

MINNESOTA GEOLOGICAL SURVEY

PRISCILLA C. GREW, *Director*

**MIDDLE AND LATE ORDOVICIAN
LITHOSTRATIGRAPHY AND
BIOSTRATIGRAPHY OF
THE UPPER MISSISSIPPI VALLEY**

Robert E. Sloan, Editor



Report of Investigations 35
ISSN 0076-9177

UNIVERSITY OF MINNESOTA

Saint Paul - 1987

**MIDDLE AND LATE ORDOVICIAN
LITHOSTRATIGRAPHY AND
BIOSTRATIGRAPHY OF
THE UPPER MISSISSIPPI VALLEY**

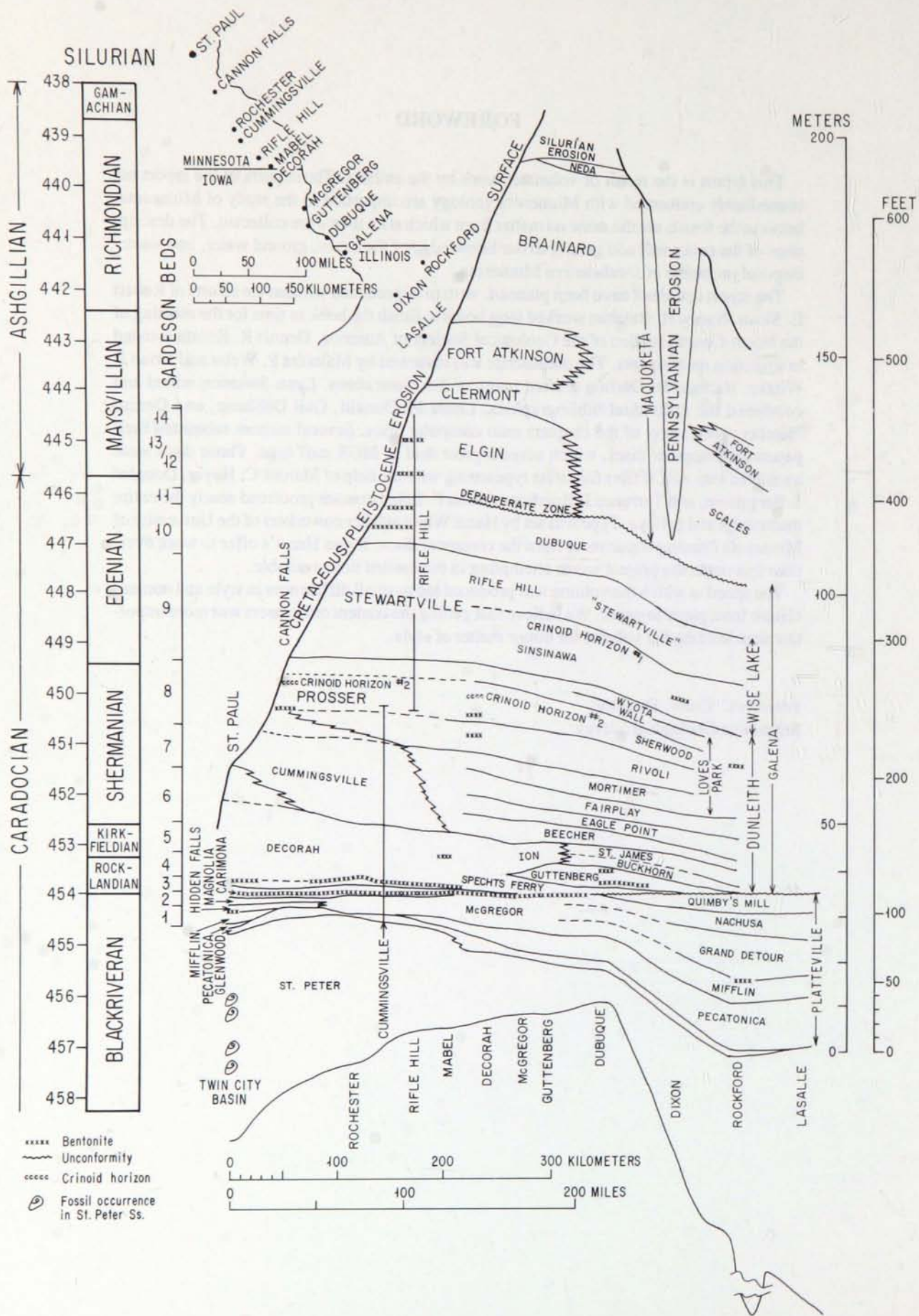
FOREWORD

This report is the result of volunteer work by the authors. Those parts of the report not immediately concerned with Minnesota geology are important to the study of Minnesota, because the fossils are the same no matter from which state they were collected. The descriptions of the rocks will add greatly to our knowledge of the caves, ground water, and waste-disposal problems of southeastern Minnesota.

The report could not have been planned, written or produced without the efforts of Robert E. Sloan. Nancy H. Balaban worked long hours to finish the book in time for the meeting of the North-Central section of the Geological Society of America. Dennis R. Kolata assisted in soliciting manuscripts. The manuscript was reviewed by Malcolm P. Weiss and Brian J. Witzke. Richard B. Darling drafted many of the illustrations. Lynn Swanson edited and combined the individual bibliographies. Linda McDonald, Gail DeShane, and Denise Fletcher typed many of the chapters onto computer discs. Several authors submitted their papers on computer discs, which saved a great deal of MGS staff time. Those discs were translated into ASCII files for direct typesetting with the help of Marcus C. Hoyer, Douglas J. Bergstrom, and Terrence J. Boerboom. John F. Spletstoesser proofread nearly the entire manuscript and galleys. Type was set by Hazel White and her coworkers of the University of Minnesota Printing department from the computer discs. It was Hazel's offer to work overtime that made the project worth attempting in the limited time available.

The speed at which the volume was produced led to small differences in style and nomenclature from paper to paper. We believe that getting the content out to users was more important than holding the volume for minor matter of style.

Priscilla C. Grew, Director
Minnesota Geological Survey



Frontispiece: Stratigraphic cross section of Middle and Late Ordovician rocks between St. Paul, Minnesota, and LaSalle, Illinois, with correlations, zones, and absolute ages.

CONTENTS

	Page
FOREWORD, Priscilla C. Grew	iii
PREFACE, Robert E. Sloan	1
HISTORY OF STUDY OF THE MIDDLE AND LATE ORDOVICIAN ROCKS OF THE UPPER MISSISSIPPI VALLEY, Robert E. Sloan	3
TECTONICS, BIOSTRATIGRAPHY AND LITHOSTRATIGRAPHY OF THE MIDDLE AND LATE ORDOVICIAN OF THE UPPER MISSISSIPPI VALLEY, Robert E. Sloan	7
LITHOSTRATIGRAPHY OF THE PLATTEVILLE, GALENA AND MAQUOKETA GROUPS IN NORTHERN ILLINOIS, Dennis R. Kolata	21
GENERAL SECTION OF THE MIDDLE AND LATE ORDOVICIAN STRATA OF NORTHEASTERN IOWA, Calvin O. Levorson, Arthur J. Gerk, Robert E. Sloan, and Lynne A. Bisagno	25
MIDDLE AND UPPER ORDOVICIAN STRATIGRAPHY IN THE IOWA SUBSURFACE, Brian J. Witzke	40
THE ST. PETER SANDSTONE OF SOUTHEASTERN MINNESOTA, James H. Mazzullo and Robert Ehrlich	44
THE ST. PETER FAUNA, Robert E. Sloan	50
CHEMICAL CORRELATION OF K-BENTONITE BEDS IN THE MIDDLE ORDOVICIAN DECORAH SUBGROUP, UPPER MISSISSIPPI VALLEY, Dennis R. Kolata, Joyce K. Frost, and Warren D. Huff	52
CORRELATION OF ORDOVICIAN K-BENTONITES BY PHENOCRYST CHEMISTRY, Scott D. Samson, Philip R. Kyle, and E. Calvin Alexander, Jr.	57
CORROSION SURFACES IN THE PLATTEVILLE AND GALENA STRATA OF SOUTHEASTERN MINNESOTA, David Dathe	59
THE WAGNER QUARRY CYSTOID BED: A STUDY IN PROSSER (SHERWOOD) PALEOECOLOGY, Robert E. Sloan and David A. DesAutels	60
PLATTEVILLE AND DECORAH TRILOBITES FROM ILLINOIS AND WISCONSIN, Lawrence Lynch DeMott, edited by Robert E. Sloan, Frederick C. Shaw, and Ronald P. Tripp	63
MIDDLE AND UPPER ORDOVICIAN OSTRACODA OF MINNESOTA AND IOWA, Frederick M. Swain	99
OSTRACODA OF THE SUPERFAMILIES DREPANELLEACEA, HOLLINACEA, LEPERDITELLACEA, AND HEALDIACEA FROM THE DECORAH SHALE OF MINNESOTA, Frederick M. Swain and James R. Cornell	102
BRACHIOPODS AND TRILOBITES OF THE SARDESON BEDS IN THE TWIN CITIES, William F. Rice and Eric P. Hedblom	131
THE SYSTEMATICS AND BIOSTRATIGRAPHY OF THE BRACHIOPODA OF THE DECORAH SHALE AT ST. PAUL, MINNESOTA, William F. Rice	136
DISTRIBUTION AND SIGNIFICANCE OF CONODONTS IN MIDDLE AND UPPER ORDOVICIAN STRATA OF THE UPPER MISSISSIPPI VALLEY REGION, Walter C. Sweet	167
BRYOZOA FROM ROCKLANDIAN (MIDDLE ORDOVICIAN) ROCKS OF THE UPPER MISSISSIPPI VALLEY REGION, Olgerts L. Karklins	173
THE MIDDLE ORDOVICIAN CRINOID FAUNA OF THE TWIN CITIES AREA, James C. Brower	177
UPPER MISSISSIPPI VALLEY CHAMPLAINIAN AND CINCINNATIAN ECHINODERMS, Dennis R. Kolata, James C. Brower, and Terrence J. Frest	179
ORDOVICIAN PELECYPODS FROM THE UPPER MISSISSIPPI VALLEY, John Pojeta, Jr.	182
STRATIGRAPHIC RANGES OF MIDDLE AND LATE ORDOVICIAN GASTROPODA AND MONOPLACOPHORA OF MINNESOTA, Robert E. Sloan and Gerald F. Webers	183
BIOSTRATIGRAPHY OF THE MIDDLE AND LATE ORDOVICIAN CEPHALOPODS OF THE UPPER MISSISSIPPI VALLEY AREA, John A. Catalani	187
BIOSTRATIGRAPHY OF LATE ORDOVICIAN SOLITARY RUGOSE CORALS IN THE UPPER MISSISSIPPI VALLEY REGION, Robert J. Elias	190
TRACE FOSSILS FROM MIDDLE ORDOVICIAN PLATTEVILLE FORMATION, Kayo Dokken	191
DESCRIPTION OF MAJOR OUTCROPS IN MINNESOTA AND IOWA, Robert E. Sloan, Dennis R. Kolata, Brian J. Witzke, and Gregory A. Ludvigson	197
REFERENCES CITED	224
ORDOVICIAN TIME SCALE, Robert E. Sloan	232

The University of Minnesota is committed to the policy that all persons shall have equal access to its programs, facilities, and employment without regard to race, religion, color, sex, national origin, handicap, age, veteran status, or sexual orientation.

PREFACE

This report grew from conversations between Dennis Kolata and Robert Sloan at various Geological Society of America conventions starting several years ago. It became very apparent to both of us that there was a wealth of unpublished and unorganized data on lithostratigraphy and biostratigraphy of the Middle and Late Ordovician rocks of the Upper Mississippi valley region. It also became very apparent that organization of these data on a regional rather than state basis would lead to significant advances in understanding these rocks, their faunas, and relationships to those of other areas. The bed tracing that has been done makes it possible to pool the available paleontological data throughout the entire region, and recognize regional biofacies differences on a very precise chronological basis. This report is the first fruit of this regional study; more are in progress.

At the spring 1985 meeting of the North Central Section of the Geological Society of America, we decided to host a major symposium on these rocks, with accompanying field trips at the spring meeting in St. Paul, Minnesota, in 1987. We then solicited volunteers for a guidebook for the field trips; that guidebook grew beyond our anticipations into this report.

We have included many graphic sections with as much detail as possible. All were drawn at a scale of 1:48 and reproduced at a scale of 1:64. This scale is a useful one because architects scales and model railroad scales (S scale) are readily available in this proportion. An ordinary fractional inch scale can also be used to scale off measurements, $1/16$ inch on the drawing equals 4 inches on the outcrop.

The most complete faunal lists available for the region have been those of Stauffer and Thiel (1941) compiled by Stauffer, mostly

from the final reports of the Minnesota Geological and Natural History Survey. These lists are now 45 years out of date for most groups, and in any event did not take into account the data from other states in the region. In addition the stratigraphic intervals used for the old lists were based on an old, rather coarse subdivision, particularly of the Galena Group. The more recent works of Weiss, Templeton and Willman, Sloan, and Levorson and Gerk, have resulted in a traceable litho- and chrono-stratigraphic terminology of high precision. The stratigraphically controlled fossil descriptions of DeMott, Bayer, Weiss, Kolata, Webers, Rice, Swain, Brower, and Veinus, can now be extended throughout the region.

The inclusion of Webers' (1966) conodont study in Sweet's (1984) Composite Standard Section; and Kunk and Sutter's (1984) date on the T3 bentonite of Tennessee; and Kolata and others (1986) precise correlation of the T3 bentonite with the Deicke K-bentonite now permit absolute dating of all events within this region to a degree of precision never before contemplated.

The frontispiece figure is a summary of all these relationships and, with Figure 1.1, permits transposition of all terminology of any vintage to any other, and most particularly to the current Minnesota and Illinois classification. It will also permit estimation of absolute age to the precision of measurement of the most recent radioactive dates, ± 3 m.y. for an individual date, and ± 0.1 m.y. for the cluster of basal Rocklandian dates of Kunk and Sutter (1984). This figure shows the entire outcrop belt within which there has been detailed bed tracing. To use this figure, simply locate the horizon of any fossil or bed in the outcrop belt by inspection, trace beds (or proportionally between beds) to the Cummingsville or Rifle Hill section, and then horizontally to the time scales.

DEDICATION

This report is fondly dedicated to the four amateur paleontologists who have given most to the study of the Middle and Late Ordovician of the Upper Mississippi valley.

The first was Wilbur H. Scofield, 1840 to 1895, pharmacist, postmaster, teacher and city council member of Cannon Falls, Minnesota, who led Winchell, Clarke, Schuchert and Ulrich to the major fossil localities in southern Minnesota, and who, with Ulrich, wrote the major monograph on snails and monoplacs of this age.

The next was Frederick William Sardeson, 1866 to 1958, of Minneapolis. He graduated from the University of Minnesota in 1891, Phi Beta Kappa, discovered the St. Peter fossils and zoned the Ordovician of Minnesota that year, and received a masters degree in 1892. He received a Ph.D. degree from Freiburg in 1895, returned to the University of Minnesota as a Scholar in Paleontology, then Instructor, and rose to be Assistant Professor, but was dismissed because of personality conflicts with W. H. Emmons in 1914. He then took up a career as a consulting geologist, continuing to work on Ordovician problems until 1940 as his hobby. He published 50 papers between 1891 and 1914, and at least 95 more as an amateur. He amassed a large and very important personal collection of over 100,000 specimens, which was purchased for the University of Minnesota in 1947. Many of his papers are still worth reading, and we are by no means through working up the fruits of his collecting as you will see in reading this report.

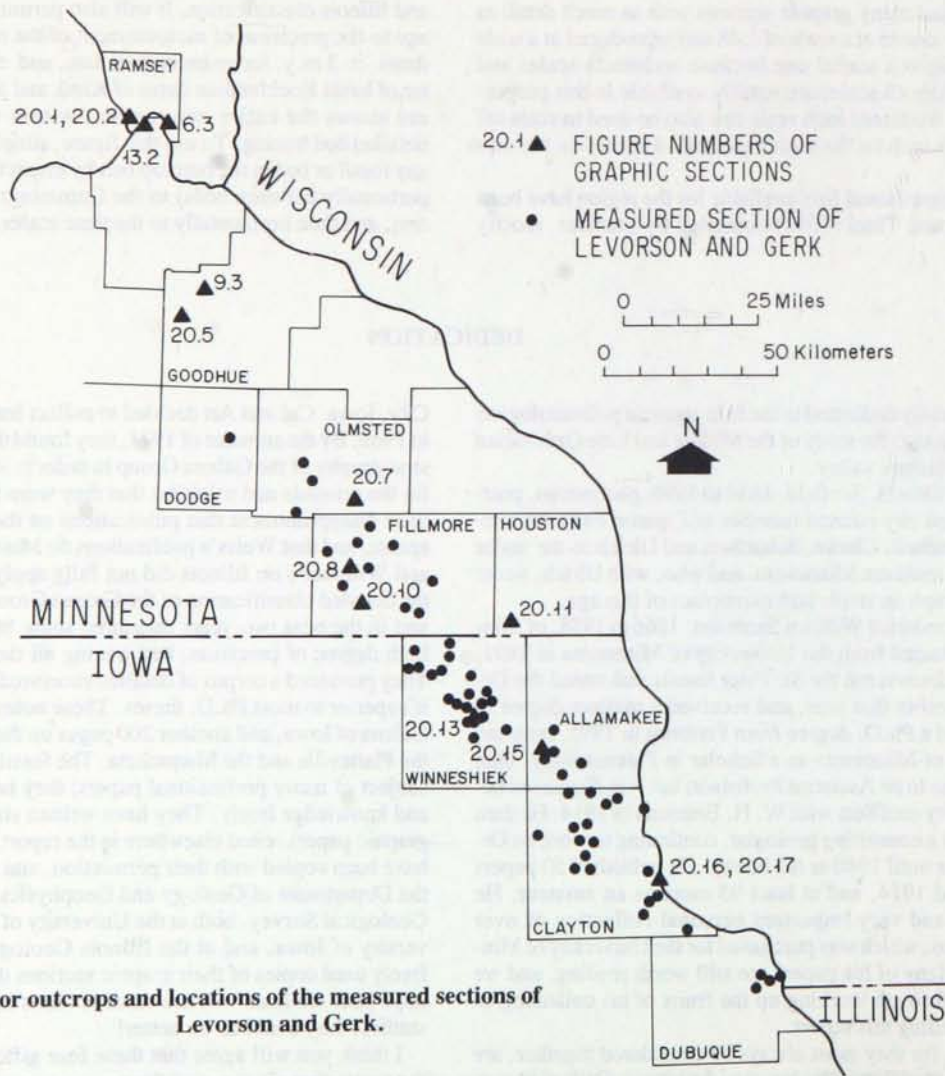
The latest pair, for they must always be considered together, are Calvin O. Levorson of Riceville, Iowa, and Arthur J. Gerk of Mason

City, Iowa. Cal and Art decided to collect fossils as a serious hobby in 1969. By the summer of 1971, they found they needed to know the stratigraphy of the Galena Group in order to locate the best localities for the crinoids and trilobites that they were finding. They found to their disappointment that publications on the Galena in Iowa were sparse, and that Weiss's publications on Minnesota, and Templeton and Willman's on Illinois did not fully apply to Iowa. They traced the detailed classification of the Galena Group of Illinois into Iowa, and in the next two years measured some 80 sections in Iowa at a high degree of precision, bed tracing all the way into Minnesota. They produced a corpus of detailed measured sections and notes that is superior to most Ph.D. theses. These notes total 600 pages on the Galena of Iowa, and another 200 pages on the Galena of Minnesota, the Platteville and the Maquoketa. The fossils they collected are the subject of many professional papers; they have shared their fossils and knowledge freely. They have written six very important stratigraphic papers, cited elsewhere in the report. Their important notes have been copied with their permission, and have been deposited in the Department of Geology and Geophysics, and in the Minnesota Geological Survey, both at the University of Minnesota, at the University of Iowa, and at the Illinois Geological Survey. We have freely used copies of their graphic sections throughout this report. I hope your students will use these sections as a model for their own studies, they could do no better!

I think you will agree that these four gifted amateurs deserve all the praise that we can give them.



Left to right, Frederick W. Sardeson, Calvin O. Levorson, and Arthur J. Gerk.



HISTORY OF STUDY OF THE MIDDLE AND LATE ORDOVICIAN ROCKS OF THE UPPER MISSISSIPPI VALLEY

Robert E. Sloan

Department of Geology and Geophysics
University of Minnesota, Minneapolis, MN 55455

Middle and Late Ordovician rocks of the Upper Mississippi valley have been studied since the 1850's. The history of development of the nomenclature of the Ordovician of the Upper Mississippi valley is summarized in Winchell and Ulrich, 1897, Weiss, 1957, Templeton and Willman, 1963, and Willman and Kolata, 1978, it will not be repeated here in total, except in the form of Figure 1.1. However, significant changes will be noted so that the stratigraphic position of old and important collections can be determined as closely as possible. A collection of handwriting samples of paleontologists directly concerned with Minnesota fossil collections is also shown in Figure 1.1 so that the approximate time of collection of fossils can be determined from the oldest labels. This, in turn, will permit determination of the probable stratigraphic usage at time of collection and the most likely horizon.

Figure 1.1 shows in tabular form the development of the Minnesota classification of these rocks, and the relationship of these units to those of Illinois. A following paper by Kolata discusses the development of the Illinois classification. The two major classifications occur because of significant facies differences due to proximity of the Minnesota rocks to the Transcontinental Arch in central Minnesota. The Iowa classification is more similar to that of Illinois, but has some other variants discussed in the paper by Witzke and the sections of Levorson and Gerk.

MINNESOTA STUDENTS OF THE ORDOVICIAN ROCKS OF THE UPPER MISSISSIPPI VALLEY

Newton Horace Winchell was the first competent state geologist of Minnesota (two had been appointed earlier with unfortunate consequences), and the first to study all the Ordovician of Minnesota. Hired in 1872 for the Minnesota Geological and Natural History Survey, he began teaching at the University in 1873 and founded the Department of Geology in 1874. Ordovician rocks were described as part of a program of county reports with maps at a scale of 1/4-inch to the mile. I have found these maps commonly better in Ordovician geology than those published in the 1930's. Winchell was responsible for assembling the team of the amateur Wilbur H. Scofield and professionals Edward O. Ulrich, John M. Clarke, and Charles Schuchert, who wrote the magnificent monographs that appeared as Volume III part I (1895) and part II (1897) of the *Geology of Minnesota*. This major publication is the basis for much of our current paleontology on Ordovician snails, clams, brachiopods, bryozoans, trilobites, sponges, cephalopods and ostracods. Winchell, with Schuchert, described many of the Ordovician brachiopods. In addition to being the State Geologist, and a Professor at the University of Minnesota, Winchell founded the *American Geologist*, in which a number of critical papers on Minnesota geology and paleontology were published. On his death, it was sold to Charles Rollin Keyes of Des Moines, Iowa, and the name was changed to *Pan-American Geologist*. It was where Sardeson published most of his papers after 1914.

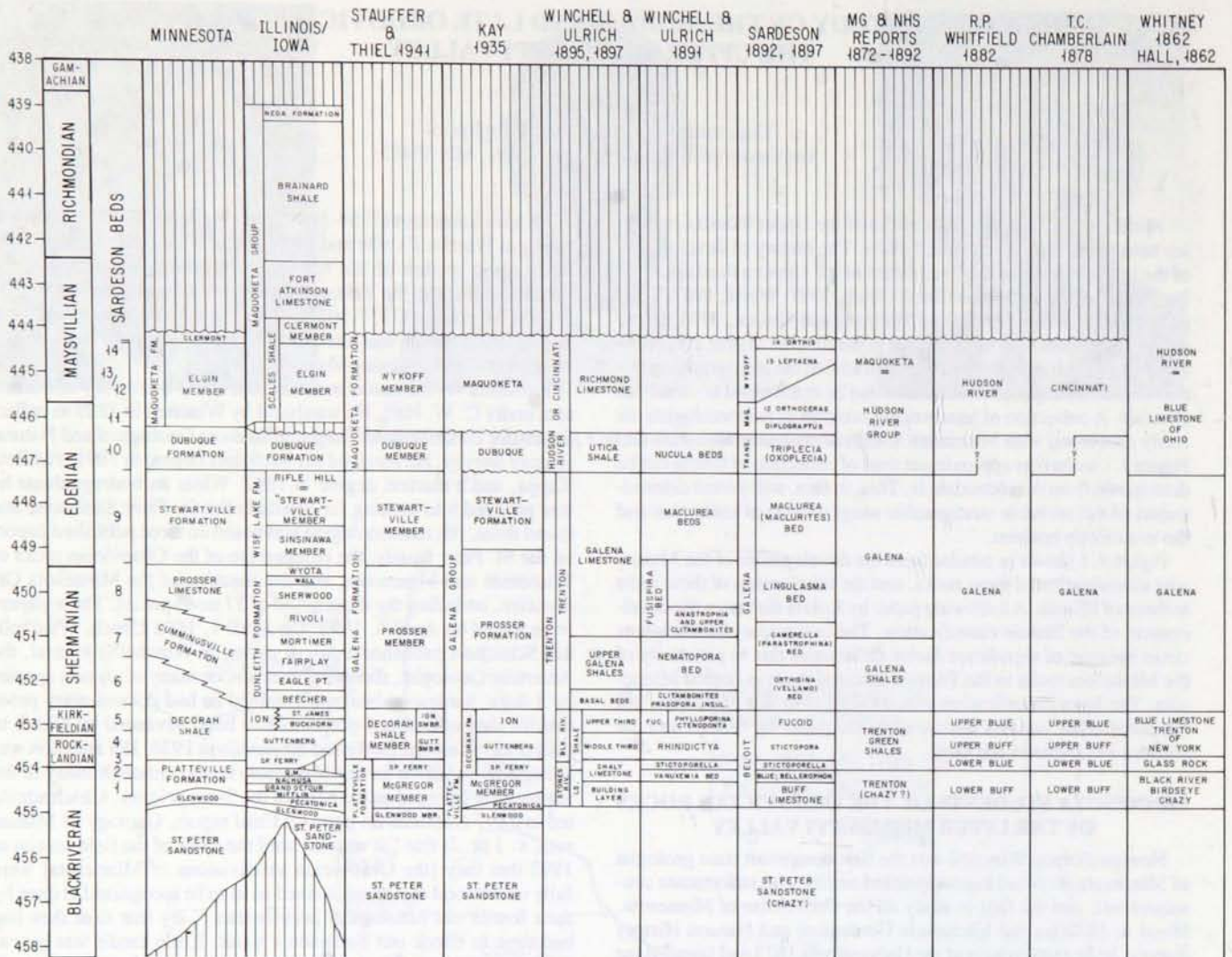
Edward Oscar Ulrich (1857-1944) was employed by Winchell from 1886 to 1897 as a paleontologist and wrote the monographs on sponges and corals, ostracods, bryozoa, and with Scofield, the snails, that appeared in *Geology of Minnesota*, v. III, parts 1 (1895) and 2 (1897). Most of the writing was complete by 1891. Many of the type and figured specimens went to the U.S. National Museum with Ulrich.

Charles Schuchert (1858-1942) was originally Ulrich's assistant, then was Winchell's aide and with Winchell was responsible for the brachiopod section of the Minnesota monographs. Many of the specimens went to the Yale collections when Schuchert left.

John M. Clarke (1857-1925) of the New York Survey and New York State Museum was hired by Winchell to write the monographs on trilobites and cephalopods.

