MAP MF-1835-I

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MAPS SHOWING THICKNESS AND LIMESTONE-DOLOSTONE RATIOS OF SELECTED PALEOZOIC CARBONATE UNITS IN THE NORTHERN MIDCONTINENT, U.S.A.

Compiled by Walden P. Pratt and Craig J. Wandrey

FOLIO OF THE NORTHERN MIDCONTINENT AREA

Prepared in cooperation with the
GEOLOGICAL SURVEYS OF ARKANSAS, ILLINOIS,
IOWA, KANSAS, MINNESOTA, MISSOURI, NEBRASKA,
OKLAHOMA, AND WISCONSIN

MISCELLANEOUS FIELD STUDIES MAP
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PRATT AND WANDREY—THICKNESS AND LIMESTONE-DOLOSTONE RATIOS, PALEOZOIC CARBONATES, NORTHERN MIDCONTINENT, U.S.A. 1:1,000,000, MAP MF-1835-I

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FOLIO NOTE

This set of maps is part of a folio of maps and cross sections of the northern Midcontinent area, bounded by lat 36°-46° N. and long 88°-100° W., prepared under the U.S. Geological Survey (USGS) Midcontinent Strategic and Critical Minerals project. This project is a cooperative activity between the USGS and the geological surveys of the included states. Other maps in this folio published to date include USGS Miscellaneous Field Studies Maps MF-1835-A through H (Mugel, 1986; Jorgensen and others, 1986; Marvin, 1988; Pratt, 1987; Anderson, 1988; Hills and others, 1991; Mugel and Pratt, 1991; Pratt, 1993) and USGS Miscellaneous Investigations Maps I-1853-A (Sims, 1990) and I-2214 (Sims and others, 1991). No additional maps in this folio are planned at present, but a report on regional potential of the carbonate rocks for undiscovered Mississippi Valley-type lead-zinc sulfide deposits is in preparation.

INTRODUCTION

These maps of major carbonate units were prepared as an aid to regional appraisal and prospecting for Mississippi Valley-type (MVT) lead-zinc(-copper-silver-nickel-cobalt) sulfide deposits in the northern Midcontinent. A widely accepted general model for the genesis of MVT deposits—predominantly stratabound galena-sphalerite deposits in shallow-water platform carbonate host rocks—invokes upward movement of metal-bearing brines from an underlying aquifer to a site in the carbonate section where the metals are precipitated as sulfides (Leach and Rowan, 1986; Palmer and Hayes, 1989). Implicit in this model are the presence of a window or edge in the next underlying shale unit, the function of which is to focus upward migration of brines into the potential host rocks; and, for many workers, a shale caprock overlying the host unit. The preceding publication in this series (Pratt, 1993) shows the areal extent of eight principal Paleozoic shale units in the project area. The present publication shows the other main part of this depositional model—specifically, the areal extent, thickness, and carbonate lithofacies of the region's three principal carbonate units that have proven potential as host rocks. As shown in figure 1, from the bottom up these units are (1) the Upper Cambrian carbonate units (Bonneterre or Eau Claire Formations and equivalents), which are the principal host rocks of MVT deposits in the Southeast Missouri district (Snyder and Gerdemann, 1968; Heyl, 1983); (2) the Middle and Upper Ordovician carbonate units (Galena Group or Viola Limestone and Kimmswick Limestone and equivalents), host rocks in the Upper Mississippi Valley district (Heyl, 1968); and (3) the Mississippian (Kinderhookian-Osagean-Meramecian) carbonate units (Chouteau Group, Burlington Limestone, Keokuk Limestone, and Ste. Genevieve Limestone and equivalents), which are host rocks in the Tri-State (Kansas-Missouri-Oklahoma) district (Brockie and others, 1968) and in the Illinois-Kentucky fluorspar district (Grogan and Bradbury, 1968).

An earlier publication in this series, MF-1835-D (Pratt, 1987), attempted to define permissive lithologies for MVT deposits by showing the carbonate-clastic and limestone-dolostone ratios of the Sauk sequence—rocks of Cambrian and Early Ordovician age. That map was not effective as a regional prospecting guide because of the preponderance of dolostone over limestone when the Sauk sequence is considered in its entirety. However, it was that failure that led us to the approach of mapping the limestone-dolostone ratio for the three thinner stratigraphic units shown on the set of maps in this report.

