MINNESOTA GEOLOGICAL SURVEY

MATT S. WALTON, *Director*

CEDAR VALLEY FORMATION (DEVONIAN) OF MINNESOTA AND NORTHERN IOWA

John H. Mossler

Report of Investigations 18

UNIVERSITY OF MINNESOTA

Saint Paul · 1978

ERRATA

CEDAR VALLEY FORMATION (DEVONIAN) OF MINNESOTA AND NORTHERN IOWA

CONTENTS

ILLUSTRATIONS

TABLES

CEDAR VALLEY FORMATION (DEVONIAN) OF MINNESOTA AND NORTHERN IOWA

by

John H. Mossler

ABSTRACT

The Middle to (?)Upper Devonian Cedar Valley Formation of southern Minnesota and northern Iowa is divisible into three members--the basal Solon Member, medial Rapid Member, and upper Coralville Member. The Solon Member is approximately 70 feet (21 m) thick in Minnesota, where it is divided into three facies--a basal and upper facies composed of fossiliferous dolostone, and a middle facies of dolomitic fossiliferous calcilutite that apparently thins to the south and is absent in northern Iowa. The overlying Rapid Member is composed of argillaceous dolostone as much as 70 feet (21 m) thick, and is divided into two facies. The uppermost Coralville Member is at least 110 feet (33.5 m) thick in Minnesota and adjacent northern Iowa, and is subdivided into six facies; the basal facies is fossiliferous dolostone, the four succeeding facies are composed of sparsely fossiliferous dolostone and pelletal calcilutite, and the top facies contains a stromatoporoid biostrome.

The Solon Member represents transgression of marine water across the region and most of its carbonate rocks are interpreted to have been deposited above wave base in shallow marine water. The Rapid Member represents the maximum transgression of marine waters, and its carbonate rocks are interpreted to have been deposited in deeper water, below wave base. The basal fossiliferous dolostone facies of the Coralville Member is interpreted to have been deposited above wave base in shallow marine water, like the Solon dolostones, and it marks the beginning of regression of marine waters from the area. Succeeding facies of the Coralville are interpreted to be tidal flat deposits and associated near-shore lagoonal deposits.

The top four facies of the Coralville Member in southern Minnesota and northern Iowa are absent in east-central Iowa, where this member is less than half as thick as it is in the northern area. It is not known whether this is the result of non-deposition or penecontemporaneous or postdepositional erosion.

Intensive dolomitization of the Cedar Valley Formation in Minnesota and northern Iowa has obliterated much of the fossil material and obscured rock fabrics and textures. Silicification is minor; there are a few chert nodules in the Rapid Member.

INTRODUCTION

The Devonian Cedar Valley Formation extends throughout much of the north-central part of the United States. Regional correlations of the formation and its areal distribution are discussed by Collinson and others (1967), who considered it to be Middle to Late Devonian in age. The formation is particularly well exposed in east-central Iowa, where it was originally named and defined (McGee, 1891). The present member names (fig. 1) were first applied by Keyes (1931), but were not widely accepted until Stainbrook (1941) used them after having found that other names he had proposed had been pre-empted. Numerous paleontological studies have been made of Cedar Valley fossils, particularly in east-central Iowa, but it is only recently that a sedimentological study based on recent advances in carbonate sedimentary petrology has been made (Kettenbrink, 1973).

The only systematic lithostratigraphic study of the Cedar Valley Formation in Minnesota is an unpublished thesis by Kohls (1961). Published studies predating Kohls' work present outcrop and well sample data in reports on ground water (e.g., Thiel, 1944) or in general reports on Paleozoic rocks of southeastern Minnesota (e.g., Stauffer and Thiel, 1941); none are systematic studies of the formation.

The Cedar Valley Formation was deposited in the Ancestral Forest City basin of Iowa and adjoining states. In Minnesota the formation was deposited in the Hollandale embayment, a lowland that extended into southeastern Minnesota from the northern margin of the basin (Austin, 1970, 1972). The formation crops out in southeastern Minnesota in Fillmore and Mower Counties and is present in the subsurface throughout most of Mower and Freeborn Counties (pl. 1; see also Austin, 1972, p. 471). It has a maximum recorded thickness of 500 feet (152 m) in the basin depocenter in southwestern Iowa (Collinson and others, 1967). In Minnesota, where it has been beveled by post-Devonian to Cretaceous, as well as some more recent erosion, restudy of well cuttings indicates a maximum thickness of about 200 to 250 feet (61 to 76 m) (pl. 1).

Throughout most of the Ancestral Forest City basin, the Cedar Valley overlies the Middle Devonian Wapsipinicon Formation. However, along the margins of the basin it overlaps the Wapsipinicon and overlies still older formations. In Minnesota it overlies the Ordovician Maquoketa Formation.

The Upper Devonian Shell Rock Formation, which unconformably overlies the Cedar Valley in much of north-central Iowa, is absent in Minnesota. Original descriptions of the Shell Rock Formation by Belanski (1927) have been modified by Koch (1970), who has shown that the contact between it and the Cedar Valley is stratigraphically higher than originally assumed, and that some beds earlier assigned to the Shell Rock belong in the Cedar Valley. Restudy of the Cedar Valley Formation of southern Minnesota is timely because as originally defined, the Shell Rock

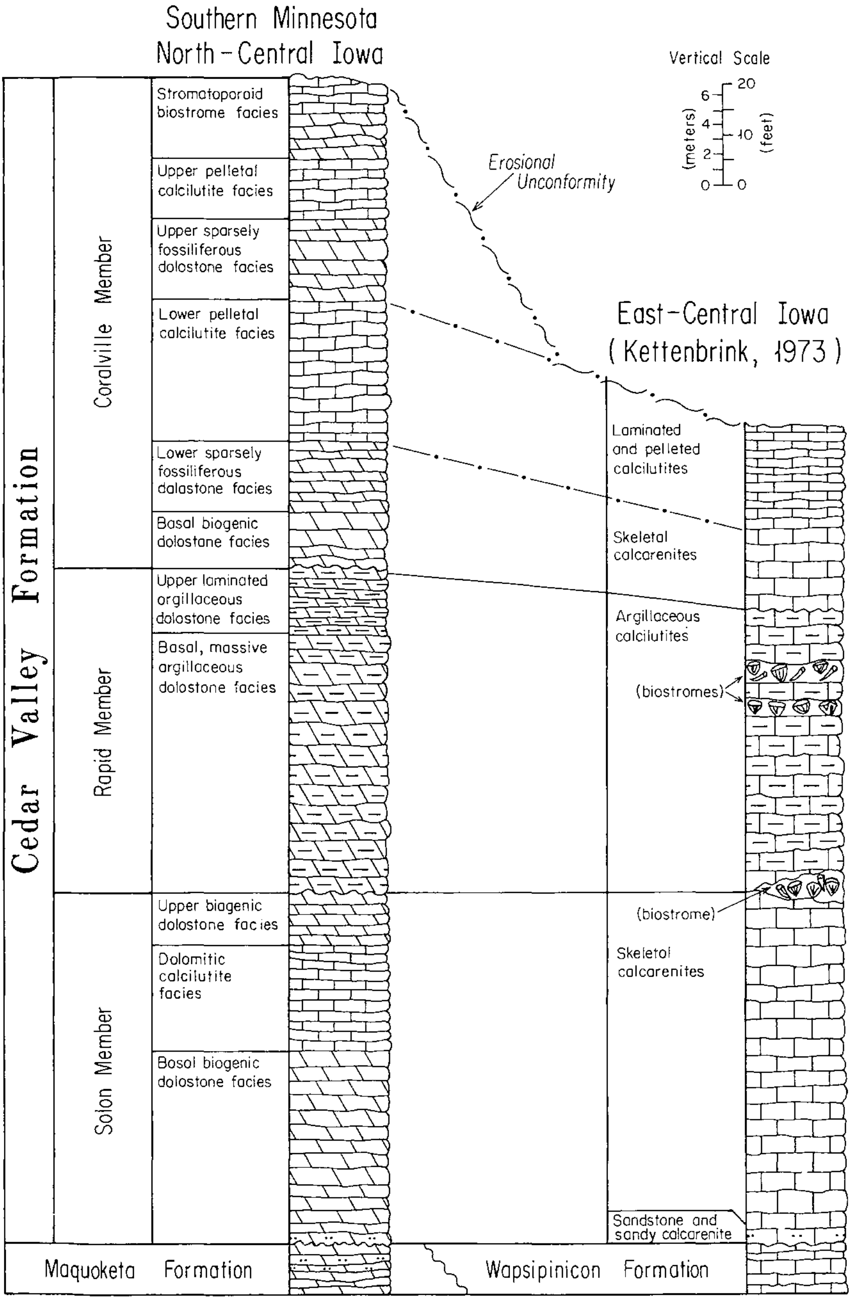


Figure 1 -- Composite stratigraphic sections of Cedar Valley Formation showing lithofacies of Cedar Valley for southern Minnesota-northern Iowa and for east-central Iowa (Kettenbrink, 1973) and correlation of lithofacies between the two areas.

was interpreted to extend into Minnesota (Sloan and Austin, 1966).

Outcrops shown on Figure 2 were measured, described, and sampled in the field in southern Minnesota and adjacent northern Iowa. Laboratory analyses included thin section analysis, binocular microscope examination of hand specimens, insoluble residue analysis, X-ray identification of clay minerals from shale seams, X-ray determination of calcite/dolomite ratios in carbonate rocks, identification of heavy minerals from the coarse fraction of shale seams, and description and correlation of water-well samples.

Grabau's (1904) classification was used to describe limestones seen in outcrops. Dolostones were classified by crystal size (Folk, 1959) because dolomite is secondary and a classification based on hydrologic factors is unsuitable. Folk's (1959) classification was used to describe thin sections of the carbonate rocks.

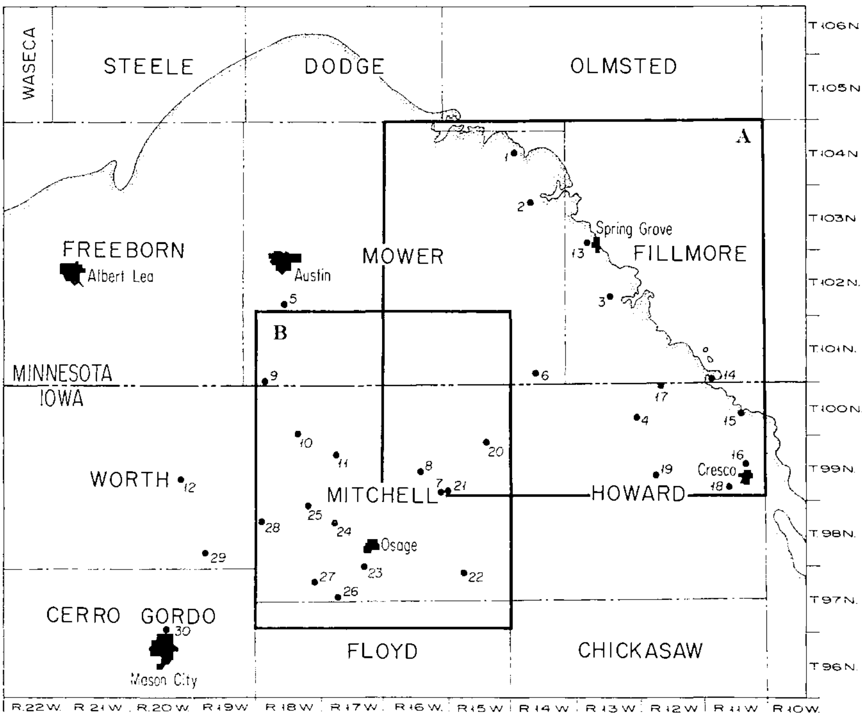


Figure 2 -- Index map showing locations of measured sections. Rectangles lettered A and B show areas covered by Plates 2A and 2B. Shaded line is erosional edge of Cedar Valley Formation. Location descriptions are given in the appendix.

STRATIGRAPHY

In contrast to the outcrop belt in east-central Iowa, which is dominantly limestone, the Cedar Valley Formation of north-central Iowa and southeastern Minnesota has been extensively dolomitized, and much of the fossil material and rock fabric have been obliterated. Nonetheless, most facies described in east-central Iowa (Kettenbrink, 1973) can be traced into the northern outcrop belt.

Solon Member

In Minnesota, the upper and lower parts of the Solon Member consist of thick-bedded, fossiliferous, finely crystalline dolostone separated by a medial zone of medium-bedded, slightly fossiliferous dolomitic calcilutite (pl. 2a). Division of the member into facies is made on the basis of this compositional variation. The Solon Member is about 70 feet (21 m) thick in Minnesota.