Frederick W. Sardeson was a student at the University of Minnesota under C. W. Hall. He was hired by Winchell in 1889 to collect fossils for C. D. Walcott for the Minnesota Geological and Natural History Survey. He received his bachelors degree in 1891, Phi Beta Kappa, and a masters degree in 1892. While an undergraduate he was prodded into looking for fossils in the St. Peter Sandstone and found them. His masters degree was based on three published papers on the St. Peter fossils, the comparison of the Ordovician rocks of Wisconsin and Minnesota, and the zonation of the Minnesota Ordovician, including the description of 37 new species. These papers were issued on April 6, 1892. On April 1, 1892 Ulrich, Winchell, and Schuchert published a pair of papers in Winchell's journal, the *American Geologist*, scooping Sardeson on many of his new species by 5 days. Sardeson always maintained he had documentary proof that the date of authors' preprints had been advanced by Ulrich to gain priority, and he published the details in 1926. His zonation was taken over by Ulrich for the Minnesota strata, although many of the names were changed on the basis of the 5-day priority. Ulrich admitted in 1897 (footnote on page C, Final report, *Geology of Minnesota*, v. 3 pt. 2) that "it was not until the close of the field season of 1892 that they [the Ordovician subdivisions of Minnesota] were fully understood and characterized so as to be recognized at once by their fossils and lithological peculiarities." By that time they had had time to check out Sardeson's work. Little credit was given. Sardeson was appointed a graduate assistant at the University of Minnesota from 1892 to 1894, then went to Freiburg for a Ph.D. On returning to the University in 1895, he was appointed a Scholar in Paleontology, and an Instructor in 1889, rising to the rank of Assistant Professor in 1905. His work was extremely good by any standards; he published more than anyone else in the department. Under the new administration of the autocratic W. H. Emmons, his contentious personality led him to be fired in 1913, effective 1914, having published 50 papers. He then worked for the Minnesota State Securities Commission as a geologist making field investigations of mining and oil securities until 1934. He continued to study the Minnesota Ordovician as an amateur, publishing at least 95 more papers until 1940, mostly in the *Pan-American Geologist*. In my opinion, his work was superior to that of his successor: he was far more prolific and his work has lasted longer. He anticipated many of the conclusions of this report, in papers that the past two generations of paleontologists have ignored, I suspect mainly because they were published in Keyes' idiosyncratic journal.

Clinton R. Stauffer was hired to replace Sardeson in 1914 and remained until his retirement in 1944. He wrote nine papers on paleontology and stratigraphy while here, of which the only sizable and lasting contribution was "Paleozoic and Related Rocks," *Minnesota Geological Survey Bulletin* 29, written with George A. Thiel in 1941. Stauffer was responsible for most of the measured sections. These are difficult to use, and all too often he misidentified the formation at a locality by as much as 300 feet vertically. The effect on the 1935 geologic map of Minnesota was interesting, to say the



GENERAL MUSEUM, UNIVERSITY OF MINNESOTA. (GEOLOGICAL COLLECTION.)

NAME: *Rhynchotrema ainsliei*

FORMATION: *Winchell*

SPECIALTY: *Ordovician shales*

LOCALITY: *Minneapolis*

REGISTER No. 324

COLLECTOR: *N.H. Winchell*

GEOLOGICAL AND NAT. HIST. SURVEY

THE GENERAL MUSEUM, UNIVERSITY OF MINN. (GEOLOGICAL COLLECTION.)

NAME: *Rhynchotrema ainsliei*

FORMATION: *Winchell*

SPECIALTY: *Ordovician shales*

LOCALITY: *St. Lawrence*

REGISTER No. 8207

COLLECTOR: *F.M. Swain*

GEOLOGICAL AND NAT. HIST. SURVEY

Orthisina americana

Clitambonites *Whitf.*

Orthisina bed

F. W. Sardeson

Geol. and Nat. Hist. Sur. of Minn.

PREPARED BY *E.O. Ulrich*

Finkelburgia?

St. Lawrence dol.

St. Lawrence

W. C. Bell

THE UNIVERSITY OF MINNESOTA PALEONTOLOGICAL COLLECTION

Name: *Rhynchotrema ainsliei*

Formation: *Winchell*

Locality: *St. Lawrence*

How Obtained: *M.S. of S. Coe.*

C. R. Stauffer

Types

Green River

+ Eagle Spring

Orthisina

Atal

Cole

Swain

Collected by *D. WALLACE*

Spring 63

Campus

R. E. Sloan

Figure 1.1. History of nomenclature for the Ordovician strata of the Upper Mississippi valley and samples of handwritten collection labels.

least. Whenever he met what is now the Cummingsville Formation he would misidentify it, usually as the Prosser, sometimes as the Ion, occasionally as the Stewartville, and once as the Dubuque. Many of his sections were pieced together with a plane table, although no comment to that effect was ever made. They are always interesting to interpret. He assembled a species list of all taxa recorded for each formation in the state, and collected many choice fossils. He had a total of seven graduate students, four of whom, including his niece, received Ph.D.s.

Frederick M. Swain was hired in 1946 to replace Stauffer, as a micropaleontologist-stratigrapher. Most of his work has been on ostracods from outside of Minnesota. His Ordovician work locally was supervising theses on the subsurface Ordovician of northwestern Minnesota by Thomas N. Bayer (1959), bryozoans by Olgerts Karklins (1966), and ostracoda by Donald Hansen (1951), James Cornell (1956), and John Burr (1958), and is summarized elsewhere in this report.

W. Charles Bell was the fourth paleontologist at the University of Minnesota. He was hired in 1946 with Swain, but left to go to the University of Texas in 1953. Most of his work was on the Minnesota Cambrian while at Minnesota. His main contributions to the study of the Minnesota Ordovician were advising Malcolm P. Weiss's Ph.D. thesis and Otto P. Majewski's 1953 masters thesis on the Platteville of the Twin Cities basin. He was also responsible for purchasing Frederick W. Sardeson's personal collection of fossils, including many of his type specimens, in 1947. This immediately doubled the size of the Ordovician collections at the University of Minnesota, and provided a wealth of very fine specimens with much more adequate horizon data than any of the Winchell or Stauffer collections.

Malcolm P. Weiss was a student of W. Charles Bell, and did his thesis field work in 1950 and 1951 as the first of Bell's planned campaign to redescribe the Minnesota Ordovician. He received his Ph.D. degree in 1953 with what was up to that time the largest thesis in the history of the department. The thesis was published as a series of five papers between 1954 and 1957; the unpublished part was the detailed description of most of his more than 60 measured sections and the precise locations and horizons of his fossils. These unpublished data are on file at the Minnesota Geological Survey and in the reading room of the Department of Geology and Geophysics, University of Minnesota, and should be consulted by any serious student of these rocks. The thesis remains one of the most important documents in Ordovician paleontology and stratigraphy. Weiss's map was the best geologic map that could be made in the absence of topographic maps, and he greatly improved on the old zonation of these rocks. He named two new units and formally defined the old stratigraphic names from the Winchell era. The culmination of these works was the 1956 GSA guidebook for Southeastern Minnesota and Iowa, assembled by Sloan, Weiss, Agnew, and Bell (Schwartz and others, 1956).

Robert E. Sloan was introduced to Minnesota geology by W. Charles Bell. I was his teaching assistant in a field geology course in southeastern Minnesota for 1 week in the summer of 1953, just before I replaced him as the macroinvertebrate paleontologist. It was very apparent that little more needed to be done on the Cambrian of Minnesota, and that the most productive use of my time was to continue his planned campaign on the Ordovician and to reinvestigate the Minnesota Cretaceous. Bell and Weiss had demonstrated the traceability of what are now called the Deicke and Millbrig K-bentonites. I observed that the limestone and shale interbeds between them could also be traced between St. Paul and McGregor, Iowa, and began work on the Platteville. Bell had pointed out the failings of Stauffer and Thiel (1941), so I began mapping in the Rochester region for the Minnesota Geological Survey. With no immediate money for publication, my mapping program expanded to all of southeastern Minnesota, and finally was published as the St. Paul Sheet (Sloan and Austin, 1966). Meanwhile, my graduate students

worked on Platteville bed tracing (Ford, 1958; Hoeft, 1959) the Maquoketa (Bayer, 1965, 1966, 1967), and Ordovician conodonts (Thompson, 1959; Anderson, 1959; Webers, 1961, 1966). The unpublished data were summarized by me in 1972, in a paper based on 75 sections measured in detail in Minnesota, at an average spacing of 5 km (3 miles). It demonstrated that all the beds of the Platteville could be traced over a distance of 300 km (200 miles) from St. Paul to McGregor, Iowa.

Preston Cloud joined the Department of Geology and Mineralogy in 1961 as professor and chair, but had little impact on the Ordovician collections or paleontology, spending all his time on administrative matters and Precambrian paleontology. He left in 1965.

Thomas N. Bayer described the subsurface Winnipeg and Red River Formations of northwestern Minnesota in 1959, and the unusual repetitive faunas of the Maquoketa in Minnesota in a 1965 Ph.D. dissertation, published in 1967. J. Keith Rigby, Sr. and Thomas N. Bayer described some additional species of the unique Maquoketa sponge fauna in 1971.

T. Donald Wallace was a retired Lieutenant of the St. Paul police department, and a knowledgeable commercial collector of fossils. He was hired by Cloud as curator of paleontology in 1963, and reorganized the University of Minnesota fossil collection to its present form. The collections had been housed in six separate locations in Pillsbury Hall in a variety of antiquated wooden cabinets; they are now housed together in modern bug and dust proof cabinets. He added greatly to the collections in the process of reorganizing them by donating rare and unusual specimens from his own collections. He retired in 1975.

John H. Mossler has published studies of the K-bentonites (Mossler and Hayes, 1966), on subsurface mapping of Paleozoic rocks, on sedimentation and diagenesis in the Platteville of Minnesota (1985), and on the general classification of the Paleozoic rocks of Minnesota (Mossler, 1987).

OTHER SIGNIFICANT STUDENTS OF THE ORDOVICIAN ROCKS OF THE UPPER MISSISSIPPI VALLEY

I do not list all non-Minnesota students of these rocks, only those whose studies bear on the classification of Minnesota rocks; omission does not mean unimportant.

Allen F. Agnew studied the Middle and Late Ordovician rocks of Iowa from 1945 to 1947, and received his Ph.D. in 1949, publishing it in 1955. His work was the first of the major post-war studies of Ordovician rocks of the Upper Mississippi valley, and was of seminal importance in the development of the others.

Simultaneously with the Bell-Weiss campaign, a similar campaign was mounted by the Illinois Geological Survey. Paul Herbert, Jr., did a Ph.D. thesis on the Decorah Shale in 1949. J.S. Templeton and H. B. Willman studied the balance of the Middle Ordovician. Their work was published as a guidebook in 1952, but not as a formal publication until 1963. Their main contribution was the development of a system of formations and members for the Galena and Platteville that subdivided these units, previously of formation rank but now raised to the level of groups. These members could be recognized over large areas and greatly eased the problem of mapping and identification of short local sections.

In 1952 H. B. Whittington of Harvard and J. S. Templeton of the Illinois Geological Survey made extensive collections of Platteville and Decorah trilobites from northern Illinois and southeastern Wisconsin. These collections lay fallow until the late Lawrence L. DeMott undertook them in 1955 and added more specimens to them. This developed into DeMott's Ph.D. dissertation (1963) which was very influential even though not published. The revised thesis is included in this volume.

Calvin O. Leverson of Riceville, Iowa, and Arthur J. Gerk of Mason City, Iowa, a pair of very energetic amateurs, began to collect

6 • HISTORY OF STUDY

trilobites and crinoids from the Galena Group in northeastern Iowa in 1969. They found few publications with any detail, and determined that much more detailed stratigraphy was necessary to locate crinoid beds. They began tracing the Templeton and Willman Galena Group members and Weiss's Minnesota units into Iowa. Between July 1971 and 1972, they showed that the Templeton and Willman units were traceable throughout the Iowa outcrops (Levorson and Gerk, 1972a, b, 1983; Levorson and others, 1979). By 1974, they had measured 62 Galena sections and had accumulated 600 pages of typed notes on detailed measured sections, fossil collections, and graphic sections at a scale of 1:48. They continued to add another 200 pages of notes on 20 Minnesota sections, and on several Platteville and Maquoketa sections. This field work is of fully professional quality. Except for the papers cited, this corpus of work remains largely unpublished, although the fossils from their collections have been the source of several papers on echinoderms.

With their permission, copies of their work have been filed with the University of Iowa, the Illinois Geological Survey, and the Department of Geology and Geophysics and the Minnesota Geological Survey, at the University of Minnesota. This material should be consulted by any serious student of these rocks. Some extracts are included in this report.

Dennis R. Kolata grew up in Rockford, Illinois, and as a young amateur, he made many collections of fossils from the surrounding area. As a professional, he has published important papers on the echinoderms (1973, 1975, 1977, 1986), on the revision of the Templeton and Willman units (Willman and Kolata, 1978), the Maquoketa of Illinois (Kolata and Graese, 1983), and the detailed bed tracing of K-bentonites from their source near Birmingham, Alabama, to the Ozarks and Minnesota (Kolata and others, 1986, and earlier).

TECTONICS, BIOSTRATIGRAPHY AND LITHOSTRATIGRAPHY OF THE MIDDLE AND LATE ORDOVICIAN OF THE UPPER MISSISSIPPI VALLEY

Robert E. Sloan

Department of Geology and Geophysics
University of Minnesota, Minneapolis, MN 55455

ABSTRACT

The Deicke K-bentonite, by correlation with the T-3 ash bed of Tennessee is 454.2 Ma in age (Kunk and Sutter, 1984; Kolata and others, 1986; Samson, 1986). The Deicke K-bentonite is a major provincial extinction event. At the species level, the conodont extinction was 10%, the brachiopod extinction was 39%, the gastropod extinction was 80%, trilobite extinction was 90% and the echinoderm extinction was 100%. This appears to be the Black River-Trenton boundary. The level of generic extinction is much lower. A second major extinction at a level of about 90 percent, took place during the lower part of the Stewartville Dolomite (Sinsinawa strata) during about 0.8 m. y., as a result of shoaling from 50 m depth to about 5 m depth.

Absolute ages of the regional Middle and Late Ordovician and all other strata with a CSS number can be calculated by virtue of the inclusion of Webers' (1966) Cummingsville and Rifle Hill sections in Sweet's (1984) Composite Standard Section; and the detailed bed tracing of the past three decades of all Middle and Late Ordovician strata between St. Paul, Minnesota and Rockford, Illinois; the age of the Deicke; and the age of the Ordovician-Silurian boundary. Duration of the Upper Mississippi valley column is 17 m. y. Absolute standing crop of plankton of these seas ranged from 0.1 to 12.5 kg per sq m, based on the quantitative plankton kill beneath the Deicke and the conodont abundance index measured for the entire section. This index (conodonts per 100 gm of sediment) in turn correlates precisely with inferred height of the Transcontinental Arch. Depths of deposition of these rocks varied from 2 to 50 m (6 to 160 feet); bottom slopes were negligible throughout the region. Abundant clams, bryozoa and *Isotelus* represent the shallow end. *Ischadites* and *Dolichoharpes* the deeper end of this spectrum. Rate of deposition averaged 12.6 mm per 1000 years.

Differences between the Illinois and Minnesota classifications of Mohawkian and Cincinnati rocks are due to tectonic reasons dating from the Proterozoic. The Transcontinental Arch in Minnesota is the Great Lakes Tectonic Zone (GLTZ), a suture between two Archean terranes. Southeastern Minnesota Paleozoic rocks were de-

posited in the Keweenaw rift valley/Midcontinent Geophysical Anomaly which persistently subsided throughout the Middle and Late Ordovician; deposition was continuous. Illinois rocks were deposited on the flanks of the Wisconsin Arch and have minor unconformities due to eustatic sea level fluctuations and local uplifts which coincide in time with pulses of uplift of the GLTZ. Detailed bed tracing over the 540 km between St. Paul, Minnesota and LaSalle, Illinois permits precise extension of local zones based on conodonts, ostracods, bryozoa, brachiopods, mollusks, echinoderms and trilobites over the entire region. By virtue of Sweet's (1984) CSS this zonal synthesis can be extended to the rest of the continent with a high degree of precision. Croixan sandstones stripped off the GLTZ were the source of the Blackriveran St. Peter Sandstone and basal Winnipeg Formation. The Decorah and Cummingsville Formations were formed from sediments eroded from the underlying Proterozoic shales and were deposited 40% faster in the Twin Cities than at the Iowa-Minnesota state line. A 300-m uplift of the GLTZ at the beginning of the Rocklandian produced the Decorah Shale-Cummingsville Formation wedge in Iowa and Minnesota simultaneously with a 0.8-m. y. unconformity in northern Illinois, and the upper part of the Winnipeg Formation in the Williston basin. The Prosser to Fort Atkinson Formations correlate precisely with the Red River Dolomite of the Williston basin. The Transcontinental Arch was completely submerged during the deposition of the Prosser and Stewartville formations, but was again uplifted to form the source of the siliciclastics of the Dubuque Formation and at least some of those of the Maquoketa Formation. During this uplift, the 0.09-m. y. unconformity beneath the depauperate zone was produced in Illinois and Iowa. Uplift of the GLTZ appears to have had a short periodicity of from 35,000 to 70,000 years based on the cyclicity of clay content in the Cummingsville Formation, and roundness in the St. Peter Sandstone. A longer periodicity of from 0.20 to 0.37 m. y., with a mean period of 0.30 m. y., is also evident from the cyclicity of the abundance of conodonts in the Cummingsville section and the longer cycles of roundness in the St. Peter Sandstone.

MIDDLE AND LATE ORDOVICIAN ROCK UNITS OF MINNESOTA AND ILLINOIS

The Illinois Galena Group members and Platteville Group formations are traceable time/rock units bounded by traceable beds, and recognizable over large areas. However, due to facies changes, they are not the first-order mapping units in Minnesota. The experience gained in mapping fifteen 15-minute quadrangles showed me that the Middle and Late Ordovician mappable units in Minnesota are the St. Peter Sandstone, Glenwood shale, Platteville limestone, Decorah Shale, Cummingsville shaly limestone, Prosser Limestone, Stewartville dolomite, Dubuque shaly limestone and Maquoketa shaly dolomite. Detailed lithic descriptions are included in chapter 20. Recently, on my recommendation, the Minnesota Geological Survey raised Weiss's Galena members to formation rank and the Galena to group rank in Minnesota (Mossler, 1987). This brings the Minnesota classification of Ordovician rocks closer to that of the surrounding states.

There are good and sufficient reasons for the remaining differences between the Illinois and Minnesota classifications. In Illinois, the main problem is that the Platteville and Galena Groups form a monotonous sequence of carbonates 100 m (330 feet) thick. Determination of stratigraphic position in this sequence requires the definition of many time/rock units differentiated on the basis of key horizons of ash beds, variations in clastic content, hardgrounds, small disconformities, and a few distinctive fossils. In Minnesota, on the other hand, the proximity of the Transcontinental Arch introduced more siliciclastic sediment to the carbonate sequence. The proportion of siliciclastics to carbonate varies much more in the 200 km (125 miles) from St. Paul to Iowa, than from northern Iowa to southern Illinois. Minnesota rocks were deposited in a tectonic basin; no unconformities exist in the Minnesota sequence, and the thickest pure carbonate sequence is only 40 m (130 feet) thick. The rock units are alternately carbonate and siliciclastic defined and are very obvious.

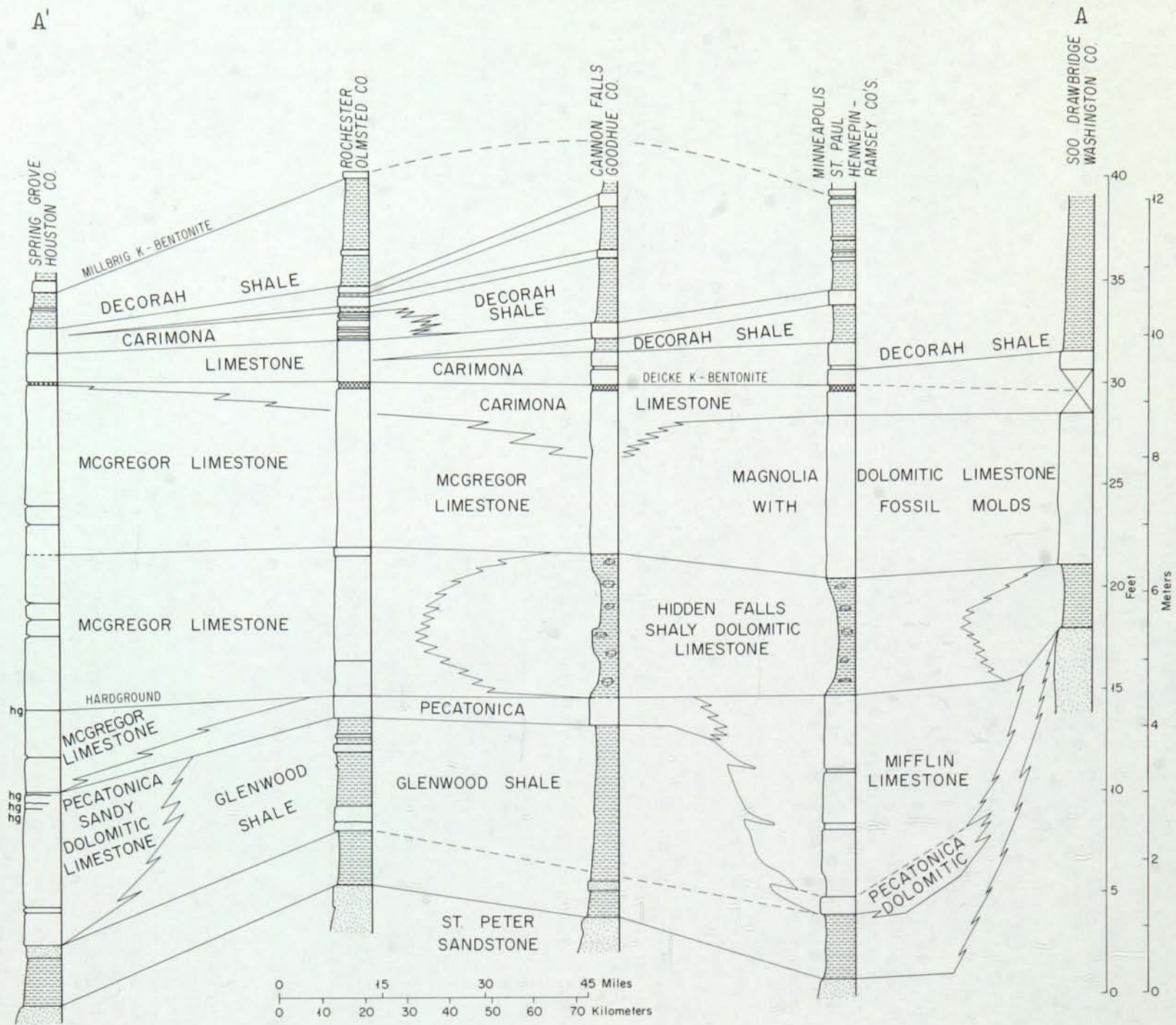


Figure 2.1. Bed tracing of the Plattville Formation between St. Paul and Spring Grove, Minnesota (modified from Sloan, 1972).

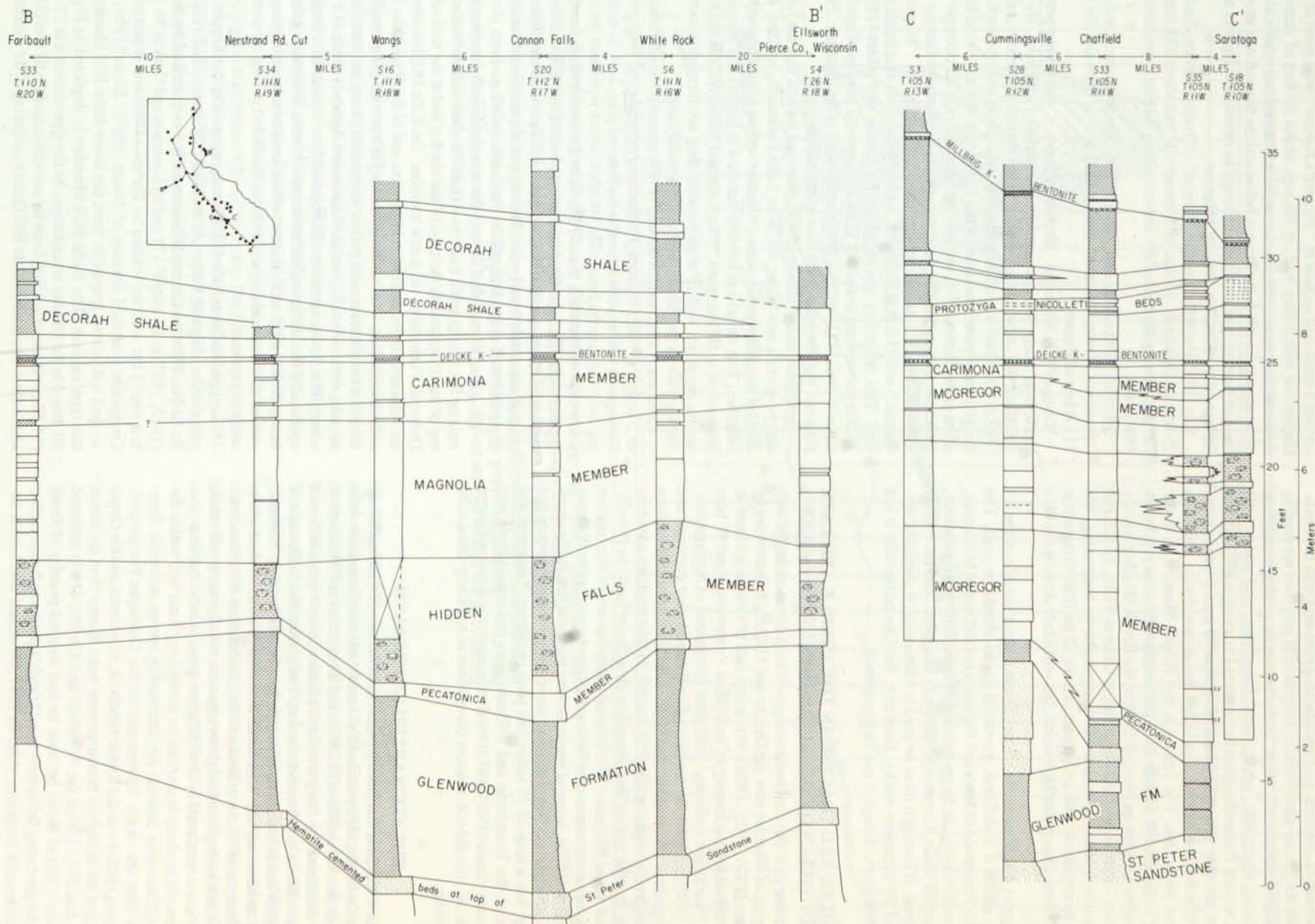


Figure 2.2. Bed tracing of the Platteville Formation between Ellsworth, Wisconsin, and Faribault, Minnesota, and between Saratoga and Cummingsville, Minnesota (modified from Sloan, 1972).

In Minnesota, the rock unit boundaries associated with the Decorah Shale wedge are diachronous; for practical purposes we need to use a strictly rock classification. Such reasons for geologic mapping as highway aggregate, agricultural limestone, and water-well drilling require that rock names be restricted to a single lithic type as much as possible. The Illinois members can be traced into Minnesota as time/rock units (and should be), but do not always remain in the same formation. For example, the Rivoli Member is in the Prosser Limestone at the hamlet of Cummingsville. Due to a facies change involving the increase of clastics, the Rivoli Member is at the top of the Cummingsville Formation at Cannon Falls, 75 km (50 miles) to the northwest, but it is still recognizable by bed tracing. We are not by any means able at this time to trace all the Illinois members of the Galena Group into Minnesota, but will likely do so in the next decade.

