UW Extension

Wisconsin Geological and Natural History Survey
3817 Mineral Point Road
Madison, Wisconsin 53705-5100
TEL 608/263.7389 FAX 608/262.8086
http://www.uwex.edu/wgnhs/

*James M. Robertson, Director and State Geologist*

# Aggregate resources of the Sinnipee Group in eastern and southern Wisconsin

*Prepared for the Wisconsin Department of Transportation, Geotechnical Section*

Bruce A. Brown

1999

Open-File Report 1999-07

iii + 37 p

## Table of Contents

## List of Illustrations

### Figures



### Tables



### Plate

AGGREGATE RESOURCES OF THE SINNIPEE GROUP
IN EASTERN AND SOUTHERN WISCONSIN

## INTRODUCTION

The Sinnipee Group (Galena/Decorah/Platteville Formations) is an important source of crushed stone aggregate in much of eastern and southern Wisconsin. The outcrop area of the Sinnipee Group is a belt twenty or more miles wide that stretches from Marinette County south through the Fox Valley to the Beloit area, and west to the Mississippi River (Figure 2). It also includes a small area in western Wisconsin, in Pierce and St. Croix counties, that was not examined in this study. Rocks of the Sinnipee Group are predominantly dolomite or dolostone (magnesium carbonate as dominant mineral), but may locally include significant amounts of shale and shaly dolomite. Limestone, (calcium carbonate as the dominant mineral) is known to be a significant rock type in the Sinnipee Group only in southwestern Wisconsin.

Shaly, or argillaceous carbonate rocks, limestones and dolostones with high clay content, commonly break down much faster when exposed to natural weathering than do pure carbonate rocks. As a result, aggregates produced from argillaceous carbonate rocks commonly perform poorly in tests such as soundness that are designed to simulate the effects of weathering. For this reason, it is important to understand the the regional variation in shale content within the Sinnipee Group, as both shale interbeds and clay-rich carbonate rocks, to be able to evaluate and predict performance of these rocks as aggregates for concrete and asphalt paving.

The need for a study to investigate the relationship between shale content and performance of Sinnipee Group aggregate was suggested by reports of aggregate failure by premature weathering, which resulted in mild to severe pitting of asphalt and concrete pavement surfaces (Figure 1). Review of historic soundness test results compiled by the Wisconsin Department of Transportation established a record of poor to marginal soundness for a large number of Sinnipee

Group quarries located throughout the outcrop region. In the resulting study, quarries and other exposures throughout the outcrop area of the Sinnipee group were examined and sampled. Lithologic and stratigraphic information was recorded in the field, and samples of produced material, channel samples from producing quarry faces, and samples representing specific formations were collected and tested for soundness by both the sodium sulfate method (AASHTO T104) and the alcohol-water freeze-thaw (AASHTO T103) methods. This report provides a general description of the geology of the Sinnipee Group in Wisconsin. It also attempts to interpret soundness and freeze-thaw test results in relation to the geology at specific quarry sites throughout the outcrop area, to identify the characteristics that determine the performance of these rocks as crushed stone aggregate.

**Figure 1** Pitted surface of asphalt pavement on Hwy 18 west of Montfort, Iowa County. Surface pits are caused by deterioration of aggregate particles under exposure to weathering for approximately one year. Lens cap is approximately 2 inches wide.

## STRATIGRAPHY OF THE SINNIPEE GROUP

A detailed description and stratigraphic analysis of the Sinnipee Group is beyond the scope of this report. For a more detailed description of the rock units and a discussion of the origin of stratigraphic names used in southwest Wisconsin and northern Illinois, the reader is referred to the comprehensive geologic studies of Agnew and others (1956), Heyl and others (1959) and Willman and Kolata (1978). The stratigraphy of the Sinnipee Group in eastern Wisconsin is described in detail by Simo and others (1996, 1997) and Choi (1995, 1998). The generalized and abbreviated descriptions provided in this report draw extensively on these sources.

The formal stratigraphic names used by geologists to describe the various rock units within the Sinnipee Group are summarized in Figure 3. This table relates the formal names recognized by the Wisconsin Geological and Natural History Survey (Ostrom,1967) to the southwest Wisconsin terminology of Agnew and others, (l956) and the terminology for northern Illinois of Willman and Kolata (1978). It also provides a correlation with preliminary divisions recently proposed for northeastern Wisconsin (Simo and others, 1996, 1997, Choi, 1995, 1998). Also included in Figure 2 are the informal names historically used in the lead-zinc mining district of southwestern Wisconsin.

# Sinnipee Group Outcrop Area in Wisconsin

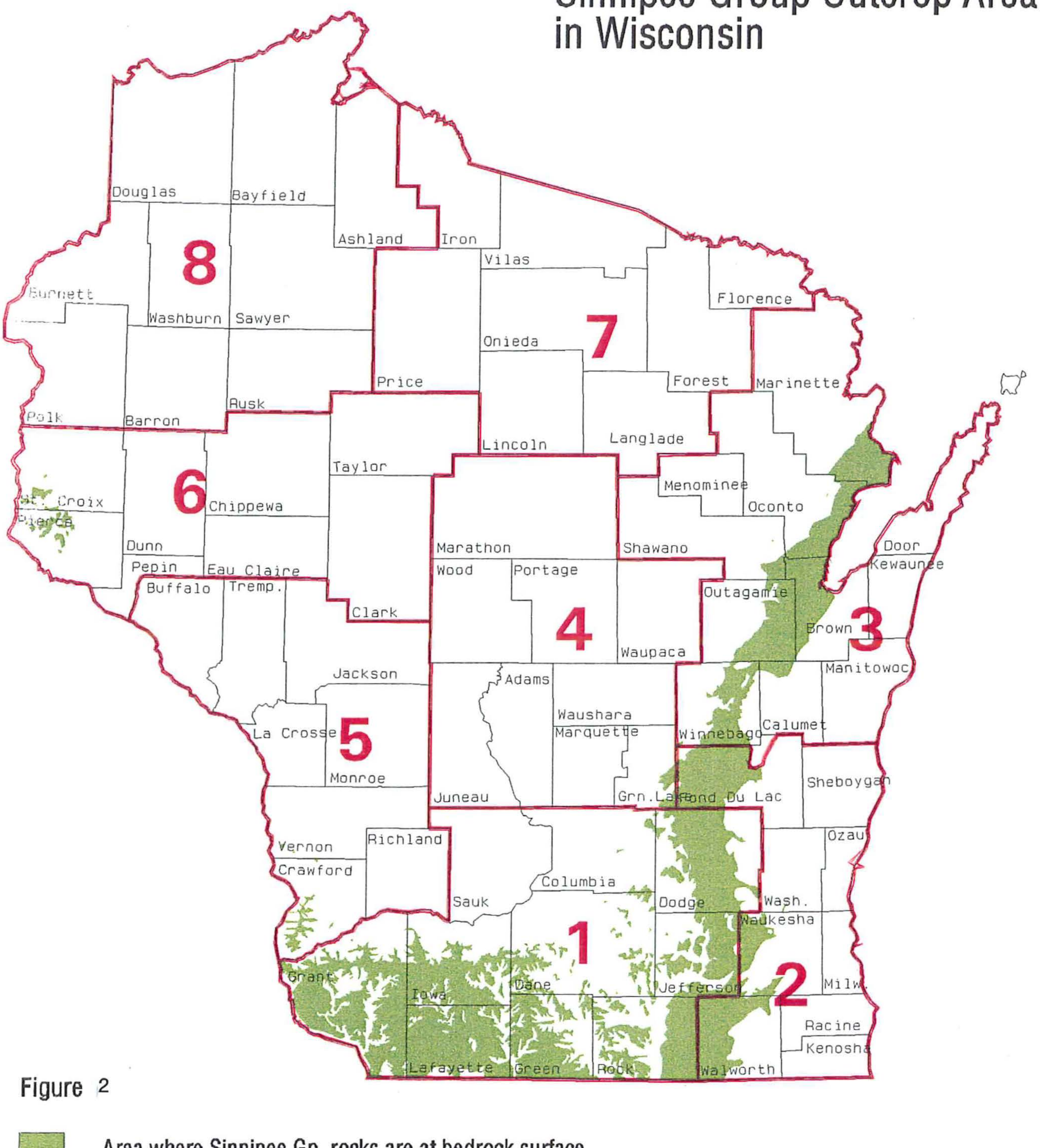


Figure 2

Area where Sinnipee Gp. rocks are at bedrock surface

Outlines of WISDOT Districts

TABLE 1. Stratigraphic terminology for the Sinnipee Group in Wisconsin. Correlations in northeast Wisconsin are tentative, based on work in progress.