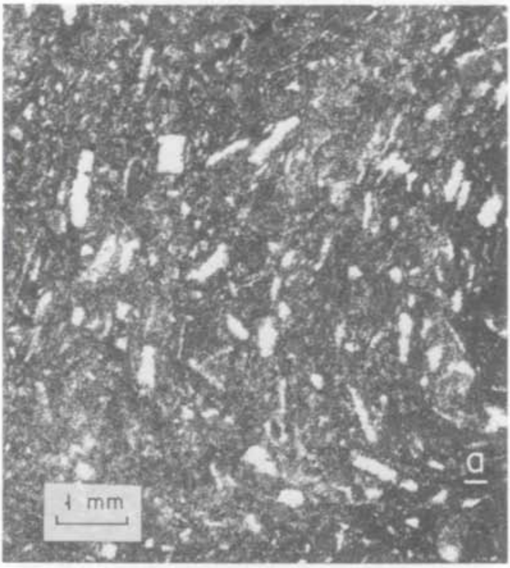
Basal Biogenic Dolostone Facies

The lower biogenic dolostone facies of the Solon Member is approximately 38 to 42 feet (12 to 13 m) thick. It is a thick- to medium-bedded, yellowish-gray (5Y7/2) to grayish-orange (10YR7/4), finely crystalline, fossiliferous dolostone. Recognizable fossil material indicates a normal marine assemblage in which brachiopods, corals and pelmatozoans predominate. Most of this fossil material was disarticulated and finely comminuted prior to deposition. Subsequent leaching of most of these fragments formed abundant moldic (1/8 inch; 3.2 mm diameter) porosity (fig. 3a). Only rare pelmatozoan ossicles were not dissolved. The abundance of moldic porosity indicates that the rock may originally have been a grain-supported rock (calcarenite).

Mean insoluble residue content for individual outcrops studied is low, ranging from 1.3 to 3.4 percent, and variation is also low, supporting the inference that the rock was originally a calcarenite.

Except for rare pelmatozoan ossicles, calcite is secondary, and occurs as coarse spar lining large vugs and fractures, or as large poikilotopic crystals that surround many dolomite rhombs, in a manner reminiscent of sand crystals in detrital (quartz) sandstones.

A 3- to 4-foot (0.9 to 1.2 m) interval of sandy dolomite is extensively developed at the base of the Solon Member in east-central Iowa (Kettenbrink, 1973). No similar zone has been observed in Minnesota, although Kohls (1961) observed scattered carbonate pebbles and minor detrital grains of silt- to very fine-sand-sized quartz and chert in the basal few inches of the Solon Member. Dolostones of the Maquoketa Formation underlying the Solon Member are much sandier (fig. 3b).



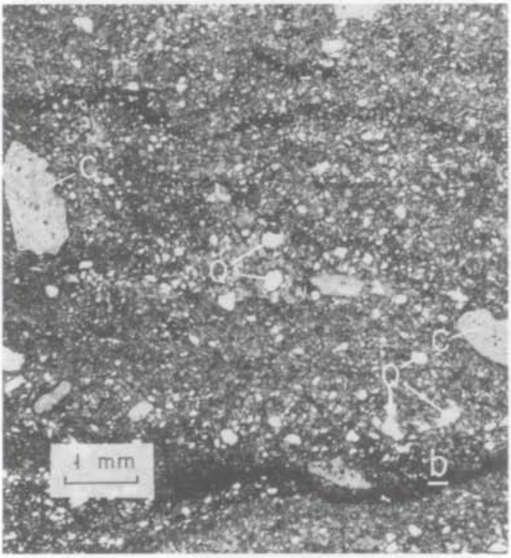


Figure 3a -- Photomicrograph of basal biogenic facies of Solon Member (loc. 1). Voids (white rectilinear areas) are formed by leaching of fossil fragments.

Figure 3b -- Photomicrograph of sandy dolostone of Maquoketa Formation (loc. 1). Dolostone contains abundant grains of chert (C) and quartz (Q).

Kohls (1961) subdivided the basal biogenic dolostone facies into four units on the basis of lithologic features that generally are subtle (e.g., weathering characteristics) or hard to apply in the field (e.g., insoluble residue types). The facies does contain one distinctive zone, 8 to 12 feet (2.4 to 3.7 m) thick, which is characterized by abundant large molds of colonial corals. The best exposure of this zone is at locality 3 (fig. 2; pl. 2a) in Fillmore County. South of locality 3 in northern Iowa, this zone apparently passes into the "rhombohedral calcite zone" (Dorheim and Koch, 1966) that is characterized by large vugs, apparently formed by leaching of colonial coral skeletons and subsequently filled with coarse calcite spar. This coralline zone may be laterally equivalent to profunda zone biostromes found in the Solon limestones of eastern Iowa.

Dolomitic Calcilutite Facies

Directly overlying the biogenic dolostone facies is an interval 21 feet (6.4 m) thick composed of thick-bedded, dolomitic, slightly fossiliferous, light olive-gray (5Y6/1) to grayish-orange (10YR7/4) calcilutite (pl. 2a). Dolomite content ranges from more than 90 percent near both base and top to less than 5 percent in the center of this unit.

The calcilutite of this facies is composed of microspar, which probably represents recrystallized clay-sized carbonate (micrite). Most fossil material is preserved as molds that later filled with calcite spar; these molds, like those in the basal facies, usually are small (1/8 inch; 3.2 mm) and represent comminuted fragments. Secondary calcite also occurs as poikilotopic crystals in intensively dolomitized parts of the facies, and lines the subspherical vugs, 1 to 2 inches (2.5 to 5 cm) in diameter, that characterize this facies. Mean insoluble residue content is uniformly low (tbl. 1), just as it is in the biogenic dolostone facies; it ranges from 0.5 to 3.0 percent (Kohls, 1961).

Distribution of this facies appears to be restricted to the eastern limb of the Hollandale embayment. There is only one outcrop (loc. 2, fig. 2 and pl. 2a) where the entire unit is exposed; however other outcrops may contain its basal dolomitic part. This facies apparently thins toward the south and is replaced by dolostone in north-central Iowa. No equivalent unit is found in east-central Iowa (Kettenbrink, 1973).

Upper Biogenic Dolostone Facies

A thin, 10-foot (3-m) interval of dolostone similar to the basal biogenic dolostone facies overlies the dolomitic calcilutite facies at locality 2 (pl. 2a). The dolostone is unconformably overlain by Pleistocene till, so the exact thickness of the facies is unknown.

The contact of the Solon and Rapid Members is not exposed in the study area in Minnesota. In east-central Iowa where it is

Table 1 -- Insoluble residue content, Cedar Valley Formation outcrops.

Member	Facies	Location number (Keyed to index map)	Mean insoluble residue content (percent)	Ranges of Values	Number of samples analyzed	Thickness (feet)
Coralville	Stromatoporoid biostrome	11	3.7	1.0 - 4.5 (58)e	6	16.3
	Upper pelletal calcilutite	11	3.3	0.8 - 24.6	8	15.6
		27	3.0	0.7 - 7.6 (75)e	10	11.9
	Upper sparsely fossiliferous dolostone	11	10.5	7.9 - 11.2	2	5.5
		26	4.1	1.8 - 24	14	19.1
	Lower pelletal calcilutite	8	5.2	1.3 - 11.8 (23-98)e	15	14.2
		6	5.2	1.1 - 7.5 (40-88)e	16	26.3
		26	3.5	1.7 - 3.7 (68-80)e	8	12.0
		23	3.7	0.6 - 13.5 (27-87)e	21	24.0
	Dolomitic phase	10	3.6	0.9 - 11.2	8	12.9
		25	4.2	1.1 - 5.3	5	15.3
	Lower sparsely fossiliferous dolostone	8	4.0	1.4 - 9.3	8	12.3
		10	13.6	1.4 - 19.7 (34-94)e	9	14.5
		6	5.5	1.7 - 12.9	4	4.7+
		23	8.7	2.4 - 13.7 (28.4)e	8	15.2
	Basal biogenic dolostone	9	2.8	1.3 - 3.5 (12.3)e	11	13.7
		7	2.5	1.7 - 3.3	5	19.7
		8	4.3	2.2 - 5.2	4	10.9
		10	3.5	1.9 - 4.5	3	8.0
Rapid	Upper laminated argillaceous dolostone	9*	13.0	1.5 - 7.7 (81.6)e	4	2.8
		7	12.3	0.8 - 24.1 (37.8 - 80.2)e	15	17.2
		8	8.6	6.6 - 8.9	2	3.8
	Basal massive argillaceous dolostone	17*	8.3	5.1 - 12.8	12	16.3
		4*	8.7	6.1 - 16.0	13	23.2
		5*	17.2	15.0 - 18.7	18	36.8
		18	8.6	7.0 - 13.4	7	31.2
Solon	Basal biogenic dolostone and dolomitic calcilutite	2*	1.7	0.5 - 3.1 (50)e	16	26.9
	Basal biogenic dolostone	1*	2.1	1.0 - 5.1	8	13.9
		13*	2.8	1.5 - 4.7	9	13.7
		15*	3.4	2.3 - 6.4	18	29.4
		3*	1.3	0.8 - 1.8	13	19.8
		16	2.1	1.2 - 4.0	7	32.0

* Analyses from Kohls (1961)
e extreme insoluble residue values from thin shaly beds

exposed, it usually is a disconformity that is easily recognized because overlying Rapid calcilutites have three or four times as much insoluble residue as underlying calcarenites assigned to the Solon (Kettenbrink, 1973).

Rapid Member

The Rapid Member is approximately 65 feet (20 m) thick in Minnesota, and like the underlying Solon Member, it has been intensively dolomitized in Minnesota and northern Iowa. It is characterized by thick-bedded to massive, argillaceous, slightly fossiliferous, light-gray (N-7) to grayish-yellow (5Y8/1) dolostone. The unit is subdivided into two lithofacies (pl. 2a).

Basal Massive Argillaceous Dolostone Facies

The basal facies is thick-bedded to massive, slightly fossiliferous dolostone, 50 to 52 feet (15 to 16 m) thick (fig. 4a). This facies is characterized by high insoluble residue, with mean content for four outcrops ranging from about 8 to 17 percent (tbl. 1). Outcrops of this facies are characterized by numerous subspherical vugs, 1 to 1.5 inches (2.5 to 4 cm) in diameter, that usually are lined with calcite spar. These vugs also characterize the upper part of the Rapid Member in northern Iowa (Dorheim and Koch, 1966).

At one outcrop (loc. 17, fig. 2), rock assigned to this facies is calcilutite. This outcrop, like that of the dolomitic calcilutite facies of the Solon Member, is on the eastern limb of the Hollandale embayment, and this may indicate less pervasive dolomitization in that area.

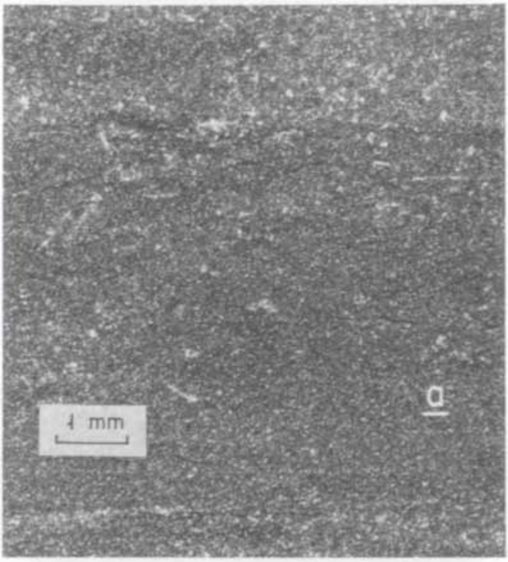
Chert nodules occur along one bedding plane (locs. 4 and 19, pl. 2a) in the southern part of the study area; this is the only significant occurrence of chert observed in the Cedar Valley during the course of this study.

Biostromes similar to those in the upper Rapid Member in east-central Iowa (Zawistowski, 1971; Kettenbrink, 1973) were not observed in the study area.

Upper Laminated Argillaceous Dolostone Facies

The upper 13 feet (4 m) of the Rapid Member of northern Iowa and southern Minnesota is characterized by laminated dolostone with some graded bedding (fig. 4b), thin shale partings, and rare intraclasts, including very minor intraclastic fossiliferous calcilutite.

Kohls (1961) included this interval in the basal part of the overlying Coralville Member. It is included here in the Rapid Member because it has a closer lithologic affiliation with that member and because this makes the Rapid-Coralville contact of the study area consistent with the contact as it is drawn in east-



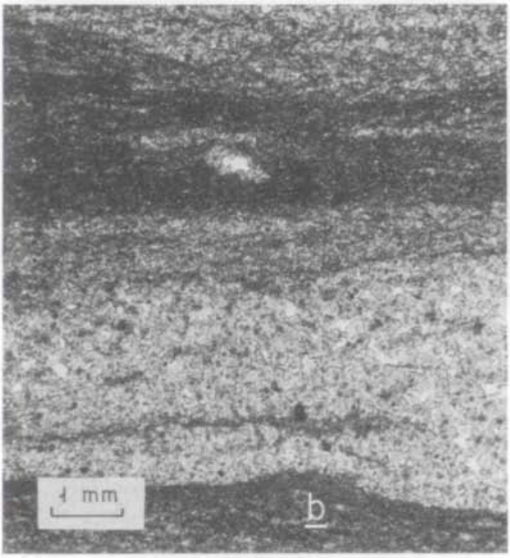


Figure 4a -- Photomicrograph of finely crystalline dolostone of the basal massive argillaceous dolostone facies of the Rapid Member (loc. 5).