I suggest that if someone wishes to use a name outside of the region in which it is defined, quotation marks should be used. The Dunleith Formation of Iowa and Illinois is not defined in Minnesota, but its equivalents can be recognized in three different formations, the Decorah Shale, Cummingsville shaly limestone, and the Prosser Limestone. If Dunleith must be used in Minnesota, it should be surrounded by quotation marks. Similarly, the Cummingsville is not defined in Iowa, though it can be recognized.

DETAILED BED TRACING IN THE MIDDLE AND LATE ORDOVICIAN OF THE UPPER MISSISSIPPI VALLEY

In Minnesota, detailed bed tracing over long distances began with the tracing of what are now the Deicke and Millbrig K-bentonites by Sardeson (1924, 1925, 1926). Weiss and Bell (1956) traced these in detail and added the tracing of individual "corrosion zones," later called "corrosion surfaces," still later recognized as hardgrounds. Sloan (1972) added the tracing of individual clay partings and coarse-grained calcarenites, based on 75 detailed measured sections at 5-km (3 mile) spacing (Figs. 2.1 and 2.2). His students added insoluble residue curves and conodont abundance logs. In Illinois, Templeton and Willman (1963) traced many features of this type but came to some erroneous conclusions that were corrected in Willman and Kolata (1978), because sections were too far apart. In my experience, a 3-mile spacing of sections leaves little room for error in bed tracing, but a leap of 70 miles can pose problems. Levorson and Gerk took the Templeton and Willman units and traced them into Minnesota. Stone (1980, 1983) tried to increase the detail of Galena bed tracing, but did not measure his sections in sufficient detail to be convincing.

THE STEWARTVILLE PROBLEM

Since 1963 there has been a problem in the use of the term Stewartville Dolomite. After some 45 years of varied and imprecise definition of this term, Weiss in 1957, and Templeton and Willman in 1963, redefined the Stewartville Dolomite in two quite different fashions: Weiss's is more inclusive; Templeton and Willman's is less so. What is more confusing is that Templeton and Willman named another unit the Wise Lake Formation, which was an absolute synonym of Weiss's Stewartville. Differences between stratigraphic terminologies of neighboring states usually can be tolerated, but the same term used in very different ways is unacceptable.

There are no sharp demarcations in lithology from well within the Prosser Limestone through the intervening orange dolomitic limestones into the shaly limestones of the Dubuque Formation. Sardeson (1892c) was the first to subdivide these units into his Opel zones, but his thickness measurements were thinner than the actual rocks. In 1897, Ulrich (in Winchell and Ulrich, 1897) renamed Sardeson's Opel zones because he had wrested priority of fossil names by predating Schuchert's and Ulrich's preprints 5 days earlier than Sardeson's preprints. Also in 1897, Winchell and Ulrich de-

scribed a measured section in "Prosser's Ravine" with most of the Galena, in which they had, at the top, about 50 feet of massive dolomitic limestone with *Maclurea*. Ulrich named two subdivisions of these rocks in 1911, the Prosser below and the Stewartville above, without naming type localities, although he mentioned a quarry near Stewartville, as well as Prosser's Ravine.

Kay (1935b) redescribed the "Prosser's Ravine" section, finding 15 feet of Dubuque, 60 feet of Stewartville and about 134 feet of Prosser, placing the base of the Stewartville at the first appearance of *Maclurina*.

Stauffer in Stauffer and Thiel (1941) again redescribed the "Prosser's Ravine" section, listing 54.3 feet of Stewartville and 111.4 feet of Prosser.

Weiss (1957) relocated "Prosser's Ravine" (no living person knew it as such; the current name is Mahood's Creek). He described this section in far greater detail than any previous author (Fig. 20.8), noted a gradual transition throughout the section from the generally pure limestone of the Prosser, to the dolomitic limestone of the Stewartville, and into the crinoidal pure limestone of the Dubuque. He proposed a definition of the Stewartville that put the more dolomitic units together, totalling 85 feet at "Prosser's Ravine" and 75 feet at Rifle Hill, which by then was a far better section. This definition was seconded by Agnew and others (1956). This is the working definition of the Stewartville used in Minnesota since Weiss (1953) and it is firmly entrenched in the literature. From personal experience it is the first-order mapping unit.

Templeton and Willman (1963) proposed instead that the larger unit be given a new name, the Wise Lake Formation, and that it be divided into a lower Sinsinawa Member and an upper Stewartville Member. This definition became standard in Illinois and is equally entrenched in the literature. Wise Lake and Stewartville in the Minnesota sense are widely used because they are formation names. Stewartville in the Illinois sense is less widely used.

Levorson, Gerk, and Broadhead (1979) named three subdivisions or "beds" of the Dubuque Formation, lowering the base of the Dubuque to a distinctive traceable marker bed (Fig. 2.3). In ascending order they are the Frankville Member, which represents the transition interval between the old Stewartville (either sense) and the typical Dubuque; the Luana Member, which has thick shale interbeds in Minnesota; and the Littleport Member, which includes the gradual transition from typical Dubuque shale and limestone to the Elgin Member of the Maquoketa Formation in Minnesota.

The solution proposed here to this nomenclatural dilemma is to rename the stratigraphic interval—from the corrosion surface at the top of the Sinsinawa to the base of the marker bed at the base of the Dubuque Formation—as a new member, the Rifle Hill Member of the Stewartville Formation in Minnesota and of the Wise Lake Formation in Illinois. This will replace the Stewartville Member of the Illinois classification, and permit Minnesota to use the term Stewartville, without confusion, in Weiss's and Agnew's sense as it has since 1953. At the same time Illinois will have a term that cannot be confused with a different but homonymous unit. Both states gain the best possible type section, one which has been more thoroughly studied than most others, and with the likelihood of long-term continuity of exposure.

The type locality is Rifle Hill Quarry, operated by the Kapper Aggregate Co. of Spring Valley, in the NE¹/₄NW¹/₄ sec. 35, T. 102 N., R. 12 W., Fillmore County, Minnesota. It was described by Weiss (1953, 1957) as locality F-171 and by Levorson and Gerk as M-106. It is one of the sections studied by Webers (1966) and is part of the Composite Standard Section of Sweet (1984). Sloan (1959) described a dendroid graptolite from the lower Rifle Hill Member at the type section. The Rifle Hill Member is depicted in Figure 20.10a-d in the chapter on outcrops. At the type section it is 37' 11" (11.56 m) thick, extending from the corrosion surface 69 feet (21 m) above the water level in Rifle Hill Quarry, at the top of the Sinsinawa

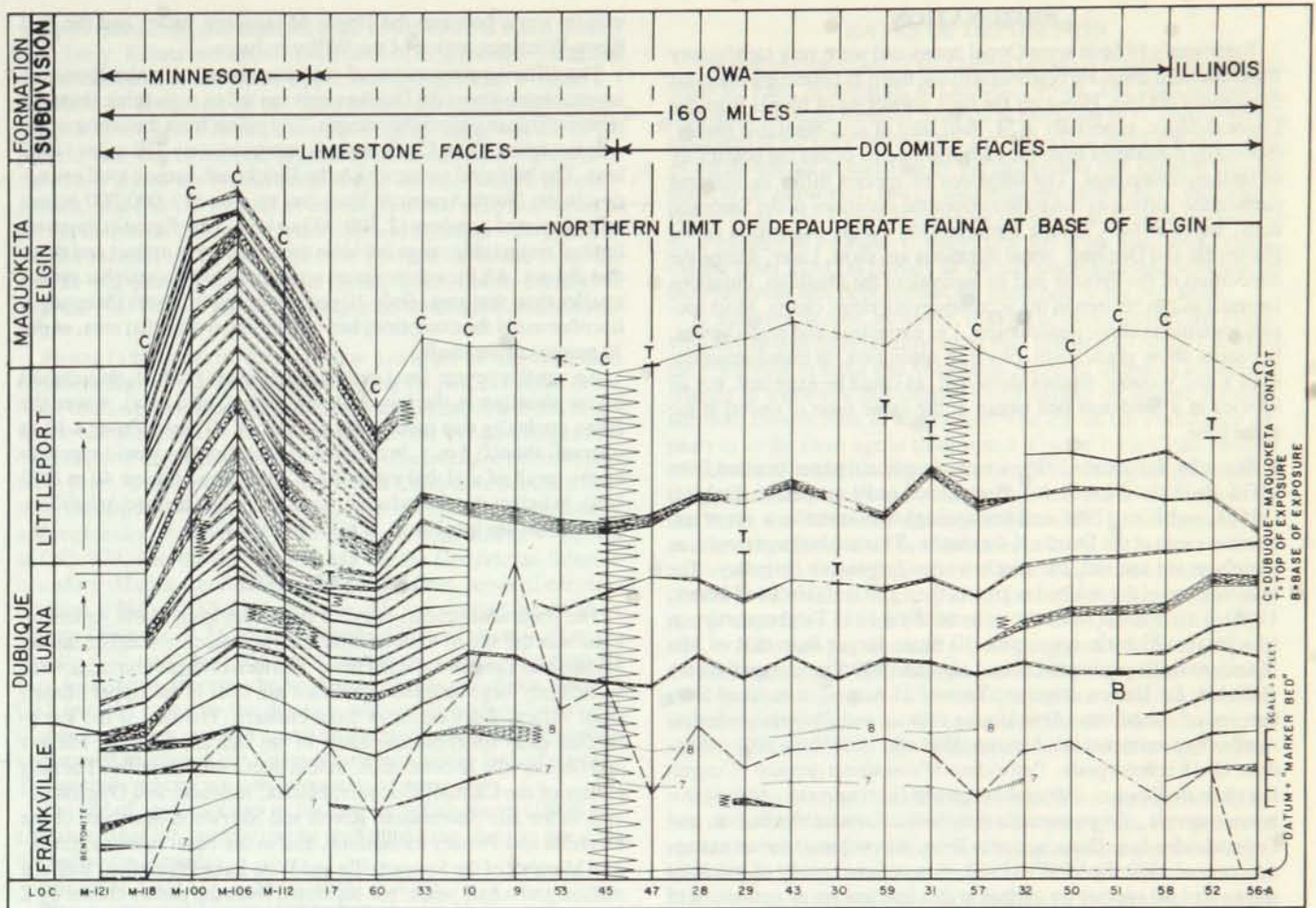


Figure 2.3. Bed tracing of the Dubuque Formation between Spring Valley, Minnesota, and Galena, Illinois (from Levorson and others, 1979). Base line conforms to base of the "marker bed". Symbols: XXX—bentonite beds; vertical hachures numbers 7 and 8—sparry calcarenite bands; heavy dashed line—lowest shale parting in alternating carbonate and shale beds used as datum for base of the Dubuque Formation by previous authors. (Note that prominent shale beds occur below this datum (e.g. loc. 9) but are not within the alternating carbonate and shale units.)

Member, to the base of the marker bed at the base of the Frankville Member of the extended Dubuque of Levorson and others (1979) at 106' 11" (32.60 m) above the water surface. Like the Sinsinawa, it has the Swiss-Cheese weathering surface which is the result of differential dolomitization of bioturbated lime muds and is so very characteristic of the Minnesota Stewartville. The Rifle Hill Member includes the portion of the Stewartville with abundant *Maclurites* that is poorest in numbers of fossils and taxa. The *Paleosynapta flaccida* zone occurs in the upper part of the member and extends upward into the basal Frankville Member. The upper *Receptaculites* zone extends from the top of the Sinsinawa Member into the lower part of

the Rifle Hill Member, which represents the shallowest environment of deposition in the entire Galena Group, the purest carbonate (least insoluble residue), the invasion of the fauna of the Red River Formation, and the time of the most complete submergence of the Transcontinental Arch. It has the lowest abundance of conodonts in the entire Galena Group, probably reflecting the lack of supply of nutrients from the Arch. It is distinctively orange in color, much more so than the yellow orange of the Sinsinawa. It is commonly stylolitic; in contrast to the multiple corrosion surfaces of the Sinsinawa, none have been found in the Rifle Hill Member.

BIOZONATION

Sardeson's 14 beds were Opper zones and were very satisfactory zones for their time. He continued to use them as collecting intervals throughout his life. However the bulk collecting of fossils from the Decorah Shale, especially in St. Paul, and of acid-insoluble fossils, especially conodonts from the carbonate units, offers the possibility of further refinement. The durations of species differ in different parts of the section as can be seen from the durations of the Sardeson beds. Early in the Caradoc transgression during deposition of the Platteville and Decorah, zonal durations are short. Later, during the deposition of the Prosser and its equivalent the Dunleith, durations increase as can be seen in the accompanying range charts. Most species transitions show punctuation, i.e. extinction and replacement, but some show gradualism, phyletic speciation, or transformation. Rice's and Webers' studies show that, as could be expected, not all species in a Sardeson bed began at the same time or ended at the same time.

Work by Sardeson (1926, a very significant paper omitted from MGS Bulletin 34, which I discovered only recently), DeMott (1963), and Rice (1985 and continuing) demonstrates a major extinction event at the Deicke K-bentonite. This ash bed represents, as closely as we can tell, the Blackriveran-Trentonian boundary. The total volume of the ash bed is greater than 330 km³ (Huff and others, 1986). This is about twice the volume of the 1915 Tambora eruption (the largest historic eruption), 10 times larger than that of Mt. Mazama which produced Crater Lake, and 400 times larger than the 1980 Mt. St. Helens eruption. Two of 21 natural or residual form species of conodonts (*Scyphiodus primus* and *Polyplacognathus ramosa*) go extinct at this horizon (Webers, 1966) for a 10% extinction. Of 18 brachiopods, 7 go extinct (*Pionodema conradi*, *Campylorthis deflecta*, *Strophomena plattinensis*, *Oepikina minnesotensis*, *Trigrammaria winchelli*, *Pseudolingula eva*, and *Orbiculoidea lamellosa*; see also Rice, this volume) for an extinction rate of 39%; DeMott's (1963, this volume) study of trilobites shows 9 of 10 species go extinct at this horizon for an extinction of 90%. Among gastropods, 48 of 60 species go extinct at this horizon, for an extinction rate of 80% (Sloan, this volume). All the echinoderm species in the Platteville terminate at the Deicke K-bentonite (Kolata and others, this volume)! It is possible that there are multiple extinctions near this horizon due to the cluster of four major Rocklandian ashes (Kolata and others, 1986), but the Deicke is clearly the most important; in more than 100 exposures I have seen no evidence of a benthic organism digging out of this ash bed. No other single horizon in this sequence of rocks has as many extinctions as this event.

The replacing species of the Carimona and Spechts Ferry Members must have been in existence elsewhere in the North American continent, presumably on the other, northern, side of the Transcontinental Arch. The only area south of the Transcontinental Arch where the benthos may have survived is in the southwestern part of the U.S., notably New Mexico. The species invaded the depopulated area, but not all at the same time. *Isotelus gigas* and *Eomonorachus intermedius* were the pioneer invading trilobites. The rest of the Gutenberg trilobites (see DeMott's and Hedblom's range charts in this volume) came in roughly a quarter million years later. Similarly some brachiopods took longer to repopulate the area than others (see Rice's range chart); eight species present in Sardeson's beds 2 and 4 or 5 are totally missing from bed 3. This difference in times of migration back into the area may be related to differences in modes of larval distribution, in particular, residence time in the plankton.

This implies that the Spechts Ferry and Platteville faunas are, in part, contemporary (homotaxial), although allopatric and poses an interesting problem in correlation which might produce some small errors. It does not have a serious effect in the Upper Mississippi valley region, but might cause errors of correlation of perhaps 1 or 2

million years between the Upper Mississippi valley and the Red River-Winnipeg region of the Williston basin.

The differing proportions of extinction between major classes of invertebrates across the Deicke event can tell us something about the relative sizes of geographic ranges. The radius from the center of the volcano to the Twin Cities basin is approximately 750 miles (1200 km). The half circle over which the Deicke ash caused total extinction in the North American Plate has an area of 1,000,000 square miles in round numbers (2,500,000 sq km). That figure is the outer limit of geographic range between those that went extinct and those that did not. All the echinoderms apparently had geographic ranges smaller than that area. Only 10 percent of the trilobites (*Sceptaspis lincolnensis* is the exception) had ranges larger than that area, as did 20 percent of the snails.

An equally severe local extinction, if more gradual, was caused by the shoaling in the lower Stewartville (Sinsinawa), where the fauna gradually was reduced by a factor of 90 percent over a 10-m interval, about 0.8 m.y. in duration. This extinction would appear to be the result of a global eustatic sea level drop of some 40 m (130 feet). Whether this was glacially caused, as was the late Ashgillian-Gamachian sea level drop, is at present unknown.

VOLCANIC ASHES

The present southeast coast of the Ordovician North American Plate was the site of a subduction zone and much volcanism during Middle and Late Ordovician time. Thirteen of these eruptions were sufficiently large to leave significant ash beds in the Upper Mississippi valley. They occur in three clusters. The first is the Rocklandian-early Kirkfieldian cluster of the Deicke, Millbrig, Elkport and Dickeyville K-bentonites, in less than a million years. The next cluster of the Calmar, Conover, Nasset, Haldane, and Dygerts occurs in the late Shermanian Rivoli and Sherwood Members of the Dunleith and Prosser formations, and in the basal Edenian Sinsinawa Member of the Stewartville and Wise Lake Formations within a million and a half years, but separated from the earlier cluster by 2 million years. The third cluster of four unnamed ashes occurs in the late Edenian Dubuque Formation and Elgin Member of the Maquoketa Formation in Minnesota. The lower two, at least, are feldspathized shales (Weiss, 1954b). A few other ashes are known from isolated localities. This cluster needs much more study than it has received.

RADIOACTIVE DATING AND CHRONOLOGY

The key to understanding the absolute ages, rates of sedimentation, rates of evolution and extinction, and synchrony of tectonic events and other processes of short duration lies in a synthesis of data of many types. While we have known of the K-bentonites since Sardeson's pioneer work starting in 1924, and our knowledge of details of distribution and correlation has increased steadily, the major contributions have been in the last 5 years (summarized in Kolata and others, 1986; Samson, 1986). They are now directly traceable by fingerprinting techniques for distances of 1600 km (1000 miles), as well as by the classic bed tracing techniques.

These K-bentonites are igneous rocks that are interbedded within the normal marine sediments and altered to varying degrees by diagenetic processes. Direct dating of these beds has been done by fission-track dates (Ross and Naeser, 1984 and references therein) and by argon 40/argon 39 techniques (Kunk and Sutter, 1984). The fission-track methods have given a standard deviation of between 10 and 16 million years. The argon/argon techniques produce a standard deviation of about 3 million years and show promise of solving much of the internal inconsistency of the fission-track dates.

Kunk and Sutter (1984) dated the T-3 bentonite of Tennessee as 454.2 ± 3 Ma on the basis of biotite. The mean age of their whole Rocklandian cluster of dates is 454.0 Ma; considering the number of

samples dated (56), the standard error of the mean is much smaller than 3 m.y. Kolata and others (1986 and earlier) precisely correlated the Deicke K-bentonite of the Upper Mississippi valley with the T-3 bentonite of Tennessee on the basis of rare element fingerprinting. Samson (1986) demonstrated that the fingerprinting was not of the phenocrysts, but of the fine-grained groundmass, that the cores of the zircon grains are Precambrian in age with an Ordovician overgrowth, and that the biotites of the original ash were converted to pseudomorphs of leucoxene in the Upper Mississippi valley, relieving the misgivings of some that the absence of biotite from the Deicke was primary and that the Deicke could not be correlative with the T-3. There is now no doubt that the Deicke is the same as the T-3.

Sweet (1984) performed a Shaw analysis of the abundant conodont distribution data gathered during the past 2 decades (none of the older data were satisfactory due to small sample size and insufficient sample density). This provided the first wholly independent correlation of the Middle and Late Ordovician rocks of North America in years. It also provided a quantitative Composite Standard Section, making allowances for varying rates of deposition both locally and regionally. With a date for the Deicke K-bentonite of 454.2 Ma at CSS 979, and the date of 438 Ma for the Ordovician-Silurian boundary (Harland and others, 1982; and Sutter, personal communication, 1984) at CSS 1277, it is possible to calculate the duration of one of Sweet's 79.5 Conodont Standard Time Units as 0.33 m.y., and his CSS units as 0.0544 m.y. Sardeson's beds average 1.32 m.y. in duration. Because the Sardeson beds are included in Sweet's CSS, we can calculate the duration and age of each of these beds (Table 1), and we can also calculate the precise duration of species and unconformities in the Upper Mississippi valley by bed tracing. This permits precise rate measurements of many sorts.

The age of any other unit or horizon for which Sweet (1984) has calculated the CSS number can be converted to an absolute age with the following formula:

$$\text{Age (Ma)} = [(1277 - \text{CSS}) 0.0544] + 438$$

Please note that Sweet (1984) puts the Black River-Trenton boundary at the base of the Platteville at Cummingsville Annex, although the trilobites place it at the Deicke K-bentonite. We have seen this sort of problem before, but now we know how significant the difference is: the difference in calculated age is 0.5 million years. A likely solution to this truly minor dilemma is to recalculate the Composite Standard Section using all taxa, not just the conodonts.

DURATION OF UNCONFORMITIES

At Rockford, Illinois, there is a significant unconformity between the Quimbys Mill (just earlier than the Deicke K-bentonite) and the top 0.36 m (1'2") of the Guttenberg. The missing interval is 14 CSS units; the duration of the unconformity is thus approximately 0.8 m.y. The missing interval is the Rocklandian and part of the Kirkfieldian. This unconformity decreases to the northwest, and disappears at Guttenberg, Iowa. In Minnesota, deposition of the Dubuque Formation and the Maquoketa Group was continuous, but in Iowa southeast of Decorah, they are separated by the hardground and associated sediments known as the Depauperate zone. The duration of the unconformity represented by the hardground is difficult to interpret, but Levorson and Gerk estimate that the Rifle Hill section (M-106, see Figure 20.10, this volume) has about 1 m of rock that is missing in Iowa, that is 1.6 CSS units, or approximately 0.09 m.y.

The duration of the unconformity between the St. Peter Sandstone and the underlying Shakopee Formation of latest Canadian age (about 490 Ma.) is approximately 31 m.y., almost twice the duration of the combined Mohawkian and Cincinnati.

The many corrosion surfaces-corrosion zones-hardgrounds in the carbonates do not appear to represent a significant amount of time, individually or collectively.

RATES OF DEPOSITION

The rate of deposition of the Galena Group is remarkably uniform from St. Paul, Minnesota, to Dubuque, Iowa. The thickness of the Dubuque-through-Beecher interval at Dubuque is 92 percent of the thickness of the same interval at Cummingsville and Rifle Hill. Most of the difference is taken up by the increase in rate of deposition of shale to the northwest, and by the small unconformity of the Depauperate zone. The Decorah Shale was deposited 40 percent faster in St. Paul than in Fillmore County, near the Iowa line (Rice, 1985). On the other hand, as closely as we can determine the carbonate of the Platteville was deposited at the same rate in the two areas.

In northern Illinois, however, the rate of deposition of the Platteville Group was significantly faster than that of the Galena Group or the Platteville in Iowa and Minnesota. DeMott found no significant change in trilobites that cannot be explained by deeper water in northern Illinois than in Minnesota. The top of the Pecatonica appears to be the same age in Illinois as it is in the Twin Cities basin in Minnesota. The Mifflin in both places represents the deepest deposition, presumably under the control of eustatic sea level changes. On that basis, the Platteville was deposited about 3 times faster in Illinois near Rockford, than in Minnesota or Iowa.

Based on the Cummingsville and Rifle Hill sections between the Deicke K-bentonite and the top of the Dubuque Formation, the mean rate of deposition is then 90.85 m in 7.2 m.y., or 12.619 m per 1 m.y. = 12.6 mm per thousand years—roughly 1 inch = 2000 years in round numbers. Depth changes are small compared to total sediment accumulation, and so the rate of deposition most likely was determined primarily by rate of crustal subsidence. Wave dispersal of algal micrite is a likely way of ensuring uniform carbonate deposition.

Assuming the same rate of crustal subsidence during the deposition of the St. Peter Sandstone as for the later rocks, the estimated age of the first transgression of the Champlainian sea into the Upper Mississippi Valley would be about CSS 893, or close to the upper Blackriveran-Ashbyan boundary at CSS 905. The conodonts are comparable to the Glenwood conodonts, as are the molluscs, which are known throughout the middle third of the 47 m (155') Twin Cities section (see Chapter 6, this volume).

Because the Glenwood shale in Minnesota is laterally equivalent to the Mifflin, the Pecatonica, and the top of the St. Peter Sandstone, it is quite clear that no significant regional unconformity separates the Ancell Group (St. Peter + Glenwood) from the Platteville Group of Illinois.

DURATIONS OF THE RANGES OF SPECIES

The 18 Decorah Shale brachiopods from the St. Paul brickyard exposure that have their entire range within the exposed rocks have a mean vertical range of 13.08 ± 6.3 m (42.9 feet), equivalent to an average range of 9.4 ± 4.5 m (30.8 feet) at Cummingsville (Rice, 1985). This converts to an average duration of the range of brachiopod species of 0.8 m.y. during the Rocklandian.

Sardeson's beds themselves differ in duration. The Platteville, and Spechts Ferry beds (1, 2 and 3) average 0.23 m.y. in duration, and Decorah beds 4 and 5 are 0.6 m.y. each; Dunleith or Cummingsville and Prosser beds 6, 7, and 8 average 1 m.y. each; bed 9, the Stewartville, is 1.8 m.y. long; and bed 10, the Dubuque, is 0.9 m.y. Except for bed 10, there is a more or less steady slowing of rates of extinction and replacement or evolution. This makes good theoretical sense. One would expect high rates of evolution and short temporal ranges early in a major transgression such as the Caradocian, followed by declining rates of evolution and lengthening temporal ranges as the new communities became stabilized (Simpson, 1944).

Table 2.1. Duration of Sardeson's beds and Maquoketa to St. Peter formations by CSS number and absolute age.