| Group | Formation | Member | Lead-Zinc District Terms | | Illinois Terminology Willman & Kolata (1978) | Northeast Wisconsin Simo and Others (1996) |
|---|---|---|---|---|---|---|
| Sinnipee | Galena | Dubuque | Shingle Rock | | Dubuque | C 3 - C 5 |
| | | Wise Lake | Upper Receptaculites | | Stewartville | |
| | | | | | Sinsinawa | |
| | | Dunleith | Upper Cherty | | Wyota | |
| | | | | | Loves Park | |
| | | | Lower Recep. | | Fairplay | |
| | | | Lower Cherty | | Eagle Point | |
| | | | Buff | | Beecher | |
| | | Ion Submember | Ion | Gray | St. James | C 2 |
| | | | | Blue | Buckhorn | C 1 |
| | Decorah | Guttenberg | Oilrock | | Guttenberg | |
| | | Spechts Ferry | Claybed | | | |
| | Platteville | Quimby's Mill | Glassrock | | Quimby's Mill | B 6 |
| | | Nachusa | McGregor | Magnolia | Nachusa | B 3 - B 5 |
| | | Grand Detour | | | Grand Detour | |
| | | Mifflin | | Mifflin | Mifflin | B 2 |
| | | Pecatonica | Quarry Beds | | Pecatonica | B 1 |

Figure 4 is an idealized section made up of generalized columns that represent quarry and outcrop descriptions and drill hole logs from across the entire Wisconsin outcrop region, from Marinette County to western Grant County. Individual columns are based on field observations made in this study, and on descriptions by Choi (1995) and Simo and others (1996) in eastern Wisconsin, and Willman and Kolata (I978) and Choi (1998) in southwest Wisconsin.

Several important aspects of the regional lithologic variability within the Sinnipee Group are easily seen in Figure 4. The Galena and Platteville Formations can be recognized and correlated across the entire outcrop area. The Decorah Formation is recognized only in southern Wisconsin, reaching significant thickness only in the southwest. The lower beds of the Galena Formation (Ion beds or Buckhorn and St James Members in south, C1 and C2 in northeast) are generally more shaly than the overlying Galena. This interval can be followed continuously across the entire outcrop area, and is an important marker. The upper members of the Galena are generally pure carbonate in the southwest and southeast, but become shaly in northeast Wisconsin. The Platteville Formation contains two or more shaly intervals in southern Wisconsin, but is relatively shale free in the northeast.

The regional variation in shale content is the result of local differences in depositional environment and sediment supply throughout the time of Sinnipee Group deposition. A significant factor during much of the time of Galena deposition was a sediment source to the northeast, which resulted in the increase in the number and thickness of shale beds to the north of Winnebago County. The Wisconsin Arch is a north to northwest trending linear feature that separated the Michigan Basin from sedimentary basins to the south and west, probably influencing the distribution of sediment, particularly fine silt and clay, at the time the Platteville and Decorah formations were being deposited. The lateral continuity of the Ion lithologies suggests that the Wisconsin Arch may not have been an important barrier during early stages of Galena deposition, but may have been influential in restricting the area of Decorah deposition. For a complete discussion of the depositional history and regional sequence stratigraphic setting the reader is referred to Choi (1998), Simo and others (1997).

The following section provides a brief description and a summary of the important lithologic characteristics which can be used to identify the various stratigraphic units of the Sinnipee Group in the field.

## Platteville Formation

The Platteville Formation consists of dolostone and shaly dolostone in most of Wisconsin, although limestone may be present locally in the extreme west near the Mississippi River. It varies in thickness from about 50 feet in western Grant County to around 100 feet in the Rockford-Beloit area. East of the Wisconsin Arch, the Platteville thins northward from a maximum of 115 feet in the subsurface of Kenosha county (Choi 1995) to from 35 to 45 feet northeast of Lake Winnebago (Simo and others, 1995). In northwestern Illinois and southwestern Wisconsin, Willman and Kolata (1978) divided the Platteville Formation into five members, based on clay content and bedding characteristics. These five members were recognized and extended into southeast Wisconsin by Choi (1995). The six unit preliminary subdivision of the Platteville Formation in northeastern Wisconsin proposed by Simo and others (1996) is generally equivalent to the units named and defined in these other areas of exposure. The shale content is much less in the northeast, making identification of the units somewhat more difficult in the field.

Figure 3. Lower beds of Platteville Formation (Pecatonica equivalent) near Porterfield, Marinette County. White St. Peter Sandstone is visible in quarry floor. Gray beds of lower 5 feet are shaly, sandy dolomite. Light colored middle unit is sandy dolomite with abundant rounded quartz grains.

*Pecatonica Member*

The Pecatonica Member is a pure and massive-bedded dolostone at the base of the Platteville Formation. Historically the Pecatonica Member was referred to as the quarry beds because it was used as a building stone. It is typically light brown to buff in color and varies from 18 to 25 feet thick in southwestern Wisconsin. The Pecatonica Member generally has low clay content, with only thin shale partings present locally. Beds commonly appear mottled by darker colored irregular spots, which are burrows of ancient marine organisms, subsequently filled by darker sediment. These burrows are common in most of the fine grained carbonate beds of the Platteville Formation. Floating sand grains are common near the basal contact of the Pecatonica Member throughout southern Wisconsin, and probably represent grains reworked from the underlying Glenwood and St. Peter sandstones. The upper beds of the Pecatonica Member are generally thick and massive, and are easily distinguished from the thin, nodular, shaly beds of the overlying Mifflin Member. The upper contact surface of the Pecatonica Member is commonly marked by a pitted surface containing sulfide (pyrite or marcasite) nodules.

East of the Wisconsin Arch the Pecatonica Member thins from about 25 ft thick in Kenosha County to less than 5 ft thick in Winnebago County(Choi, 1995). North of Green Bay, the sand content of the Pecatonica Member (B1 unit) increases until near the base it becomes a sandy dolostone or locally a dolomitic sandstone in the area of Porterfield in Marinette County, (Figure 5).

*Mifflin Member*

In southwestern Wisconsin and northern Illinois, the Mifflin Member typically consists of 15 to 20 feet of gray, shaly, fine-grained limestone or dolostone. Bedding is typically thin (1 to 2 inches) and variable. Carbonate beds are separated by thin, irregular beds of greenish-gray shale (Figure 6). On weathered faces, the shale is commonly eroded away emphasizing the thin resistant carbonate layers. The Mifflin Member is the most fossiliferous member of the Platteville Formation, locally containing a diverse assemblage of marine fossils described by Willman and Kolata (1978). The gray color and the distinctive thin nodular bedding of the Mifflin Member make it easy to distinguish from the buff colored and massive beds of the underlying Pecatonica Member, and from the overlying Grand Detour Member (Figure 7).

The term McGregor Formation is used in older literature (Agnew and others, 1956) for the Mifflin Member and the overlying Grand Detour and Nachusa Members, which were formerly combined and named the Magnolia Member in Wisconsin. The name Trenton is an obsolete term still occasionally used to refer to this stratigraphic interval (Figure 2).

Figure 4. Typical modular or wavy bedding of the Mifflin Member. Light colored irregular beds are fine slightly argillaceous carbonate mudstone. Darker material is interbedded shale and shaly dolomite.

East of the Wisconsin Arch, the Mifflin Member thins to the north. Choi, (1995) described up to 30 feet of shaly, wavy-bedded Mifflin in drill core from Kenosha County, and only1 foot or less in a quarry section at Ripon. Simo and others (1996) described a 10 foot interval of gray, slightly argillaceous dolostone in the same stratigraphic position (unit B2) in northeastern Wisconsin that may be a lateral equivalent. This unit thins to the south and is not present in southern Winnebago County.