Figure 4b -- Photomicrograph of size grading of dolomite crystals in upper laminated argillaceous dolostone facies of the Rapid Member (loc. 7). Apparent graded bedding in unit is due to size variations of constituent dolomite crystals.

central Iowa. In Minnesota the contact between the Rapid and Coralville Members appears to be a disconformity, as it is farther south in Iowa (Kettenbrink, 1973).

Coralville Member

The Coralville is the uppermost member of the Cedar Valley Formation. It is the most varied and thickest member of the formation in northern Iowa and southern Minnesota, attaining a thickness of at least 112 feet (34 m) in the study area, which is twice its thickness in east-central Iowa (fig. 1).

Eroded beds of the Rapid and Coralville Members in east-central Iowa are overlain by Upper Devonian calcarenites of the State Quarry Formation that may either postdate upper Coralville beds of northern Iowa and southern Minnesota, or be channel deposits contemporaneous with them (Kettenbrink, 1973; Collinson and others, 1967). Current paleontological and stratigraphic evidence is ambiguous and it is unclear whether thinning of the Coralville Member in east-central Iowa is due to post-depositional erosion or is penecontemporaneous with deposition of Coralville beds elsewhere.

The Coralville Member is divided into six facies in the study area: a basal biogenic dolostone facies, four succeeding facies composed of sparsely fossiliferous dolostone and pelletal calcilutite and a top facies that contains a stromatoporoid biostrome (fig. 1; pl. 2b).

Basal Biogenic Dolostone Facies

The basal facies of the Coralville Member resembles the basal biogenic dolostone facies of the Solon Member. It is massive to thick-bedded, grayish-orange (10YR7/4) to pale yellowish-brown (10YR6/2), very fine to finely crystalline, biogenic dolostone, and 10.5 to 14.3 feet (3.2 to 4.4 m) thick. Its mean insoluble residue content is low, ranging from 2.5 to 4.3 percent (tbl. 1). Dolomitization is pervasive; X-ray analyses indicate that the carbonate in the rock is nearly always more than 50 percent dolomite by weight. Almost all calcite is secondary and occurs as spar that lines vugs, microfractures and fossil molds, or as large crystals that poikilotopically enclose many dolomite crystals.

The basal biogenic dolostone facies is characterized by numerous elongate (6 to 8 inches; 15 to 20 cm in length) calcite-lined vugs that probably represent leached colonial corals and stromatoporoids. Fossils are almost invariably leached, and some beds contain numerous small pores or vugs caused by leaching of finely comminuted fossil fragments.

This facies is considered to be equivalent to the lower part of the basal skeletal calcarenite facies of the Coralville Member of east-central Iowa (fig. 1; Kettenbrink, 1973).

Lower Sparsely Fossiliferous Dolostone Facies

Overlying the basal biogenic dolostone facies is dolostone that resembles it except for scarcer skeletal grains and thinner bedding. It is a thin- to medium-bedded, yellowish-gray (5Y7/2) to grayish-orange (10YR7/4), fine to medium crystalline, sparsely fossiliferous dolostone that is 13.5 to 14 feet (4 to 4.3 m) thick.

Some beds are laminated, but most are structureless. The rock's mean insoluble residue content is somewhat higher than that in the underlying facies (tbl. 1); dolomite content is high (50 percent or more of total carbonate), and calcite generally is a secondary mineral in vugs and molds.

This facies is considered to be equivalent to the upper part of the basal skeletal calcarenite facies of the Coralville of east-central Iowa (Kettenbrink, 1973).

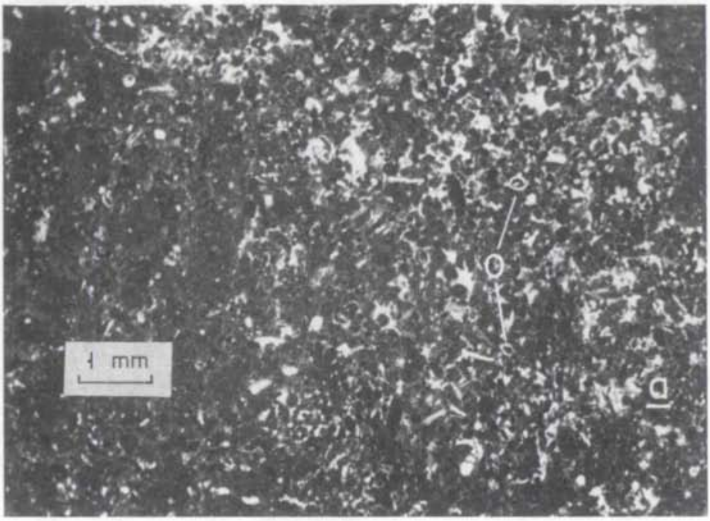
Lower Pelletal Calcilutite Facies

The preceding facies are overlain by a unit of pelletal calcilutite that is 28 to 29 feet (8.5 to 8.8 m) thick (pl. 2b). Although bedding ranges from very thin and platy to massive, most of the rock is very thin to medium bedded. It is composed of light-gray (N-7) to medium light-gray (N-6) to yellowish-gray (5Y7/2), pelletal calcilutite and calcarenite, fossiliferous calcilutite and calcarenite, and finely crystalline dolostone. It contains several thin shale partings, and its mean insoluble residue content, ranges from 3.5 to 5.2 percent. (tbl. 1).

Some limestone beds in this facies change laterally into dolostone. This was observed on a local scale within the confines of individual quarries (locs. 6 and 8, fig. 1 and pl. 2b). On a regional scale, dolomitization is more intense in a westerly direction; outcrops and well cuttings from the Coralville in the western part of the study area are mostly dolostone (pl. 2b).

Limestones of this facies are quite variable. The most abundant are pelmicrites and pelsparites (fig. 5a) or variants of these types that contain subordinate amounts of other grain types--either intraclasts or skeletal grains. Although some pelletal limestones are structureless, most are laminated; some have very even, thin, parallel laminations that are interpreted to be current laminations. Others have less regular laminae with small crinkles and domes that are ascribed to trapping of sediment by algal mats. The fauna contained in all pelletal limestones are dominantly ostracodes and calcispheres (probable algal spores). The pelletal calcilutite beds have generally been slightly dolomitized and contain scattered dolomite rhombs that commonly have been pseudomorphically replaced by calcite.

Minor, generally pelletal, biomicrite (fig. 5b) in this facies contains fossil assemblages dominated by pelmatozoans,



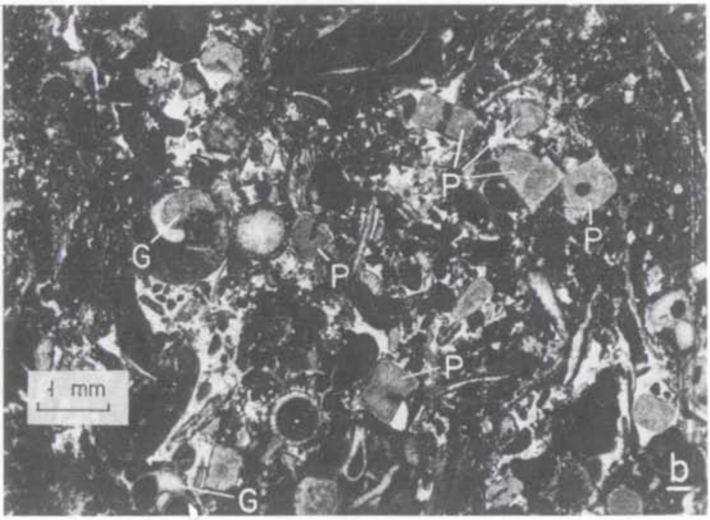


Figure 5a -- Photomicrograph of pelsparite from lower pelletal calcilutite facies, Coralville Member (loc. 23). Rock is sparsely fossiliferous (Ostracode (O)).

Figure 5b -- Photomicrograph of pelletal biomicrite from the lower pelletal calcilutite facies of the Coralville Member (loc. 8). Biomicrite contains a varied fossil assemblage that includes pelmatozoans (P) and gastropods (G).

brachiopods, oncolites (algal biscuits) and ostracodes. Stalked and hemispherical stromatoporoids, calcareous algae and corals are present, but rare. One of the biomicrite units was observed to extend throughout most of the study area (locs. 6, 8, 23 and 25, fig. 2 and pl. 2b), in contrast to individual beds of pelletal and intraclastic limestone which apparently have little lateral continuity.

A third type of limestone in the lower pelletal calcilutite facies consists of intramicrites and intrasparites that occur in very thin zones, invariably less than a foot (30 cm) thick. The intraclasts are flat pebbles of pelletal limestone similar to that in the pelsparites and pelmicrites (fig. 6a).

Some possible desiccation cracks were observed on bedding planes of some limestone beds. However, no well developed polygonal shrinkage cracks or birdseye (lamellar-fenestral) structures were observed in this facies in the study area, although they were reported from equivalent rocks in east-central Iowa (Kettenbrink, 1973). The absence of these features suggests that the sediments were deposited in slightly deeper water in northern Iowa and southern Minnesota.

The lower pelletal calcilutite facies is considered to be equivalent to the laminated and pelletal calcilutite described by Kettenbrink (1973) in the upper part of the Coralville Member of east-central Iowa, i.e., the Straparollus zone of Stainbrook (1941) (fig. 1).

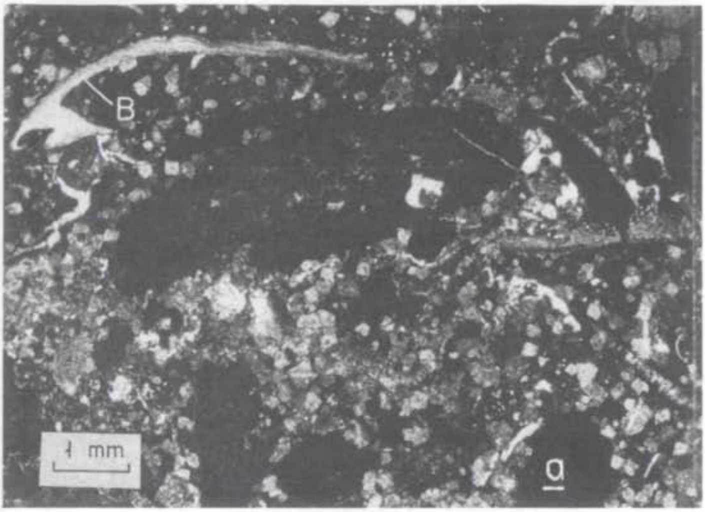
Upper Sparsely Fossiliferous Dolostone Facies

A massive to laminated dolostone, lithologically similar to the dolostone that underlies the lower pelletal calcilutite, also overlies it. This upper sparsely fossiliferous dolostone facies ranges in thickness from 16 to 19 feet (4.9 to 5.8 m). It is composed of yellowish-gray (5Y8/1) to light-brown (5YR5/6), medium- to thick-bedded, generally finely crystalline dolostone.

Most dolostone in this facies is massive and has faint burrow(?) mottles; some has very thin, regular laminations interpreted to be current laminations. Although most of it is sparsely fossiliferous or unfossiliferous, some contains abundant fossils, most notable of which are brachiopods, pelmatozoans and ostracodes. Individual beds of this facies are difficult to trace from one outcrop to the next, which may reflect a highly variable depositional regime. No equivalents to this unit and succeeding facies are present in east-central Iowa.

Upper Pelletal Calcilutite Facies

The upper pelletal calcilutite facies is 9.8 to 15.6 feet (3 to 4.8 m) thick. It is characterized by yellowish-gray (5Y7/2) pelletal calcilutites with variable bedding ranging from thin and platy to massive. Mean insoluble residue content is low, between



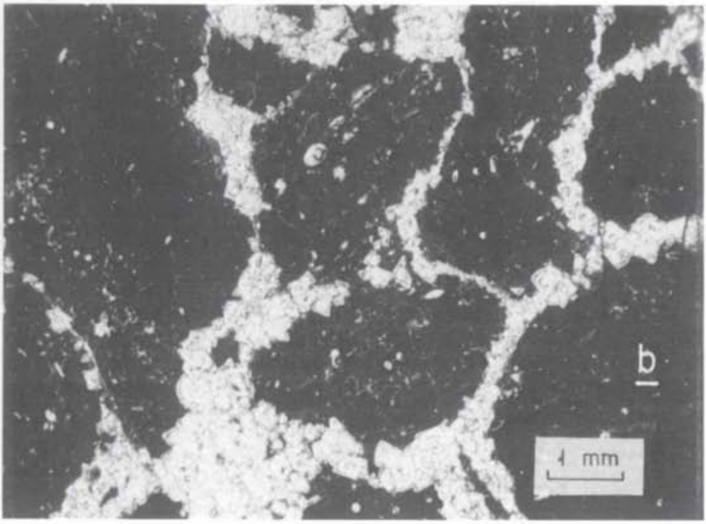


Figure 6a -- Photomicrograph of intrasparite from lower pelletal calcilutite facies, Coralville Member (loc. 26). Intraclasts are surrounded by coarsely crystalline dolomite crystals. Brachiopod shell (B) above.