<u>Sardeson bed</u>	<u>Stratigraphic name</u>	CSS (base)	Age at base (Ma)	Duration (m.y.)
	Base of Silurian	1277	438.0	-
	Unconformity (top Maquoketa, Iowa-Illinois)	1258.5	439.0	1.00
	Neda Oolite, Iowa	1256.6	439.05	0.05
	Brainard Shale, Iowa	1198.2	442.2	3.2
	Fort Atkinson, Iowa	1175.4	443.4	1.2
	Clermont Shale, Iowa	1165.9	443.9	0.5
	Erosion interval, Minnesota (top Maquoketa in Minnesota)	1144.1	455.1	-
	Maysvillian (~Caradoc-Ashgill boundary)	1136	445.7	-
	Elgin Shale	1110.9	447.0	3.1
10 <u>Triplecia</u> (<u>Oxoplecia</u>)	Dubuque	1094.3	447.9	0.9
	Base Edenian	1065	449.5	-
9 <u>Maclurea</u> (<u>Maclurites</u>)	Stewartville (Wise Lake)	1062.6	449.7	1.8
8 <u>Lingulasma</u>	Prosser (Sherwood to Wall)	1048.1	450.5	0.8
	Cummingsville-Prosser contact	1033.9	451.2	-
7 <u>Camarella</u> (<u>Parastrophina</u>)	Cummingsville and lower Prosser (Mortimer and Rivoli)	1027.2	451.6	1.1
6 <u>Orthisina</u> (<u>Vellamo</u>)	Cummingsville (=Beecher to Fairplay)	1004.4	452.8	1.2
	Base Shermanian	997	453.2	-
5 <u>Fucoid</u>	Upper Decorah (=Ion, Buckhorn and St. James)	993.8	453.4	0.6
4 <u>Stictopora</u> (<u>Rhinidictya</u>)	Middle Decorah and Guttenberg	983.1	454.0	0.6
	Millbrig K-bentonite	983.1	-	-
3 <u>Stictoporella</u>	Spechts Ferry and Carimona	979.1	454.2	0.2
	Deicke K-bentonite	979.1	454.2	-
2 <u>Bellerophon</u>	Magnolia and Hidden Falls (=Grand Detour, Quimbys Mill)	974.7	454.5	0.3
	Mifflin and Pecatonica	970.4	454.7	0.2
	Glenwood Formation	967.0	454.9	0.2
	Top of Ashbyan	905	458.2	-
	St. Peter Sandstone at St. Paul	893	458.9	4.0

ESTIMATES OF DEPTH OF DEPOSITION AND BOTTOM SLOPE

The depth of deposition of these rocks was always shallow, although there are no signs of emergence, at least in Minnesota. Green algae (Chlorophyta) including *Vermiporella*, *Fisherites* (= *Receptaculites*), and *Ischadites* are major carbonate producers in these rocks. Because the red light, on which green algae depend for photosynthesis, is extinguished at shallower depths than other wavelengths, these algae are usually restricted to depths less than 50 m (Ginsburg and others, 1972). *Ischadites* is most common in the Prosser, which represents the deepest facies of these rocks. I infer that the depth range of the Minnesota Middle and Late Ordovician was from sublittoral to 50 m or about 150 feet.

Chatterton and Ludvigsen (1976) developed a classification of trilobite biofacies which they interpreted as a bathymetric gradient. From shallowest to deepest these are (1) *Bathyurus* biofacies; (2) *Isotelus* biofacies; (3) *Calyptaulax-Ceraurina* biofacies, typified by those genera and *Sphaerexochus* and *Cybeloides*; and (4) *Dimeropyge* biofacies, typified by that genus and *Dolichoharpes*, as well as by the acanthoparyphiniids and *Carrickia* which were extinct by the time of the Galena Group. *Bathyurus extans* is present in both the Magnolia and Carimona Members, which represent the shallowest facies recorded. *Isotelus* is present throughout all the units of the section, but is most common in the Pecatonica, Carimona, Decorah, Dubuque and Maquoketa. The next deeper facies, typified by *Calyptaulax*, and *Cybeloides*, is more typical of the Mifflin, Cummingsville, and Prosser. *Dolichoharpes* and *Sphaerexochus* represent the deepest part of the third facies, transitional to the fourth facies and occur only in the Prosser in Minnesota, and in the Mifflin and Prosser in Illinois.

Cisne and others (1984) investigated the faunas of the Platteville, Decorah Shale and lower Dunleith at Guttenberg, and the Platteville and lower Decorah at St. Paul from the standpoint of depth estimates inferred from variations in biofacies. The extremes of their biofacial components were bryozoans and *Doleroides* for the shallower component and *Paucicrura* and *Sowerbyella* for the deeper component. They inferred a near 0 m depth for the St. Paul section, and a 5 m depth for the basal Decorah Shale at Guttenberg, Iowa. They show a shoaling during the Spechts Ferry, deepening during the Guttenberg, shoaling again after the Guttenberg, and redeepening during the upper Ion and lower Dunleith (Cummingsville equivalent). Trends agree in the two sections after a correction for a miscorrelation of the St. Paul section inherited from Templeton and Willman's (1963, fig. 24) miscorrelation of the Millbrig K-bentonite in St. Paul with the Elkport K-bentonite of Guttenberg.

Megaripples with a wavelength of 60 cm, and amplitude of 5 cm occur in the Carimona and throughout the Decorah Shale in Minnesota. These have usually been assumed to represent shoaling, with storm wave removal of fines, and reshaping of coarse bottom debris, mostly shells.

The ratio of benthic mollusks to brachiopods would appear to represent a depth gradient, with the benthic mollusks a shallower and articulate brachiopods a deeper facies. This would be best measured by absolute counts of specimens, but the trend can also be measured by numbers of taxa. The simple ratio of brachiopods divided by the sum of clams and snails agrees with the other estimates. The Stewartville and St. Peter agree in having nearly identical lowest ratios of $1/16$ and $1/15$; the others are more balanced.

To combine all the types of data, I suggest the following: the shallowest depth recorded in the Minnesota section is the brassy oolite horizon at 19 m (63 feet) and the two horizons of gypsum crystals in the Decorah Shale of St. Paul; nothing else even approached being out of water. The deepest facies represented is the *Ischadites* acme zone in the Sherwood Member of the Prosser (Dunleith in Iowa and Illinois). I arbitrarily place this at 50 m depth on the basis of modern green algae distribution and the extinction of red light with depth.

The *Lingula-Isotelus* facies of the Carimona and Dubuque, I interpret to be relatively shallow, from 10 to 25 m, but always below low tide because there are no signs of stromatolites, raindrop craters or mudcracks, which are well preserved locally in the Canadian Shakopee dolomite. The mollusc-rich horizons of the Magnolia and Stewartville I interpret to be very shallow, 10 m or less in depth, but below low tide. *Fisherites* would appear to extend deeper than *Maclurites*, perhaps to 20 m. The bryozoan-*Doleroides* community of Cisne, I interpret to be about 10 m depth or less, the *Sowerbyella* (or *Eoplectodonta* = *Thaerodonta*)-*Paucicrura* community I interpret to be about 15 to 25 m depth. The intermediate trilobite community of *Calyptaulax-Cybeloides-Ceraurus* I interpret to be of 20 to 50 m depth, with *Sphaerexochus* and *Dolichoharpes* representing the deeper part of that facies.

This synthesis of depth facies produces patterns of depth changes consistent with those based on wavelength of ripples and other sedimentary structures. It also produces a relatively simple curve of depth against stratigraphic interval. The depth curve for the Elgin Member of the Maquoketa in Minnesota is based on proportions of the series *Ctenodonta-Isotelus-Eoplectodonta* (= *Thaerodonta*) which dominate increasingly greater depths; the data are from Bayer (1967).

During the deposition of the Sinsinawa equivalent of the Stewartville Formation of Minnesota, the depth of deposition gradually shoaled from 50 m to 10 m while only 10 m of rock accumulated. This is the interval in the Galena Group which has the greatest density of hardgrounds ("corrosion zones"); slow deposition during shoaling may be the reason for this. It is also the interval with the most extinctions in the whole Middle Ordovician. The resulting upper Stewartville fauna is essentially the classic Red River or "Arctic Richmond" fauna.

Clearly the regional bottom slope was very flat, with relief on the order of 10 to 20 m (30 to 60 feet) or less in 500 km (300 miles). A considerable amount of carbonate mud must have been put into suspension during temporary lowering of wave base during major storms, only to settle out after the storm subsided.

PLANKTON STANDING CROP

Primary productivity and standing crop of plankton in the sea is usually determined by concentrations of nitrates and phosphates, the limiting nutrients in Liebig's "Law of the Minimum". It is usually measured in grams of wet plankton per square meter. The Diecke K-bentonite provides a spot estimate of primary productivity, because it caused a quantitative plankton kill and the organic matter is still preserved as a petroliferous shale. I sampled the bottom 1 cm of the Diecke at Cannon Falls some years ago. Dr. Francis Ting was kind enough to determine total nitrogen in an aliquot, and with this figure, I calculated the equivalent amount of wet organic material per square meter. The figure was 2.5 kg per square meter, close to that of modern productive shallow tropical seas.

Conodont abundance in conodonts per 100 grams of sediment appears to be the best measure of local primary productivity. The conodont animal was nektonic, and fed directly on the zooplankton and phytoplankton. It seems reasonable to infer that conodont abundance is directly proportional to the plankton abundance. We have routinely calculated conodont abundance for each sample studied for conodonts since 1959. Logs of this statistic are shown with the graphic sections in Chapter 20. The range of values is from 0 to 1500 conodonts per 100 grams of rock. The conodont density in the beds surrounding the Diecke K-bentonite at Cannon Falls was 300, implying that the total range of productivity in absolute values was from 0.1 kg per sq m to 12.5 kg per sq m. In general the lowest values occur in the Stewartville, and the highest values occur in the Carimona and Spechts Ferry. It will be shown that these figures relate closely to the uplift and exposure of the nearby Transcontinental Arch.

TECTONICS AND SEDIMENTATION

Minnesota Ordovician sediments were deposited in a large bay (the Hollandale embayment) between the Transcontinental Arch in central Minnesota, the Wisconsin Dome and Arch to the east, and the Sioux Quartzite islands to the west (Figs. 2.4 and 2.5). On the northern side of the Transcontinental Arch lay the Williston basin of the Dakotas, Manitoba, and Saskatchewan. The rocks are generally similar on the two sides of the Transcontinental Arch but have differing names. The Winnipeg Formation of the Williston basin in the Minnesota subsurface and Manitoba outcrop is shown by its conodont fauna to be the same age as the interval from the St. Peter Sandstone to the Cummingsville Formation (Bayer, 1959). The overlying Red River Dolomite corresponds to the Prosser to Fort Atkinson Limestones, on the basis of the typical upper Red River coral *Bighornia* in the Fort Atkinson Limestone of Iowa (Elias, 1981) while the Stony Mountain Shale corresponds to the Brainard Shale and Neda Formation. The sand-poor Winnipeg Formation corresponds to the siliciclastic-rich first half of the Middle Ordovician Upper Mississippi valley sequence. It appears that most of the sand on the Arch went to the south side to produce the St. Peter.

The Transcontinental Arch is composed of Precambrian rocks that were involved in several tectonic events. The Arch is mainly the Great Lakes Tectonic Zone (GLTZ, Sims and others, 1980); most of the historic earthquakes in Minnesota are along this structure. The GLTZ still stands above the older Archean crust in Minnesota, under the Cretaceous and Pleistocene sediments. The topographic high is about 100 m (300') above the adjacent Archean, the width is about 80 km (50 miles). The Arch has a strike of S70°W and is composed of granite plutons, and folded and thrust Animikian sediments, mostly shales, of varying metamorphic grade up to the garnet and staurolite zone (Morey and Sims, 1976). The GLTZ can be traced through northern Wisconsin and Michigan, into Ontario, to Sudbury. To the southwest, the extension may be the Colorado Lineament (Sims and others, 1980). The GLTZ was offset by the development of the Keweenaw rift valley about 1.1 b.y. ago. The Keweenaw rift crossed the GLTZ at an angle of about 20°, with the total offset about 160 km (100 miles). In Wisconsin and Northern Michigan the GLTZ is on the south side of Lake Superior, in Minnesota it is northwest of the extension of the lake. The axis of the Hollandale Embayment and the origin of the persistently depressed nature of the basin is the Keweenaw Midcontinent rift. The crust in the rift is dominantly basalt, to a depth of 10 km (6 miles), interbedded near the top with red stream sandstone and shale. This thick pile of basalt is the cause of the Midcontinent geophysical anomaly, in which the mass of the basalt increases the local acceleration of gravity to the highest values in the continent. Minnesota Ordovician rocks are superimposed on this major crustal feature. Northern Illinois Ordovician rocks, instead, were deposited over the south-trending Wisconsin Arch, which behaved as a positive feature.

During the Caradocian, a global transgression of sea level occurred, restoring the sea level to the former high level reached during the Canadian-Arenigian. Locally the first sign of this is the spread of the marine St. Peter Sandstone over the karst surface developed during the long Whiterockian unconformity. The eustatic sea level rose until it reached the highest level during the deposition of the Prosser, during the Shermanian, then sank a little, and finally dropped precipitously during the end of the Ashgillian (Brenchly and Newall, 1984), apparently under glacio-eustatic control at that time. Basement subsidence under the developing pile of carbonates apparently determined the observed rates of deposition.

The apparent source of the St. Peter Sandstone was the Late Cambrian Croixan sandstone sequence that covered the Transcontinental Arch. These sands still occur as close to the axis of the GLTZ as 50 km (35 miles). The volume of the St. Peter in the Hollandale embay-

ment is approximately equal to the restored volume of Croixan sediments stripped off the south half width of the arch. The sands of the north half width went to the Williston basin. With the sandstones removed, the bedrock consisted of the pre-Mt. Simon residuum (Morey, 1972) and the underlying Animikian slates and schists. The Glenwood Shale has a much higher percentage of garnets than the underlying St. Peter (Thiel, 1935, 1937; Ernst, 1954); small sand-size garnets are common in these metamorphic rocks near the crest of the arch.

The Mifflin Member of the Platteville reflects deepening of the sea to about 50 m. A pulse of uplift in the central Minnesota source caused the deposition of the Hidden Falls Member, briefly increasing the clay enough to spread out to the margins of the Twin Cities artesian basin, a basin separated from the rest of the Hollandale embayment by a transform fault offset of the Keweenaw trough to the southeast. At least one basement fault was active during this time. The clay component of the Hidden Falls Member spread into the trough on the eastern side of the Red Wing-Rochester anticline (Saratoga section, Fig. 2.2).

At the beginning of the Rocklandian, basal Trentonian, a major pulse of uplift produced a much greater supply of clay to the Hollandale embayment. The clay of the Decorah Shale reached all the way to northern Illinois, a distance in outcrop at right angles to the source of 370 km (230 miles). The maximum thickness of the Decorah Shale wedge is 27 m in St. Paul. Restoring the clay of the Decorah Shale wedge back to the crest and southern half width of the Transcontinental Arch requires an uplift of 300 m (1000 feet) to produce the shale. This uplift is exactly correlative with the 0.8-m.y. unconformity in northern Illinois on the Wisconsin Arch; with the Deicke-Dickeyville cluster of large ash beds; with the depression of the Twin Cities basin marked by the increase in the Deicke-Millbrig interval; and with the highest local productivity as shown by the conodont density curves, presumably the result of nutrients being eroded off the arch. Very slightly later (Sardeson's bed 4), another small basement fault in Fillmore and Houston Counties with a total throw of 15 m (50') served to thin the Decorah Shale at Spring Grove underpass (Fig. 20.12) to almost half the regional value.

This unique concurrence of unusual events might be sheer coincidence, but the precision of correlation is too great for me to believe that. It would appear to be a case of internal deformation in the North American Plate produced by an increase in the rate of subduction or by a collision of another continental plate on our east coast. Quinlan and Beaumont (1984) discuss similar deformation in the Eastern Interior of the continent. The shallow interval from the Deicke K-bentonite to the base of the Prosser Limestone appears to correlate exactly with the Marathon region, west Texas, unconformity of Finney (1986). The Keweenaw trough subsided so that the Deicke-Millbrig interval is 2 to 3 m (8-11') while on the Wisconsin Arch at Rockford, Illinois, about 10 m (30') was eroded or never deposited. With the gradual erosion of the Transcontinental Arch, the width of the clay belt steadily narrowed. The arch was submerged during the deposition of the Prosser Limestone and Stewartville Formation of the Galena Group. Some Platteville and Glenwood rocks were eroded during the deposition of the later Decorah, some weathered and reworked conodonts belonging to taxa otherwise found only below the Deicke are found offshore. The timing of pulses of uplift of the Arch can be deduced from the sawtooth profile of the Cummingsville Formation by converting the thickness of pairs of pure and shaly carbonate units in the Cummingsville to time. The pulses appear to have occurred at intervals ranging from 35,000 years to 70,000 years. Mazzullo's (this volume) short cycles of irregular and rounded St. Peter sand grains appear to be of similar frequency. There is a longer cycle as well, which can be seen in Mazzullo's 10 feet to 15 feet cycles of roundness, and in the cycles of conodont density in the Cummingsville section (Fig. 20.7) which

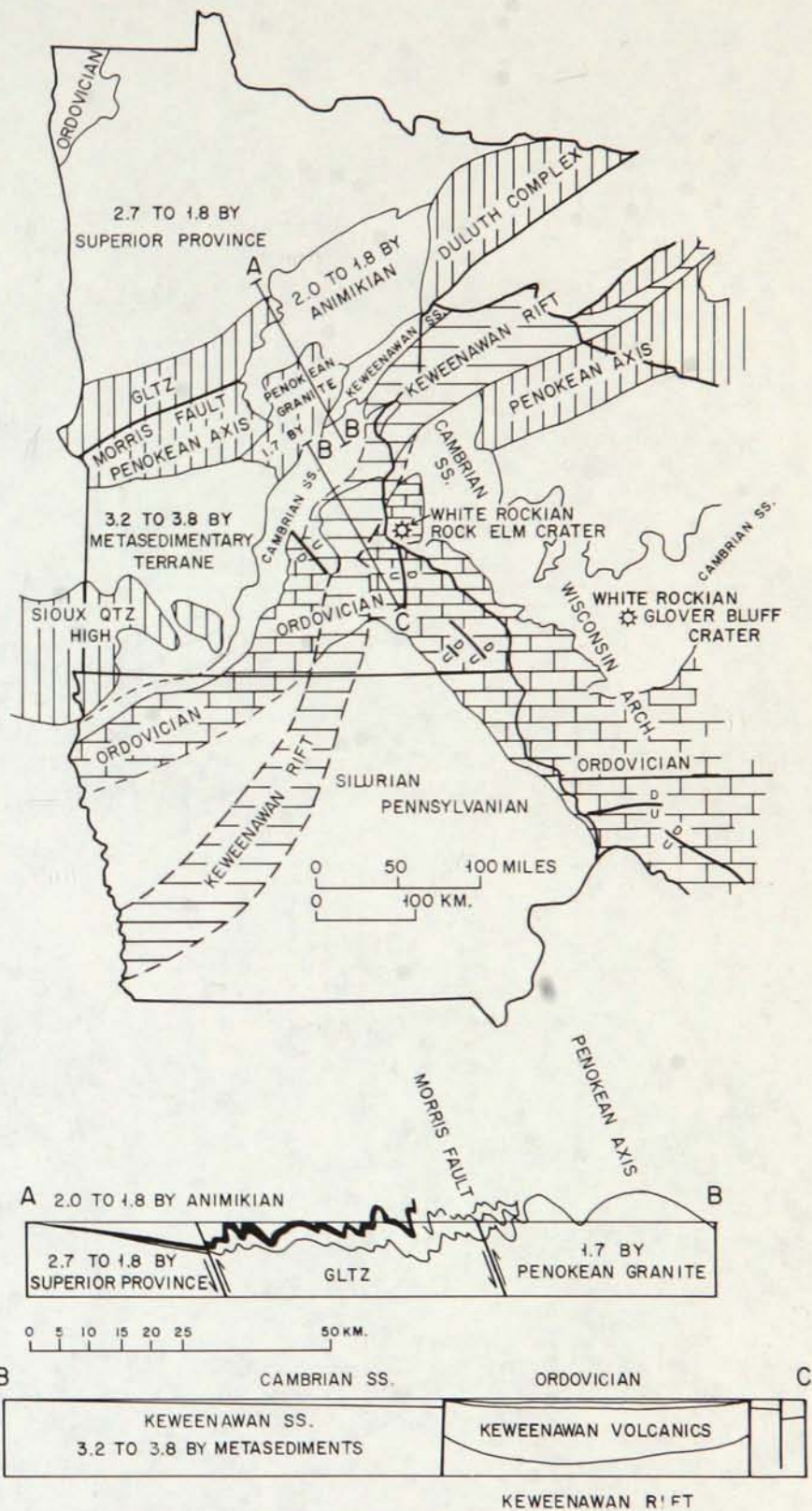


Figure 2.4. Tectonic map and cross sections of the Lake Superior and Upper Mississippi valley regions. Transcontinental Arch shown in vertical lines, Keweenaw rift in horizontal lines, Ordovician rocks in brick pattern. Adapted from Sims and others (1980).

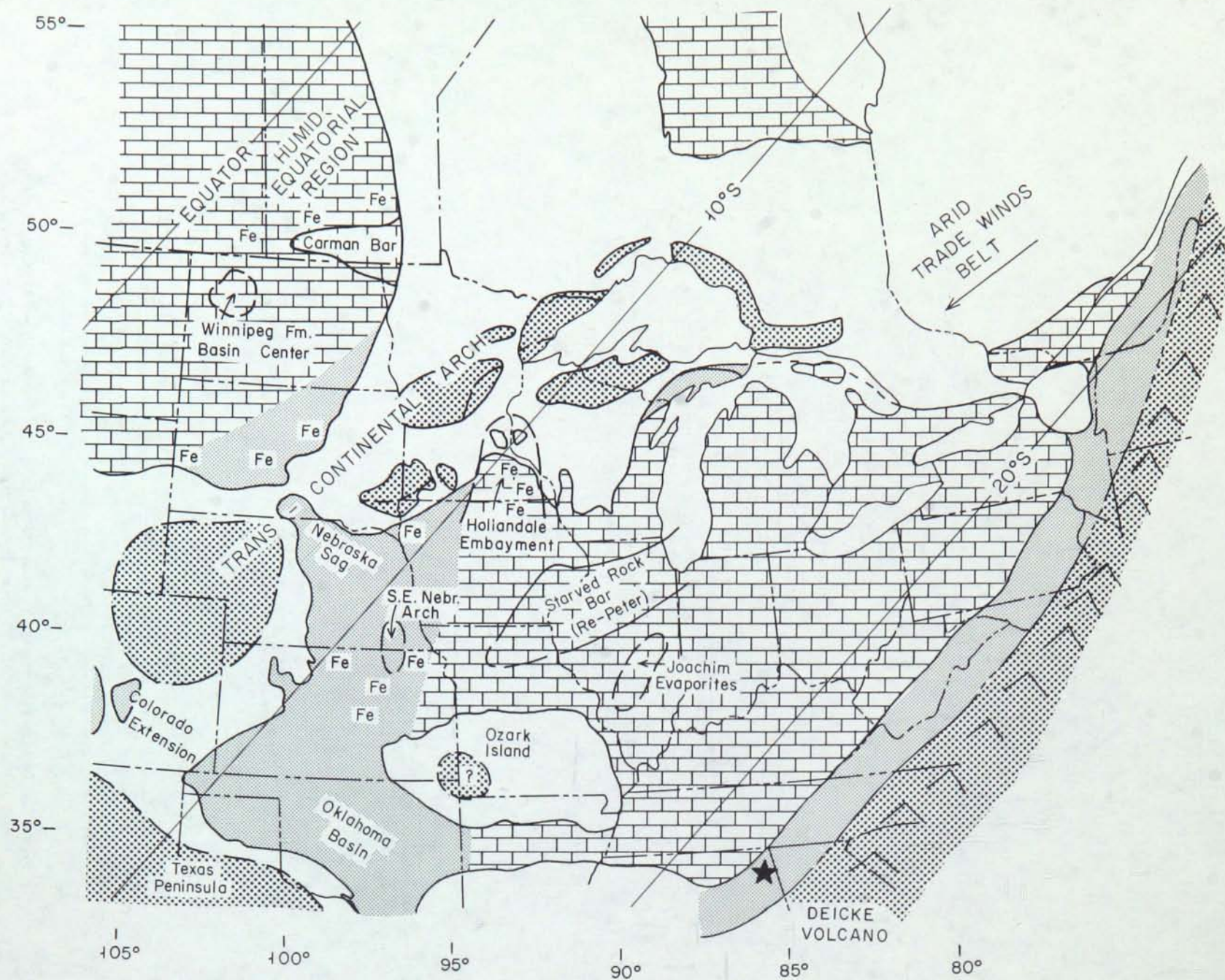


Figure 2.5. Middle and Late Ordovician paleogeography of the eastern half of the United States and Canada, to show the specific highland areas making up the Transcontinental Arch. Heavy line corresponds to present erosional edge of Middle and Late Ordovician rocks. Fe, known occurrences of oolitic hematite/geothite ironstones. Modified from Witzke (1980).

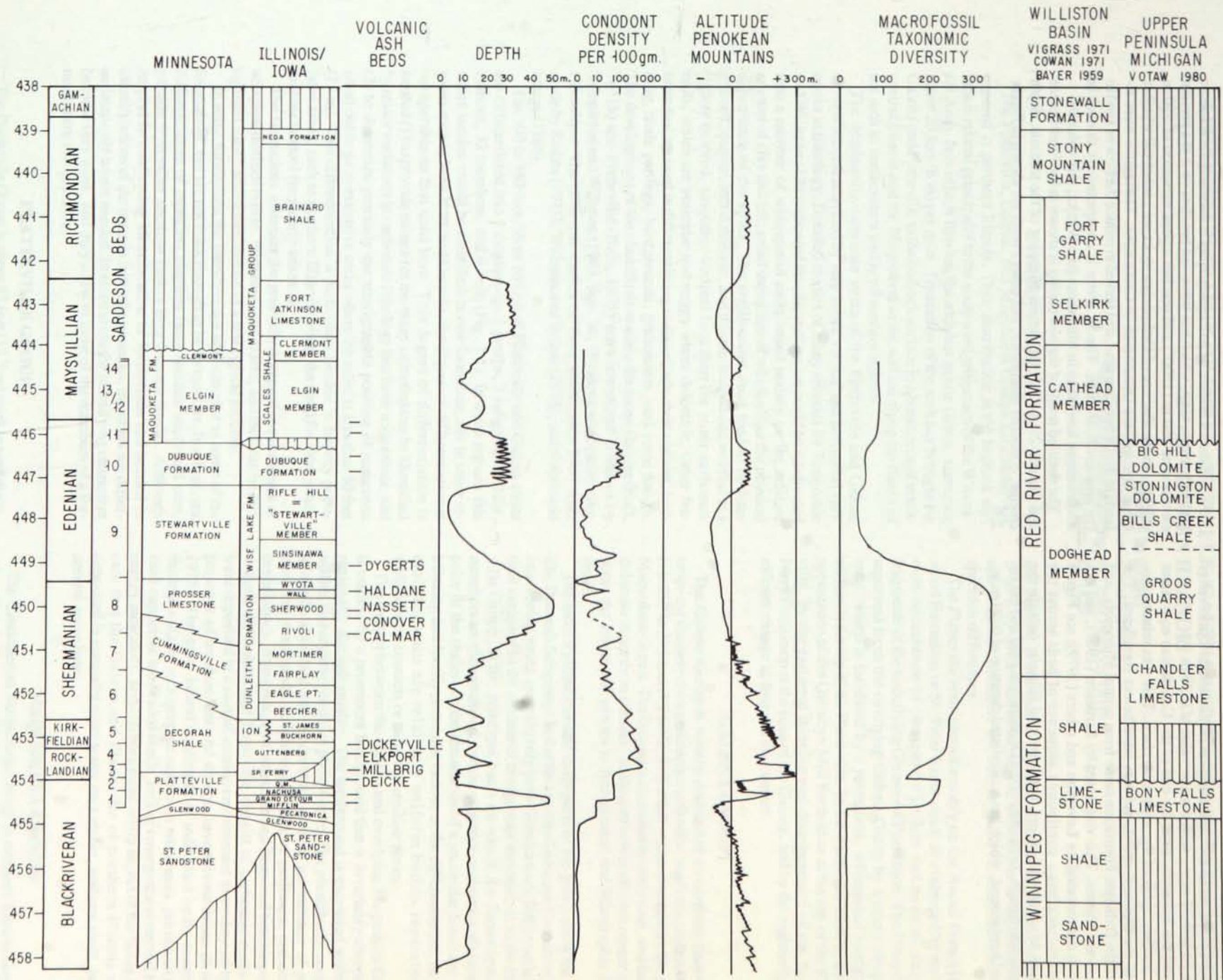


Figure 2.6. Summary correlation chart of Middle and Late Ordovician time-stratigraphic units, nomenclature of Minnesota, Iowa, Illinois, Upper Peninsula of Michigan, and Williston basin sections, elevation of the Transcontinental Arch, depth of deposition in Minnesota, macrofossil taxonomic abundance, and conodont abundance log.

vary from 8 feet to 15 feet; the duration of this longer cycle varies from 0.20 to 0.37 m.y., with a mean value of 0.30 m.y.