*Grand Detour Member*

Figure 5. Quarry face near New Glarus, Green County, showing buff weathering dolomite of Grand Detour Member overlying gray-weathering and thin bedded Mifflin Member.

The Grand Detour Member is defined in Northern Illinois, but has not been extensively studied and described in southern Wisconsin. Willman and Kolata (1978) consider it to be the most variable unit within the Platteville Formation. It is approximately 20 feet thick on the Illinois border and thickens to the south. The predominant lithology is pure to shaly dolostone that commonly appears dark blue gray on fresh surfaces. Clay content varies widely both vertically and laterally, and bedding varies locally from thin to thick. The upper part of the unit is commonly thin to medium bedded with red-brown shale partings. The lower part is typically a moderately pure dolostone, typically containing nodules and discontinuous beds of white chert.

East of the Wisconsin Arch, the Grand Detour Member and the overlying Nachusa Member are represented by 20 to 30 feet of relatively pure dolostone containing some discontinuous chert beds. Correlation of this interval is not yet well established into northeastern Wisconsin, but the stratigraphic interval corresponds to units B3 through B5 (Figure 3).

Nachusa Member

The Nachusa Member consists of 15 to 25 feet of massive, thick-bedded relatively pure doloStone in northern Illinois (Willman and Kolata 1978). It thins to the northwest across southern Wisconsin to a thickness of 2 feet or less in the area of Mineral Point. The Nachusa Member is absent west of the Mineral Point area (Figure 4). It is locally cherty and may contain vugs (cavities). In southwestern Wisconsin, the massive fine grained beds can resemble the overlying Quimby's Mill Member. The purple-brown color typical of the Quimby's Mill Member in that region is a reliable distinguishing feature.

Figure 6. Contact of lower Galena on Platteville (C-6) in northeast Green Bay area. Top of stick is at contact Note the marked change from massive buff-brown Platteville to green-gray shaly beds of lower Galena.

*Quimby's Mill Member*

The Quimby's Mill Member consists of 10 to 15 feet of fine-grained, medium to thin bedded, pure to argillaceous limestone or dolostone in the area of Rock and Green Counties. It thins to the west, to less than a foot thickness in western Grant County. In southwestern Wisconsin the Quimby's Mill Member is typically medium brown to dark purplish brown lithographic (very fine grained) limestone that weathers to a light tan surface color. It is hard and brittle and breaks with a conchoidal (shell like) fracture. It was called the "glassrock" by miners because it shattered with a sound like breaking glass when struck. The Quimby's Mill Member thickens eastward toward the Wisconsin Arch, becoming more dolomitic and locally cherty. Beds are typically separated by thin dark brown shale partings, and burrows are common.

Choi (1998) described 10 to 15 feet of Quimby's Mill Member east of the Wisconsin Arch in southeastern Wisconsin. Simo and others (1996) suggest that the B6 unit of northeastern Wisconsin may be equivalent to the Quimby's Mill Member. The B6 unit consists of 2 to 3 feet of pure, orange-brown, vuggy, fine-grained dolomite with a prominent pitted surface marked by pyrite nodules at the top. Due to the absence of the Decorah Formation in the northeast, this surface is overlain directly by the green shaly beds of the lower Galena (Figure 8).

Decorah Formation.

The Decorah Formation In Wisconsin is subdivided into the Guttenberg Member (dolostone) and the Specht's Ferry (shale) Member (Ostrom, 1967). In Illinois, Willman and Kolata (1978) classify the Decorah as a subgroup of their Galena Group, which can lead to confusion regarding terminology. The recent work of Choi (1995) and Simo and others (1996) suggests that the Decorah Formation is not present in eastern Wisconsin north of Jefferson County (Figure 3). In southeastern Wisconsin, the Decorah Formation is represented by a thin slightly argillaceous carbonate unit which Choi (1995) considers to be equivalent to the Guttenberg Member.

*Guttenberg Member*

The Guttenberg Member consists of argillaceous to pure limestone and/or dolostone with characteristic red-brown shaly partings. Willman and Kolata (1978) described 14 feet of gray to light gray, fine-grained, argillaceous and very fossiliferous limestone at Dickeyville in Grant County (column 1 of Figure 4). Bedding at this locality is in part wavy and lenticular (Figure 9), and ranges from 2 to 8 inches thick. Beds are separated by dark red-brown, organic-rich shale partings which produce an odor of petroleum when freshly broken. In the lead-zinc district of southwest Wisconsin, the Guttenberg was called the "oilrock" because of these organic shales. To the east at Mineral Point, the unit thins to 8.5 feet of gray to buff argillaceous dolostone, with red-brown shale partings. At South Wayne in eastern Lafayette County the Guttenberg Member consists of around 8' of buff to pinkish-gray dolostone. Willman and Kolata (1978) describe only 1foot of coarse, vuggy, buff to brown dolostone with red-brown shale partings at Rockford, Illinois, near the axis of the Wisconsin Arch.

Choi (1995) described a 1 to 3 foot thick shaly carbonate bed which occurs below the Galena Formation in southeastern Wisconsin, and considers it to be equivalent to the Guttenberg Member. This bed is traceable as far north as the Fort Atkinson area, where it apparently pinches out (column 8, Figure 4). The Guttenberg is well exposed In the roadcuts along Hwy 151 southwest of Madison, between Blue Mounds and Barneveld, where it consists of 4 to 5 feet of shaly gray dolostone and shale (Figure 11).

Figure 7. Contact of Decorah and Platteville Formations in a roadcut on Hwy 35 west of Dickeyville, Grant County (column 1 of Figure 4). The Spechts Ferry Member (in middle of photograph) consists of interbedded limestone and green shale. The Guttenberg Member is the overlying thin bedded unit. Massive bed below shale is the Quimbys Mill Member, less than 1 foot thick at this location.

*Spechts Ferry Member*

The Spechts Ferry Member is present only in extreme southwestern Wisconsin, and consists of 8 feet or less of green fossiliferous shale interbeded with limestone, (Willman and Kolata, 1978). The Spechts Ferry Member is exposed along with the overlying Guttenberg Member and the Quimby's Mill Member of the Platteville in road cuts on Hwy 35 west of Dickeyville, Grant County, (Figure 9). It thins rapidly to the east to less than 1 foot of clay shale and fine shaly limestone in the Mineral Point area. The Spechts Ferry Member is not present east of Iowa County and no equivalent unit is recognized in eastern Wisconsin.

## Galena Formation

The Galena is considered a group in Illinois and a formation in Wisconsin. This situation causes minimal confusion in the field because the names in use for the various subunits are the same, only the grouping of units differs between states. Willman and Kolata (1978) divided the Galena into five formations, the lower two of which are the Guttenberg and Spechts Ferry, which are considered members of the Decorah Formation in Wisconsin, (Figure 3). The Wisconsin Geological Survey considers the Galena to be a formation consisting of the Dunleith, Wise Lake, and Dubuque Members,(Ostrom, 1967). The more shaly lower part of the Dunleith Member is called the Ion Submember in Wisconsin. This unit, known informally as the "gray" and "blue" of the Lead-zinc district, is equivalent to the Buckhorn and St,James members in Illinois and the C1 and C2 units in northeastern Wisconsin (Figure 3). The Ion is a distinctive slghtly to very shaly interval that can be recognized across the entire outcrop area in Wisconsin. In areas where the Ion is very shaly, it is easily distinguished from the overlying pure dolostone of the Dunlieth Member by the greenish gray color of weathered surfaces and the interlayered green shale beds. In early reports, the Ion was sometimes included in the Decorah Formation because of the similar shaly character and appearance.

The Galena Formation of southwest Wisconsin is very continuous and uniform in character over a wide area (Delgado, 1983). Bedding is medium to thick, and individual beds have been thoroughly homogenized by burrowing organisms. Beds of nodular chert are present in several zones throughout the

Galena Formation. The chert commonly contains fossil fragments, suggesting an origin by replacement of carbonate sometime after deposition. The Galena Formation is continuous across the Wisconsin Arch. The Ion interval maintains a nearly constant thickness throughout the outcrop area (Figure 4). Choi (1995) recognized the presence of the same rock units in southeastern Wisconsin as are present in southwest Wisconsin and Northern Illinois, and kept the same system of names. The Ion is represented in northeastern Wisconsin as units C1 and C2. Simo and others (1996) described a significant increase in shale content throughout the lower half of the Galena Formation in the northeast, which makes continuation of units above the Ion more tenuous (Figure 4).