The specific reason for showing the limestone-dolostone ratio on these maps is that the limestone-dolostone interface (defined as the 1:1 ratio) is considered to be one of the most important controls of ore deposition

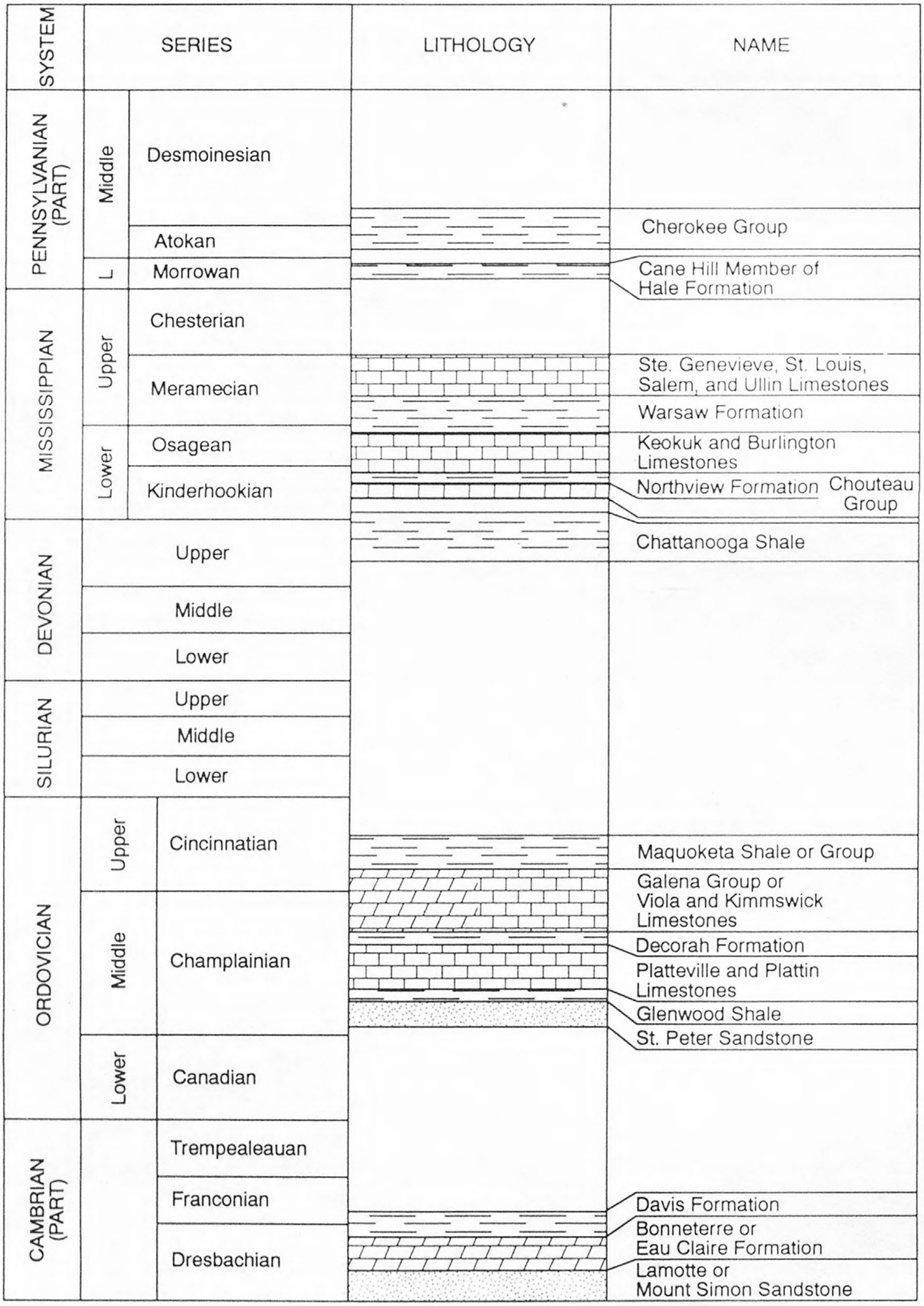

Figure 1. Stratigraphic relationship of principal carbonate units in the northern Midcontinent region having potential as Mississippi Valley-type (MVT) host rocks, and their relation to selected shale units and sandstone aquifers. Blank sections are formations not pertinent to this report. Names are in current usage by participating state geological surveys. Modified from Adler (1986).