During the Edenian, near the end of the Caradocian equivalent strata, another uplift of the arch took place. This was minor compared to the Decorah uplift, but was nonetheless significant. The shale of the Dubuque Formation came from central Minnesota, and thins toward Illinois. This was noted by Sardeson (1927), and has best been documented by Levorson and others (1979); see Figure 2.3. Minnesota has a continuous sequence of beds across the Dubuque-Maquoketa contact, but Iowa and Illinois, outside the Keweenawan trough, instead have the Depauperate zone and the associated hardground, which has a calculated duration of 0.09 m.y.

An additional feature of paleogeography is the Early Proterozoic Sioux Quartzite high, which has wave-cut benches on it at a present elevation of 460 m (1500') and reaches a peak elevation of 550 m (1800'). In the absence of Ordovician rocks we cannot tell whether these benches are Ordovician or Cretaceous. These hills were islands in the Ordovician seas, and served to reduce the flow of sand to the area south of them. The St. Peter is conspicuously thinner in northwestern Iowa than in Minnesota (see Witzke, this volume).

The detailed result of the bed tracing is shown in the Frontispiece and Figures 2.1 to 2.3; the details of timing of the tectonic, depth change, conodont abundance, and other events are shown in Figure 2.6.

LITHOSTRATIGRAPHY OF THE PLATTEVILLE, GALENA AND MAQUOKETA GROUPS IN NORTHERN ILLINOIS

Dennis R. Kolata

Illinois State Geological Survey
Natural Resources Building, 615 East Peabody Drive
Champaign, IL 61820

INTRODUCTION

The Platteville, Galena, and Maquoketa Groups are extensively exposed in northern Illinois. Their distribution at the bedrock surface is related principally to the southward projection of the Wisconsin Arch. In northern Illinois, the arch has gentle slopes, averaging about 20 feet (6 m) per mile. Truncation of the arch has brought the Galena and Platteville to the bedrock surface in a broad area of north-central Illinois and the Maquoketa to the surface along the flanks of the arch in northeastern and northwestern Illinois.

The dominantly carbonate strata of the Platteville and Galena Groups are characterized by very subtle vertical and horizontal variations in lithology. Detailed studies of many sections by Templeton and Willman (1963) showed that the succession could be subdivided into a number of widespread units based mainly on the relative amount of clay and silt, small variations of which affect the physical appearance of the strata. The argillaceous units tend to be finer grained, denser, less dolomitic, and thinner bedded and weather to a lighter colored, smoother vertical face than the purer carbonate units, which are vesicular and vuggy where dolomitic. Other features that are used in differentiating units include chert content, bedding, shale partings, hardgrounds, grainstones, and some fossils. The development of the classification since the terms Galena (Hall, 1851b) and Platteville (Bain, 1905) were introduced is shown by Templeton and Willman (1963, figs. 16, 19) along with earlier classifications. The principal studies of these strata since 1963 were made by Kolata (1975), Willman and Kolata (1978), and Kolata and others (1986).

The 300 to 350 feet (90 to 105 m) of Platteville and Galena strata are differentiated into 1 megagroup, 2 groups, 3 subgroups, 10 formations, 32 members, and 9 beds (Fig. 3.1). In some regions this entire section would be classified as one formation, but in other regions such as New York and Ontario, the degree of differentiation is comparable to that used here. This degree of differentiation is needed (1) to provide names for the many units that can be identified by minor variations in carbonate lithology that have wide extent, and (2) to determine precisely the stratigraphic position of numerous small outcrops in extensive areas where the relief is less than 50 feet (15 m). This differentiation is particularly needed in heavily populated areas, such as northern Illinois, where the need for close stratigraphic control frequently arises.

The formations maintain the generally accepted requirements of adequate distinctiveness, thickness, and extent, and they can be recognized easily after examination of a few typical sections.

In some formations the members are as distinctive as some of the formations, but are not thick enough to be formations. In others, the differentiation of members requires more detailed study and comparison with other sections before they become useful. Although helpful in confirming identification of formations and needed in identifications of the units in limited exposures, members are differentiated only where needed. In some areas the identifying characters become very weak, and only a few or none of the members of a formation are recognizable.

PLATTEVILLE GROUP

The Platteville Group is about 45 feet (13.5 m) thick in northwestern Illinois and thickens eastward to 135 feet (40.5 m) in north-central

Illinois. It consists of five dolomite and limestone formations (Fig. 3.1) differentiated largely on differences in argillaceousness and shaliness; members are differentiated on similar but less conspicuous differences.

The Platteville rests unconformably on the Ancell Group (Glenwood Formation or St. Peter Sandstone), as evidenced by the common occurrence of phosphatic pellets and nodules and also fragments of the underlying Glenwood Formation. The Platteville is separated from the overlying Galena Group by a minor unconformity, which is indicated by a prominent, widespread hardground surface at the top of the Platteville, by the westward thinning and disappearance of the Quimbys Mill Formation at the top of the Platteville, by the eastward thinning and disappearance of the Spechts Ferry Formation at the base of the Galena, and by the regionally significant change in fauna at the contact.

GALENA GROUP

The Galena Group is widely distributed in northern Illinois; it crops out in many river and stream cutbanks, roadcuts, and quarries. It is 250 to 275 feet (75 to 82.5 m) thick where overlain by the shaly Maquoketa Group. The Galena is dominantly carbonate, and largely dolomite in northern Illinois. At the extreme northwest corner of the state, the lower part grades to fine-grained and lithographic limestone.

The most argillaceous and shaly parts of the group are at the base (the Decorah Subgroup) and at the top (the Dubuque Formation); the intervening strata are relatively pure (Kimmswick Subgroup). Vertical variation in the content of terrigenous material, as in the Platteville Group, is the principal basis on which the formations and members are differentiated, but the presence or absence of chert, the color of the shales, or the abundance of a particular fossil are contributing and locally dominant factors in the differentiation. In general, the units are relatively uniform bodies separated by well-defined contacts or narrow transition zones.

The contact between the Galena and overlying Maquoketa Group is marked by a prominent hardground that is invariably abrupt and regionally disconformable. The hardground is encrusted with iron sulfide and cryptocrystalline phosphorite. The phosphorite contains a locally abundant and moderately diverse assemblage of phosphatized gastropods, scaphopods, bivalve molluscs, orthoconic cephalopods, ostracods, and articulate and linguloid brachiopods.

Both the Galena and Platteville consist of carbonate rocks that were deposited in a normal marine environment as evidenced by the presence of an abundant and diverse invertebrate fauna (Kolata, 1975). The great lateral continuity of individual beds, consistent thickness of thin stratigraphic units over wide areas, preservation of mud-supported unabraded shells, lack of emergence or normal high-energy indicators, and offshore quiet-water aspect of the fauna indicate that the Galena and Platteville of northern Illinois were deposited in normally quiet water on a stable, uniform shelf, below normal wave base.

MAQUOKETA GROUP

The Cincinnati Maquoketa Group in northern Illinois consists primarily of olive-gray and greenish-gray shale and some dolomite and limestone; the group is generally about 200 feet (60 m) thick.

Due to post-Silurian erosion, the Maquoketa is missing in north-central Illinois. It rests disconformably on the Galena Group and is disconformably overlain by Silurian strata, which locally truncate the upper part of the Maquoketa (Fig. 3.2). Where the Silurian strata were removed by erosion, the Maquoketa is overlain by strata of Pennsylvanian or Pleistocene age.

The Maquoketa Group is divided into four formations in northern Illinois in ascending order:

Scales Formation—a mainly light-olive-gray to olive-black, silty, calcareous, laminated to intensely bioturbated shale, locally containing biogenic carbonates and phosphorite. The Argo-Fay Bed (Kolata and Graese, 1983) is a 1- to 2-foot (0.3 to 0.6 m) bed of hard, brownish-black to black, carbonaceous, fissile clayshale that occurs in the basal part of the Scales in northwestern Illinois.

Fort Atkinson Formation—a light-olive-gray to olive-gray and yellowish-brown to dark-yellowish-brown, pure to argillaceous, crinoid-bryozoan-brachiopod lime or dolomite packstone and grainstone, and to a lesser extent, wackestone.

Brainard Formation—a mainly greenish-gray to dark-greenish-gray, silty, fossiliferous, calcareous shale with interbeds of dolomite or limestone.

Neda Formation—a blackish-red to very dusky-red, silty, he-

matitic shale containing flattened, concentrically layered, iron-oxide spheroids about 0.50 mm in diameter.

In northwestern Illinois, where the Fort Atkinson Formation grades to shale, the entire stratigraphic section is referred to as the Maquoketa Group undifferentiated (Fig. 3.2).

The Maquoketa was deposited on a broad shelf in a widespread epicontinental sea. Most Scales sediments accumulated in relatively deep, oxygen-poor water that was infrequently mixed. Local deposits of phosphorite were probably formed by upwelling of phosphate-rich water at the continental margin. Near the end of Scales deposition, there was a gradual shallowing of the sea in northern Illinois and a reduced influx of terrigenous material. The relatively pure, fossiliferous carbonates of the succeeding Fort Atkinson Formation were deposited in shallow, well-aerated water of normal marine salinity. The Brainard Formation records two depositional environments: the base largely marks a change to predominantly shale deposition in a relatively deep, oxygen-poor environment, whereas in the upper Brainard, the locally abundant and diverse fauna indicate shallower, more aerated conditions. The Neda appears to be, in part, a product of lateritic weathering during the Richmondian (late Ordovician) glacio-eustatic drop in sea level.

SERIES	STAGE	MEGA-GROUP	GROUP	SUB-GROUP	FORMATION	MEMBER	BED	
CHAMPLAINIAN	TRENTONIAN	OTTAWA	Galena		Dubuque			
				Kimmiswick	Wise Lake	Stewartville		
						Sinsinawa	Dygerts Bentonite	
				Kimmiswick	Dunleith	Wyoto		
						Wali	Loves Park	Haldone Bentonite
						Sherwood		Nasset Bentonite
						Rivoli		Conover Bentonite Colmor Bentonite
						Mortimer		
						Fairplay		
						Eagle Point		
						Beecher		
						St. James		
						Buckhorn		
				Decorah	Guttenberg	Glenhaven	Dickeyville Bentonite Elkport Bentonite	
						Garnavillo		
					Spechts Ferry	Glencoe	Millbrig Bentonite	
				Castlewood	Deicke Bentonite			
	Platteville		Plattin	Quimbys Mill	Strawbridge			
					Shullsburg			
					Hazel Green			
			Plattin	Nachusa	Everett			
					Elm			
					Eldena			
			Plattin	Grand Detour	Forreston			
					Stillman			
					Cowen			
				Mifflin				
	Platteville		Pecatonica	Oglesby				
				Medusa				
				New Glarus				
				Dane				
				Chono				
Hennepin								

Figure 3.1. Classification of the Platteville and Galena Groups in northern Illinois.

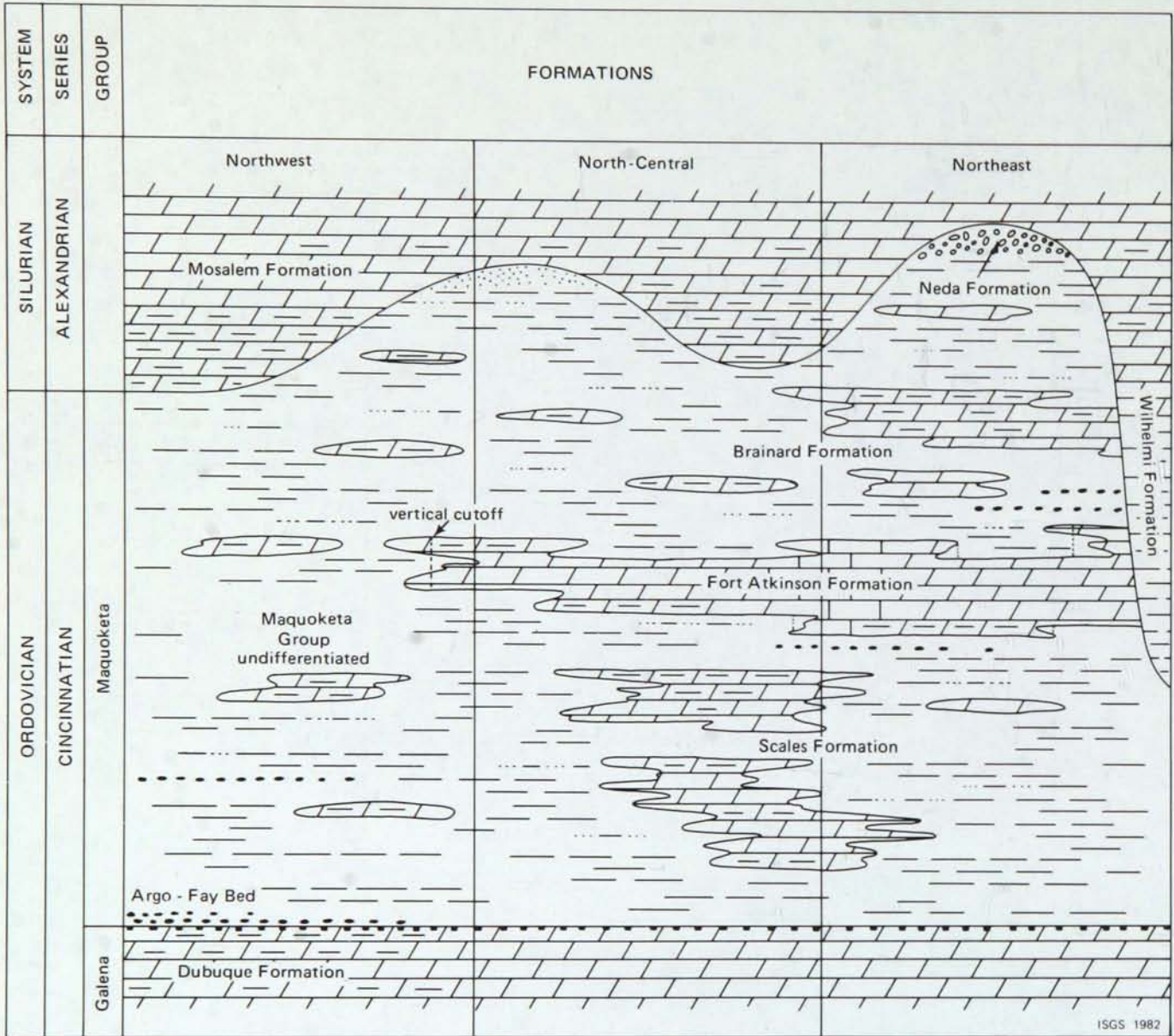


Figure 3.2. General stratigraphic relations of the Maquoketa Group in northern Illinois.

GENERAL SECTION OF THE MIDDLE AND LATE ORDOVICIAN STRATA OF NORTHEASTERN IOWA

Calvin O. Levorson¹, Arthur J. Gerk², Robert E. Sloan³, and Lynne A. Bisagno³

¹Box 13, Riceville, IA 50466

²714 3rd Ave SW, Mason City, IA 50401

³Department of Geology and Geophysics, University of Minnesota, Minneapolis, MN 55455

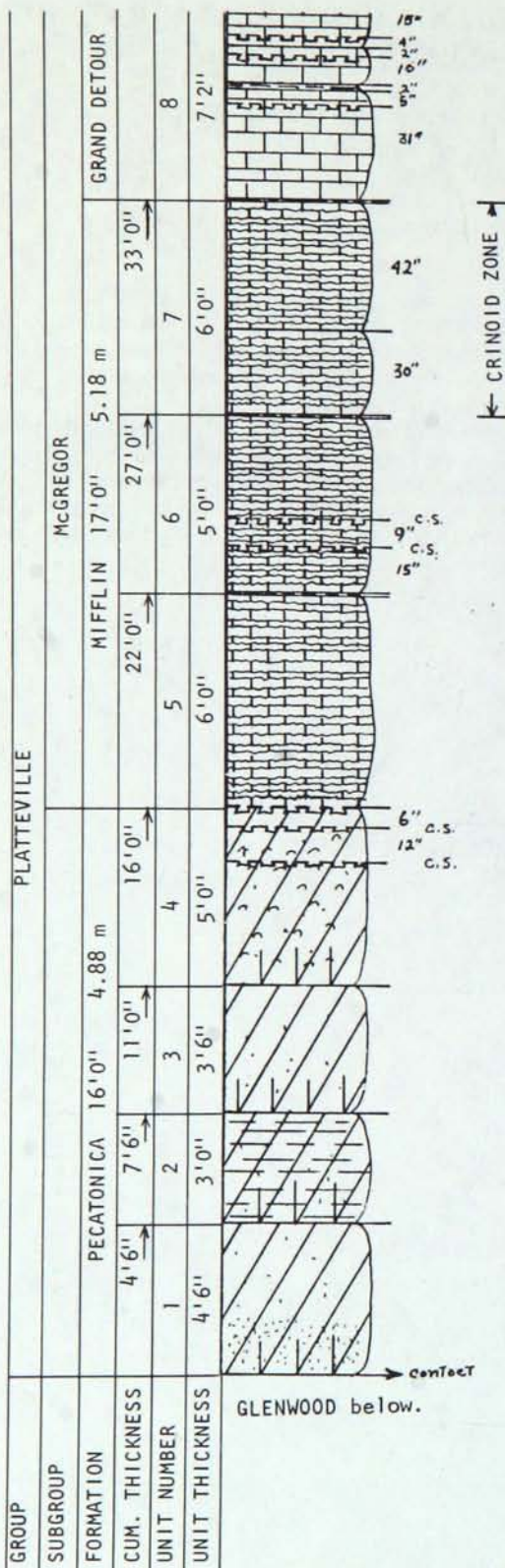
Levorson and Gerk have published descriptions of the Galena Group of northeastern Iowa (1972a,b, 1983) and the Dubuque Formation (Levorson and others, 1979) but have not yet published an account of the entire sequence of carbonates and shales, or of the common fossils to be found in these rocks. Bisagno reviewed all 60 of their measured sections of the Galena Group and listed all the fossils noted, by member. In 1975 Levorson drew a general section (Fig. 4.1a-m) of all strata from the base of the Platteville Formation to the top of the Maquoketa Formation by combining average parts of the more complete and typical measured sections. This provides useful information on the Platteville and the Maquoketa Formations

not otherwise available, and so it is included here. It also presents some of the variation in the Decorah Formation from the continuous shale section of Fillmore County, Minnesota, and Decorah, Winnebago County, Iowa, to the almost completely carbonate section near Dubuque, Iowa.

The fossil range chart (Fig. 4.2) differs slightly from the others in this book. Only the obvious fossils were listed, that is, those most common or of particular interest to Levorson and Gerk; it is not an exhaustive list. Identifications are only to genus. The data are useful for extending the ranges of fossils, albeit not precise enough to show initiation or termination.

ABBREVIATIONS IN LEVORSON AND GERK'S SECTIONS

C.S. = corrosion surface
 L&G = Levorson and Gerk (1972)
 L,G&B = Levorson and others (1979)
 M&H (1966) = Mossler and Hayes (1966)
 P,D&C = Parker, Dorheim, and Campbell (1959)
 SCB = sparry calcarenite bed
 T&W = Templeton and Willman (1963)



15"
4"
10"
16"
21"

CRINOID ZONE

1/2" prominent shale parting, top of Mifflin Member.
Limestone, hard, calcarenitic, shaly minor bedding surfaces with 1"-4" beds. Very fossiliferous in Clayton and southern Allamakee Counties, fossils fewer but common in Minnesota. All echinoderms of Platteville collected in this unit at top of Mifflin. Unit within which the large ostracod *Eoleperditia fabulites* is collected. *Porocrinus*, and other unknown crinoids. Well-preserved brachiopods common.

1/2" prominent shale parting.

Limestone slightly thicker bedded than Unit 5, (1"-4") crinkly beds; more silty at minor bed partings, fossils mostly fragmented, but occasional complete specimens.

C.S., pyritic.
C.S., pyritic.

1/2" prominent shale parting.

Limestone, hard, calcarenitic, weathers to 2"-3" crinkly surfaced beds on argillaceous streaks on face of fresh major beds. Fossils mostly fragmented.

Units 5-6-7 commonly referred to as the "Thin Brittle Beds" of the McGregor (Calvin, 1906 and others).

C.S., dark-gray, pyritic everywhere present.
C.S., pyritic; absent south of Allamakee County, Iowa.
C.S. pyritic; absent south of Mabel, Minn.

Unit 4: Massive dolomitic limestone and dolomite, fucoidal. Small (3/4") calcite-filled vugs common to unit. Fossils scarce.

Massive dolomite or dolomitic limestone, purer than below. Fossils scarce.

Dolomite or dolomitic limestone, massive, thick- to thin-bedded, argillaceous to more rarely shaly. Fossils scarce.

Massive dolomite or dolomitic limestone, more sandy near base. Fossils scarce.

GENERAL SECTION - ORDOVICIAN STRATA
Section prepared by C.O. Leverson from data he and A.J. Gerk gathered during period from 1970 through 1975. This section includes strata measured within NE Iowa, SE Minnesota, SW Wisconsin, and NW Illinois, to provide an average of these. February 1975; minor revision RES, 1987.

Figure 4.1. General section Ordovician strata in northeastern Iowa.

Figure 4.1 continued.

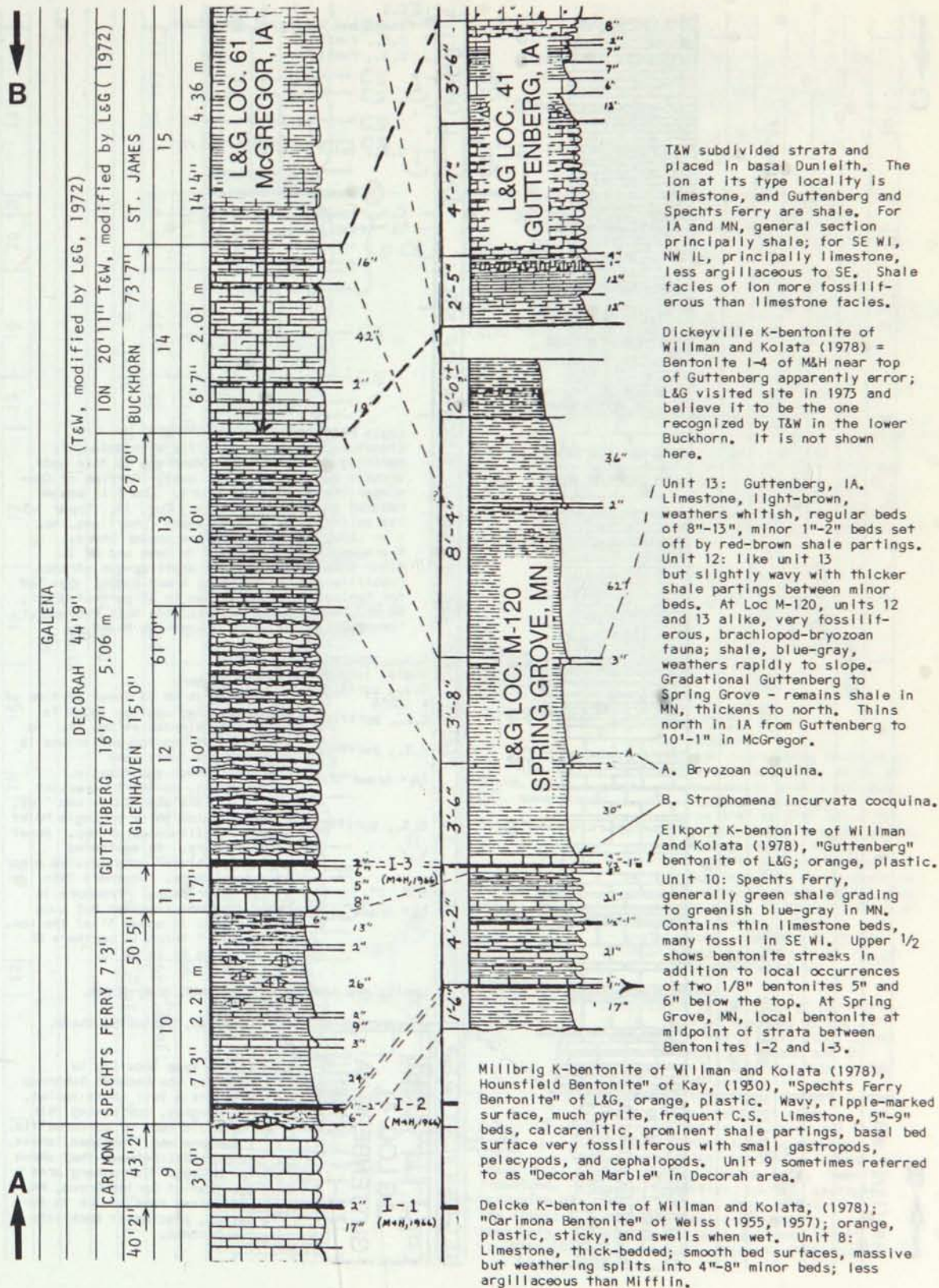


Figure 4.1 continued.

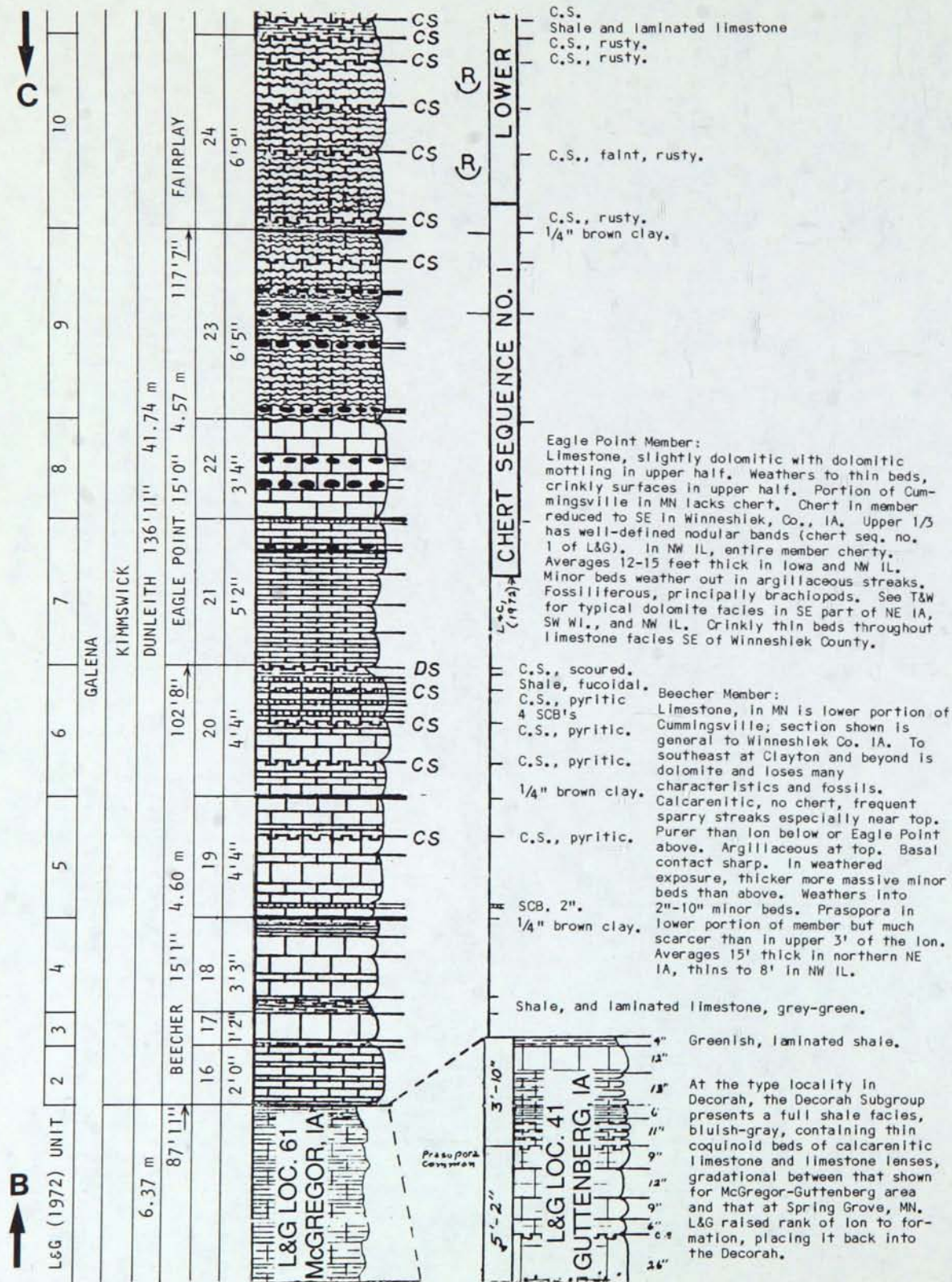


Figure 4.1 continued.