Figure 6b -- Photomicrograph of intraclasts in puddingstone bed, upper pelletal calcilutite facies, Coralville Member (loc. 28). Angular unoriented intraclasts are surrounded by medium to coarsely crystalline dolomite.

3.0 and 3.3 percent (tbl.1). As in the lower pelletal calcilutite facies, some limestone beds in this facies change laterally to dolostone within the confines of individual quarries (loc. 11, fig. 2 and pl. 2b), and many limestone types are represented. The most abundant are stromatoporoid biomicrite, intramicrite and intrasparite, and laminated pelmicrite. Some of the latter have irregular, curled and cracked laminations interpreted as due to trapping of sediment by algal mats. Others have regular laminations interpreted as current laminations.

Important differences between the lower and upper calcilutite facies of the Coralville Member include the absence of oncolites and domed algal mats in the upper facies, and the presence of stromatoporoid biomicrite, which is rare in the lower facies. In addition, the upper facies contains tabular beds of rock as much as 4 to 4.5 feet (1.2 to 1.4 m) thick composed of large, angular intraclasts of pelmicrite within a matrix of finely crystalline dolomite and minor calcite spar (fig. 6b). These beds are similar to the puddingstone described by Kettenbrink (1973) in east-central Iowa. Fragments in the puddingstones have no apparent orientation, in contrast to the other intraclastic rocks in which clasts have an imbricate or a horizontal orientation, and the puddingstone layers are several times thicker than layers of intramicrites and intrasparites. Finally, the upper pelletal calcilutite facies contains a few beds with probable fenestral-laminar or birdseye fabric (locs. 26 and 27, fig. 2 and pl. 2b), and some beds with shrinkage or desiccation cracks.

Stromatoporoid Biostrome Facies

The stromatoporoid biostrome facies is a 16-foot (4.9-m) interval of carbonate at the top of the Coralville Member, observed at only one location (loc. 11, fig. 2 and pl. 2b) within the study area; it is tentatively correlated with exposures of the upper Coralville southwest and west of the study area in Cerro Gordo and Worth Counties, Iowa (locs. 12, 29 and 30, fig. 2). Lithologically it appears to have a close affinity with the "Mason City beds" and "cement ledge" that crop out in the Mason City area. The outcrop at locality 11 apparently is an outlier because it is on a topographic high. The stromatoporoid biostrome facies is composed of a basal zone 8.75 to 9.25 feet (2.7 to 2.8 m) thick of fine to medium, biogenic to unfossiliferous dolostone overlain by a zone 6 to 7 feet (1.8 to 2.1 m) thick of stromatoporoid biomicrite.

Upper Contact of the Cedar Valley Formation

The Cedar Valley is overlain by the Nora Member of the Shell Rock Formation in southwestern Mitchell County, and in adjoining areas to the southwest. The contact is a conspicuous erosional unconformity. Beds at the top of the Coralville Member are truncated, and the overlying basal beds of the Nora Member have variable thicknesses that reflect irregularities of the eroded surface. The Nora is medium crystalline dolostone that contains scattered hemispherical and stalked stromatoporoids along the margins of its outcrop belt in Mitchell and Worth Counties, and tabular stromatoporoids farther southwest (Koch, 1970).

Elsewhere in the study area, beds of the upper Coralville are overlain by Pleistocene glacial drift and by Cretaceous(?) detrital sedimentary rocks and iron-rich weathering residuum.

Shale Partings in the Cedar Valley Formation

Numerous thin, 2- to 3-inch (5- to 7.6-cm) shale partings are present in the Cedar Valley Formation. They are most abundant in the lower pelletal calcilutite facies of the Coralville Member, but are also relatively common in the upper pelletal calcilutite of this member and in the upper laminated dolostone facies of the Rapid Member. Some, but far fewer, occur in other facies as well.

Because previous study by Kohls (1961) indicated that some of the shale seams were possibly potassium bentonites, 40 clay separates from different localities and stratigraphic intervals were subjected to X-ray analysis. With one exception, all were composed of well-crystallized illite, and some contained trace amounts of kaolinite. The exceptional separate was composed of minor illite and randomly interstratified mica-montmorillonite interpreted as "degraded illite," or illite that has been weathered and leached of interlayered potassium ions. None of the shale partings had X-ray patterns similar to those reported in the literature for Paleozoic potassium bentonites, which characteristically are interstratified mica-montmorillonite with 20 to 30 percent montmorillonite (Weaver, 1953).

Heavy mineral separates run on 10 shale samples were characterized by a suite that is predominantly zircon, tourmaline and garnet, typical of Paleozoic detrital heavy mineral suites. Many of the grains are abraded. None of the sample contained a suite dominated by subhedral to euhedral apatite, clear euhedral zircon and biotite, which characterize heavy mineral suites described from Paleozoic bentonites elsewhere (Weaver; 1953; Mossler and Hayes, 1966).

Both heavy minerals and clay mineralogy suggest a detrital origin for the shale seams. The distribution of the seams is possibly a result of paleoenvironmental factors because they are most abundant in facies interpreted to be tidal flat deposits.

PALEOENVIRONMENTAL INTERPRETATION

Widespread dolomitization has obliterated many features that could serve to interpret the paleoenvironment of the Cedar Valley Formation of southern Minnesota and northern Iowa, and for some facies it is therefore necessary to extrapolate interpretations that Kettenbrink (1973) proposed for east-central Iowa.

Solon Member

The basal biogenic dolostone facies of the Solon Member is characterized by abundant fossil remains, and most beds have abundant, closely packed moldic porosity. Therefore the rock appears to have been grain supported (calcarenite), rather than mud supported (calcilutite). Because of dolomitization, it is impossible to determine whether interstices between grains were originally filled or partly filled with micrite, or were voids. However, the low insoluble residue content suggests that the rock did not have an appreciable clay-sized component. Like its equivalent in east-central Iowa, this facies is interpreted to have been deposited in shallow normal marine water, above wave base (Kettenbrink, 1973). The abundance of corals at the top of this facies indicates conditions favorable for development of bioherms.

The dolomitic calcilutite facies of the Solon Member was originally a mud-rich sediment deposited either below the depth where waves and currents winnowed sediment, or alternatively, in shallow subtidal water to the lee of barriers such as sand bars and biostromal mounds. Its fossil remains are mainly brachiopods and pelmatozoans, indicative of shallow marine water. This facies has no correlative facies in Iowa, and apparently was restricted to southeastern Minnesota.

Dolostone similar to the basal facies of the Solon Member overlies the dolomitic calcilutite, and indicates a return of the former depositional regime.

Rapid Member

The basal massive argillaceous dolostone facies of the Rapid Member is characterized by a high content of detrital clay- to silt-sized material and low content of sand-sized and larger skeletal and detrital grains. It is highly dolomitized, but is inferred to have originated as mud-supported sediments deposited in deeper water farther from shore than the underlying Solon carbonates, and hence to represent maximum transgression of marine water during deposition of the Cedar Valley Formation.

The upper facies of the Rapid, the laminated argillaceous dolostone, contains intraclasts, graded bedding and truncated laminations that suggest intermittent currents of sufficient energy to rework sediment. This facies probably represents the transitional interval between the deep, quiet water environment of the lower facies of the Rapid, and the shallow, agitated water environment of the basal biogenic dolostone facies of the Coralville.

Coralville Member

The basal biogenic dolostone facies, like the basal facies of the Solon Member, has well developed, closely packed, fossil-moldic porosity, indicating that it originally was a grain-supported rock. It is laterally equivalent to the basal skeletal calcilutite facies of the Coralville of east-central Iowa (Kettenbrink, 1973) that is interpreted to be a shallow subtidal marine deposit above wave base.

The overlying facies is sparsely fossiliferous dolostone that appears to be lithically similar to the basal biogenic dolostone except for a larger component of clay-size material. One possible interpretation is that it was deposited in shallow subtidal marine water where turbulence was low because most energy was dissipated farther from shore (Laporte, 1969).

The lower pelletal calcilutite facies is characterized by pelletal carbonate that has a restricted fossil assemblage dominated by ostracodes and "calcispheres." This unit contains conspicuous intraclastic beds, planal to domed algal mats, oncolites, and desiccation cracks--features indicating that the rock was deposited in a tidal flat environment (Lucia, 1972).

The upper sparsely fossiliferous dolostone facies has none of the characteristics of the tidal flat zone mentioned above. It has burrow mottling and a marine fauna dominated by pelmatozoans and brachiopods, and apparently was a mud-supported rock prior to dolomitization. It is interpreted to represent either a lagoonal or shallow, subtidal, low-energy environment.

The upper pelletal calcilutite facies, like the lower pelletal calcilutite facies, contains features indicative of tidal flat deposition. These include a restricted fossil assemblage, intraclasts, planar laminated sediment of probable algal origin, probable birdseye fabric and desiccation cracks. This facies also contains limestone beds with abundant fossil material, most notably hemispherical stromatoporoids, which may represent periodic incursions of shallow marine, probably lagoonal waters.

The dolostone and stromatolitic limestone of the stromatoporoid biostrome facies represents a final incursion of shallow marine waters during deposition of the Cedar Valley Formation.

In summary, the Solon and Rapid sedimentary rocks indicate transgression of marine waters across the area, and Coralville carbonates indicate regression of marine waters and prograding deposition of very shallow marine intertidal and supratidal sediments.

DOLOMITIZATION AND OTHER DIAGENETIC ALTERATIONS

The most conspicuous and extensive diagenetic alteration in the Cedar Valley Formation is dolomitization, the cause of which is unknown. Widespread dolomitization of facies interpreted to be subtidal indicates that evaporative pumping (Illing and others, 1965) and capillary concentration (Shinn and others, 1965) cannot be primary causal mechanisms. Moreover, rocks associated with tidal flat facies are commonly the least dolomitized. One popular hypothesis proposes dolomitization by downward seepage refluxion of hypersaline brines through carbonate sediments (Adams and Rhodes, 1960; Deffeyes and others, 1965). The presence of extensive evaporite (anhydrite) deposits in the Cedar Valley in Iowa (Collinson and others, 1967) lends support to this hypothesis.

Many analogies have been drawn between recent dolomites that formed from hypersaline magnesium-rich brines and occurrences of dolomite in ancient rock. Recently, however, many authors have indicated that dolomite will form in less saline waters if parameters such as pH (Lippmann, 1968; Zenger, 1972), solution composition and concentration (Badiozamani, 1973; Folk and Land, 1975; Von der Borch, 1976), and temperature (Usdowski, 1968) are altered from those for normal marine water. Because of the present controversy about the mechanisms responsible for ancient dolomites, any hypothesis about the formation of the replacement dolomites in the Cedar Valley Formation is necessarily tentative.

There does not seem to be conclusive evidence for more than one stage of dolomitization in the Cedar Valley carbonates. Marked compositional variation of the dolomite such as the presence of an iron-rich phase that would indicate multi-stage dolomitization, appears to be lacking. Geopetal structures with multiple stages of cementation are also lacking. On the other hand, Kettenbrink (1973) observed some silica nodules that apparently replaced calcium carbonate prior to dolomitization because they preserve the microstructures of replaced fossils, obliterated in surrounding dolostones. He also observed other nodules that apparently formed after dolomitization because they contain dolomite crystals as inclusions. Although he thought these relationships might indicate the presence of two stages of dolomitization, he did not rule out a single stage of varying intensity in which dolomite and silica formed concurrently.

Other conspicuous authigenic minerals observed in the Cedar Valley Formation of Minnesota and adjoining northern Iowa are pyrite, limonite-goethite, coarsely crystalline calcite spar, and chert. The pyrite and chert, like dolomite, evidently formed during early diagenesis of the formation. Most of the limonite-goethite and calcite is interpreted to be the result of near-surface weathering.

Another mineral of probable authigenic origin in the Cedar Valley Formation is siderite. It is associated in minor quantities with hematite-goethite iron deposits in Fillmore and Mower Counties, Minnesota, and apparently formed as weathering residuum on the lower part of the Solon Member during the Cretaceous or Tertiary (Bleifuss, 1966, 1972). Bleifuss (1966) discusses various hypotheses that could explain these deposits; they fall into four categories: (1) bog iron ore deposits (Winchell, 1884; Allen, 1909; Howell, 1916); (2) weathering and replacement of bedrock (Stauffer and Thiel, 1941, 1944, 1949; Andrews, 1958;

Austin, 1963; Sloan, 1964); (3) weathering supplemented by pre-concentration of iron (Stauffer and Thiel, 1949; Andrews, 1958; Sloan, 1964); and (4) weathering of a primary siderite facies of the Cedar Valley Formation (Bleifuss, 1966, 1972). No systematic study of these iron ore deposits was undertaken, but discussion of the siderite associated with these deposits is necessary because Bleifuss (1972) indicated that it might be a primary marine sediment and, if so, it has to be accounted for as one of the sedimentary facies of the Cedar Valley.