in many Midcontinent MVT districts. Snyder (1968, p. 278), in a review of these districts, stated "The favored locus for ore occurrence is at or near the limestone-dolomite interface. Mineralization in undolomitized limestone in the major Midcontinent districts is rare. Ore is almost as rare well within the dolomitized area." In the Southeast Missouri district the limestone-dolostone interface is an intertonguing zone several miles wide, which separates nearly pure limestone on one side of the interface from nearly pure dolostone on the other (Thacker and Anderson, 1979); the dolostone is developed regionally and is believed to be the result of late diagenetic processes (Lyle, 1977). In the Upper Mississippi Valley district the principal host rocks are the Upper Ordovician Platteville Limestone, Decorah Formation, and Galena Group; these rocks change from predominantly dolostone in the eastern part of the district to predominantly limestone in the western part (Heyl, 1968, p. 437). Snyder (1968, p. 278) states that "the Galena formation [where it contains] ore is dolomite; away from ore bodies it is limestone." In the two districts where the host rocks are Mississippian, the limestone-dolostone control is less evident. In the Tri-State district the dolostone is not developed regionally, but is present as central cores within the Mississippian limestones; the ores surround these dolostone cores and are present in fractured jasperoid zones at the limestone-dolostone contacts (Brockie and others, 1968, p. 417). In the Illinois-Kentucky fluorspar-zinc-lead district the host rocks are Mississippian limestones with only minor dolostone, which is believed to be secondary and not diagenetic (Grogan and Bradbury, 1968, p. 386); but these deposits are mainly structurally controlled and are not typical MVT deposits.

Despite these exceptions, we believe the limestone-dolostone interface model is useful as a first-cut prospecting tool, especially if combined with other potential ore controls such as faults, folds, or regional distribution of shales as underlying windows or overlying caprocks. The reason for the control by the limestone-dolostone interface is not known, but as the foregoing examples indicate, such control does seem to be empirically valid. We do not speculate here on either the timing or the cause of the regional dolomitization. As stated previously, Lyle (1977) believed that the regional dolostone in the Viburnum Trend is diagenetic; Snyder (1968, p. 278) held the same view for Midcontinent MVT deposits in general. The cause of regional dolomitization is a subject of great controversy (Hardie, 1987) and is far beyond the scope of this study.

However, it is widely agreed that the Midcontinent MVT deposits are of hydrothermal origin, and a more direct indicator of hydrothermal activity in some places is coarse crystalline, sparry dolomite—not the same as the regional, diagenetic dolostone discussed above. Occurrences of sparry dolomite reported on drill logs are indicated on maps A and B by a five-pointed star; on map B the stars indicate occurrences through a vertical interval of 10 feet or more.

PREPARATION OF MAPS

These maps were compiled from maps of each state at 1:1,000,000 scale, prepared in 1988 by the following individuals: J.D. McFarland, III (Arkansas); S.J. Hageman, G.K. Maynor, J.W. Baxter, and D.R. Kolata (Illinois); R.M. McKay, O. Plocher, and B.J. Witzke (Iowa); Pieter Berendsen and K.P. Blair (Kansas); J.H. Mossler (Minnesota); C.M. Seeger (Missouri); M.P. Carlson (Nebraska); K.S. Johnson and D.J. Smith (Oklahoma); and B.A. Brown and E.C. Lawson (Wisconsin). The principal sources of data were drill-hole lithologic logs in the libraries of each of the state geological surveys. Data points are shown on the three maps, and additional data regarding the drill holes are summarized in another map in this folio (Mugel, 1986). The Cambrian and Ordovician maps were compiled by the senior author directly from the maps of each state. The state maps use the Lambert conformal conic projection and the regional map uses the Albers equal area projection; the resulting north-south error is about 1/8 inch (at map scale) for each degree of latitude, so the line work and data points were adjusted visually, a $1^\circ \times 1^\circ$ quadrangle at a time. In many of the areas covered by these two maps, the transition from a predominantly limestone lithology (limestone-dolostone ratio greater than 4) to a predominantly dolostone lithology (ratio less than 1/4) occurs over a relatively short distance of 25 miles or less; and in those areas the isopleths for ratios of 2 and 1/2 were omitted.

For the Mississippian rocks, the maps of each state were originally digitized and merged, and boundary inconsistencies resolved, by the junior author, using the USGS personal computer mapping program GSMAP version 3.0. The map was later transferred to Dynamic Graphics' Interactive Surface Mapping system, running on a Digital VAX 4300 minicomputer, for final editing. The more fully developed detail of the Mississippian map is a result of the larger number of data points and is not related to the use of a computer to compile the map. We acknowledge the assistance of Scarlett Tang and David Vaughan in transfer and final preparation of the Mississippian map.