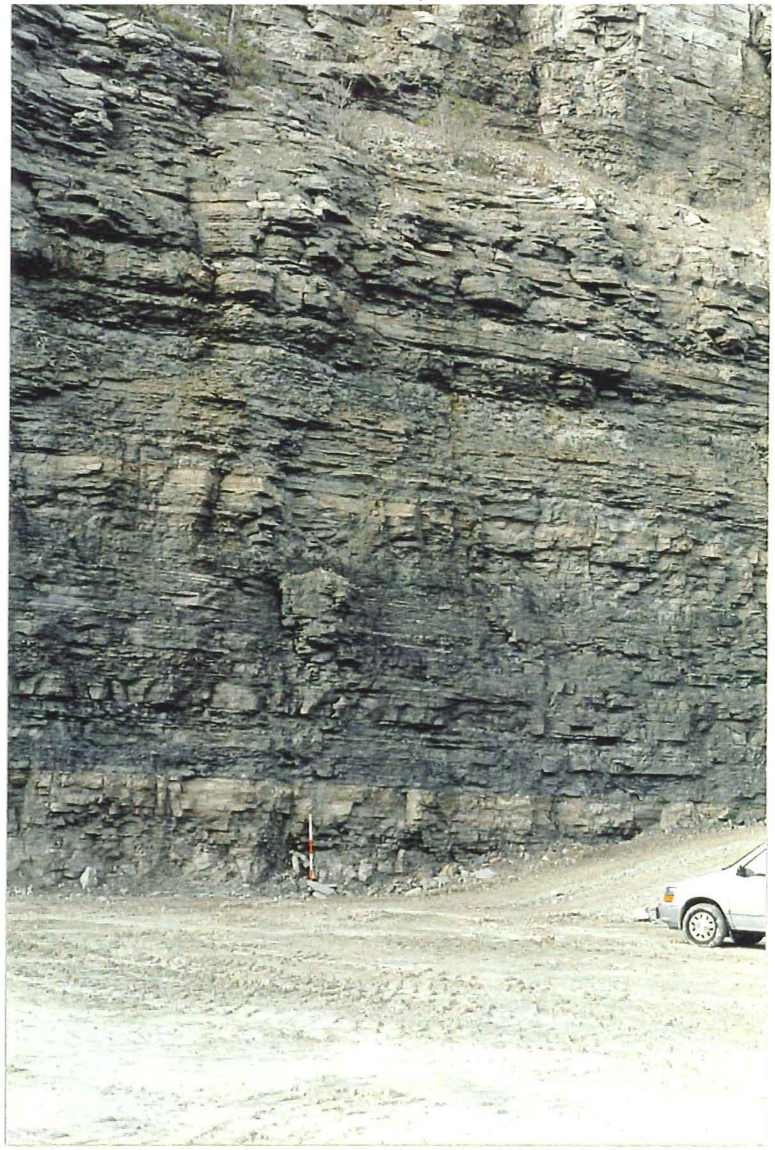

Figure 8. Lower beds of Galena Formation at Duck Creek, Brown County (site NE-8). Top of measuring stick is at top of Platteville Formation. Very shaly C1 and C2 units (Ion) are between base and light colored bed at middle of photograph. Light colored beds at top of face are non-shaly C5 unit.

Figure 9. Typical lower Galena of southwestern Wisconsin, exposed in road cut on Hwy 151 east of Barneveld, Iowa County. The Ion is the darker interval below the prominent bedding plane marked by water seepage. Dark gray beds at base of cut are shaly dolostone of the Guttenberg Member of the Decorah. Note buff color and pitted weathering typical of overlying Dunleith Member.

*Dunlieth Member*

Willman and Kolata (1978) describe the Dunlieth Member as consisting of 120 to 135 feet of slightly argillaceous cherty dolostone in northern Illinois. With the exception of the Ion beds at the base, the Dunlieth Member has a significantly lower clay content than the underlying Decorah Formation, but is slightly less pure than the overlying Wise Lake Member. In southwestern Wisconsin, the Dunleith Member typically consists of light brown to buff dolomite which weathers to a characteristic rough and pitted surface in road cuts and quarry faces (Figure 11). Bedding in the Dunlieth Member is generally medium to thick, and massive. Discontinuous thin beds and nodules of chert are common in the lower Dunlieth above the Ion. The informal name "lower cherty" is commonly given to this interval.

*Wise Lake and Dubuque Members*

The Wise Lake Member consists of about 75' of light brown pure, vuggy dolostone, distinguished from the underlying Dunleith by the lack of chert. The Wise Lake Member is the uppermost widely exposed and quarried unit of the Galena in Wisconsin, and is sometimes referred to as the "upper non-cherty". The Dubuque Member is poorly exposed or eroded, and is consequently not an important source of aggregate in Wisconsin. Wilman and Kolata (1978) describe the Dubuque as consisting of 35' to 40' of well bedded dolomite that is pure and thick bedded in the lower 10' but becomes increasingly shaly upward. In Minnesota the upper Dubuque consists of interbedded dolomite and shale. The contact between the Dubuque Member and the underlying Wise Lake Member is gradational. The contact with the overlying Maquoketa Shale is easily identified in drill core and cuttings but is seldom exposed in Wisconsin.

Summary of Sinnipee Group Stratigraphy

The Sinnipee Group occupies a stratigraphic position above the St. Peter Sandstone and the Prairie du Chien Group (dolostone) and below the Maquoketa Shale, units from which it is easily distinguished in the field and in drilling samples. It consists predominantly of dolostone and shaly dolostone, with minor sandy dolostone present locally in the lower beds . In Wisconsin, the Sinnipee Group is subdivided into the Galena, Decorah and Platteville Formations (Figure 3). The Galena Formation is further subdivided into the Dunleith, Wise Lake, and Dubuque Members, and the Ion Submember. The Ion, which is equivalent to the Buckhorn and St. James Members as defined in Illinois, is a recognizable unit of variably shaly dolostone at the base of the Galena Formation present throughout the Wisconsin outcrop area. The Dunleith and overlying members are predominantly clean massive dolostone in all areas of Wisconsin except the northeast, where shale interbeds and shaly dolostone increase significantly throughout the lower Galena.

The Decorah Formation consists of shaly dolostone and shale in southwestern Wisconsin. The Spechts Ferry Member, which is predominantly shale, is present only in the extreme southwest. The Decorah Formation is represented by a thin shaly dolomite equivalent to the Guttenberg Member in southeastern Wisconsin, but is not present north of Jefferson County. From Jefferson County northeast to the Michigan border, the Ion beds at the base of the Galena Formation directly overly the Platteville Formation.

The lithologic character of the Platteville Formation, particularly the shale content, is typically more variable in southwestern Wisconsin than in the northeast. North of Lake Winnebago, the Platteville consists of relatively pure dolostone throughout its thickness. South of the Ripon area, the middle beds of the Platteville, the Mifflin and Grand Detour Members, become more shaly. The Nachusa and Quimbys Mill Members and the basal Pecatonica Member remain relatively pure, massive-bedded dolostones throughout southeastern Wisconsin. This pattern continues westward into southwestern Wisconsin, where most shaly carbonate occurs in the Mifflin and Grand Detour Members This variability of clay/shale content within the Platteville Formation, as well as the presence or absence of the Decorah Formation, probably reflects the varying depositional conditions and sediment sources active at the time the Sinnipee Group was deposited, and the control of sediment distribution by regional features such as the Wisconsin Arch.

From an aggregate resource perspective, this observed pattern of regional variability in shale content within the Sinnipee Group is very important. With the exception of the Ion beds, the Galena Formation is a pure carbonate and a good aggregate source throughout southwestern and southeastern Wisconsin. Shale in the lower and middle Galena does, however become a potential problem in the northeast. The Platteville Formation is generally a pure carbonate and a good aggregate source north of Lake Winnebago, but certain members (Mifflin, Grand Detour) become shaly to the south and west. Because of this regional variability, it is particularly important to know position within the stratigraphic sequence, and position relative to the shaly intervals, in order to realistically evaluate the aggregate resources of a potential site or existing quarry.