The principal argument against a primary origin is presented by Berner (1971, p. 199-200), who states that iron carbonates should be unstable in the marine environment because high sulfate concentrations in seawater under anoxic conditions should always lead to considerable sulfate reduction and formation of iron sulfides. As discussed previously, evidence from this study indicates the Solon apparently formed in a normal shallow marine environment. Another argument is the invariable close association of the iron ore and siderite, which nearly always occurs as nodules enclosed in goethite (Bleifuss, 1966, p. 44-45). X-ray analyses did not reveal any siderite in samples from unreplaced Solon Member outcrops (locs. 2, 3 and 16, fig. 2 and pl. 2a), that contain the stratigraphic interval in which the ore bodies occur.

Berner (1971, p. 200) attributes most siderite concretions in marine sedimentary rock to depositional alteration by non-marine, low-calcium, anaerobic ground water. The interpretation proposed by Stauffer and Thiel (1949)--replacement of limestone by siderite by surface waters during weathering and subsequent oxidation of the iron-enriched carbonate to form the ore--seems to provide the most plausible theory for the origin of the ore.

RECOGNITION OF THE CEDAR VALLEY FORMATION AND ITS MEMBERS IN THE SUBSURFACE

Criteria used to distinguish among members and facies in surface exposures rely heavily on differences in rock fabrics. However, because these fabrics are usually too large to be preserved in well cuttings, criteria useful in the subsurface are variations in color, detrital content, and crystal size of the dolostones (tbl. 2).

No major problems are encountered in distinguishing the upper contact of the Cedar Valley Formation in Minnesota, where the Upper Devonian Shell Rock is lacking and the overlying detrital units are distinctively different from the carbonates of the Cedar Valley.

The underlying carbonates of the Maquoketa are also distinctive because they contain chert, arenaceous dolostone (fig. 3b) and some sublithographic limestone, in contrast to the uniformly non-cherty and non-arenaceous dolostones of the Cedar Valley carbonates.

Table 2 -- Recognition criteria.

Rock unit above/below geologic contact	Dominant lithologies of formations above/below geologic contact	Criteria used to distinguish the Cedar Valley Formation from adjacent formations and to distinguish among members of the Cedar Valley.
Ostrander Mbr., Windrow Fm./ Cedar Valley Fm.	shale, quartzose sand, gravel/dolostone, limestone and shale	Contact is distinctive except where Ostrander shale lies directly on Cedar Valley carbonates and it may be confused with Cedar Valley shale. Ostrander shale has a high kaolinite content. Cedar Valley shale is mostly illite and less than 10 percent kaolinite.
weathering residuum (Cretaceous?)/ Cedar Valley Formation	clay and shale/ dolostone, limestone and shale	Reddish-brown color and high kaolinite content distinguish residuum from grayish-green illitic Cedar Valley shales (e.g, Parham, 1970, p. 21-22, 102). Residuum contains some fragments of weathered Cedar Valley carbonate.
upper part of Coralville Mbr. (Lower pelletal calcilutite facies and overlying units)/ lower part of Coralville Mbr.	sublithographic limestone and interbedded dolostone/dolostone	Presence of sublithographic limestone in upper part of Coralville is distinguishing feature. In western part of study area where Coralville is principally dolostone, contact cannot be distinguished.
lower part of Coralville Mbr. (basal biogenic dolostone; lower sparsely fossiliferous dolostone)/ Rapid Mbr.	dolostone/dolostone	Lighter color (light yellowish gray versus light brownish gray to medium gray) and fewer detrital clay- and silt-sized grains distingish Coralville dolostone from Rapid dolostone. Coralville dolostone contains some fractures and vugs lined with calcite spar. Color change at top of Rapid Mbr. may be gradational, obscuring contact.
Rapid Mbr./ Solon Mbr.	dolostone/dolostone	Darker color (light brownish gray to medium gray versus light grayish yellow), higher content of detrital material and presence of thin streaks of finely disseminated pyrite distinguish Rapid dolostone from Solon dolostone. Solon dolostone generally is characterized by calcite spar, limonite-goethite fragments and moldic porosity. Rapid dolostone is generally more finely crystalline than Solon dolostone (aphanocrystalline to very finely crystalline versus fine to medium crystalline.)
Solon Mbr./ Maquoketa Fm.	dolostone/dolostone, limestone and chert	Chert and limestone are scarce or absent in Solon Mbr., whereas the Maquoketa Fm. consists of light-gray sublithographic limestone containing black blebs or rods which are fossil fragments replaced by chert and fine-grained pyrite. Drusy quartz and white to medium-gray and light brownish-gray chert are commonly associated with Maquoketa limestones and dolostones. Maquoketa contains minor arenaceous dolostone.

ECONOMIC GEOLOGY

The present major use of the Cedar Valley Formation in the study area is for rock aggregate and agricultural lime. The upper and lower pelletal calcilutite facies and adjacent dolostones of the Coralville Member are the stratigraphic intervals most widely utilized for aggregate. The dolomitic calcilutite facies of this member is quarried near Grand Meadow (loc. 2, fig. 2 and pl. 2a) and would probably be more widely used if it were more extensively exposed. Most quarries located in other stratigraphic intervals are old and no longer used, probably because quarries in the Coralville Member provide better aggregate. Exceptions are some quarries in the Rapid Member near Cresco, Iowa, and Austin, Minnesota.

Limestone from a local, abnormally thick interval of the upper part of the Coralville Member near Mason City, Iowa, is used for portland cement. This interval is stratigraphically higher than most of the Coralville exposed in the study area; it is tentatively correlated with the stromatoporoid biostrome facies, which is exposed within the area of this study only near St. Ansgar, Iowa (loc. 11, fig. 2 and pl. 2b), and does not extend into Minnesota because of post-Devonian erosion. Lower limestone intervals, such as the lower and upper pelletal calcilutites, contain high-calcium limestone beds, but these are interbedded with high-magnesium dolomite that would make them unsuitable for manufacture of portland cement (c.f., Thiel and Stauffer, 1947; Prokopovich and Schwartz, 1956).

Iron ore was formerly mined from weathering residuum of the basal biogenic dolostone of the Solon Member in Fillmore County, Minnesota, but this is no longer profitable.

Another resource of the Cedar Valley Formation is ground water--as an aquifer it is sufficient to provide water for many small domestic wells in Mower and Freeborn Counties, although municipal wells derive their water from the St. Peter or Jordan formations.

ACKNOWLEDGMENTS

Clarence Folgero, Leroy, Minnesota and other well drillers provided samples from wells in Mower, Freeborn and adjoining counties. Quarry operators allowed access to pits and quarries on their properties. Richard Darling drafted the illustrations. John Splettstoesser reviewed the text and illustrations.

REFERENCES CITED

Adams, J.E., and Rhodes, M.L., 1960, Dolomitization by seepage refluxion: American Association of Petroleum Geologists Bulletin, v. 44, p. 1912-1920.

Allen, R.C., 1909, The occurrence and origin of the brown iron ores of Spring Valley, Wisconsin: Michigan Academy of Sciences Report 11, p. 95-103.

Andrews, G.W., 1958, Windrow Formation of the Upper Mississippi Valley region, a sedimentary and stratigraphic study: Journal of Geology, v. 66, p. 597-624.

Austin, G.S., 1963, Geology of clay deposits, Red Wing area, Goodhue and Wabasha Counties, Minnesota: Minnesota Geological Survey Report of Investigations 2, 23 p.

———, 1970, Deep stratigraphic test well near Hollandale, Minnesota: Minnesota Geological Survey Report of Investigations 12, 52 p.

———, 1972, Paleozoic lithostratigraphy of southeastern Minnesota, _in_ Sims, P.K., and Morey, G.B., _eds_., Geology of Minnesota: A centennial volume: Minnesota Geological Survey, p. 459-473.

Badiozamani, K., 1973, The Dorag dolomitization model--application to the Middle Ordovician of Wisconsin: Journal of Sedimentary Petrology, v. 43, p. 965-984.

Bayer, T.N., 1967, Repetitive benthonic community in the Maquoketa Formation (Ordovician) of Minnesota: Journal of Paleontology, v. 41, p. 417-422.

Belanski, C.H., 1927, The Shellrock Stage of the Devonian of Iowa: American Midland Naturalist, v. 10, p. 317-370.

Berner, R.A., 1971, Principles of Chemical Sedimentology: New York, McGraw-Hill, 240 p.

Bleifuss, R.L., 1966, The origin of the iron ores of southeastern Minnesota: Ph.D. thesis, University of Minnesota, Minneapolis, 125 p.

———, 1972, The iron ores of southeastern Minnesota, _in_ Sims, P.K., and Morey, G.B., _eds_., Geology of Minnesota: A centennial volume: Minnesota Geological Survey, p. 498-505.

Collinson, Charles, and others, 1967, Devonian of the north-central region, United States, _in_ International Symposium on the Devonian System, Calgary: Alberta Society of Petroleum Geologists, v. 1, p. 933-971.

Deffeyes, K.S., Lucia, F.J., and Weyl, P.K., 1965, Dolomitization of Recent and Plio-Pleistocene sediments by marine evaporite waters on Bonaire Netherlands Antilles, in Pray, L.C., and Murray, R.C., eds., Dolomitization and limestone diagenesis, a symposium: Society of Economic Paleontologists and Mineralogists Special Publication 13, p. 71-88.

Dorheim, F.H., and Koch, D.L., 1966, Devonian of northern Iowa, Cedar Valley, Shell Rock and Lime Creek: Iowa Geological Survey Guidebook for the Thirtieth Annual Tri-State Geological Field Conference, 45 p.

Folk, R.L., 1959, Practical petrographic classification of limestones: American Association of Petroleum Geologists Bulletin, v. 43, p. 1-38.

Folk, R.L., and Land, L.S., 1975, Mg/Ca ratio and salinity: Two controls over crystallization of dolomite: American Association of Petroleum Geologists Bulletin, v. 59, p. 60-68.

Grabau, A.W., 1904, On the classification of sedimentary rocks: American Geologist, v. 33, p. 228-247.

Howell, J.C., 1916, The iron deposits near Waukon, Iowa: Iowa Geological Survey Bulletin 25, p. 33-101.

Illing, L.V., Wells, A.J., and Taylor, J.C.M., 1965, Penecontemporary dolomite in the Persian Gulf, in Pray, L.C., and Murray, R.C., eds., Dolomitization and limestone diagenesis, a symposium: Society of Economic Paleontologists and Mineralogists Special Publication 13, p. 89-111.

Kettenbrink, E.C., Jr., 1973, Depositional and post-depositional history of the Devonian Cedar Valley Formation, east-central Iowa: Ph.D. thesis, University of Iowa, Iowa City, 191 p.

Keyes, C.R., 1931, Stratigraphic geology: Pan-American Geologist, v. 56, p. 316-318.

Koch, D.L., 1970, Stratigraphy of the Devonian Shell Rock Formation of north-central Iowa: Iowa Geological Survey Report of Investigations 10, 123 p.

Kohls, D.W., 1961, Lithostratigraphy of the Cedar Valley Formation in Minnesota and northern Iowa: Ph.D. thesis, University of Minnesota, Minneapolis, 200 p.

Laporte, L.F., 1969, Recognition of a transgressive carbonate sequence within an epeiric sea: Helderberg Group (Lower Devonian) of New York State, in Friedman, G.M., ed., Depositional environments in carbonate rocks: Society of Economic Paleontologists and Mineralogists Special Publication 14, p. 98-119.

Lippmann, F., 1968, Synthesis of $BaMg(CO_3)_2$ (Norsethite) at 20° C and the formation of dolomite in sediments, in Muller, G., and Friedman, G.M., eds., Recent developments in carbonate sedimentology in Central Europe: New York, Springer Verlag, p. 33-37.

Lucia, F.J., 1972, Recognition of evaporite-carbonate shoreline sedimentation, in Rigby, J.K., and Hamblin, W.K., eds., Recognition of ancient sedimentary environments: Society of Economic Paleontologists and Mineralogists Special Publication 16, p. 160-191.

McGee, W.J., 1891, The Pleistocene history of northeastern Iowa: U.S. Geological Survey Annual Report 11, pt. 1, p. 189-577.

Mossler, J.H., and Hayes, J.B., 1966, Ordovician potassium bentonites of Iowa: Journal of Sedimentary Petrology, v. 36, p. 414-427.

Parham, W.E., 1970, Clay mineralogy and geology of Minnesota's kaolin clays: Minnesota Geological Survey Special Publication 10, 142 p.