The Manson astrobleme in northwestern Iowa, a conspicuous feature that appears on all three maps, is a

Late Cretaceous (65.7 Ma) impact structure that extends into the Precambrian basement (Sims, 1990; Anderson and Hartung, 1992).

These maps should be considered as reconnaissance in nature because of the variable spacing of data points, the variable nature of the data, and the small scale of compilation. As would be the case with conventional geologic maps at this scale, those wishing to use them for prospecting purposes should consult the original sources (maps or drill logs) and make their own detailed interpretations.

UPPER CAMBRIAN CARBONATE PACKAGE (MAP A)

DEFINITION

The Upper Cambrian carbonate package is ideally defined as the carbonate rocks of the Bonneterre or Eau Claire Formation and equivalents, bounded at the bottom by the Lamotte or Mount Simon Sandstone and equivalents, and at the top by shale of the Davis Formation and equivalents. Depicting this ideal on a map, however, has proved to be somewhat elusive because of several kinds of stratigraphic problems.

The first stratigraphic problem has to do with regional facies changes. In westernmost Iowa, most of Missouri, and southern Illinois, the defined interval is dominantly carbonate and can be visualized in simple form as a north-northwest oriented elongate prism thickening generally toward the northeast, with an eastward inflection in southwestern Missouri and a massive bulge in southeastern Missouri. However, as the interval thickens eastward, its carbonate content gradually gives way to siliciclastic sediments, and eventually (in easternmost Iowa and Wisconsin) the interval thins again owing to erosion.

The stratigraphy in Illinois presents another problem, in that the defined upper boundary of the interval (Davis Member of the Franconia Formation) is not present in many areas, and in some places the Bonneterre is directly overlain by carbonate rocks that extend all the way up to the St. Peter Sandstone (Middle Ordovician). In other places the Eau Claire contains no carbonate rocks, and the first carbonates above the Mount Simon are in the overlying Galesville Sandstone, Ironton Sandstone, or Franconia Formation (Upper Cambrian). Thus the western limit of the Bonneterre-Eau Claire carbonates in the mapped region is a normal erosional or nondepositional pinchout and can be shown as a zero isopach, but the eastern limit is a facies change that occurs gradually over many tens of miles.

A third problem involves the definition of the mapped interval. The specifications for the contributing state maps were written without cognizance of the facies changes just described, and called simply for isopachs of the total thickness of the Bonneterre or Eau Claire Formations, including thickness of clastic units except those that are specifically excluded at the top and base (that is, the Davis Formation above and the Lamotte or Mount Simon Sandstone below). Most of the state contributors took these specifications at face value and contoured the total thickness of the interval. The Illinois contributor, however, perceived that the underlying purpose of the map was to show the thickness of *carbonate* as a potential host rock, and accordingly contoured the thickness of carbonate only—more specifically, "the first carbonate unit above the Mt. Simon sandstone that is greater than 20 feet thick, and is greater than 50 percent carbonate. If several carbonate units greater than 20 feet thick were present in the Eau Claire Formation proper, separated by significant breaks, the thickest was used" (S.J. Hageman, written commun., 1988). Consequently the Illinois map is not compatible in this regard with the other state maps, a fact that was not realized until long after the maps had been submitted and the compilation contracts completed.

Map A attempts to resolve these problems as follows. In Illinois, the isopachs show only the thickness of the thickest carbonate unit in the Bonneterre or Eau Claire Formation, but in all the other states the isopachs show the total thickness of the Bonneterre or Eau Claire Formation. These relationships are shown diagrammatically in figure 2. A 1:1 carbonate:siliciclastic isopleth that trends southeastward across Iowa and Missouri indicates an approximate location of the facies transition from dominantly carbonate rocks to dominantly siliciclastic rocks. The complete disappearance of carbonates is indicated on Map A by a line labeled "facies change to siliciclastics."

THICKNESS

In Iowa and northern Missouri the Upper Cambrian carbonates thicken gradually northeastward from the pinchout to 200 feet over a distance of 100-125 miles, showing no apparent influence of either the regional slope of the basement surface or the northeast-trending Midcontinent rift zone (Sims, 1990). Two small exceptions to this rule are in west-central Iowa, where the Upper Cambrian is thin or absent over paleotopographic highs on the Precambrian basement. In southern Missouri the Bonneterre Formation thickens much more rapidly, over a distance averaging less than 50 miles. The sharp eastward inflection of the pinchout in the Kansas City-Sedalia