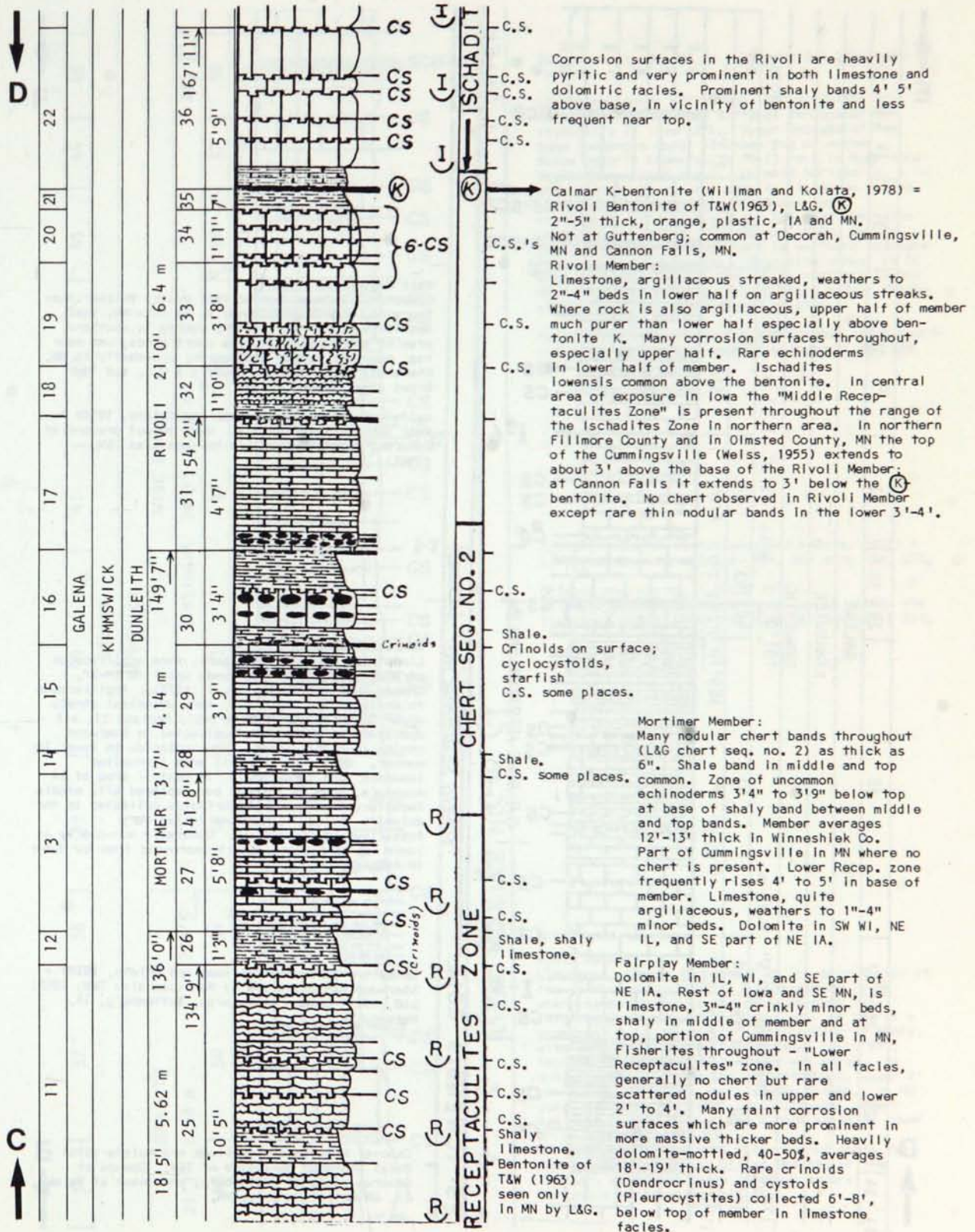


Figure 4.1 continued.

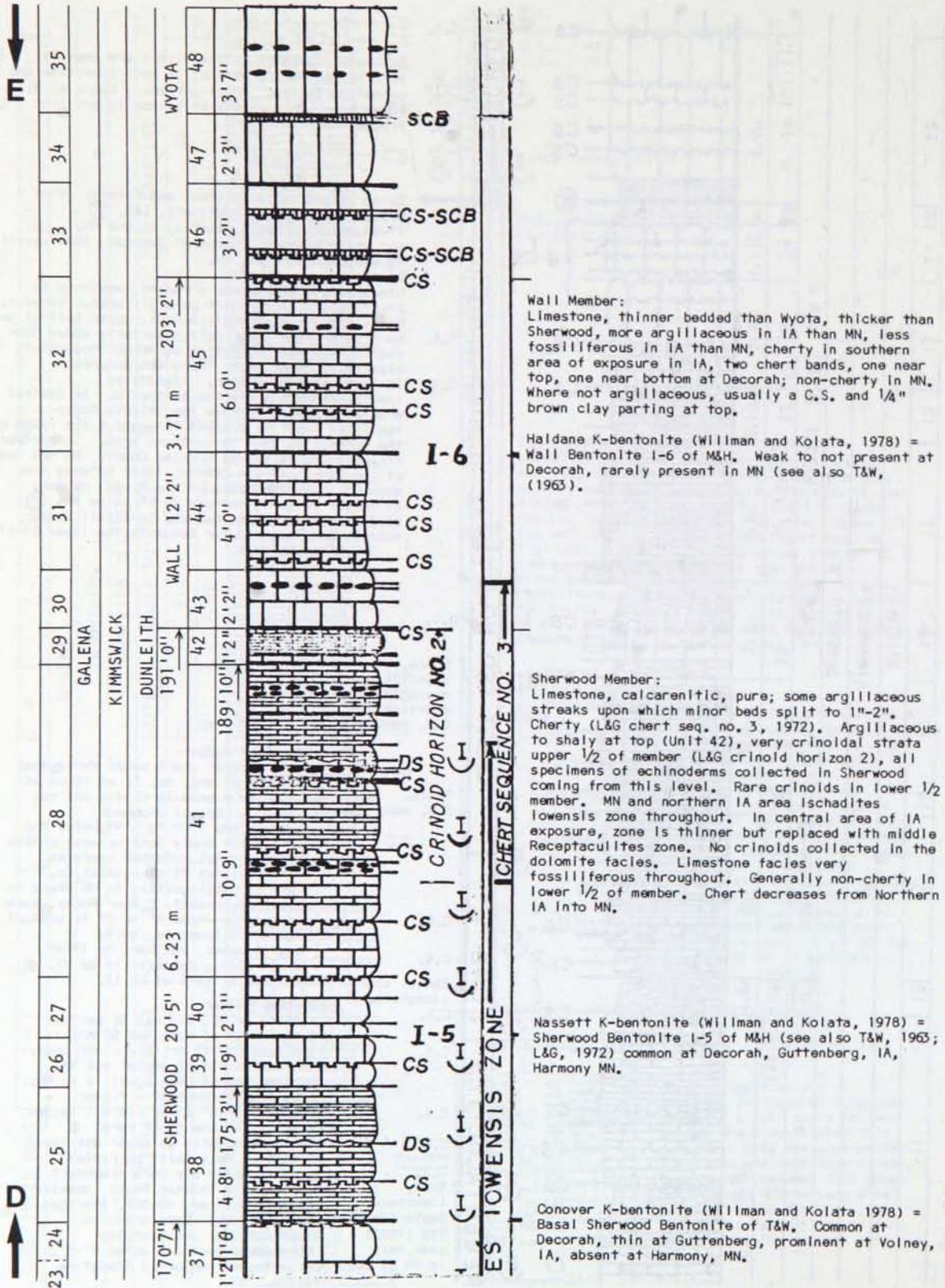
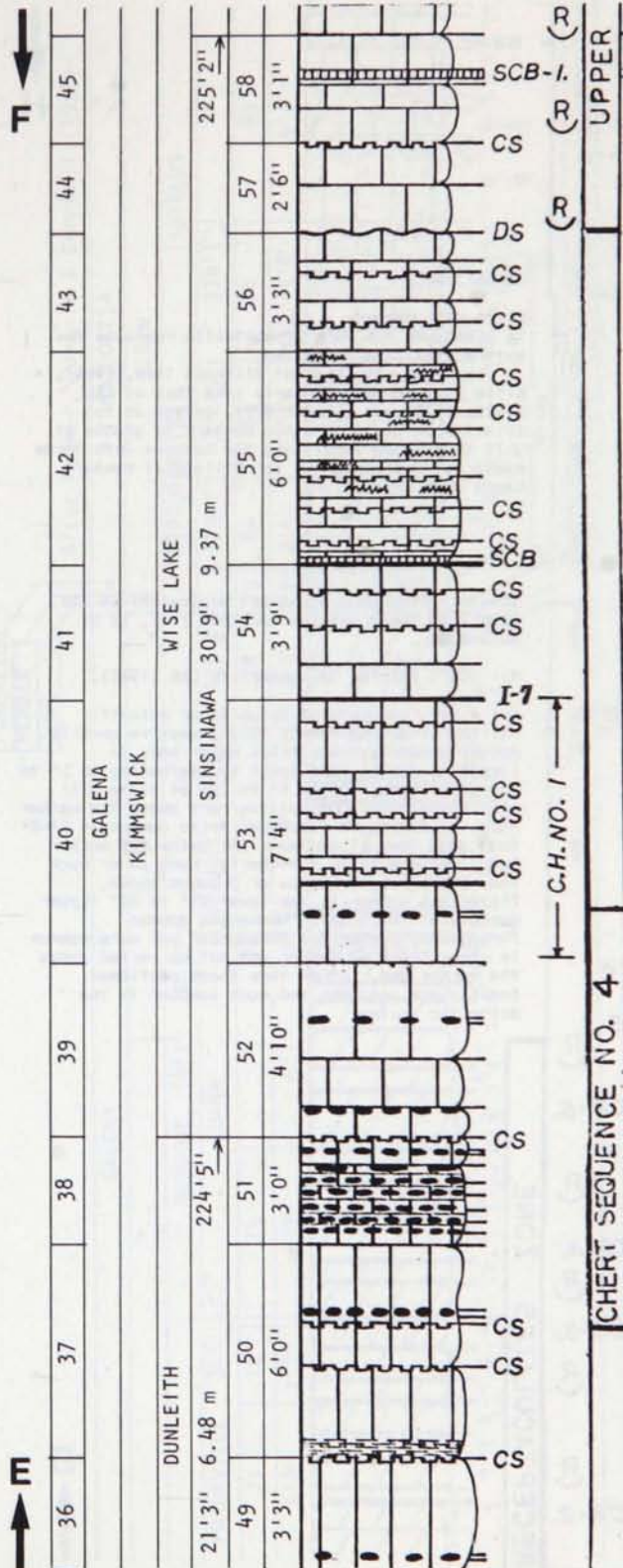


Figure 4.1 continued.



SCB No. 1 of L&G 12" to 14" below top Sinsinawa Member.
 Limestone, north Guttenberg, but dolomitic to south. Many corrosion surfaces throughout but especially in lower 2/3. Upper Receptaculites zone commences about 5' below top of member. Below Dygerts K-bentonite (I-7) rock is much more argillaceous than above. Crinoid horizon no. 1 in strata to 8' below bentonite in limestone facies. In dolomite facies (Unit 55) shows many stylolites. Frequently shown SCB near bentonite in limestone facies. Non-cherty in MN, two to four thin bands nodular chert in northern exposure mostly Winneshiek County. Bentonite normal in SE area of exposure in IA and IL; in northern IA and MN is shown as a feldspathized shale rather than a sticky clay that expands with moisture.

Agnew (1955) would separate the Prosser and Stewartville above the chert, probably in basal bed top Unit 53.

Dygerts K-bentonite (Willman and Kolata, 1978) = Sinsinawa Bentonite I-7 of M&H, see also T&W, L&G.
 Crinoid horizon no. 1 (L&G, 1972).
 All specimens of echinoderms collected within the Sinsinawa Member were from this horizon (Unit 53).

Wyota Member:
 Limestone, cherty throughout in IL, principally at top in Winneshiek County, to non-cherty in MN where member thins to as little as half the thickness shown in general section. At top is a prominent C.S. Upper 3'0" argillaceous to shaly, with many (5-7) nodular chert bands (Unit 51). Thicker bedded than Wall Member and purer. In dolomite facies southeast of Guttenberg, upper 8' shows thin beds with argillaceous flecks. In MN pure, calcarenitic, very fossiliferous. Chert seq. no. 4 of L&G, includes 2 to 4 bands in lower 8' of overlying Sinsinawa.
 At some localities in MN Weiss (1953) chose the top of the Wyota (Unit 51) as the top of the Prosser; at others chose in error several corrosion surfaces in Unit 53.

Figure 4.1 continued.

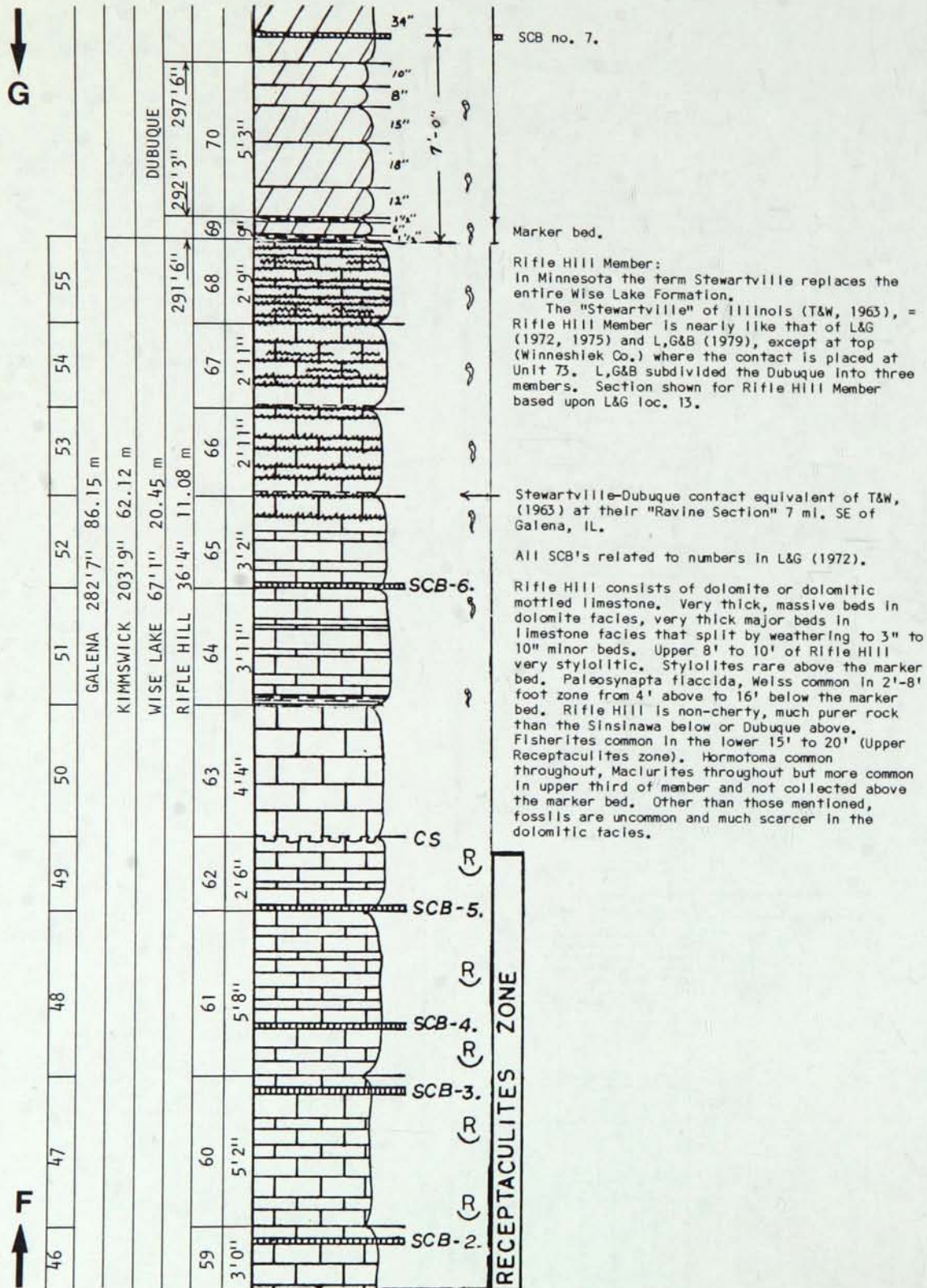


Figure 4.1 continued.

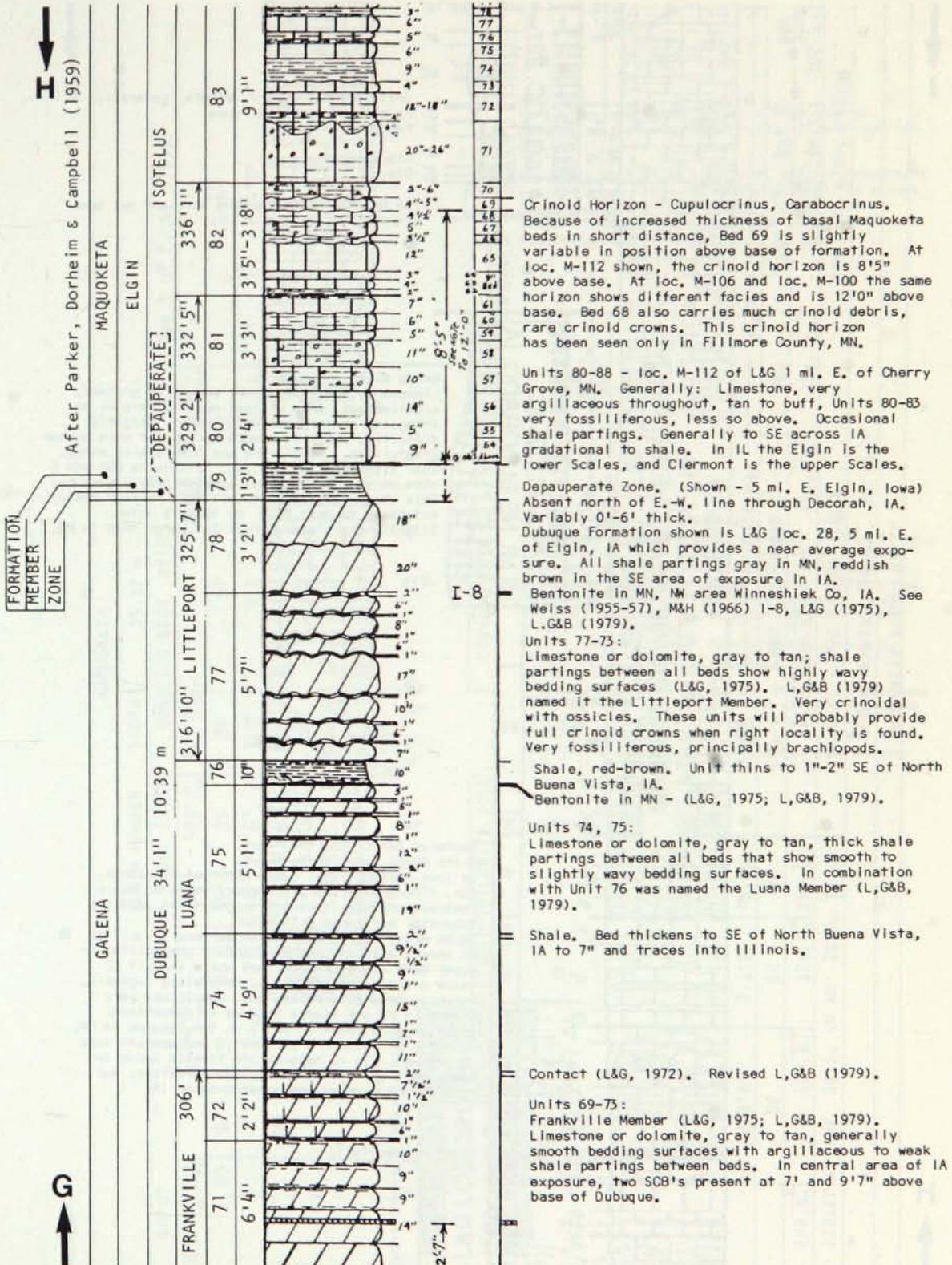


Figure 4.1 continued.

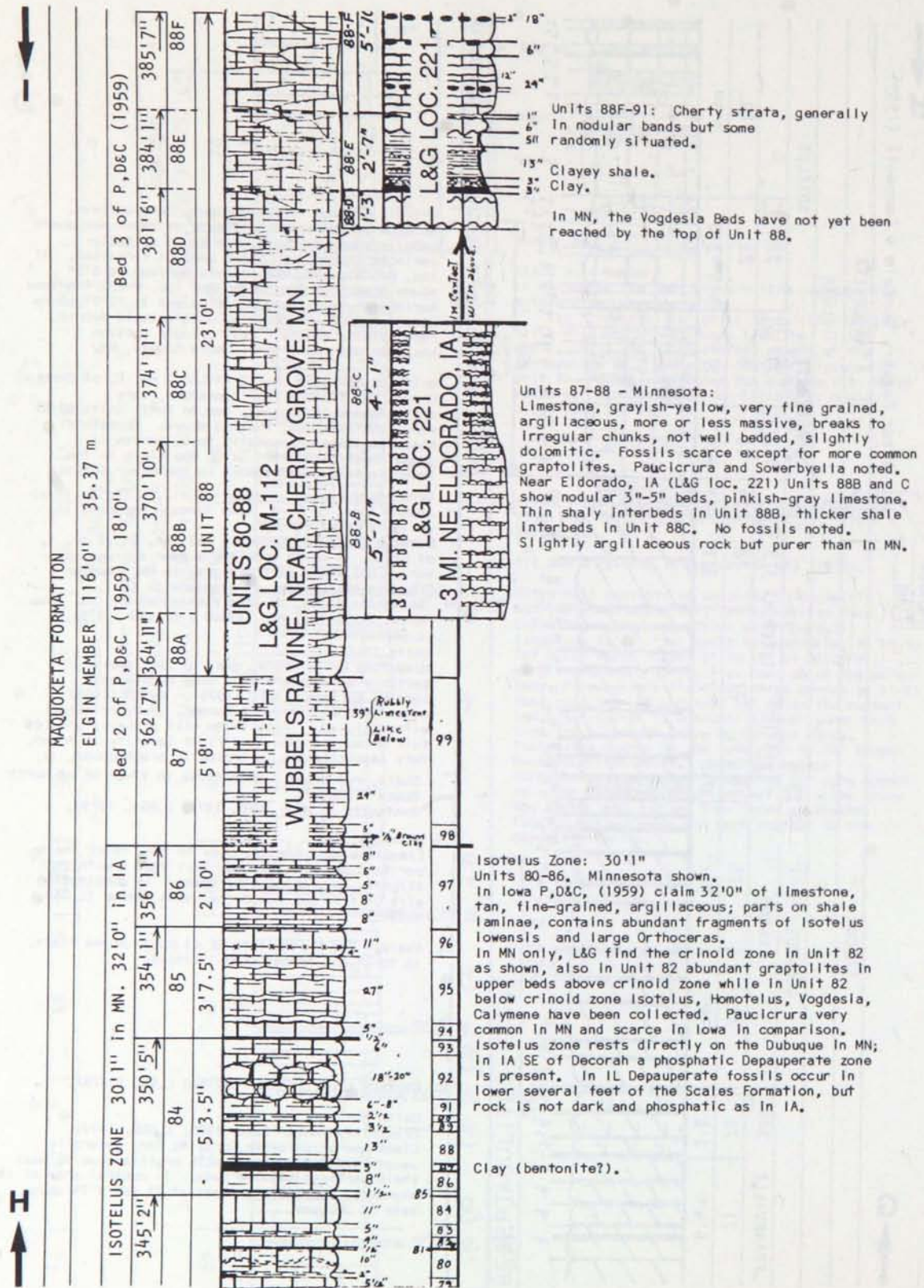
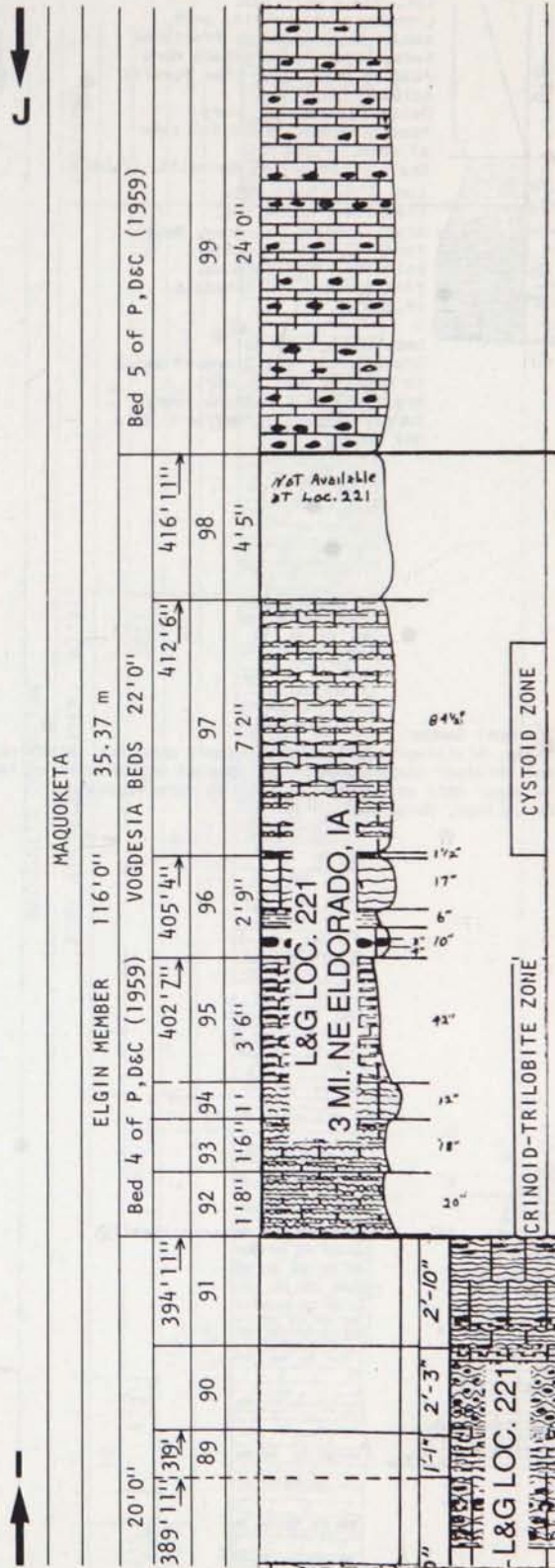


Figure 4.1 continued.