Prokopovich, N., and Schwartz, G.M., 1956, Minnesota limestone suitable for portland cement: Minnesota Geological Survey Summary Report 8, 39 p.

Shinn, E.A., Ginsburg, R.N., and Lloyd, R.M., 1965, Recent supratidal dolomite from Andros Island, Bahamas, in Pray, L.C., and Murray, R.C., eds., Dolomitization and limestone diagenesis, a symposium: Society of Economic Paleontologists and Mineralogists Special Publication 13, p. 112-123.

Sloan, R.E., 1964, The Cretaceous System in Minnesota: Minnesota Geological Survey Report of Investigations 5, 64 p.

Sloan, R.E., and Austin, G.S., 1966, Geologic map of Minnesota, St. Paul Sheet: Minnesota Geological Survey.

Stainbrook, M.A., 1941, Biotic analysis of Owen's Cedar Valley limestones: Pan-American Geologist, v. 75, p. 321-327.

Stauffer, C.R., and Thiel, G.A., 1941, The Paleozoic and related rocks of southeastern Minnesota: Minnesota Geological Survey Bulletin 29, 261 p.

———, 1944, The iron ores of southeastern Minnesota: Economic Geology, v. 39, p. 327-339.

———, 1949, The iron ores of southeastern Minnesota: Minnesota Geological Survey Summary Report 3, 6 p.

Thiel, G.A., 1944, The geology and underground waters of southern Minnesota: Minnesota Geological Survey Bulletin 31, 506 p.

Thiel, G.A., and Stauffer, C.R., 1947, The high calcium limestones of Minnesota: Minnesota Geological Survey Summary Report 1, 13 p.

Usdowski, H.E., 1968, The formation of dolomite in sediments, in Muller, G., and Friedman, G.M., eds., Recent developments in carbonate sedimentology in Central Europe: New York, Springer Verlag, p. 21-32.

Von der Borch, C.C., 1976, Stratigraphy and formation of Holocene dolomitic carbonate deposits of the Coorong area, South Australia: Journal of Sedimentary Petrology, v. 46, p. 952-966.

Weaver, C.E., 1953, Mineralogy and petrology of some Ordovician K-bentonites and related limestones: Geological Society of America Bulletin, v. 64, p. 921-943.

Winchell, N.H., 1884, Geology of Fillmore County: Minnesota Geological and Natural History Survey Final Report, v. 1, p. 268-324.

Zawistowski, S.J., 1971, Biostromes in the Rapid Member of the Cedar Valley Limestone (Devonian) in east-central Iowa: M.S. thesis, University of Iowa, Iowa City, 120 p.

Zenger, D.H., 1972, Significance of supratidal dolomitization in the geologic record: Geological Society of America Bulletin, v. 83, p. 1-12.

APPENDIX A

CEDAR VALLEY FORMATION OUTCROP DESCRIPTIONS

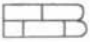
Detailed descriptions of outcrops at selected localities follow. The localities selected include representative outcrops of all facies of the Cedar Valley Formation discussed in this report. The supplemental outcrops listed in Appendix B generally duplicate described outcrops.

The key to the symbols used in preparing the figures in this appendix is as follows:

Column 1. - Formations and members. Formation name is not given for members of the Cedar Valley Formation.

Column 2. - Vertical scale in feet.

Column 3. - Lithologic column.

 limestone

 dolostone

 shale or shale parting

o o o intraclasts

∧ ∧ ∧ chert

.. .. .. rock is sandy

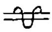
— — — rock is shaly

Column 4. - Bedding.

tk = very thick bedding, massive, >40 inches
tk = thick bedding, blocky, 12-40 inches
med = medium bedding, slabby, 4-12 inches
tn = thin bedding, 1.2 - 4 inches
(tn) = very thin bedding, 0.4 - 1.2 inches
lam = laminated, platy, 0.12 - 0.4 inches

Column 5. - Dominant color of rock unit (dry surface). Color notation from Geological Society of America Rock-Color Chart.

Column 6. - Rock fabric (primary depositional features).

(=)	faint bedding
≡	regular, even laminations
	graded bedding
	scour and fill structures
	burrows
Ω	convolute laminations
	desiccation cracks
◉	oncolites, algal biscuits

Column 7. - Texture.

1. Primary textures

Shale

Limestone--classification from Folk (1959)

biomicrite = biomicrite

biomicrosparite = biomicrosparite

pelm = pelmicrite

pelmicrosparite = pelmicrosparite

pels = pelsparite

intram = intramicrite

intras = intrasparite

micrite = micrite

foss micrite = fossiliferous micrite

micr = microsparite

2. Diagenetic textures

Dolostone--crystal size

aphan = aphanocrystalline <0.004 mm

v/f xln = very finely crystalline 0.004-0.016 mm

f xln = finely crystalline 0.016-0.062 mm

m xln = medium crystalline 0.062-0.25 mm

crs xln = coarsely crystalline 0.25-1.0 mm

v/crs xln = very coarsely crystalline 1.0-4.0 mm

3. Modifiers prefixed to rock name (to more adequately describe rock type):

pel = pelletiferous, pelletal

foss = fossiliferous

intracl = intraclastic

s = sandy

( ) = particles are a minor constituent

Column 8. - Important secondary minerals in rock.

pyr = pyrite

lmn = limonite

cht = chert (includes authigenic and detrital)

chal = chalcedony

qz = quartz (detrital)

Size:

slt = silt

f s = fine sand

crs s = coarse sand

( ) = particles are a minor constituent

Column 9. - Graphic column showing vertical variation in percentage of dolomite in carbonate rock.

Column 10.- Graphic column showing vertical variation in percentage of insoluble residue in rock.

Column 11.- Conspicuous porosity observed in outcrop:

Vugular porosity. Vugs generally 1 inch (2.5 cm) or more in diameter.

Fossil moldic porosity. Molds generally less than 1/8 inch (0.3 cm) in diameter.

Symbols are underlined if porosity is abundant, in parentheses if sparse.

Column 12.- Fossil content.

calcareous algae

brachiopods

corals

pelmatozoans

fossils (general)

gastropods

ostracodes

calcisphere structures

stromatoporoids (subspherical)

stromatoporoids (columnar)

Symbols are underlined if fossils are abundant, in parentheses if sparse.

Column 13.- Name of facies.

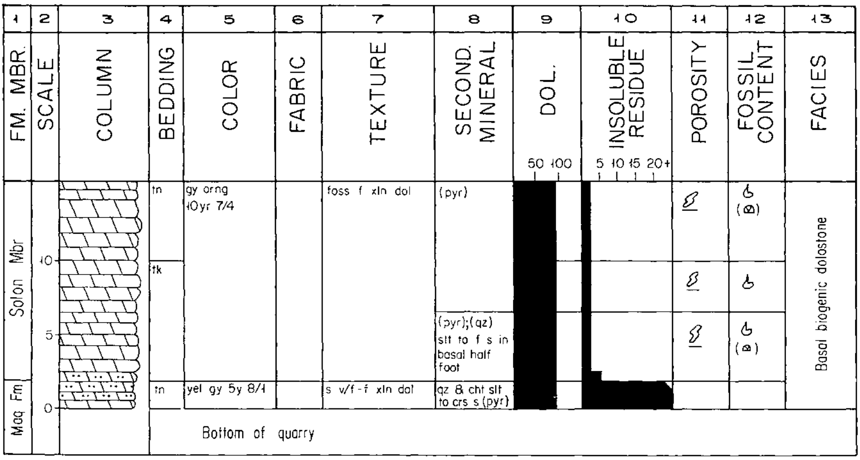


Figure A1 -- Locality 1: Quarry, SW¼ sec. 7, T. 104 N., R. 14 W., Mower County, Minnesota.

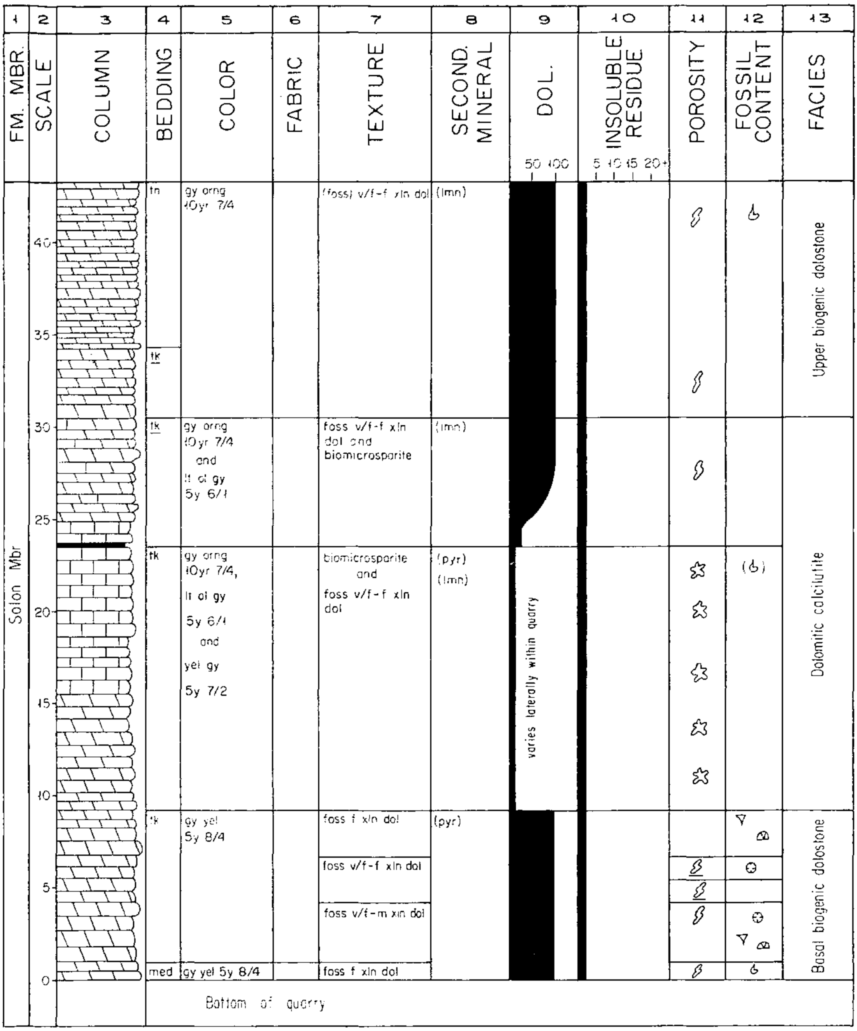


Figure A2 -- Locality 2: N¼ sec. 9, T. 103 N., R. 14 W., Mower County, Minnesota.

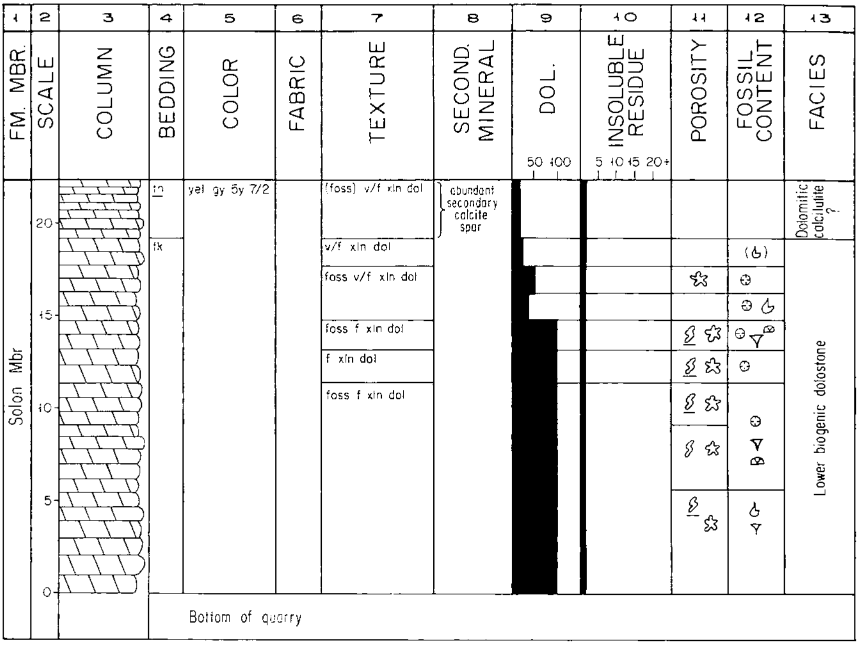


Figure A3 -- Locality 3: Quarry, NW¼ sec. 26, T. 102 N., R. 13 W., Fillmore County, Minnesota.