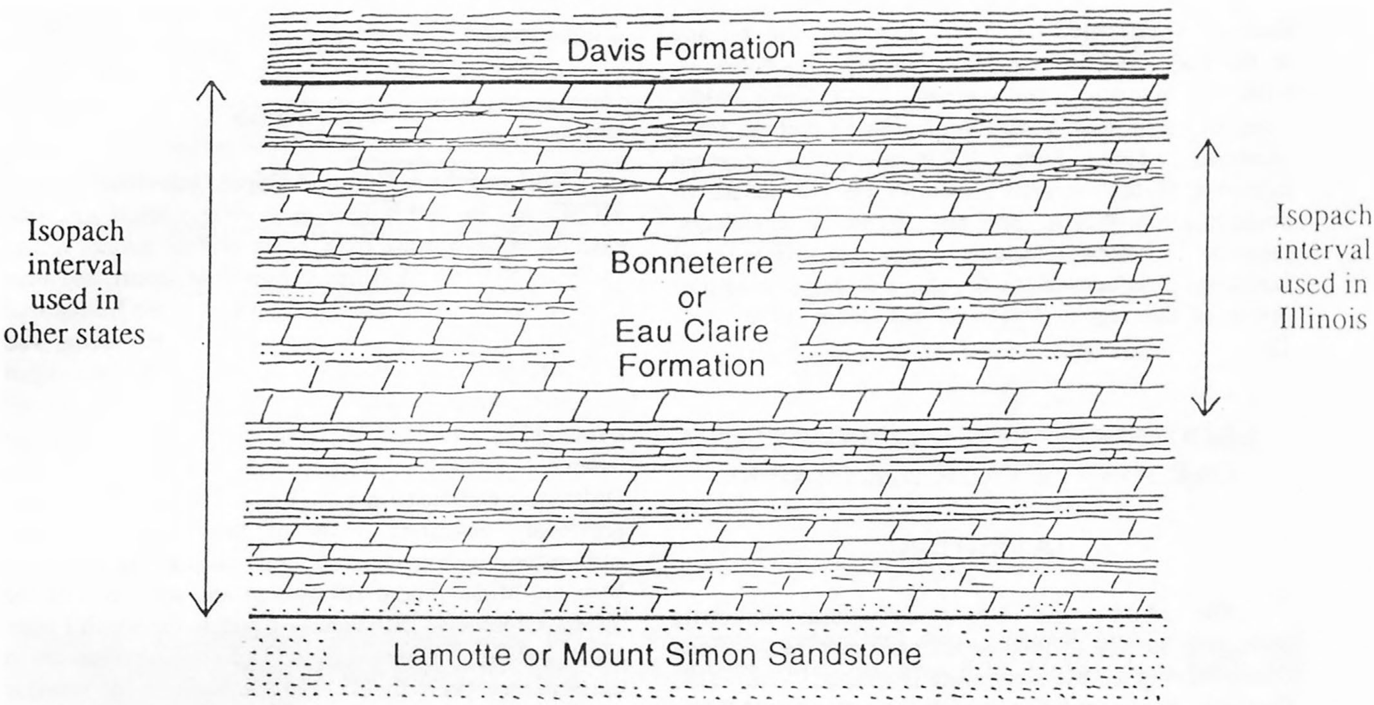

Figure 2. Diagrammatic sketch of Upper Cambrian carbonates showing relation between isopach interval used in compiling Illinois map and isopach interval used by other states.

area suggests some influence by the Central Missouri tectonic zone (Sims, 1990); the uneven thickness of the formation south of this area may reflect the influence of numerous faults, mostly of northwest trend, on the west flank of the Ozark uplift (Anderson, 1988). However, this variability in thickness of the formation, compared to its apparently uniform thickening farther north, may also be a function of closer spacing of data points in southern Missouri.

Eastward across central Missouri, the Bonneterre continues to thicken, exceeding 300 ft in much of southeastern Missouri and adjacent southwestern Illinois; it reaches a maximum thickness of more than 800 ft on the west side of the Mississippi embayment. In southeastern Missouri, numerous depositional pinchouts are present around the St. Francois Mountains, which stood as high ground in the Late Cambrian sea.

DISTRIBUTION OF LIMESTONE AND DOLOSTONE

The Upper Cambrian carbonate package is predominantly dolostone (a limestone-dolostone ratio of less than 1:4) in nearly all of Iowa and northern Illinois. In central Iowa, a small area of weaker dolomitization (1:1) is approximately centered on Des Moines and lies astride the Thurman-Redfield structural zone, which forms the eastern boundary of the Midcontinent rift zone (Anderson, 1988; compare Sims, 1990).