## AGGREGATE RESOURCES OF THE SINNIPEE GROUP

Sinnipee aggregate resources will be discussed in terms of three geographic regions, each with different geologic setting. The Northeast region includes the outcrop area from Winnebago County north to the Michigan border. The southeast region includes the area from Fond du Lac County south through Rock County. The Southwest region includes the outcrop area west of the Wisconsin Arch, from Green County west to the Mississippi River, including Crawford County. The small area of Sinnipee rocks in Pierce and St. Croix Counties was not evaluated in this study.

### Northeast Region

The most important geologic factor in the northeast region is the observed increase in shale content throughout the

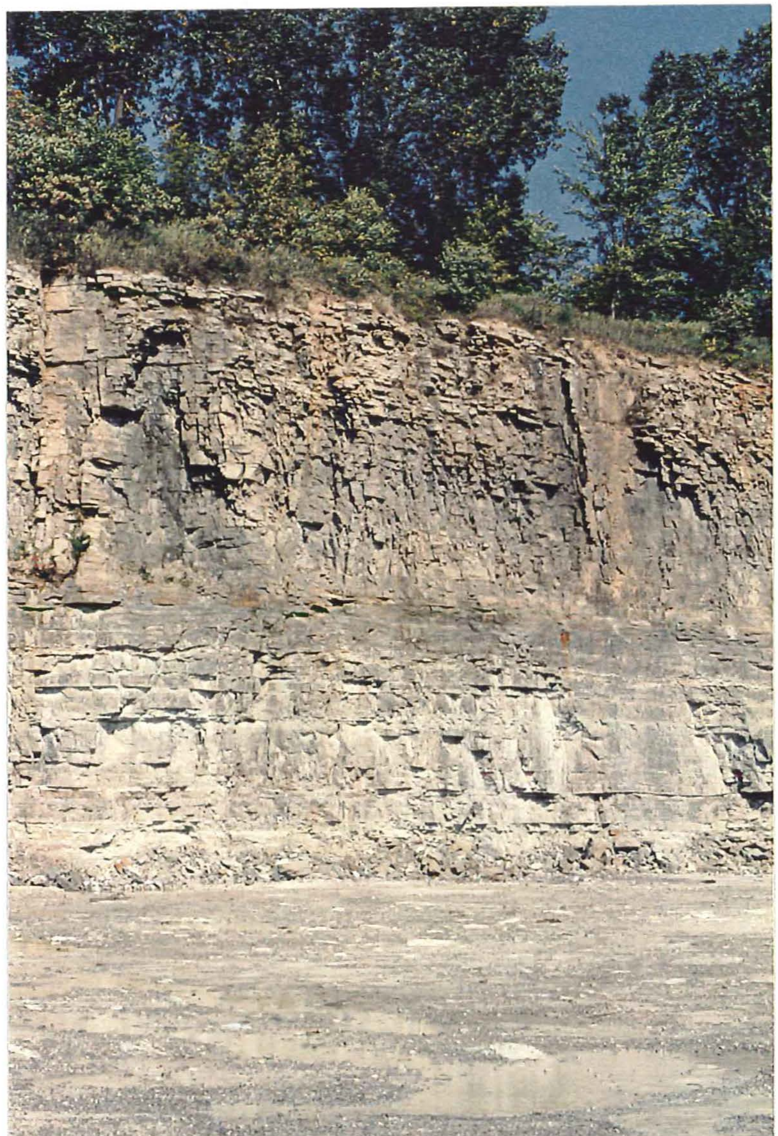

Figure 10. Platteville dolomite directly overlying dolomite of Prairie du Chien, Site - NE-21. Contact is along rust stained zone at color change near middle of face. St. Peter Formation is not present but is visible in other areas of the same quarry.

lower part of the Galena Formation (Figure 4). Knowing the stratigraphic position relative to these beds is critical in evaluating the quality of stone potential and estimating reserves at a quarry site. The Platteville Formation is a relatively pure dolostone throughout the region, and the increase in sand content of the lower beds is a minor factor in determining overall suitability.

In northeastern Wisconsin the outcrop area of the Sinnipee Group trends northeast-southwest and the beds dip to the southeast. As a result, quarries located near the western outcrop edge produce from the Platteville Formation, and locally where the St. Peter sandstone is absent, from both the Platteville and the underlying Prairie Du Chein carbonates. Quarries located along the eastern edge of the outcrop belt, near the shore of Green Bay or along the fox River, produce from the Galena Formation.

The stratigraphic position, historic soundness test ranges, and freeze-thaw results for 22 quarries examined in this study are summarized in Table 1. Both the historic record of soundness and the freeze-thaw values determined in this study can be explained by varying shale content related to stratigraphic position within the Sinnipee section. Quarries that produce exclusively from the Platteville, or Platteville plus underlying Prairie du Chein carbonates such as sites NE-6, NE-16, NE-20, and NE-21, (Figure13) generally have a history of good soundness tests. Sites NE-2, NE-5, and NE-14 are exceptions. NE-2 and NE-5 are far to the north and produce from the bottom Platteville beds, which are locally sandy and shaly. NE-14 produces from the base of the Platteville and the underlying Prairie du Chein, but sandy and shaly material is present along the contact between these formations, which may account for the range in values.

Quarries in the upper shale-free part of the Galena Formation (C-5 unit) such as NE-12 generally test well and have historically produced quality aggregate. The decrease in shale content of the Galena to the south is reflected in good soundness values at NE-18 and NE-22. In the area of Oshkosh, significant shale is present only in the Ion beds at the base of the Galena Formation (Figure 14).

The widest ranges of soundness values, with high values exceeding 10 and ranging to nearly 35, are associated with quarries that produce from the lower shaly beds of the Galena. The low values from these quarries probably represent material from the underlying upper Platteville or from less shaly beds within the lower Galena. In these cases, where the producing face contains both clean and shaly units, the historic variability in soundness values is a function of what interval was being quarried at the time of sampling.

**Table 2. Selected Quarries in Northeast region.** Geology based on field examination and sections described by Simo, et al (1996).

| SITE # | QUARRY NAME | OPERATOR | COUNTY | LOCATION | SOUNDNESS RANGE | FREEZE THAW | STRATIGRAPHIC POSITION |
|---|---|---|---|---|---|---|---|
| NE-1 | Biehl | --- | Marinette | SE NW 5 31N 22E | 5.5 | 23.3 | Lower Platteville |
| NE-2 | Porterfield | Foster | Marinette | SE SE 19 31N 22E | 2.0 - 27* | 1.5 | Lower Platteville |
| NE-3 | Snyder | Foster | Oconto | SE NE 34 27N 21E | 5.8 - 34.6* | 23.8 | Galena $C_3$, $C_4$ |
| NE-4 | Grosse | Foster | Oconto | NW NE 30 26N 21E | 2.2 - 30.1* | --- | Galena $C_3$ - $C_5$ |
| NE-5 | Duame | Duame | Oconto | E 31 29N 21 E | 4.7 - 14.9* | --- | Lower Platteville $B_1$ |
| NE-6 | Montevideo | Foster | Oconto | SW NE 3 26N 20E | 1.9 - 2.8 | --- | Lower Platteville $B_1$-$B_3$ |
| NE-7 | Chase | N.E. Asphalt | Oconto | NE 17 26N 19E | 0.4 | 2.8 | Flooded (Galena?) |
| NE-8 | Duck Creek | Daanen & Janssen | Brown | Sw Sw 10 24N 20E | 1.3 - 31.9* | 22.8 | Galena ($C_1$-$C_4$ Sample) |
| NE-9 | Ebben | Daanen & Janssen | Brown | SW NE 27 23N 19E | .3 - 31.6* | --- | $B_2$ Platteville - $C_5$ Gal. |
| NE-10 | Ulmen | N.E. Asphalt | Brown | SW SW 30 23N 20E | 1.3 - 34.6* | 11.9 | Galena $C_1$ - $C_6$ |
| NE-11 | McKeefry | McKeefry | Brown | SW SW 17 25N 19E | 6.8 - 20.8* | 3.4 | $B_1$ - $C_3$, (Platt., Sample) |
| NE-12 | Kaukauna | Murphy | Outagamie | SW SW 18 21N 19E | 2.5 | --- | $C_5$ Galena |
| NE-13 | Landwehr | Murphy | Outagamie | NW NE 33 22N 17E | .2 - 26.1 | 1.1 | $B_2$ - $C_5$ (Platt. Sample) |
| NE-14 | Skunk Hill | Murphy | Outagamie | SW 16 22N 18E | .7 - 32.8 | 2.5 | $B_1$ - $B_3$ / P.d.u. C. |
| NE-15 | Gersek | Gersek | Outagamie | SW SE 25 24N 18E | 11.5 - 30 | --- | $C_3$ - $C_4$ Galena |
| NE-16 | Freedom | N.E. Asphalt | Outagamie | NE 10 22N 18E | .2 - 1.6 | --- | $B_2$ - $B_4$ Platt. |
| NE-17 | Grundy | Michels | Winnebago | NE NE 33 19N 16E | .3 - 20.1 | 7.8 | $B_4$ - $C_2$ Gal./Platt. |
| NE-18 | Oshkosh | Vulcan | Winnebago | NE 27 18N 16E | 1.1 - 7.9 | --- | $B_4$ - $C_5$ Gal./Platt. |
| NE-19 | Jorgenson | Michels | Winnebago | 5 20N 17E | .6 - 2.2 | 4.8 | $B_1$ - $B_3$ / P.d.u. C. |
| NE-20 | Doro | Michels | Winnebago | SE SW 36 22N 15E | 2.7 - 4.4 | 7.1 | Platteville |
| NE-21 | Ben Carrie | Michels | Winnebago | NE SW 29 20N 17E | .7 - 5.9 | --- | $B_1$ - $B_4$ / P.d.u. C. |
| NE-22 | Hughes | Michesl | Winnebago | SE SW 29 17N 16E | 2.0 - 3.4 | 5.8 | Galena (undif.) |