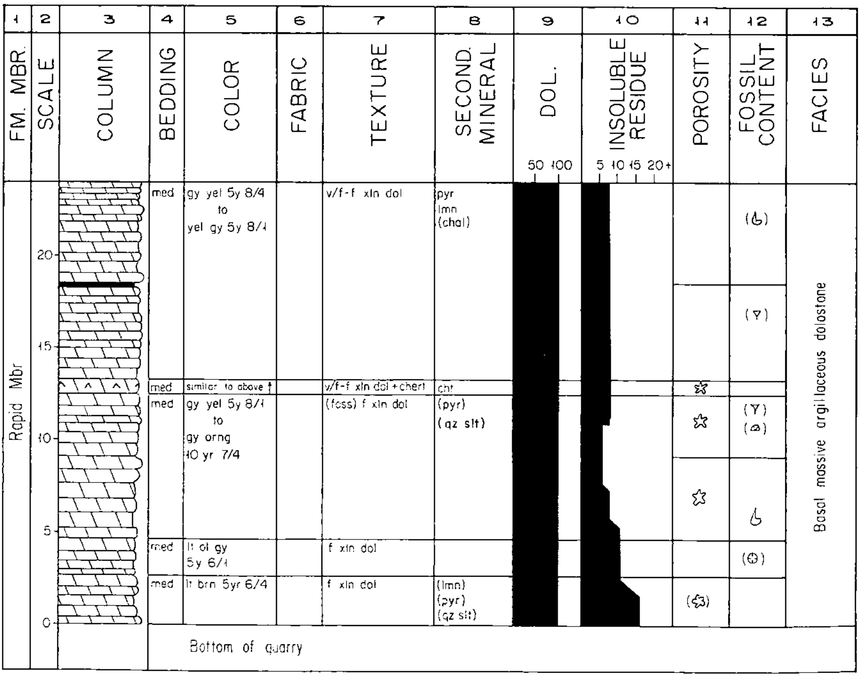


Figure A4 -- Locality 4: Quarry, SE¼ sec. 24, T. 100 N., R. 13 W., Mitchell County, Iowa.

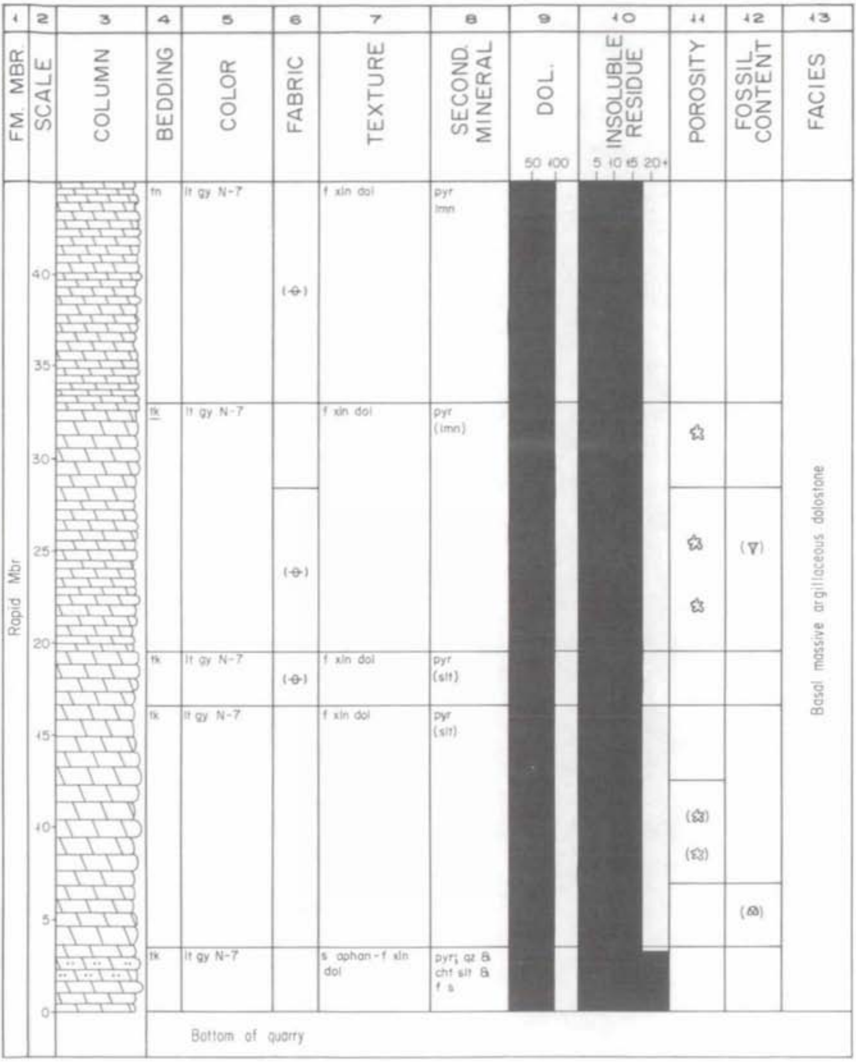


Figure A5 -- Locality 5: Quarry, S½NE¼ sec. 27, T. 102 N., R. 18 W., Mower County, Minnesota.

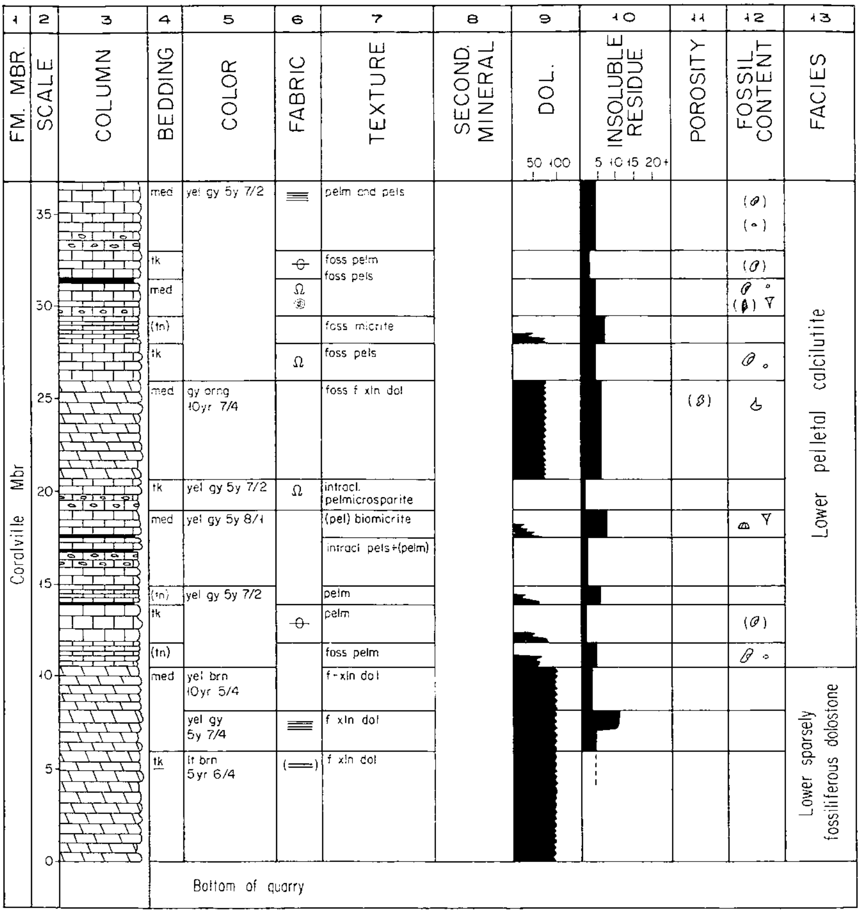


Figure A6 -- Locality 6: Quarry, NW¼NW¼ sec. 27, T. 101 N., R. 14 W., Mower County, Minnesota.

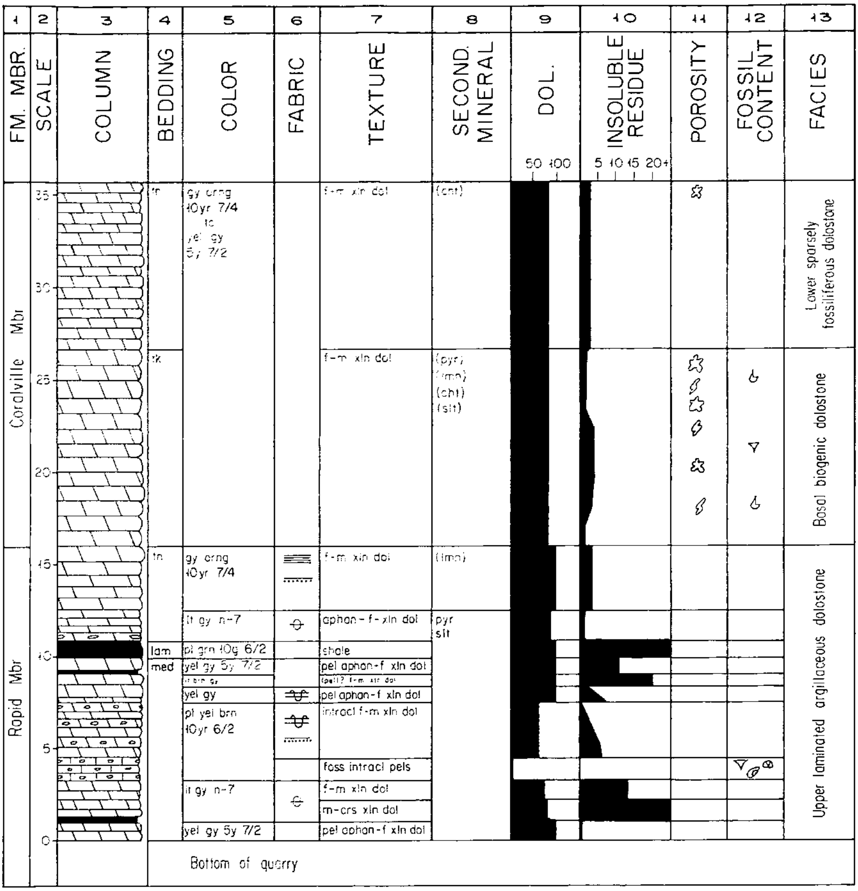


Figure A7 -- Locality 7: Quarry, SE¼SW¼ sec. 30, T. 99 N., R. 15 W., Mitchell County, Iowa.

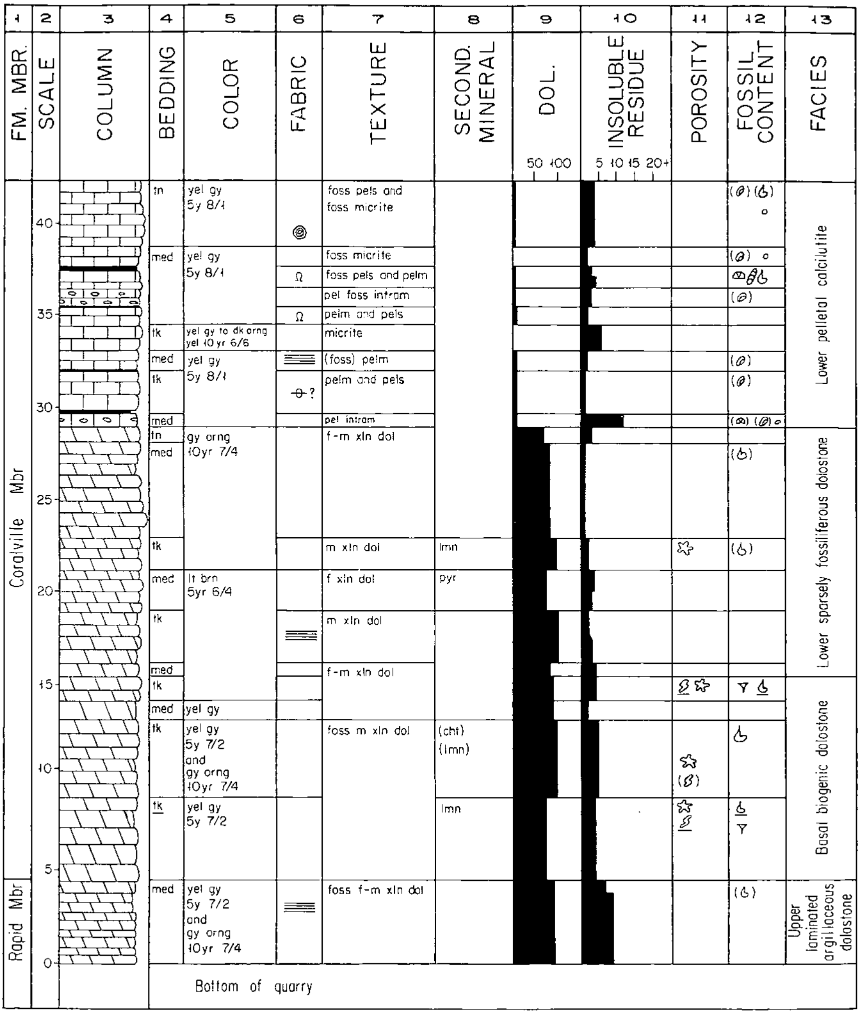


Figure A8 -- Locality 8: Quarry, center N½ sec. 22, T. 99 N., R. 16 W., Mitchell County, Iowa.