Limestone dominates in the Upper Cambrian carbonates in Missouri and southern Illinois. A semi-arcuate area of dominant limestone in south-central Missouri extends southwesterly from Warren and St. Charles counties through Gasconade, Maries, Pulaski, and Texas counties. The interface of this limestone zone with dolostone is fairly abrupt along its west side, through a distance of 10 miles or less; along the east side the interface is even more abrupt, and part of it is located along the Viburnum Trend. In Illinois, dominant limestone is restricted to a narrow area along the east side of the map area, and grades uniformly into dolostone within a transition zone about 12-15 miles wide. Comparison of map A with the regional structural maps (Anderson, 1988; Sims, 1990) shows no apparent influence of the regional structures on the pattern of dolomitization. Nor is there any discernible correlation between limestone-dolostone ratios and major areal variations of salinity in the Cambrian-Ordovician aquifer system of this region (Jorgensen and others, 1986, sheet 1).

MIDDLE AND UPPER ORDOVICIAN CARBONATE PACKAGE (MAP B)

DEFINITION

The Middle and Upper Ordovician carbonate package is ideally defined as the carbonate rocks of the Galena Group or the equivalent Dubuque, Wise Lake, Dunleith, Viola, and Kimmswick Formations of Middle to Late Ordovician age. The lower boundary of this package is the shale of the Middle Ordovician Decorah or Spechts Ferry Formations or Simpson Group, and the upper boundary is the Upper Ordovician Maquoketa, Sylvan, or Cason Shales and equivalents. In the central part of the region this definition is adequate, but to the northwest and southeast it is complicated by facies changes. To the northwest, in a zone extending from central and western Iowa into eastern Nebraska and southern Minnesota, the carbonate lithology gradually climbs up-section into the overlying Maquoketa Formation, and the carbonate at the base of the Galena Group is gradually supplanted by shale and sandstone; so that the Galena carbonate package of eastern Iowa becomes a Galena and Maquoketa carbonate package in eastern Nebraska (see fig. 3). To the southeast a different kind of facies change takes place: in northwestern Illinois the shale of the underlying Spechts Ferry Formation grades into limestone along a line fortuitously close to the Illinois-Iowa state boundary, leaving the carbonate rocks of the Galena Group resting directly on those of the Middle Ordovician Platteville Group. Therefore *in Illinois only*, the lower boundary of the Middle and Upper Ordovician carbonate package is redefined as the top of the St. Peter Sandstone (Middle Ordovician) or the top of the sandstone-shale unit of the Glenwood Formation (Middle Ordovician), and the resulting carbonate package constitutes the Ottawa Supergroup (see fig. 4). The isopachs in Illinois are shown differently (as short dashed lines) to emphasize this distinction. The pinchout of shale of the Spechts Ferry Formation in Illinois is also shown using a special line symbol.

THICKNESS

Rocks of the Middle and Upper Ordovician carbonate package are 200 ft thick or more in a broad zone that extends east-northeast from north central Kansas across southeast Nebraska, northwesternmost Missouri, and most of Iowa, to the Ordovician outcrop area in the Mississippi River valley in Minnesota, northeasternmost Iowa, and southwestern Wisconsin. This zone of thicker Ordovician carbonates overlies the central part of the northeast-trending Midcontinent rift system (Sims, 1990): where the basement surface is deeper, the Middle and Upper Ordovician carbonates are thicker. (In contrast to this, the previously described prism of the Upper Cambrian carbonates trends north-northwest, cutting directly across both the Midcontinent rift system and the trend of the thicker Ordovician carbonates—a puzzle for which I offer no explanation.) Thinning of the Ordovician carbonates to the northwest (in Nebraska) and southeast (in Missouri) is relatively uniform; in contrast, thinning to the southwest and south (in Kansas) is irregular, reflecting in part the influence of structures associated with the Nemaha ridge (compare Anderson, 1988). Southward from Kansas the carbonate package thickens again toward the Anadarko basin; in Illinois, the Ottawa Supergroup thickens southward toward the Illinois basin.

