb. There seems to be less fracturing and alteration on the south limb.

All other folds are minor anticlines and synclines less than 5 miles long having amplitudes of less than 30 feet. Most of the minor folds trend northwestward but a few trend northeastward. A few of the minor basins and folds are probably the result of settling over solution-thinned Decorah Formation. The basins in the SW¼SW¼ sec. 15, T. 90 N., R. 2 E., Iowa, and center SW¼ sec. 29, T. 2 N., R. 2 W., Wisconsin, are related to thinned Decorah that can be seen in outcrop. Broken and sheared rocks in outcrops in the area of the basins in the NW¼ sec. 29 and center sec. 31, T. 2 N., R. 2 W., Wisconsin, and in the SW¼ sec. 15, T. 89 N., R. 2 E., Iowa, indicate that they are probably the result of settling over solution-thinned members. The elongate basin in the N½ sec. 15, T. 89 N., R. 2 E., Iowa, is likely the result of slumping along a solution-widened joint. However, solution thinning of beds does not always form a basin or syncline. The Guttenberg Member has been reduced to a brown shale on the small anticline at the south end of the Eagle Point quarry (pl. 10). Although settling of beds over solution-thinned members does not always form depressions in the overlying rocks, it is the suspected reason for many of the small basins that exhibit no other cause.

JOINTS

Joints are numerous and well developed in the Dubuque North quadrangle. Two major systems of steeply dipping to vertical joints are present (fig. 24*A*, *B*). A line across the quadrangle through the centers of secs. 32 and 35, T. 90 N., R. 2 E., Iowa, approximately divides the quadrangle into north and south halves each having a distinct system of steeply dipping to vertical joints. Joints inclined less than 75° are found locally and do not seem to form systems.

The principal joints in the south half of the Dubuque North quadrangle strike N. 15° E. to N. 10° W. and N. 85° E. to S. 85° E. (fig. 24*B*). A minor set of joints strikes N. 15°–35° W. Couler Valley is parallel to joints in this set. There is no comparable northeastward set. The strike of the major joint sets in the south half of this quadrangle are similar to the principal joints in the Dubuque South quadrangle (Brown and Whitlow, 1960, fig. 17). The differences are: (a) The northward-striking joints average N. 5° E. and are more numerous than the eastward-striking joints that average N. 90° E. in the south half of the Dubuque North quadrangle; and (b) the northward-striking joints average N. 10° E. and are less numerous than the eastward-striking joints that average N. 85° W. in the Dubuque South quadrangle. The eastward-striking joints in the south half of the Dubuque North quadrangle are better formed west of Couler Valley than east of it if intensity of mining is an indicator. Most of the important mines and caves are along the N. 85° E. to S. 85° E. joint set. The northward-striking joints, although well formed, seldom have caves or important concentrations of lead or zinc ore. This major joint system is probably a conjugate joint system oriented in the shear direction for the northwestward- and northeastward-striking minor folds in the south half of the quadrangle.

The principal joints in the north half of the Dubuque North quadrangle strike N. 20°–45° E. and N. 25°–40° W. (fig. 24*A*). A minor set of joints strikes N. 65°–75° W. The major system of joints is interpreted as being a result of the forces that made the Meekers Grove anticline. The strike of the anticlinal axis indicates that the fold was caused by a northward- or a southward-directed compressional force, and the strike of the principal joints in the north half of this quadrangle are approximately the conjugate shear directions for this compression.

FAULTS

No major faults are known in the Dubuque North quadrangle, and the minor faults are inconspicuous. All faults that were mapped are in the city of Dubuque. A fault exposed in the Eagle Point quarry (SE¼ sec. 7, T. 89 N., R. 3 E., Iowa) has a vertical displacement of 4 feet and a horizontal displacement of 19 feet (Brown and others, 1955). This fault strikes N. 85° W. and parallels a major joint direction. Two faults mapped in the S½ sec. 13, T. 89 N., R. 2 E., Iowa, strike about N. 80° E. and are boundaries of a small graben which has a vertical displacement of 21 feet. These faults are exposed in bluffs along Couler Valley but are concealed by soil and rubble to the east. The strata near the two faults are highly sheared and contain much limonite. Minor displacements of a few inches along mineralized crevices are probably the result of slumping along joints.

ECONOMIC GEOLOGY

METALLIC DEPOSITS

Galena, the lead ore, and smithsonite and sphalerite, the zinc ores, are the only metallic minerals of economic value in the Dubuque North quadrangle. Galena and sphalerite are still commercially important in other parts of the mining district but have not been mined in the Dubuque North quadrangle since 1910.