Unit 99:
No section available. P,D&C (1959) used in general section. Upper 8'3" shown above from loc. 208.

Generally Unit 99 is limestone, yellowish-brown to grayish-brown, fine- to medium-grained, in places dolomitic, chert-free in upper 10'-13'; lower 11'-14' contains light-gray chert nodules and abundant fossil fragments.

Units 92-98, "Vogdesia beds":
Limestone, dolomitic, argillaceous, grayish-brown, rare nodular chert bands. Shaly in Units 92-95 with weathering. Units 92-95 crinoid-trilobite zone, such relatively common fossils collected as *Porocrinus*, *Vogdesia*, *Calymene*, *Ceraurus*, small cystoid *Pleurocystis clermontensis?*, and other trilobite fragments.
Entire "Vogdesia beds" fossiliferous with many brachiopods, occasional solitary corals, bryozoans.
Unit 97 referred to as cystoid zone by L&G because complete large specimens of the various Maquoketa species of the genus *Pleurocystites* occur.
Although Unit 98 has been seen in the field, no section was available to use in the general section. It is essentially like Unit 97.

CRYSTOID ZONE

CRINOID-TRILLOBITE ZONE

Figure 4.1 continued.

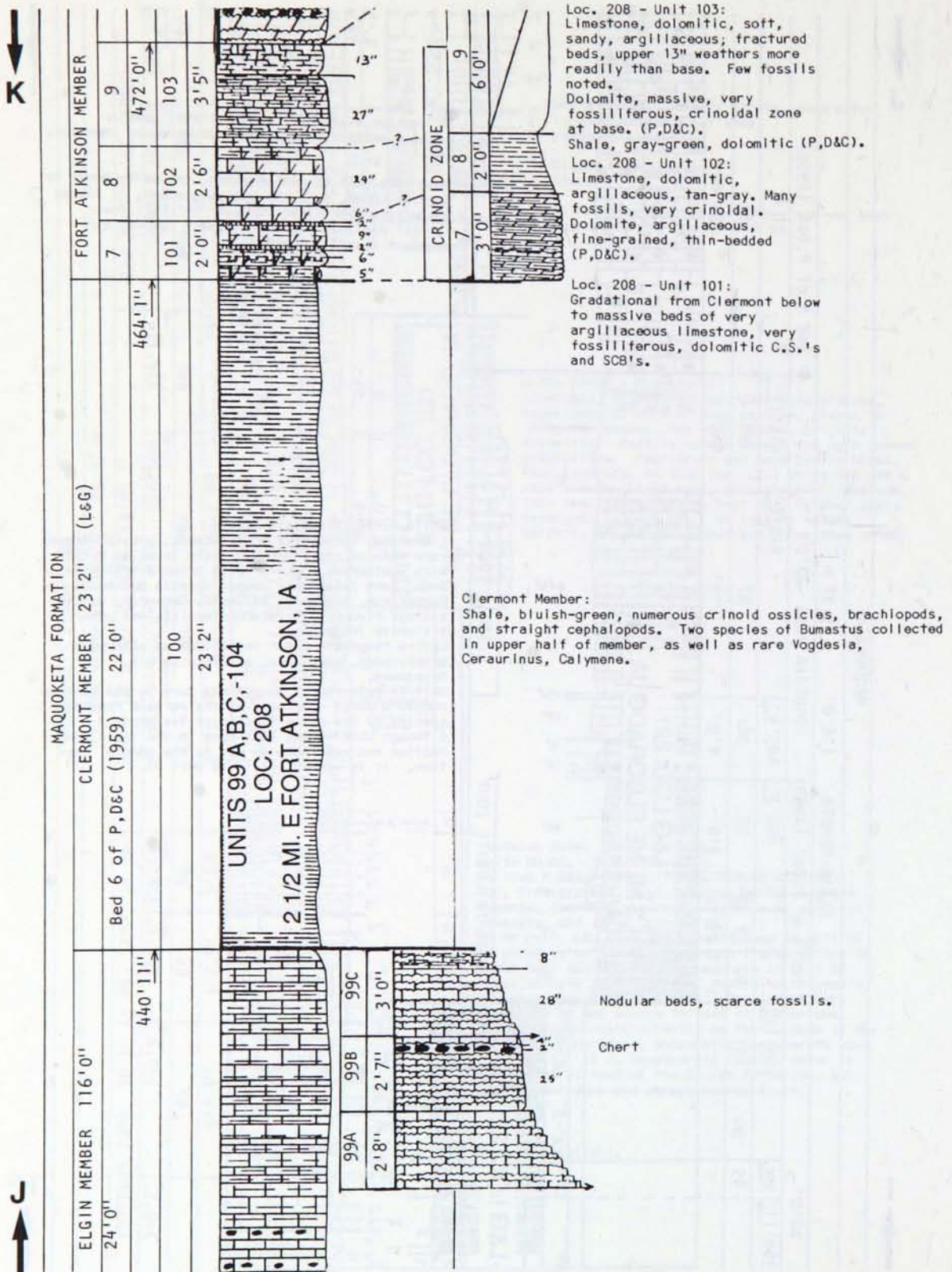


Figure 4.1 continued.

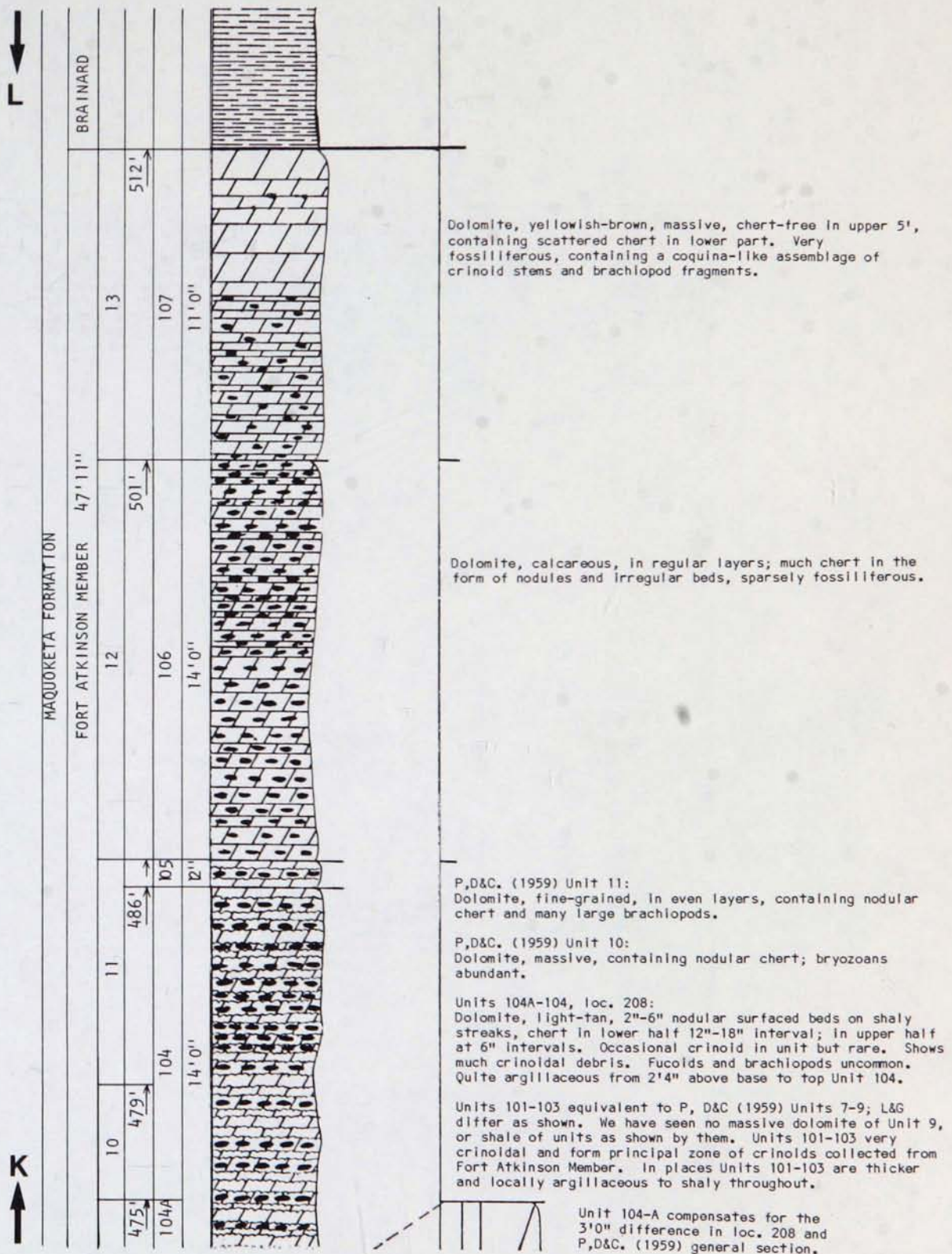
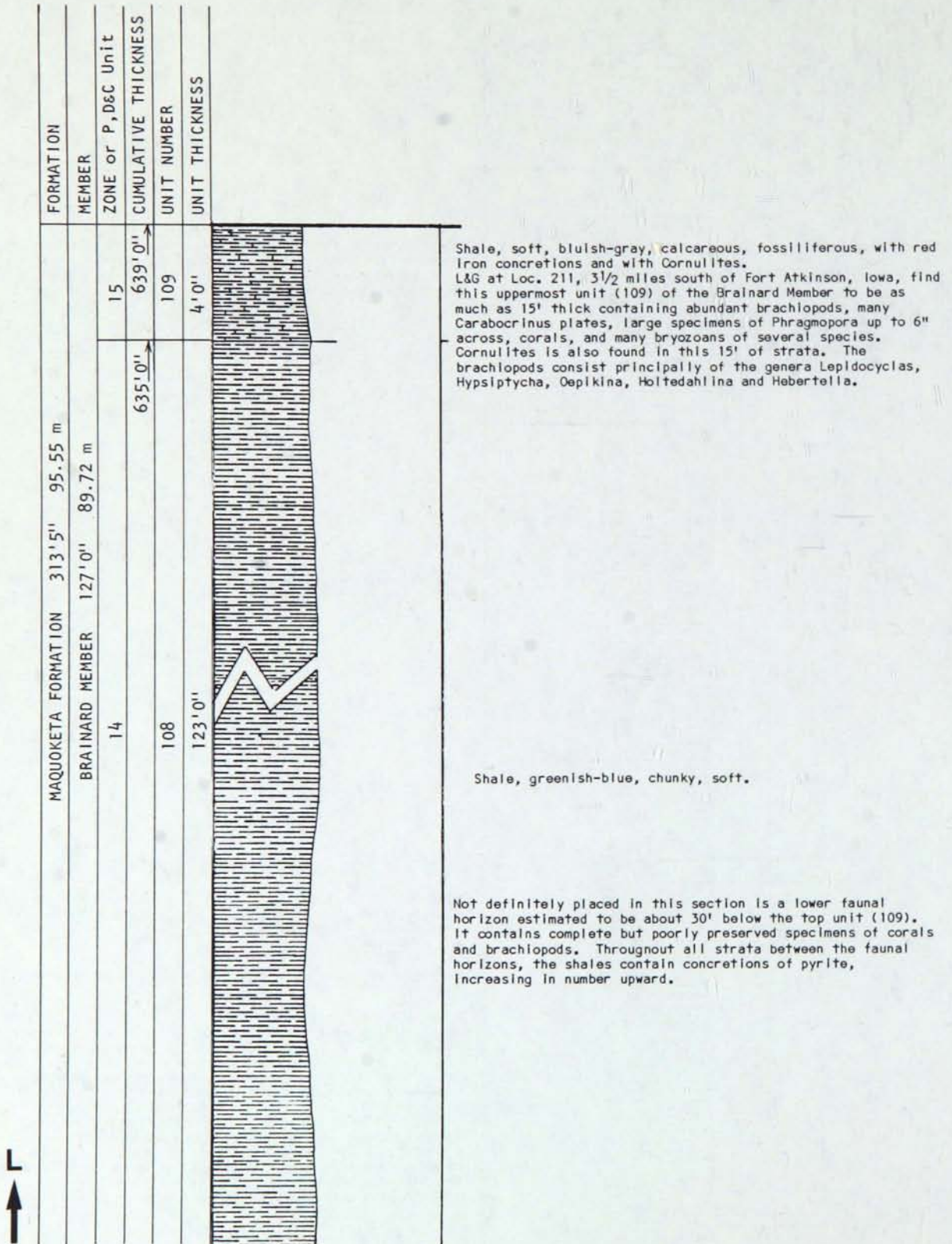


Figure 4.1 continued.



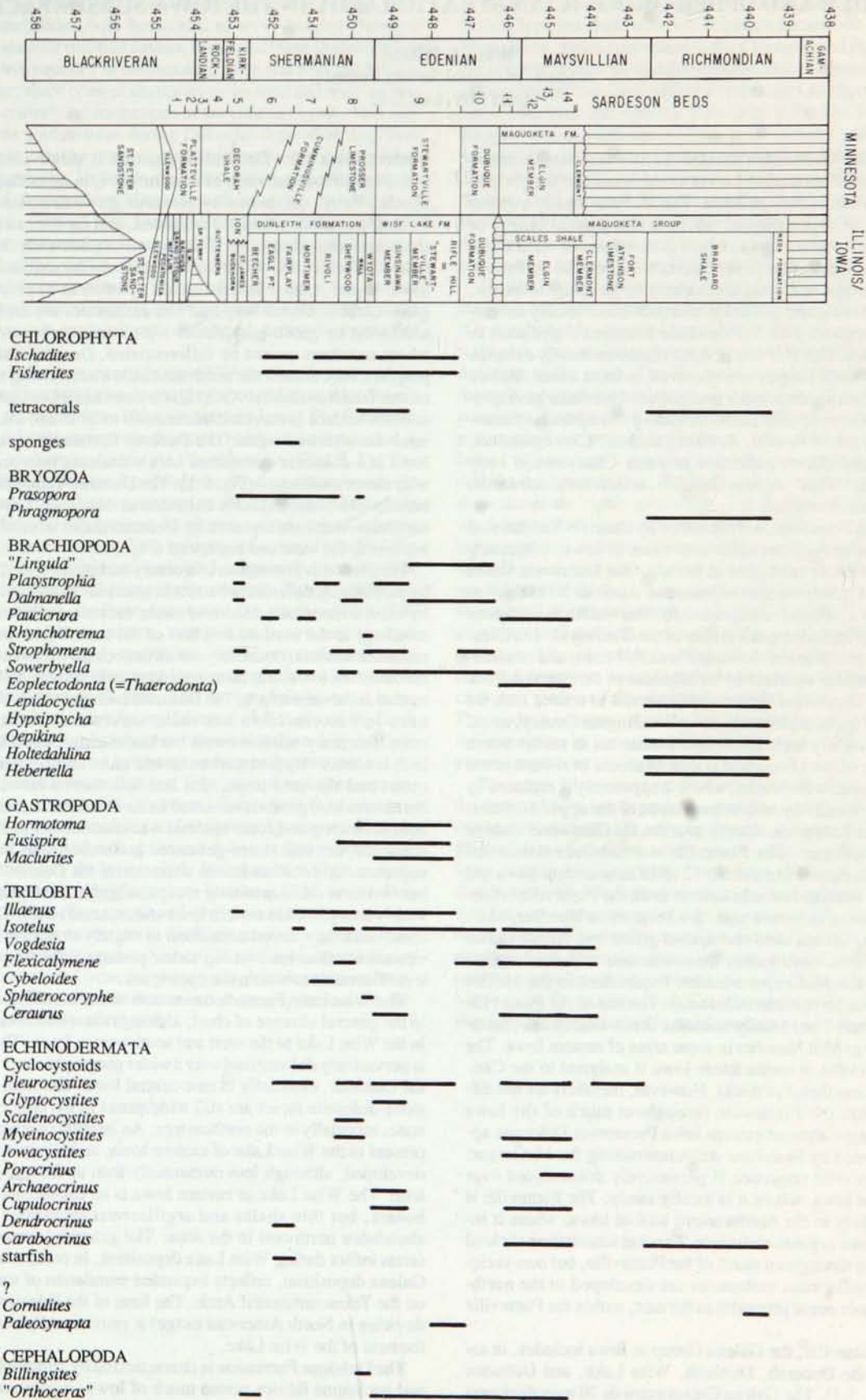


Figure 4.2. Stratigraphic occurrence of common fossils in the Galena Group from Levorson and Gerk's measured sections.

MIDDLE AND UPPER ORDOVICIAN STRATIGRAPHY IN THE IOWA SUBSURFACE

Brian J. Witzke

Iowa Geological Survey Bureau
Iowa City, IA 52242

The basal Middle Ordovician strata of the St. Peter Sandstone unconformably overlie an eroded Lower Ordovician surface (Prairie du Chien Group) across most of Iowa. The St. Peter locally overlies Cambrian strata in eastern Iowa, where it fills karstic valleys or sinks, and in northwestern Iowa, where it overlies a beveled Cambrian surface southeast of the Sioux Quartzite ridge. The St. Peter is dominantly pure quartz arenite throughout its geographic extent. However, minor shale and dolomite interbeds occur locally in eastern Iowa, and organic-rich brown shale becomes significant in northwestern Iowa. The St. Peter in Iowa is predominantly a marine unit, and bioturbated fabrics are observed in most cores. Brown shale units in northwestern Iowa and eastern Nebraska have produced an abundant conodont fauna including *Phragmodus flexuosus*, *Cahabagnathus sweeti*, *Archeognathus*, *Chirognathus*, *Curtognathus*, and others indicative of a late Chazyan and early Blackriveran age. "Fish" debris, lingulids, resserellids, ostracods, and bryozoans are also noted.

The Glenwood Formation is represented by a thin (1-3 m) interval of noncalcareous gray-green shale over most of Iowa, commonly with minor siltstone or sandstone at the top. The Glenwood shales are overlain by a quartz arenite sequence as much as 30 m thick in southeastern Iowa, which is assigned to the Starved Rock sandstone and provisionally included as a member of the Glenwood. The Glenwood shales in southeastern Iowa are locally brown and organic-rich, primarily where overlain by or adjacent to the Starved Rock Sandstone. The Glenwood brown shales served as source rock for small-scale petroleum accumulations in Washington County, Iowa. The Glenwood locally includes oolitic ironstones in northwestern Iowa. The shale of the Glenwood is thin to absent in southwestern Iowa and southeastern Nebraska, where it apparently is replaced by sandy strata and locally by oolitic ironstones of the upper St. Peter.

The Platteville Formation sharply overlies the Glenwood shale or Starved Rock sandstone. The Platteville is a carbonate-dominated unit ranging in thickness from about 12 to 18 m in eastern Iowa and from 5 to 9 m in western Iowa. In eastern Iowa the Platteville is subdivided into a lower dolomite unit, the Pecatonica Member, commonly containing quartz sand and apatite grains and clasts, and an upper wavy-bedded fossiliferous limestone unit with thin argillaceous partings, the McGregor Member (equivalent to the Mifflin and Grand Detour formations in Illinois). The top of the Platteville sequence (less than 1 m) locally contains dense limestones resembling the Quimby's Mill Member in some areas of eastern Iowa. The uppermost Platteville in northeastern Iowa is assigned to the Carimona Member (less than 1 m thick). However, members are not differentiated within the Platteville throughout much of the Iowa subsurface. In large areas of eastern Iowa Pecatonica Dolomite apparently is replaced by limestone strata resembling the McGregor. The entire Platteville sequence is pervasively dolomitized over much of western Iowa, where it is locally sandy. The Platteville is notably more shaly in the northwestern half of Iowa, where it includes some brown organic-rich shale. Diverse stenohaline skeletal biotas are present throughout much of the Platteville, but non-skeletal burrowed argillaceous carbonates are developed in the northwest. Hardgrounds occur primarily in the east, within the Platteville sequence.

Above the Platteville, the Galena Group in Iowa includes, in ascending order, the Decorah, Dunleith, Wise Lake, and Dubuque formations (Fig. 5.1). The Galena Group exceeds 70 m in thickness throughout northern and eastern Iowa, but thins to 45 m in south-

western Iowa. The Decorah Formation is subdivided into three members throughout most of eastern Iowa, in ascending order, the Spechts Ferry, dominated by greenish-gray calcareous shales, the Guttenberg, a wavy-bedded limestone, and the Ion, an interbedded shale and limestone unit. Thin brown organic-rich shales are interbedded with the Guttenberg carbonates in the southeastern half of Iowa; in places these shales contain as much as 40 percent total organic carbon. Guttenberg and Ion carbonates are replaced to the northwest by green-gray shales with minor carbonate interbeds, where members cannot be differentiated. Decorah shales thicken progressively toward the northwest in Iowa reflecting source areas on the Transcontinental Arch. Shale-dominated Decorah sequences in northwestern Iowa reach thicknesses to 29 m and locally include intervals with iron ooids. The Decorah Formation in southwestern Iowa is a dolomite-dominated unit containing interbedded shales with minor sandstones (Fig. 5.1). The Decorah-Dunleith contact is a broadly diachronous facies transition across Iowa. Lower Dunleith carbonate strata are replaced by Decorah shales or sandy-shaly carbonates to the west and northwest (Fig. 5.2).

The Dunleith Formation is a cherty carbonate unit characterized by pervasively dolomitized strata in southern and western Iowa, and by mixed limestone-dolomite strata (common dolomitic burrow mottling) in the northeastern half of the state. Nine members with remarkable lateral continuity are differentiated in the outcrop belt of northeastern Iowa, but these members have proven difficult to recognize in the subsurface. The Dunleith averages about 40 m in thickness in eastern Iowa but thins westward, in part sharing complementary relations with the underlying Decorah. The Dunleith is a relatively pure carbonate and chert unit containing argillaceous and silt-sand impurities and less chert westward in Iowa. Numerous hardgrounds are noted in the Dunleith sequence in Iowa, both in outcrop and core. Skeletal wackestones and packstones predominate, but thin storm-generated grainstone units punctuate the sequence. Stenohaline faunas characterize the Dunleith regionally, but two intervals containing receptaculitid and dasyclad algae are widely recognized in eastern Iowa and adjacent states. The receptaculitid units may record deposition in slightly shallower subtidal environments than intervening units, perhaps reflecting eustatic sea level fluctuations within the epeiric sea.

The Wise Lake Formation contrasts with the underlying Dunleith in the general absence of chert, although chert becomes noteworthy in the Wise Lake to the west and southwest in Iowa. The Wise Lake is pervasively dolomitized over a wider geographic area in Iowa than the Dunleith, especially in east-central Iowa, although mixed limestone-dolomite facies are still widespread in the eastern half of the state, especially in the northeastern. An interval of receptaculitids is present in the Wise Lake of eastern Iowa, and hardgrounds also are developed, although less numerous than in the underlying Dunleith. The Wise Lake in eastern Iowa is an exceptionally pure carbonate, but thin shales and argillaceous impurities increase in abundance northwest in the state. The general decrease in argillaceous influx during Wise Lake deposition, in comparison to earlier Galena deposition, reflects expanded inundation of source terrains on the Transcontinental Arch. The base of the Edenian (Upper Ordovician in North American usage) is provisionally correlated near the base of the Wise Lake.

The Dubuque Formation is characterized by crinoidal wackestone and packstone fabrics across much of Iowa. It commonly contains minute "cinnamon specks" (marine palynomorphs and chitino-

zoans), and a moderately diverse stenohaline fauna is present. Thin shales are interbedded with horizontal to wavy-bedded Dubuque carbonate strata over much of eastern Iowa, and these shales thicken and increase in frequency in northeastern Iowa and adjacent Minnesota. However, shale content decreases to the west and northwest in Iowa, unlike underlying formations in the Galena Group. This suggests that shale source areas during Dubuque deposition may have been localized along the trend of the Transcontinental Arch in Minnesota. Alternatively, Dubuque shale deposition may represent the distal clays of a prograding Maquoketa shale wedge derived from distant Taconic sources. The Dubuque carbonates are pervasively dolomitized across much of Iowa, but the Dubuque is chiefly limestone in most of the northeastern quarter of the state. The Dubuque was deposited in environments intermediate between the shallow subtidal with calcareous algae of the Wise Lake and the deeper water dysoxic and anoxic environments developed during deposition of the basal Maquoketa.

The Maquoketa Formation (Group in Illinois) forms the top of the Ordovician sequence in Iowa, averaging about 65 m in thickness in eastern Iowa and as thick as 100 m in western Iowa. The formation has significant facies changes in the state, being shale dominated in the east and carbonate dominated in the west (Fig. 5.3). The Maquoketa shales represent the distal margin of an extensive clastic wedge derived from Taconic sources to the east. The Maquoketa overlies a prominent hardground developed on top of the Dubuque across most of eastern Iowa. This hardground is buried and locally encrusted by phosphorites, and multiple hardgrounds occur at some localities within the basal phosphorite interval. The phosphorites contain an abundant, mollusc-dominated diminutive fauna. The basal phosphatic unit is, in turn, overlain by brown organic-rich shales, which are commonly graptolitic. The brown shales are thickest in east-central and southeastern Iowa and correlate with much of the Scales Formation of Illinois. The brown shale interval is replaced to the north and west by argillaceous carbonates of the Elgin Member. The Elgin in northeastern Iowa is dominated by trilobite micrites, which is replaced by cherty carbonate facies containing a brachiopod-crinoid fauna to the west. The basal phosphorites are absent across most of central and western Iowa, where the Dubuque-Elgin contact is conformable (no hardground present). Unique phosphatic and nautiloid-rich shale and dolomite facies occur near the transition between the brown shale facies and the Elgin carbonate shelf margin (e.g., type Maquoketa section at Graf, Iowa). Following transgression of an anoxic and dysoxic water mass across the Dubuque surface in eastern Iowa, the Elgin records a general shallowing-upward depositional sequence. In addition, lateral facies changes indicate a trend from deeper oxygen-poor depositional conditions in the southeast to shallower and more oxygenic shelf carbonate deposition to the northwest.

A second transgressive-regressive depositional cycle is recorded in the Clermont Shale and Fort Atkinson Limestone members of the Maquoketa. Strata equivalent to the Clermont and Fort Atkinson occur entirely within an undifferentiated shale sequence across much of east-central Iowa and within a carbonate and cherty carbonate interval in central and western Iowa (Fig. 5.3). The Fort Atkinson in the type area of northeastern Iowa is an isolated carbonate unit surrounded by shale strata. In that area the Fort Atkinson varies from cherty whole-shell wackestones in the lower part to grainstones at the top. The Clermont-Fort Atkinson interval in central Iowa varies from weakly laminated, largely unfossiliferous argillaceous dolomite in the lower part to cherty fossiliferous dolomite with wackestone and packstone fabrics in the upper part.