DISTRIBUTION OF LIMESTONE AND DOLOSTONE

The Middle and Upper Ordovician carbonate package is predominantly dolostone (limestone-dolostone ratio equal to or less than 1) in a continuous zone underlying eastern Nebraska; western, east-central, and southernmost Iowa; northwesternmost Missouri; and northwestern Illinois. An arm of this zone extends southwestward from northwestern Missouri across eastern Kansas. Several smaller irregular zones in which dolostone is predominant are present in south-central Kansas, around the central Kansas uplift (Anderson, 1988). In general, most of the area of predominant dolostone corresponds with most of the area of greater thickness of the Middle and Upper Ordovician carbonate package. No correlation is apparent between large or small dolostone areas and individual structures mapped by Anderson (1988). And as is the case with the Upper

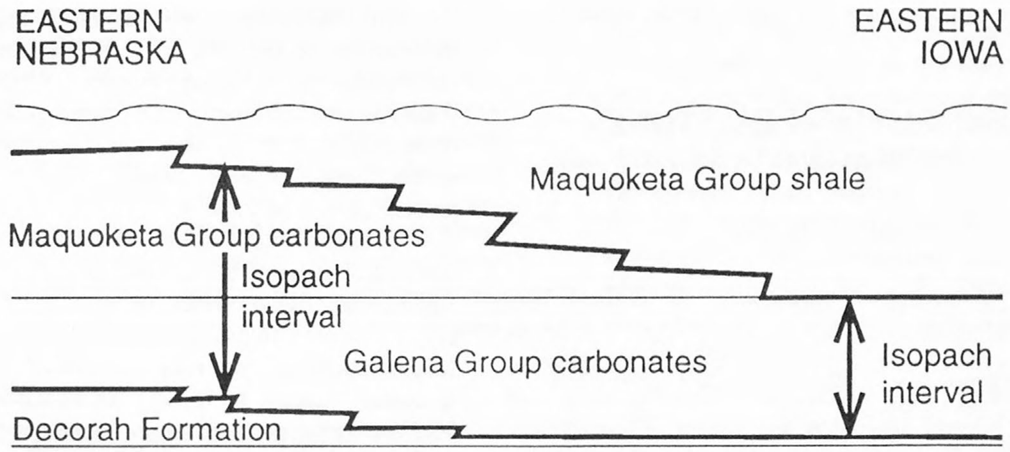

Figure 3. Diagrammatic cross-section along lat 42° N. showing generalized stratigraphy of Middle and Upper Ordovician carbonates from eastern Nebraska to eastern Iowa. Modified from R.M. McKay, Iowa Geological Survey Bureau, 1992.

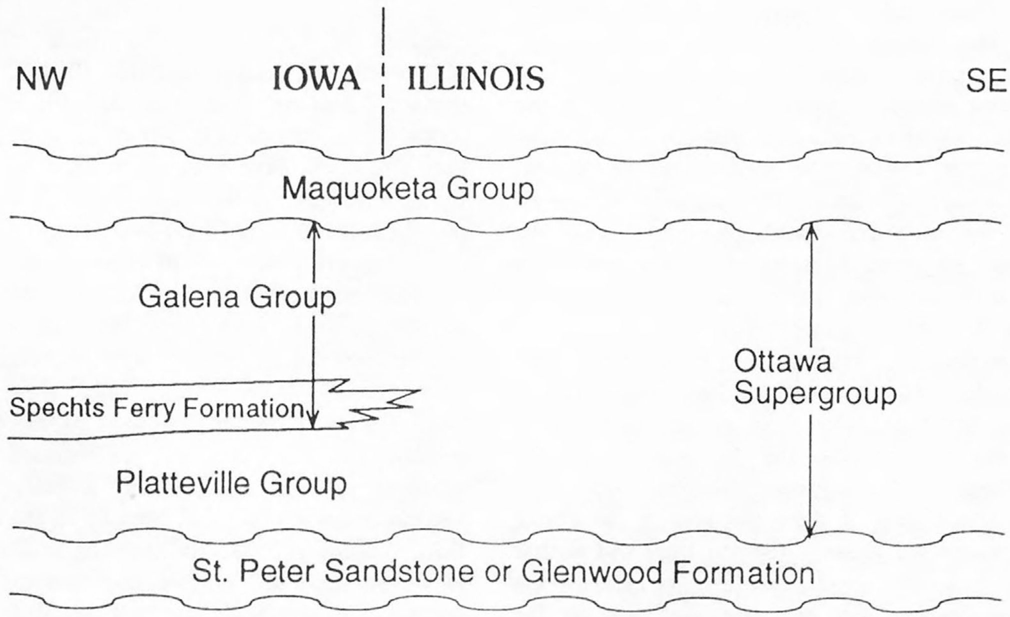

Figure 4. Diagrammatic cross-section showing generalized stratigraphy of Middle and Upper Ordovician carbonates from eastern Iowa to central Illinois.