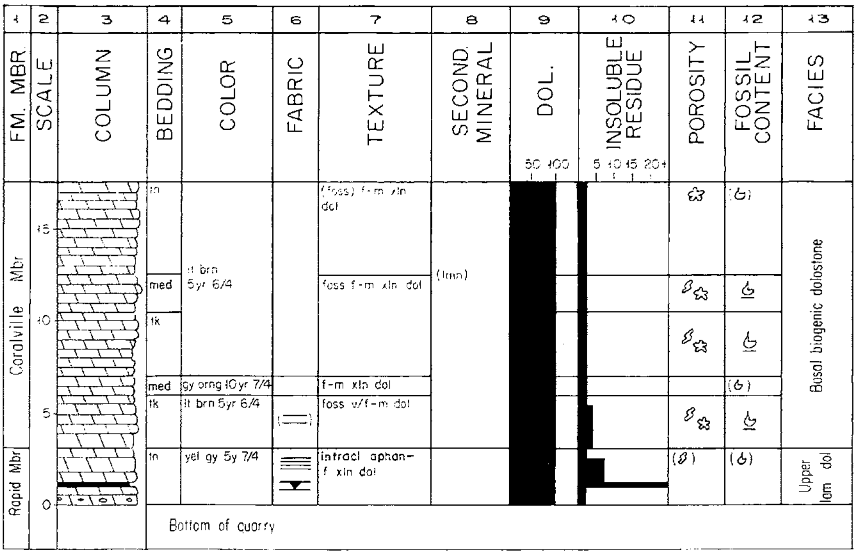


Figure A9: Locality 9: Quarry, NW¼SW¼ sec. 33, T. 101 N., R. 18 W., Mower County, Minnesota.

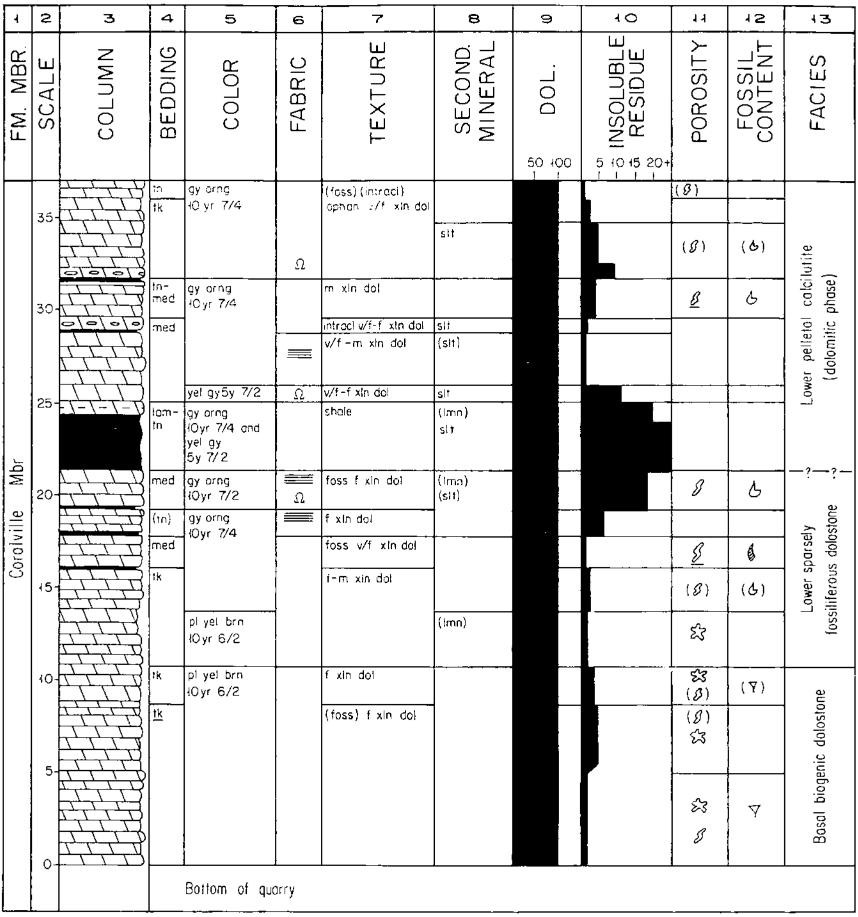


Figure A10: Locality 10: Quarry, NE¼SW¼ sec. 34, T. 100 N., R. 18 W., Mitchell County, Iowa.

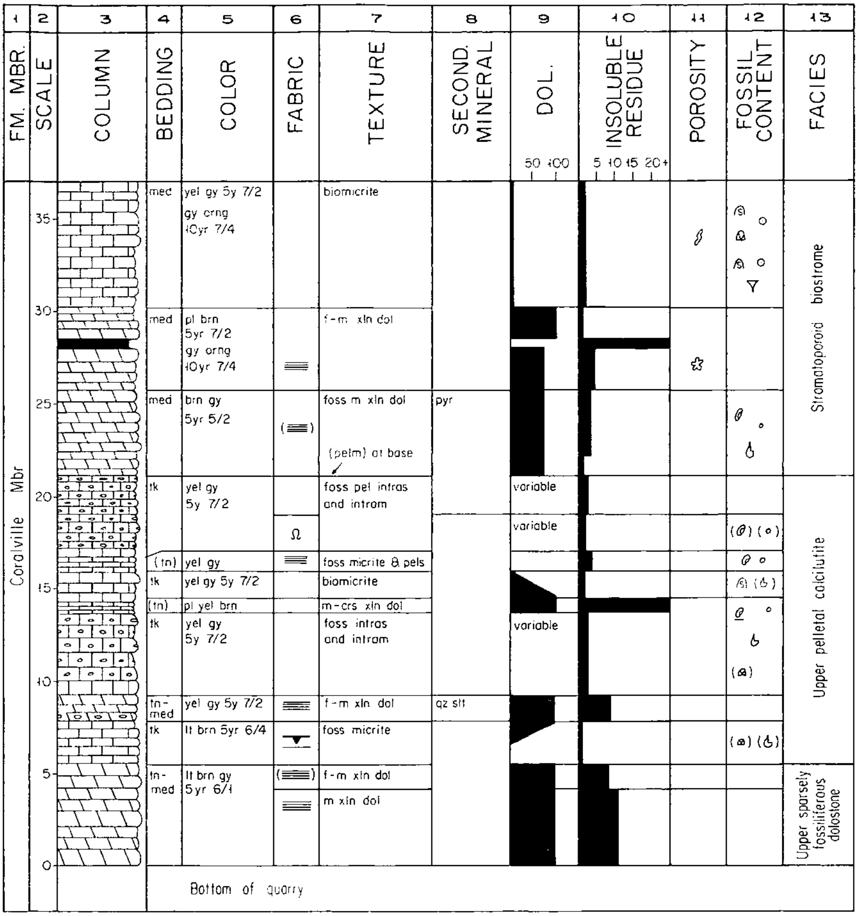


Figure A11 -- Locality 11: Quarry, NE¼SE¼ sec. 8, T. 99 N., R. 17 W., Mitchell County, Iowa.

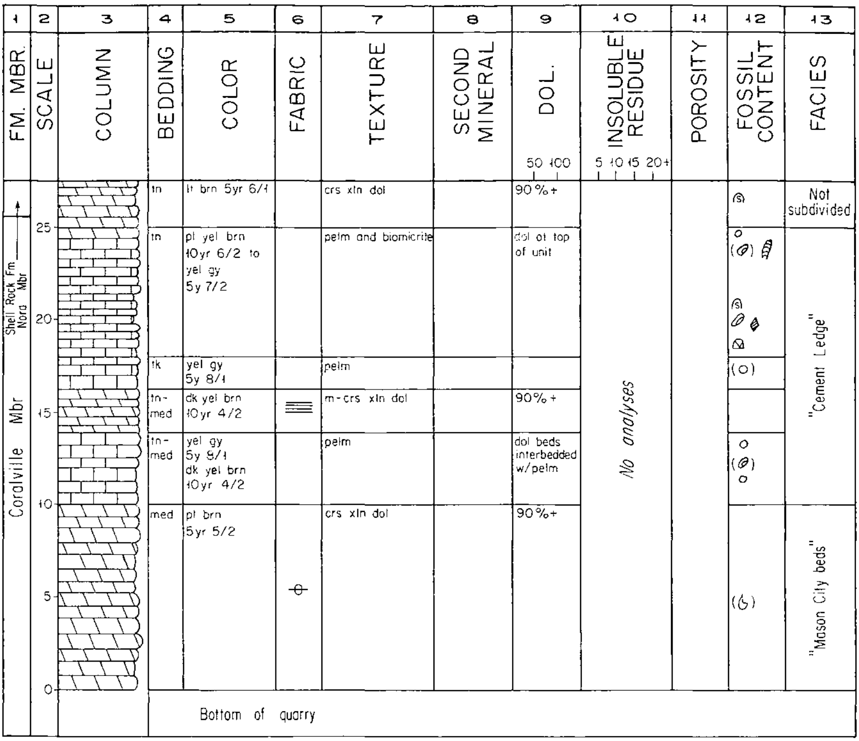


Figure A12 -- Locality 12: Quarry, SE¼ sec. 23, T. 99 N., R. 20 W., Worth County, Iowa.

Appendix B
Supplemental outcrops of Cedar Valley Formation
(Plotted on index map)

Outcrop number and type		Location	County	Units exposed and thickness (in feet)	Comments; available outcrop descriptions
13	quarry	SW$\frac{1}{4}$NW$\frac{1}{4}$ sec 33, T 103N, R 13W	Fillmore	Solon Mbr., 13.7	Contact of Cedar Valley and Maquoketa Fm. formerly exposed here; (Kohls, 1961, p. 114-115)
14	stream banks	SW$\frac{1}{4}$SW$\frac{1}{4}$ sec 32, T 101N, R 11W	Fillmore	Solon Mbr., 4; Maquoketa Fm., 66	(Bayer, 1967, p. 417)
15	quarry	NW$\frac{1}{4}$NE$\frac{1}{4}$ sec 27, T 100N, R 11W	Howard	Solon Mbr., 29.5 (Kohls, 1961, p. 120-122)	
16	quarry	center W$\frac{1}{2}$ sec 14, T 99N, R 11W	Howard	Solon Mbr., 32	
17	quarry	NW$\frac{1}{4}$ sec 9, T 100N, R 12W	Howard	Rapid Mbr., 16	(Kohls, 1961, p. 128-129)
18	quarry	SW$\frac{1}{4}$SE$\frac{1}{4}$ sec 28, T 99N, R 11W	Howard	Rapid Mbr., 35	(Dorheim and Koch, 1966, p. 20-21)
19	quarry	SE$\frac{1}{4}$NE$\frac{1}{4}$ sec 20, T 99N, R 12W	Howard	Rapid Mbr., 23	(Kohls, 1961, p. 138)
20	quarry	NE$\frac{1}{4}$NE$\frac{1}{4}$ sec 3, T 99N, R 15W	Mitchell	Coralville Mbr.,	Not measured; quarry is filled with water.

21	quarry	SE¼ sec 30, T 99N, R 15W	Mitchell	Coralville Mbr., 23.8	Coralville/Rapid contact in base of quarry; (Kohls, 1961, p. 142-145)
22	quarry	NE¼ sec 5, T 97N, R 15W	Mitchell	Coralville Mbr., 28.5	
23	quarry	SW¼ sec 35, T 98N, R 17W	Mitchell	Coralville Mbr., 39	(Kohls, 1961, p. 157-161)
24	streams & roadcuts	center S½ sec 8, T 98N, R 17W	Mitchell	Coralville Mbr., 70	
25	quarry	NE¼SE¼ sec 2, T 98N, R 18W	Mitchell	Coralville Mbr., 15.5-18	(Kohls, 1961, p. 148)
26	quarry	SE¼ sec 17, T 97N, R 17W	Mitchell	Coralville Mbr., 30-33	
27	quarry & streams	NE¼NW¼ sec 12, T 97N, R 18W	Mitchell	Coralville Mbr., 12	
28	quarry	N½ sec 7, T 98N, R 18W	Mitchell	Coralville Mbr., 15-16; Shell Rock Fm., 5-6	Shell Rock Fm./Cedar Valley contact; (Kohls, 1961, p. 166-167)
29	quarry	SW¼NW¼ sec 29, T 98N, R 19W	Worth	Coralville Mbr., 6-13; Shell Rock Fm., 6-12	Shell Rock Fm./Cedar Valley contact; (Koch, 1970, p. 88)
30	quarry	NW¼NW¼ sec 27, T 97N, R 20W	Cerro Gordo	Coralville Mbr., 20; Shell Rock Fm., 4-5	Shell Rock Fm./Cedar Valley contact; (Koch, 1970, p. 93)

E R R A T A

MINNESOTA GEOLOGICAL SURVEY REPORT OF INVESTIGATIONS 18

Page 4, Figure 2. Location 13 should read Spring Valley (not Spring Grove).

Page 23, line 5. The dolomitic calcilutite facies of the Solon Member is quarried near Grand Meadow ...