*(Historic range of soundness values provided by Paul Baeten WIS DOT Dist 3)

Southeast Region

In the southeast region, the Ion beds at the base of the Galena Formation and the Mifflin Member of the Platteville Formation are sufficiently shaly to cause soundness problems. The Ion is characterized by thin shale beds and partings, and the distinctive gray to greenish gray color (Fig 13). The upper beds of the

Figure 11. Lower Galena (Ion) overlying Platteville in quarry north of Watertown (SE-4), in southern Dodge County. Dark band in middle of face is Ion. Upper light beds are lower Dunleith, lower light beds are Platteville. Shale is abundant only in lower half of gray interval (Buckhorn Member).

Platteville are commonly dense light brown to buff colored, fine-grained dolostone, typically containing burrows filled with dark gray sediment which give the rock a spotted appearance on fresh surfaces. In the middle part of the Platteville Formation, the thin, nodular-bedded dolomites with shaly interbeds typical of the Mifflin Member can be recognized to the south of the Wapun area, and Bay area).

**Table 3. Selected Sinnipee Quarries, southeast region**. Geology based on field examination and sections described by Choi (1995)

| SITE # | QUARRY NAME | OPERATOR | COUNTY | LOCATION | SOUNDNESS RANGE | FREEZE THAW | STRATIGRAPHIC POSITION |
|---|---|---|---|---|---|---|---|
| SE-1 | Waupun 4X | Michels | Fond du Lac | SE NW 36 14N 14E | .8 - 3.2 | --- | Galena (Dunlieth) |
| SE-2 | Ripon | Ripon Lime | Fond du Lac | SW NW 20 16N 14E | 1.9 - 4.3 | --- | L. Platteville |
| SE-3 | Budde | Linck | Dodge | NW SE 10 11N 14E | 2.1 - 11.9 | 5.5 - 11.9 | L. Platt. GD/Miff./Pec. |
| SE-4 | Koplin | Linck | Dodge | SE SE 17 9N 15E | 2.0 - 14.8 | 9.6 - 29.0 | Gal. Dun/Ion/Nac./GD |
| SE-5 | Brookside | Hausz Bros. | Jefferson | NW SE 23 7N 14E | 2.8 - 4.2 | 5.6 | Platt. (above Miff) |
| SE-6 | Hausz | Hausz Bros. | Jefferson | NE SE 10 5N 14E | 3.7 - 31.5 | 5.1 - 43 | Dun./Ion/Dec./Nach. |
| SE-7 | Stark | Amon | Jefferson | SE SE 35 8N 13E | 3.4 - 16.7 | 5.1 - 35.7 | Platt. Miff/Pec./Stp. |
| SE-8 | Bjoin | Bjoin | Rock | SE SW 36 3N 11E | 1.5 - 15.4 | 1.1 - 19.6 | Dun/Ion/Dec./Platt. |
| SE-9 | Larson | Frank Bros. | Rock | SW SW 15 3N 10E | 5.4 - 12.3 | 4.0 - 16.8 | Platt. Miff/Pec. |
| SE-10 | Van Allen | Kennedy | Rock | SW SE 16 2N 13E | 1.6 | 2.0 | Galena (Dunlieth) |
| SE-11 | Frank | Frank Bros. | Rock | SE NW 2 3N 13E | 2.0 - 3.7 | --- | Galena (undiff.) |

become increasingly important as they thicken and become more shaly to the south. The upper part of the Galena Formation (Dunlieth Member) is relatively pure dolomite which begins to develop the pitted weathering surface typical of southern and southwestern Wisconsin from southern Dodge County into Jefferson and Rock Counties.

Table 2 lists the geologic formations and soundness test results for 11 Sinnipee quarries in the southeast region. SE-1 produces from the Galena Formation above the Ion, and the low soundness values reflect the southward decrease in shale content above the Ion already evident in the Oshkosh area. SE-2 produces from the lower Platteville (Pecatonica) in the Ripon area where the Mifflin Member is not present. The low values are typical for the Pecatonica Member in this region. Locations SE-3 through SE-11 were sampled for freeze thaw testing to evaluate performance of specific units. Upper Platteville (SE-5) and Galena above the Ion (SE-10) produced generally acceptable values, reflecting the absence of shale or shaly dolomite in these intervals. The remainder of locations for which a range of freeze-thaw values is given represent quarries in which both pure dolostone and shaly units were present. The low numbers represent the pure carbonate beds, the high values are from samples particularly chosen to test the Ion interval, the Decorah Formation, or Mifflin Member when present.

In the southern part of the southeast region, and to the west across the Wisconsin Arch into Rock county, establishing position within the Sinnipee section can be more difficult because of subtle changes in the character and appearance of the rocks. As a rule, the Ion becomes cleaner with less obvious shale and a less well developed gray color. This is balanced by the tendency of overlying Dunleith beds to develop the characteristic pitted weathering pattern, which makes identifying the lower limit of good Galena material easier. Figure 14 illustrates the Galena Platteville transition at Fort Atkinson (SE-6). A marked difference can be seen in how shaly the Ion-Decorah interval is and how well it stands out on a quarry face when compared to Figure 13 (Watertown area) and Figure 10 (Green

Figure 12. West face of Hausz Brothers quarry (SE-6) Fort Atkinson. Upper third of face is Dunleith Member with pitted weathering. Middle third is Ion plus 3 feet of Decorah. Lower light colored beds are Nachusa Member.

Southwest region

In southwest Wisconsin the intervals within the Sinnipee Group that contain sufficient shale or shaly dolostone to cause potential soundness problems are the basal Galena (Ion), the Decorah formation, and the Mifflin and Grand Detour Members of the Platteville Formation. The Ion/Decorah interval is easily distinguished in outcrop (Figure 11) by gray to greenish gray color, thin beds with shale partings, and thin beds of green to brown shale. This interval contrasts markedly with the overlying Dunlieth Member of the Galena Formation, which is typically buff colored and weathers to the characteristic pitted surface texture. The Dunleith Member immediately above the Ion interval also typically contains discontinuous beds of white nodular chert.

The shaly dolostone units of the Platteville Formation commonly weather to a gray color, while the purer more massive units weather to a light buff color. On weathered outcrops, road cuts, and older quarry faces, the shaly material commonly weathers away to emphasize the thin, irregular and wavy surfaced carbonate beds. This distinctive weathering style (Figure 15) is a good indicator of stratigraphic units to be avoided, or at least sampled and tested carefully, as they are likely to perform poorly in soundness and freeze-thaw tests. All examples of pavement pitting in southern and southwestern Wisconsin that were examined in this study can be attributed to use of material from the Mifflin Member, which typically develops this weathering pattern after only a relatively few years of exposure.