Galena has been known in the vicinity of Dubuque since the middle of the 17th century. Julien Dubuque, who befriended the Fox and Sac Indians, began the first systematic mining in 1788. After Dubuque's death in 1810, the Indians continued to mine galena and sell it at a smelter on an island in the Mississippi River. When the territory west of the Mississippi River was opened to settlers at the close of the Black Hawk War in 1833, lead mining was resumed by settlers from Wisconsin and Illinois. Lead production increased steadily until 1845 but began to decrease in 1847. The last of the large mines closed in 1910, and only a minor tonnage has since been produced by a few small operators. Twenty-six tons of galena concentrate from two small mines in sec. 5 and sec. 6, T. 89 N., R. 2 E., Iowa, in 1953, was the last galena produced near Dubuque.

Smithsonite, zinc carbonate, was considered gangue until 1859 when its recovery in the district to make zinc oxide began. Smithsonite became an important ore mineral by the late 1870's and production of zinc ore, mainly smithsonite, surpassed lead-ore production in 1880.

Sphalerite was first mined in Iowa in 1898, and its production surpassed the combined production of smithsonite and galena from 1906 to 1908. Zinc ore was last mined in Iowa in 1910, but 39 tons of metallic zinc was recovered in 1916–17 from ore in mine dumps.

Accurate figures of lead and zinc production from the part of the mining district in Dubuque County are not available but estimated figures for some mines and ranges are in earlier geological reports. The estimated total production of galena from 15 of the larger mines in the Dubuque North quadrangle is 40,000 short tons according to Calvin and Bain (1900), Leonard (1897), Owen (1840), Whitney (1858), and also according to an article in the November 20, 1864, edition of the Dubuque Daily Herald. Considerable smithsonite and sphalerite was mined in the vicinity of Dubuque, but there are no figures for the amount mined in this quadrangle. A mine in sec. 15, T. 89 N., R. 2 E., Iowa, is reported to have produced 300 tons of smithsonite in 1899 (Calvin and Bain, 1900, p. 543).

The zinc-lead ores and associated minerals in this quadrangle are sulfides, carbonates, and sulfates. Ore and gangue minerals known to occur in the Dubuque North quadrangle are galena, sphalerite, smithsonite, cerussite, pyrite, marcasite, azurite, malachite, limonite, calcite, dolomite, chert, barite, and gypsum (Flint and Brown, 1954; Brown and others, 1955). Barium and copper minerals are sparse and are not economically important. Copper carbonate minerals occur as minor accessory minerals with the galena at a small mine in the NE¼SE¼ sec. 4, T. 89 N., R. 2 E., Iowa. This shaft was reported to have penetrated, at a depth of 100 feet, a 3-inch sheet of green talclike clay that assayed 42 percent metallic copper (Flint and Brown, 1954). Cerussite and smithsonite occur above the water table as alteration products of galena and sphalerite, respectively.

The principal lead and zinc deposits in Iowa were in solution-widened vertical joints. Mineralized vertical joints were called crevices by the early miners, and closely spaced parallel crevices were called a range. Whitney (1858, p. 432) did not think these deposits were of the true vein type and introduced the term "gash vein" to differentiate the lead deposits in Iowa from common fissure veins.

Localization of the ores was controlled by three factors: (1) stratigraphic zones of greater solubility probably owing to local chemical composition or to greater permeability than adjacent strata; (2) well-developed steeply dipping to vertical shear joints intersecting these soluble zones; and (3) intersections of joints (Brown and others, 1955). Solutions selectively dissolved the soluble zones along joints. The resulting cavities or porous spongelike zones occur in the Galena Dolomite and are called openings (pl. 11) by local miners. These openings are discontinuous both horizontally and vertically. Extensive solution of the wallrock at the intersection of a major joint by other joints produced high cavities called chimneys. Mineralizing solutions deposited lead and zinc minerals in the openings, as indicated by minerals having euhedral crystal forms on one side and no crystal form on the opposite side. As the openings are discontinuous, the joint-controlled deposits are podlike both horizontally and vertically. The deposits were not entirely restricted to the solution-enlarged openings, but they were richer at these places (Brown and Whitlow, 1960, p. 55).

ORE-BEARING POTENTIAL

The ore-bearing potential for the formations exposed in the Dubuque North quadrangle ranges from very poor to fair. However, the most productive members in the Wisconsin and Illinois zinc and lead mines are exposed in the quadrangle.

The St. Peter Sandstone is a poor host rock for ores and is only locally mineralized with zinc or lead minerals.