Cambrian carbonate package, there is no apparent correlation between limestone-dolostone ratios and areal variations of salinity in the regional Cambrian-Ordovician aquifer system (Jorgensen and others, 1968, sheet 1).

MISSISSIPPIAN LIMESTONES PACKAGE (MAP C)

DEFINITION

The "Mississippian limestones" as defined here include Kinderhookian, Osagean, and Meramecian Series rocks above the Chattanooga (Upper Devonian and Lower Mississippian), Boice (Lower Mississippian), or Woodford (Upper Devonian and Lower Mississippian) Shales. They are essentially equivalent to the Kaskaskia II subsequence of Sloss (1988).

THICKNESS

The Mississippian limestones are exposed in a narrow northwest-trending strip that extends across central and eastern Iowa, where their outcrop pattern is influenced by the drainage courses of the Iowa and Skunk Rivers. The limestones are also exposed in several areas around the Ozark uplift, principally in Missouri and Arkansas. The upper part of this package was significantly eroded during Pennsylvanian uplift and exposure along several tectonic trends, particularly the Nemaha uplift, which extends from east-central Nebraska southward across Kansas into northeastern Oklahoma. Map C shows the pinchouts of the formations to the west against the Siouxana and Cambridge arches and the Central Kansas uplift; to the northwest against the Sioux ridge; and to the east against the Ashton arch and along the northern flank of the Illinois basin.

The sequence thickens in west-central and southwestern Iowa (northwest of the Iowa basin), and in north-central Missouri, where the greater thickness is somewhat puzzling because the sequence is on the northwest flank of the Northeast Missouri arch. The sequence is also thicker in a smaller area in the Forest City basin (along the Kansas-Missouri line) and farther south along this same trend. The thickets parts of the Mississippian package in the map area are in the Anadarko basin (more than 1,700 ft) and in the Illinois basin (more than 2,100 ft).

DISTRIBUTION OF LIMESTONE AND DOLOSTONE

Most of the dolostone is in a large area peripheral to the margins of the Nemaha uplift—extending westward from western Iowa through eastern Nebraska, then southward and southeastward into eastern Kansas. Another area of predominant dolostone is in west-central Illinois, north of the Sangamon arch. Smaller areas of dolostone are present elsewhere in Illinois, Missouri, and Kansas.

Possible correlations between the extent of dolomitization and the overall thickness of the Mississippian carbonate sequence are broad and inconclusive. In the principal dolostone area described above, the Mississippian sequence ranges from thick to thin; although in central Kansas, in the area of Mitchell, Ottawa, and McPherson counties, the high dolostone content is fairly well restricted within the 200-ft isopach. Conversely, in the two areas where the sequence is thickest—the Anadarko and Illinois basins—it is predominantly limestone.

Two possible instances of correlation between dolomitization and structure are evident. (1) In western Iowa, two large, elongate areas of dolostone trend northeast, one along the strike of the northern boundary fault zone and the other along the strike of the Thurman-Redfield structural zone and a parallel syncline. If the dolomitization in these areas is in any way related to the faults, then the faults also might have acted as channelways for mineralizing fluids. (2) In Peoria, McDowell, and Douglas counties, Illinois, four small but distinct dolostone areas coincide with local fold axes. Again, if the structures localized the dolomitization, then they also could have affected movement of mineralizing fluids. Elsewhere in the map area, dolostone zones show no apparent influence of regional or local structures.

Comparing the limestone-dolostone ratio map with the map showing salinity variations in the Mississippian aquifer (Jorgensen and others, 1986, sheet 2), the area of predominant dolostone in Iowa and Nebraska corresponds very broadly to a ground-water flow system with relatively low salinities (less than 20,000 mg/l dissolved solids), and the areas of predominant limestone in southern Illinois, southeastern Kansas, and northern Oklahoma correspond very broadly to more highly saline flow systems (20,000-200,000 mg/l dissolved solids). However, these are modern flow systems whose waters are probably meteoric as well as connate, and their possible significance in the dolomitization process is not known.

CONCLUSIONS

Except for a few minor instances in the Mississippian rocks as noted above, these map compilations show no correlation between the regional extent of predominant dolostone (presumably diagenetic) and either the thickness of the carbonate section or any known major structural trends. Nor is there any discernible correlation of the predominant dolostone areas from one carbonate package to the next—Cambrian, Ordovician, and Mississippian. We conclude that the patterns of regional dolomitization in the Upper Cambrian, Middle and Upper Ordovician, and Mississippian carbonate packages are independent of each other and of known major regional structures.

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