Figure 13. Weathered Mifflin Member in road cut north of Montfort, Grant County. Shaly interbeds (see Figure 4) weather preferentially to emphasize thin nodular carbonate beds. lens cap for scale

Table 3 summarizes test results and stratigraphic position of 15 quarries examined and sampled in southwestern Wisconsin. Quarries with consistently good soundness and freeze-thaw numbers such as sites 4, 6, 7, 13, 14, and 15,

**Table 4.** **Selected Sinnipee Quarries, southwest region**. Geology based on field examination and sections described by William and Kolata (1978).

| SITE # | QUARRY NAME | OPERATOR | COUNTY | LOCATION | SOUNDNESS RANGE | FREEZE THAW | STRATIGRAPHIC POSITON |
|---|---|---|---|---|---|---|---|
| SW-1 | Yanggen | Payne & Dolan | Dane | SW NE 7 6N 9E | 2.8 - 6.2 | 2.6 - 19.8 | Platt. G.D./Miff./Pec. |
| SW-2 | Kapec | Wingra | Dane | SW NW 7 6N 9E | 2.7 - 11.6 | 9.1 - 17.0 | Platt., Miff./Pec. |
| SW-3 | Hanley | Wingra | Dane | NW NE 34 9N 11E | 4.1 - 13.5 | 5.0 - 24.1 | Platt., G.D./Miff./Pec. |
| SW-4 | Kelley | --- | Dane | SW SE 14 6N 7E | 2.2 - 19.5 | 2.1 | Galena (Lower Dunleith) |
| SW-5 | Krueger | --- | Dane | SW SW 32 5N 8E | 4.4 | 15.3 | L. Platt., G.D./Miff./Pec. |
| SW-6 | Achenbach | --- | Crawford | NW 25 8N 5W | 7.2 | 10.8 | Galena |
| SW-7 | Teynor | --- | Crawford | SW 21 7N 6W | 3.4 | 5.0 | Galena |
| SW-8 | Croft | Croft | Grant | NW SE 24 6N 3W | 3.9 - 31 | 4.2 - 27.4 | Gal. Dunlieth/Ion/Dec. |
| SW-9 | Lemanski | --- | Grant | SW NE 32 6N 1W | 22.4 - 56.5 | 12 - 26 | Dec./QM/G.D./Miff. |
| SW-10 | Wolfey | Faith | Green | NW NW 35 3N 7E | 2.9 - 14.6 | 12.7 - 35.8 | L. Platt. G.D./Miff./Pec. |
| SW-11 | Schmidt | --- | Green | NE SE 9 1N 8E | 8.7 | 15.8 | G.D./Miff./Pec. |
| SW-12 | Petersen | --- | Iowa | NW SW 28 7N 3E | 4.5 - 8.9 | 19.6 - 34.6 | G.D./Miff./Pec. |
| SW-13 | Swiggum | --- | Iowa | NE NE 30 6N 3E | 2.1 | 1.2 | Upper Dunleith (Gal.) |
| SW-14 | Kurth/Miller | --- | Iowa | NW NW 31 6N 3E | 1.9 | 2.8 | Galena |
| SW-15 | Burgess | --- | Iowa | SE SW 15 5N 3E | 1.3 | 2.0 | Galena |

produce from the Dunleith and Wise Lake Members of the Galena Formation. The high value from location 4 probably represents incorporation of weathered material during crushing, which can always cause problems. Quarries that produce from intervals that include both pure carbonate and shaly members of the Platteville Formation or include the Decorah and Ion beds show a wide range of test values, depending on proportions of clean and shaly material in the working face at the time the aggregate was produced and tested.

Samples taken for freeze-thaw testing included both pure and shaly intervals for comparison. In cases where both tests were performed the freeze-thaw values tend to be higher than sodium sulfate soundness values suggesting that the freeze/thaw method is more sensitive to lithologies that will break down under normal weathering conditions.

Figure 14. Galena-Platteville transition in Quarry face, location SE-8 west of Janesville, Rock County. Upper third of face is Galena, with gray beds representing the Ion. Light buff unit in middle third is Nachusa Member, lower third with many gray beds is Grand Detour Member, which contains some nodular shaly beds. Mifflin Member is exposed in sump behind rock debris pile in front of car.

In the eastern part of the region, near the axis of the Wisconsin Arch, stratigraphic position within the Platteville Formation may be difficult to determine because as in the southeast, differences in appearance become more subtle (Figure 17). Pitted weathering easily identifies the Dunleith and higher Galena section, but less shale and less pronounced gray coloration can make the Decorah/Ion interval less obvious than to the northeast. The nodular bedding identifies the Mifflin Member, but can be present in the Grand Detour which can lead to confusion in small quarry faces or isolated outcrops. When in doubt, fossil assemblages listed by Willman and Kolata (1978) may be useful. It is also helpful in this and other areas to establish elevation in relation to the base of the Dunleith or top of the underlying Glenwood/St. Peter from outcrops and roadcuts located using a 1:24,000 scale topographic map.

## CONCLUSIONS AND RECOMMENDATIONS

Examples of poor soundness numbers and aggregate failure by premature weathering (pavement pitting) can in nearly all cases be related back to sources within the more shaly beds of the Sinnipee Group This relationship is further confirmed by the results of freeze-thaw testing on samples of selected shaly and non-shaly units sampled throughout the Sinnipee outcrop belt. Comparison of results of the two testing methods suggests that the alcohol-water freeze-thaw method may be a more sensitive and therefore a more reliable test to eliminate these problem materials.

Throughout the outcrop area of the Sinnipee Group in Wisconsin, it is essential to know the stratigraphic position of a quarry or potential quarry site to predict the quality and reserves of aggregate available. If the stratigraphic position of the site is known to the formation, and preferably the member level, it is possible to avoid the shaly units that are known to cause soundness problems. It is also possible to predict whether further deepening of an existing quarry will encounter shaly material.

In northeastern Wisconsin, the interval of most concern is the lower part of the Galena Formation. The greenish-gray shale and shaly dolostones of the Ion interval (C-1,C-2) should be avoided if specifications require low soundness loss, and resistance to weathering. Locally the overlying C-3 and C-4 interval, where relatively pure carbonate beds are separated by thin shale beds, may produce useable material if the rock is crushed and screened to remove the shale as fines.

The Platteville formation in the northeast region is relatively free from clay and shale, and should be considered as a good aggregate resource. Because of the southeastward regional dip of the bedding, quarries near the western edge of the Sinnipee outcrop belt are likely to be within the Platteville Formation. It is a good idea for operators to drill the floor of Platteville quarries in northeastern Wisconsin to test for presence and thickness of underlying St. Peter Sandstone. If the St. Peter is thin or absent, it may be desirable to develop the underlying Prairie du Chien carbonates at depth.

Quarries located in the eastern portion of the Sinnipee outcrop belt generally produce good quality aggregate from the cleaner upper beds (C-5) of the Galena Formation, At these sites it is again recommended that operators drill the quarry floor, because further development to greater depth will eventually encounter the shaly beds in the lower part of the Galena.

Quarries in the middle of the outcrop belt are most likely to encounter the shaly beds of the lower Galena. In this area, it is particularly important to establish relative position in the stratigraphic section. If the site is located near the Galena-Platteville contact, it is possible that after removal of several feet of shaly material, a significant thickness of good Platteville material can be quarried at depth. If a significant thickness of shaly material is present, it may be best to relocate.

In evaluating aggregate sources in northeastern Wisconsin, it is important to look for the distinctive gray-green color and presence of shale beds indicative of the lower Galena. Presence of these should indicate the need for careful evaluation and testing if high-quality aggregate is required. When prospecting for new quarry sites, it is essential to know stratigraphic position relative to the shaly intervals in order to be certain of sufficient reserves of quality aggregate to warrant further development.