The Platteville Formation is highly mineralized. Most of the zinc and lead ores in this formation in the mining district are in the McGregor and Quimbys Mill Members. However, no mineralized area of either member was observed in the Dubuque North quadrangle. Locally, the Quimbys Mill is a major ore producer in the eastern part of the mining district where it is thicker. The Pecatonica Dolomite Member contains a few important ore bodies in other parts of the zinc-lead district, but significantly zinc- or lead-mineralized rock was not observed in this member. The Glenwood Shale Member rarely contains more than a trace of zinc or lead minerals and none were observed in this quadrangle.

The Decorah Formation has the greatest potential of the formations in the Dubuque North quadrangle for the occurrence of pitch-and-flat deposits of zinc and lead ores. Pitches are veins along inclined fractures, and flats are veins parallel to bedding. The Guttenberg and Ion Members are host for much of the zinc and lead ores mined from pitch-and-flat deposits in Wisconsin and Illinois. Zinc- and lead-mineralized strata were penetrated in the Guttenberg and Ion Members in drill holes in sec. 5, T. 89 N., R. 2 E., Iowa. Sphalerite and galena are in the Guttenberg and the base of the Ion at the south side of the quarry near the center of the west side of sec. 26, T. 90 N., R. 2 E., Iowa. This is the only place in the quadrangle that zinc and lead minerals were observed in outcrop. Guttenberg fragments reported to be from the NE¼ sec. 25, T. 2 N., R. 3 W., Wisconsin, contained galena. Therefore, the Guttenberg and Ion Members in this quadrangle have potential for zinc and lead ores. The Spechts Ferry Shale Member contains zinc and lead minerals but no ore deposits in the mining district. No zinc or lead minerals were seen in this member.

The Galena Dolomite has excellent potential for zinc and lead ore in this quadrangle. All the zinc and lead ore produced in the vicinity of Dubuque was from this formation, and most of the lead ore was from the "first opening" (pl. 11). Smithsonite and sphalerite occur in this quadrangle in gash veins (Flint and Brown, 1954; Brown and others, 1955). It is possible that pitch-and-flat deposits are present in the cherty unit of the Galena as well as in the Decorah Formation. These deposits would more likely be found in the area south of the Little Maquoketa River, because streams in the other part of the quadrangle have exposed the lower half of the Galena and the Decorah without exposing any significant mineralization. Furthermore, south of the Little Maquoketa River are many mines and prospects and most of these were not mined below the top of the cherty unit. In addition, few wells penetrate rocks having a potential for pitch-and-flat deposits. Therefore exploration of rocks in the Decorah and in the lower part of the Galena Dolomite south of the Little Maquoketa River might discover this type of deposit.

The Maquoketa Shale has little potential for zinc and lead ores. It is mineralized and contains some galena and sphalerite, but no large deposits of either are known.

NONMETALLIC DEPOSITS

The principal nonmetalic deposits in the Dubuque North quadrangle are the dolomite and limestone bedrock of most of the area and the sand and gravel that composes the alluvial fill in the large valleys. The Maquoketa Shale in the quadrangle has no proven economic value, but possibly the soft shale could be used by the ceramic industry.

The quarry at the center of the west side of sec. 26, and the east side of sec. 27, T. 90 N., R. 2 E., Iowa, produces stone for riprap and crushed rock from the Galena Dolomite and the Decorah Formation. The only other quarry in this quadrangle from which rock is produced is near the center SE¼ sec. 21, T. 90 N., R. 2 E., Iowa. The large quarry at Eagle Point (SE¼ sec. 7, T. 89 N., R. 3 E., Iowa) and smaller quarries in the Dubuque North quadrangle were operated for crushed rock but are now inactive.

The beds of the Dubuque Member of the Galena Dolomite make excellent dimension stone because of their uniform thickness. Quarries in this member (SW¼ sec. 14 and NE¼ sec. 22, T. 89 N., R. 2 E., Iowa) supply most of the dimension stone used in Dubuque.

Sand and gravel are recovered from Couler Valley in the NE¼ sec. 3, T. 89 N., R. 2 E., Iowa. Although the fill of the Mississippi River valley is as much as 337 feet thick, no sand or gravel is recovered from it in this quadrangle. Sand and gravel is pumped from the riverbed a fourth to half a mile south of the Dubuque North quadrangle, and this operation plus the sand and gravel operation in Couler Valley adequately supply the demands of the area.

The total value of nonmetallic material recovered in this quadrangle far exceeds the total value of the metallic minerals recovered.

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