In southeast Wisconsin the lower 10 to 20 feet of the Galena Formation (Ion including the Decorah in south), and the Mifflin Member of the Platteville Formation will almost certainly be sufficiently shaly to cause soundness problems. The shale content of the lower Galena Formation decreases significantly to the south of Lake Winnebago, but remains locally significant throughout southeast Wisconsin. If this interval is present in a quarry face, produced material should be thoroughly tested, preferably by the freeze-thaw method. The Mifflin Member should always be avoided for any use requiring high soundness aggregate. In the southern part of the area, the Grand Detour Member immediately above the Mifflin should be carefully examined for the presence of nodular shaly beds, which can be present locally and will yield poor soundness values.

In southwestern Wisconsin, the Ion and the underlying Decorah Formation should be avoided if possible. In the eastern part of the region, these units may appear clean and shale free, but should not be considered an acceptable aggregate resource without thorough testing. In much of the southwest region, the Galena Formation is the unit at the surface and is the primary aggregate source. The Galena above the Ion is not known to have any history of soundness problems, and problems are only likely to occur in quarries developed near the base of the Dunlieth Member where further deepening will encounter the Decorah-Ion beds. The only potential problem with upper Galena material is local deep weathering which may cause poor wear values.

In southwestern Wisconsin, the Platteville Formation is a less important source of aggregate, but can be used if care is taken to avoid the Mifflin Member and shaly nodular beds in the overlying Grand Detour Member. Because the Nachusa and Quimbys Mill Members thin to the west, the Mifflin and Grand Detour Members constitute a significant thickness of the Platteville Formation in the southwestern area of Wisconsin. The Pecatonica Member at the base of the

Platteville contains almost no shale, and it is generally a good source of aggregate throughout southern Wisconsin.

The Sinnipee Group is an important source of aggregate throughout its area of outcrop in Wisconsin. The presence of shaly beds and regional variability of shale content make the Sinnipee more difficult to prospect for high quality aggregate sources than the underlying Prairie du Chien Group or the younger Silurian (Niagara) carbonates, both of which are less shaly and have a better history of soundness. It is, however, possible to develop quarries that produce high quality material from the Sinnipee Group by making use of geologic information and careful testing when evaluating existing quarries of exploring for new sources.

REFERENCES

Agnew, A.F., Heyl, A.V., Jr., and Lyons, J., 1956, Stratigraphy of Middle Ordovician rocks in the zinc-lead district of Wisconsin, Illinois, and Iowa: U.S. Geological Survey Professional Paper 274-K, p. 251-312.

Choi, Y.S., 1995, Stratigraphy and Sedimentology of the Middle Ordovician Sinnipee Group, Eastern Wisconsin: UW-Madison, Master's Thesis, 229p

Choi, Y.S., 1998, Sequence stratigraphy and sedimentology of the Middle to Upper Ordovician Ancell and Sinnipee Groups, Wisconsin, UW-Madison Ph.D. thesis, 284.

Delgado, D.J., 1983, Ordovician Galena Group of the Upper Mississippi Valley - Deposition, diagenesis, and paleoecology: Guidebook for the 13th Annual Field Conf., SEPM Great Lakes Section, 132 p.

Heyl, A.V., Jr., Agnew, A.F., Lyons, E.J., and Behre, C.H., Jr., The geology of the Upper Mississippi Valley Zinc-Lead District: U.S. Geological Survey Professional Paper 309, 310 p.

LoDuca, S.T., 1986, Stratigraphy of the Middle Ordovician Sinnipee Group in northeastern Wisconsin: UW-Milwaukee Masters Thesis, 52 p.

Mudrey, M.G. Jr., Brown, B.A., and Greenberg, J.K., 1982, Bedrock Geologic Map of Wisconsin: Wisconsin Geological and Natural History Survey, Scale, 1:1,000,000.

Ostrom, M.E., 1967, Paleozoic stratigraphic nomenclature for Wisconsin: Wisconsin Geological and Natural History Survey Information Circular No.8.

Simo, J.A., Choi, Y.S., Freiberg, P.G., Byers, C.W., Dott, R.H., Jr., and Saylor, B.Z., 1997, Sedimentology, Sequence Stratigraphy, and Paleoceanography of the Middle and Upper Ordovician of Eastern Wisconsin: in Mudrey, M.G., Jr., ed., Guide to Field Trips in Wisconsin and adjacent areas of Minnesota, 31st Annual Meeting, Northcentral Section, Geological Society of America, Madison WI, p. 95-114.

Simo, J.A., Freiberg, P.G., and Freiberg, K.S., 1996, Geologic constraints on arsenic in groundwater with applications to groundwater modeling, UW-Madison, Water Resources Center, Groundwater Research Report WRC Grr 96-01, 60 p.

Willman, H.B. and Kolata, D.R., 1978, The Platteville and Galena Groups in northern Illinois: Illinois State Geological Survey Circular 502, 75 p.

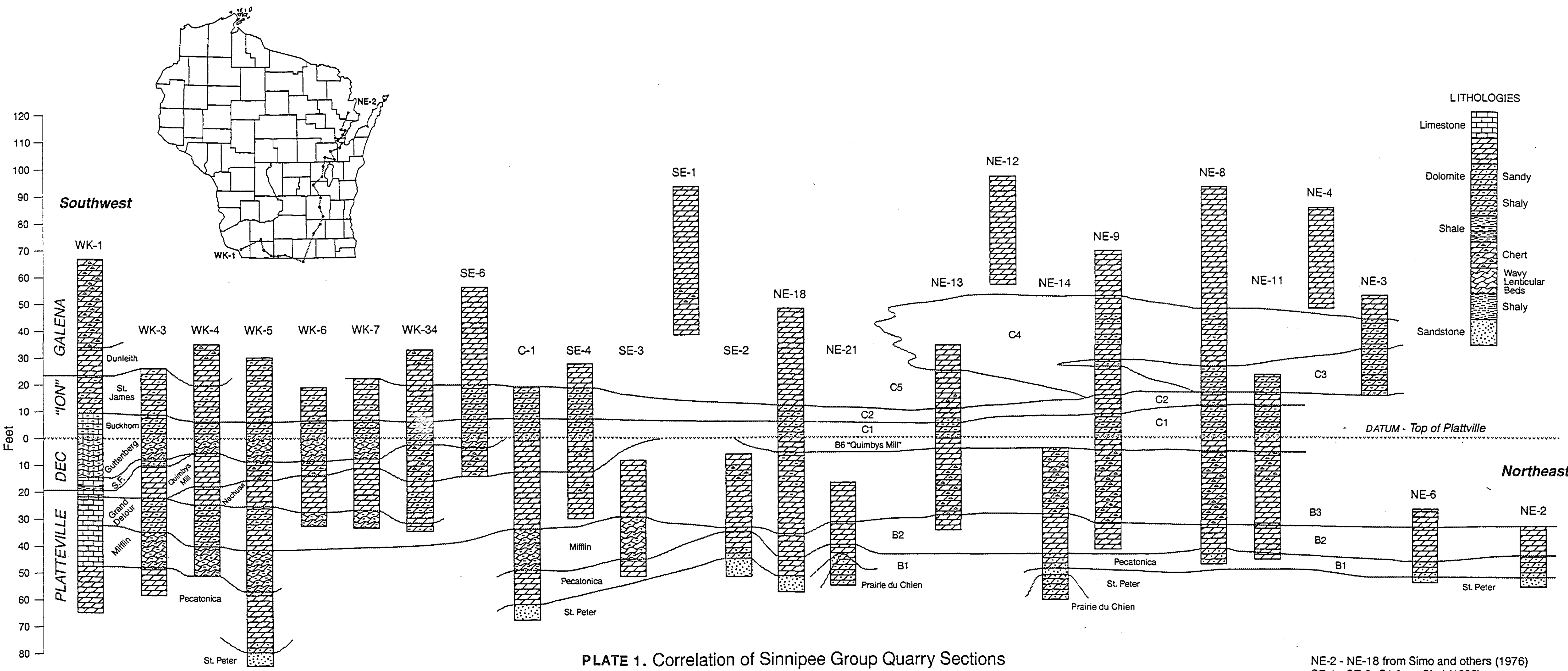


**PLATE 1.** Correlation of Sinnipee Group Quarry Sections

NE-2 - NE-18 from Simo and others (1976)
SE-1 - SE-6, C1 from Choi (1998)
WK-1 - WK-35 from Willman and Kolata (1978)