The Brainard Member overlies the Fort Atkinson and, along with the Neda Member, represents a third Maquoketa depositional cycle. It is dominated by greenish-gray dolomitic shale in eastern and central Iowa, but includes progressively more dolomite and cherty dolomite to the west. The Brainard is only sparsely fossiliferous through most of the sequence, but horizontal burrow mottling is common. Interbedded fossiliferous carbonates (wackestones to grainstones) are present in the upper part of the interval in eastern Iowa ("Cornulites" zone). Brownish-gray shales are present locally in the lower half of the Brainard; in some central Iowa cores these shales are highly graptolitic. The Brainard is a shallowing-upward depositional sequence; it is dominated by dysoxic facies in the lower part and includes normal-marine skeletal benthos indicative of shallow subtidal depositional conditions in the upper part. Where the Brainard is thickest (i.e., where sub-Silurian erosional incision is minimal), a red and maroon shale and mudstone interval, generally less than 5 m thick, is present at the top of the Maquoketa. This red interval is assigned to the Neda Member and commonly includes flattened ironstone ooids (goethite/apatite) which, in core and outcrop, are preferentially distributed within subhorizontal burrows. The Neda is interpreted as the final regressive phase of Maquoketa sedimentation in Iowa, possibly deposited in relatively sediment-starved nearshore environments.

The upper Maquoketa surface was subaerially exposed prior to the onset of Silurian deposition, and Brainard and Neda Strata are erosionally truncated to varying degrees beneath the Silurian strata across Iowa. Sub-Silurian erosional relief is greatest in eastern Iowa, locally reaching 30 m. Ordovician strata are erosionally beveled beneath Middle Devonian strata in southeastern Iowa. Truncation becomes more pronounced toward the south where rocks have been removed as far down as the upper Dunleith Formation. In northern Iowa Devonian strata typically overlie a beveled erosional surface developed on carbonate of the Elgin Member of the Maquoketa Formation. Sub-Cretaceous beveling of Ordovician strata is also documented in northwestern and northeastern Iowa.

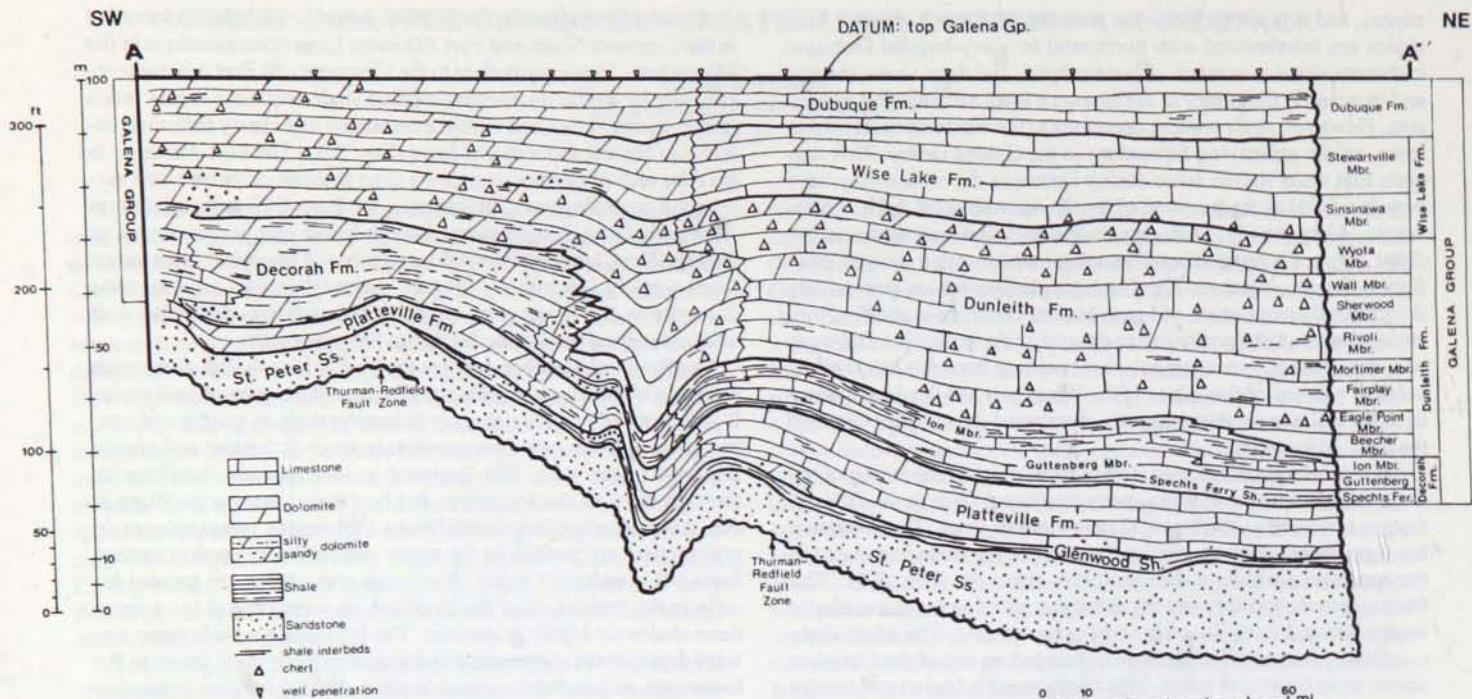


Figure 5.1. Stratigraphic cross section of St. Peter Sandstone through Galena Group sequence. Line A-A' runs from the southwestern corner to the northeastern corner of Iowa (from Witzke, 1983).

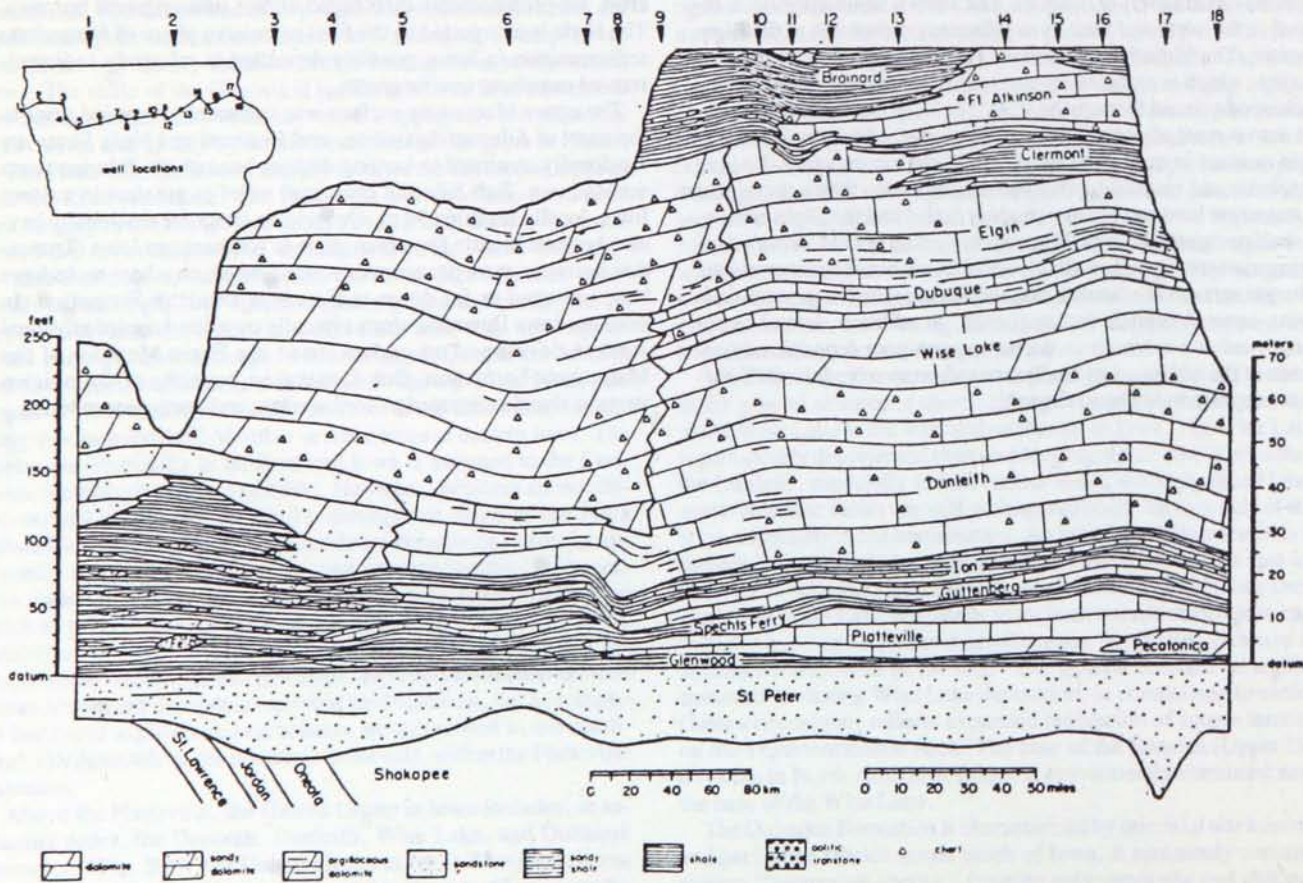


Figure 5.2. East-west stratigraphic cross section of Middle and Upper Ordovician strata in Iowa (adapted from Witzke, 1980).

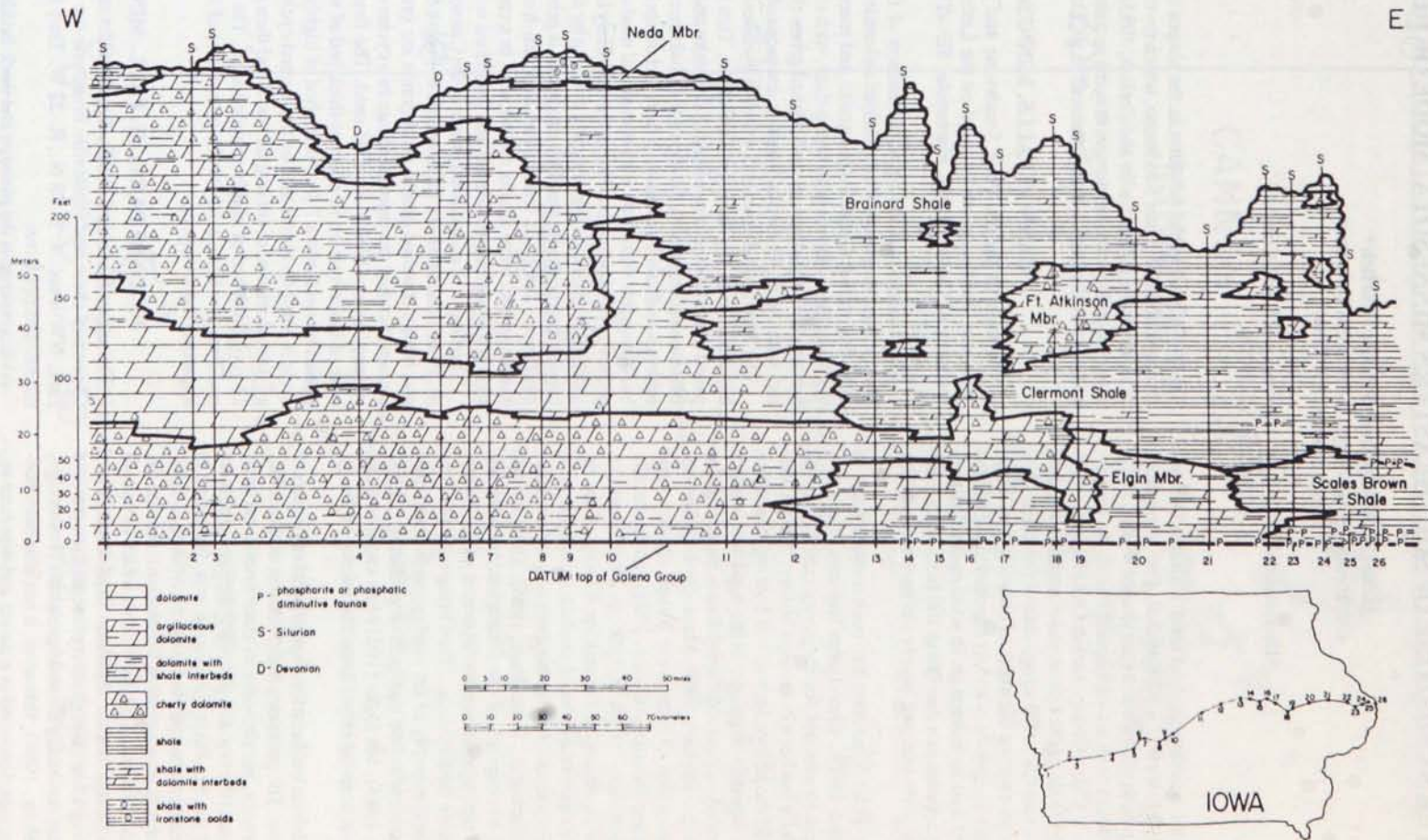


Figure 5.3. East-west stratigraphic cross section of the Maquoketa Formation in Iowa (from Witzke, 1983).

THE ST. PETER SANDSTONE OF SOUTHEASTERN MINNESOTA: MODE OF DEPOSITION

James M. Mazzullo and Robert Ehrlich*

Department of Geology, Texas A&M University
College Station, TX 77843

*Department of Geology, University of South Carolina
Columbia, SC 29208

The St. Peter Sandstone is a cratonic sheet sand of Middle Ordovician age composed of well-sorted, well-rounded, fine to medium quartz sand and rare thin beds of shale and coarse sand (Dake, 1921; Thiel, 1935). The formation rests unconformably upon the carbonate rocks of the Prairie du Chien Group (Lower Ordovician), and is conformably overlain by shale of the Glenwood Formation (Middle Ordovician). It covers a vast (225,000 sq mi) area of the upper Mississippi Valley, but has an average thickness of only 100 feet (Dapples, 1955). The St. Peter Sandstone is widely exposed in the valleys of the Mississippi River and its tributaries in southeastern Minnesota, where it generally appears as a thin (80 to 160 feet), thick-bedded, massive sandstone with rare and poorly defined sedimentary structures.

The origin of the St. Peter Sandstone has been a major topic of controversy since the mid-1800s, when James Hall and others proposed a chemical origin to account for its purity (see Sardeson, 1896). One topic of debate has been its erosion history. The textural maturity of the sand, and the known lack of soil-binding vegetation in pre-Devonian times, strongly suggest that the wind was a major erosive force on the North American continent during the accumulation of the St. Peter (e.g., Berkey, 1906; Mazzullo and Ehrlich, 1983). They also suggest that streams were broad, shallow, and poorly channelized during this time (Cotter, 1978), and generally "accomplished little in erosion" (Berkey, 1906, p. 246). However, there is very little clear evidence for the erosion history of the St. Peter Sandstone. Its unconformable basal contact is thought to be fluvial in origin (e.g., Palmquist, 1969), but there is some evidence that it may be a karst surface (e.g., Buschbach, 1961). There are rare sedimentary structures in outcrops of the formation, but they are generally diagnostic of the depositional environment of the formation rather than its erosion history (e.g., Trowbridge, 1917). The textural and compositional maturity of the sand grains is commonly presumed to be the product of eolian transport (e.g., Berkey, 1906; Mazzullo and Ehrlich, 1983), but Dake (1921) has cautioned that this maturity might have been inherited from the source of the St. Peter Sandstone.

The second topic of debate has been the depositional environment of the St. Peter Sandstone. The geometry and thickness of the formation, its massive appearance, the presence of trace fossils and body fossils of marine fauna, and the size and sorting of the sand grains are taken as evidence that the St. Peter Sandstone was deposited in coastal and shallow marine environments during the Middle Ordovician transgression (except in southwestern Wisconsin); that the St. Peter sea had gentle wind-driven longshore currents which swept silt and clay to the southwest; and that the transition from the St. Peter Sandstone to the overlying Glenwood shale represents a progressive deepening of the St. Peter sea during the transgression (Trowbridge, 1917; Dapples, 1955; Shaw, 1964). However, it has also been postulated that the St. Peter was deposited in a desert and was later reworked by the transgressing St. Peter sea (Berkey, 1906); that the St. Peter sea had strong tidal currents as does the North Sea (Amaral and Pryor, 1976); and that the transition from the St. Peter Sandstone to the Glenwood shale represents a progressive shoaling of the St. Peter sea (Fraser, 1976).

The textural maturity and massive appearance of the St. Peter Sandstone have been the major obstacles in the study of its origin.

There is considerable variation in the shapes of quartz sand grains throughout the St. Peter Sandstone, which reveals a record of its erosion history (e.g., Mazzullo and Ehrlich, 1983). Furthermore, there are some sedimentary structures in some sections that reveal a partial record of its depositional environment (e.g., Dott and others, 1986).

CANNON FALLS, MINNESOTA

The base of the St. Peter Sandstone and its contact with the Shakopee Formation are exposed on the Little Cannon River near the town of Cannon Falls, Minnesota, SE¹/₄SW¹/₄ sec. 25, T. 112 N., R. 18 W.

The Shakopee is the upper formation of the Prairie du Chien Group; it is composed of thin-bedded dolomite with minor amounts of highly rounded quartz sand grains and macrofossils. The top of the Shakopee dolomite is a karst surface, with sinkholes and solution breccia and a thin layer of mudcracked green claystone, and its contact with the St. Peter Sandstone is consequently irregular.

The Shakopee dolomite is overlain by discontinuous beds of the basal rubble of the St. Peter Sandstone. This basal rubble is composed of massive to cross-bedded dolomite and quartz sandstone; it fills the depressions on the top of the Shakopee dolomite. The basal rubble is overlain by a thin (1.5 feet) bed of tabular and trough cross-bedded quartz sandstone with occasional mud-draped ripples which grades upward into a thin (1 foot) bed of thinly laminated green, silty shale. This green shale is abruptly overlain by about 38 feet of thick-bedded quartz sandstone. This sandstone is generally massive in appearance, but faint horizontal and sub-horizontal laminated sandstone and trace fossils can be seen in some intervals when the face of the outcrop is cleaned and smoothed with a machete.

The shapes of quartz sand grains in the Cannon Falls section of the St. Peter Sandstone are summarized in Figure 6.1. Both subangular and highly rounded quartz sand grains are present throughout the section, but they are segregated into two cycles of alternating beds of subangular and highly rounded sand. The first cycle begins at the base of the formation in a 3-foot-thick bed of subangular sand, and grades upward into a 7-foot-thick bed of highly rounded sand. This cycle is abruptly terminated by the second cycle, which begins with a 7-foot-thick bed of subangular sand and then grades upward into a 23-foot-thick bed of highly rounded sand. The contact between the two cycles, which is 10 feet from the base of the formation, is not apparent on the outcrop.

MOUNDS PARK, ST. PAUL, MINNESOTA

The upper 80 feet of the St. Peter Sandstone and the overlying Glenwood shale and Platteville limestone are exposed in Mounds Park, NW¹/₄ sec. 4, T. 28 N., R. 22 W. They form the bluff above the Mississippi River.

At this outcrop is the massive and thick-bedded sandstone characteristic of the St. Peter throughout southeastern Minnesota. The sandstone is commonly bioturbated, and trace fossils can be observed on fresh exposures; rare sedimentary structures (flat beds and small tabular cross-beds) are present near the top of the formation. At this outcrop, the St. Peter Sandstone is conformably overlain by the Glenwood Formation, which is composed (from base to top) of green shale (25 inches), medium sandstone (1 inch), sandy siltstone

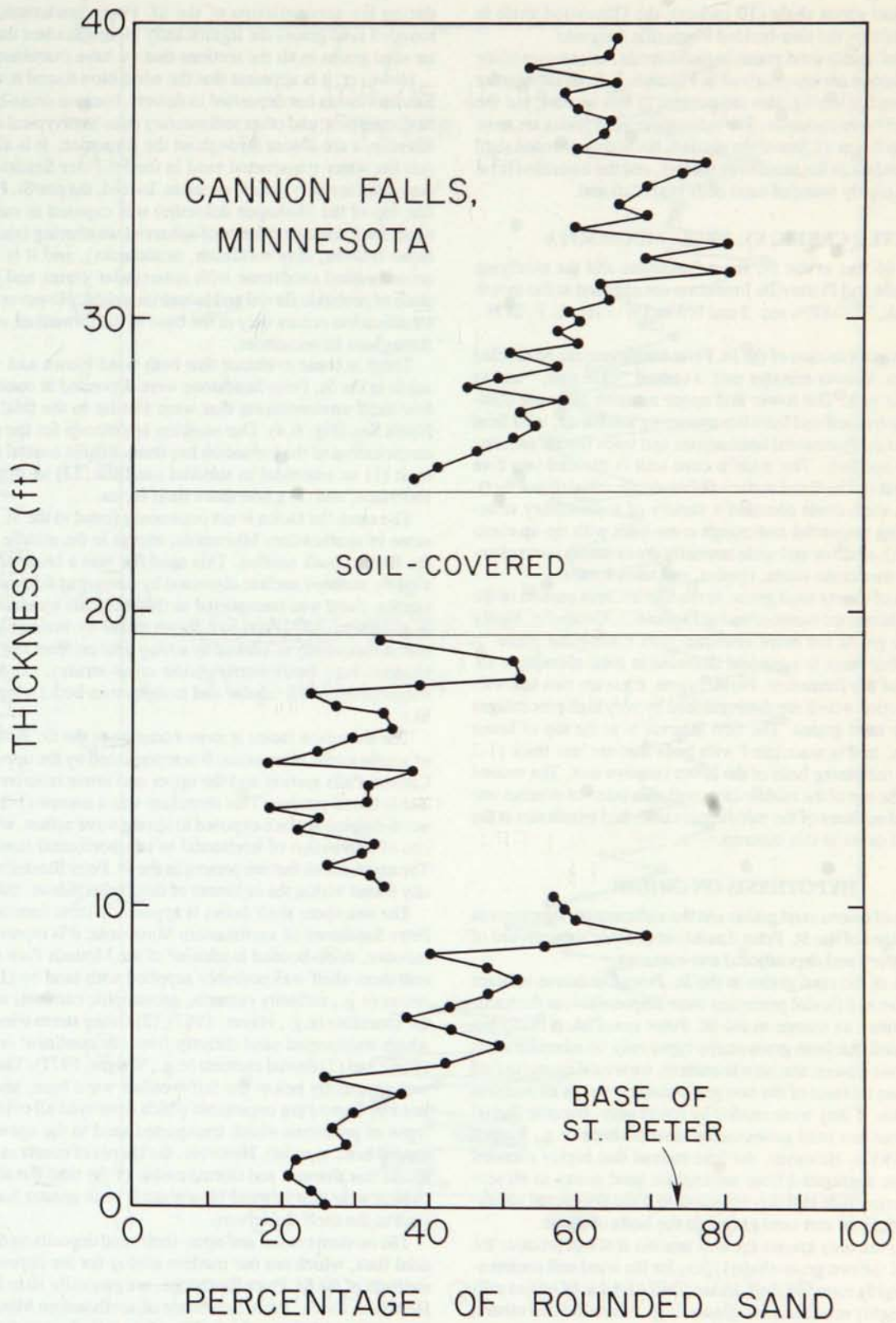


Figure 6.1. Shapes of quartz sand grains in the Cannon Falls section.

(15 inches), and green shale (10 inches); the Glenwood shale is abruptly overlain by the thin-bedded Platteville dolomite.

The shapes of quartz sand grains in the Mounds Park section of the St. Peter Sandstone are summarized in Figure 6.2. Both subangular and highly rounded sand grains are present in this section, but the latter grains are more common. The subangular sand grains are most abundant in the lower 12 feet of the section, the highly rounded sand grains are abundant in the remaining 68 feet, and the transition from subangular to highly rounded sand beds is gradational.

BATTLE CREEK, ST. PAUL, MINNESOTA

The upper 46 feet of the St. Peter Sandstone and the overlying Glenwood shale and Platteville limestone are exposed at the mouth of Battle Creek, SE¹/₄SE¹/₄ sec. 3 and NW¹/₄SW¹/₄ sec. 2, T. 28 N., R. 22 W.

The Battle Creek section of the St. Peter Sandstone can be divided into three units: a lower massive unit, a central "cave unit," and an upper massive unit. The lower and upper massive units are composed of thick-bedded and massive-appearing sandstone, with faint horizontal and subhorizontal laminations and trace fossils and rare trough cross-bedding. The middle cave unit is divided into five cosets by a series of inclined surfaces of moderate relief (0 to 4 feet). Furthermore, each coset contains a variety of sedimentary structures, including tangential and trough cross-beds with rip-up clasts (1-5 feet thick), shallow and wide mutually crosscutting scour channels, herringbone cross-strata, ripples, and trace fossils.

The shapes of quartz sand grains in the Battle Creek section of the St. Peter Sandstone are summarized in Figure 6.3. Generally, highly rounded sand grains are more abundant than subangular grains in this section, but there is a gradual decrease in their abundance toward the top of the formation. Furthermore, there are two intervals within this section which are distinguished by very high percentages of subangular sand grains. The first interval is at the top of lower massive units, and is associated with beds that are less thick (1-2 feet) than the remaining beds of the lower massive unit. The second interval is at the top of the middle cave unit; this interval overlies one of the inclined surfaces of the middle cave unit, and terminates at the top of the two caves in this outcrop.

HYPOTHESIS ON ORIGIN

The shapes of quartz sand grains and the sedimentary structures in the three sections of the St. Peter Sandstone provide some record of its erosion history and depositional environment.

The shapes of the sand grains in the St. Peter Sandstone indicate that both eolian and fluvial processes were responsible for the transport of sand from its source to the St. Peter sea. Dake (1921) has properly warned that both grain-shape types may be inherited from the source. If we assume that he was correct, we would expect to find a homogeneous mixture of the two grain-shape types in all sections of the formation if they were eroded by rivers only, because fluvial processes do not sort sand grains on the basis of shape (e.g., Russell and Taylor, 1937). However, we find instead that highly rounded sand grains are segregated from subangular sand grains in all sections, and we conclude that this segregation is the product of an erosive process that can sort sand grains on the basis of shape.

The wind is the only known erosion process that can produce the segregation of the two grain-shape types, for the wind will preferentially erode highly rounded sand grains from a source of mixed subangular and highly rounded sand grains (e.g., Mazzullo and others, 1986). Therefore, we conclude that the sandstone beds rich in highly rounded sand grains are accumulations of wind-blown sand, and (by the process of elimination) that the sandstone beds rich in subangular sand grains are accumulations of water-transported (i.e., fluvial) sand. Furthermore, we concur with Berkey (1906) that the wind, rather than streams, was the major erosion process on the continent

during the accumulation of the St. Peter Sandstone, for highly rounded sand grains are significantly more abundant than subangular sand grains in all the sections that we have examined.

However, it is apparent that the wind-blown sand in the St. Peter Sandstone was not deposited in deserts, because cross-bedding, adhesion ripples, and other sedimentary structures typical of dunes and interdunes are absent throughout the formation. It is also apparent that the water-transported sand in the St. Peter Sandstone was not deposited in rivers, lakes, or deltas. Indeed, the pre-St. Peter surface (the top of the Shakopee dolomite) was exposed in early St. Peter time, for it shows evidence of subaerial weathering (sinkholes, collapse breccia, clay residuum, mudcracks), and it is overlain by cross-bedded sandstone with subangular grains and green, silty shale of probable fluvial and lacustrine origin. However, this type of stratification occurs only at the base of the formation, and is absent throughout its remainder.

There is some evidence that both wind-blown and water-borne sands in the St. Peter Sandstone were deposited in coastal and shallow-shelf environments that were similar to the tidal flats of the North Sea (Fig. 6.4). Our working hypothesis for the depositional environment of the formation has three distinct coastal and shelf facies: (1) an intertidal to subtidal sand flat, (2) an upper to lower shoreface, and (3) a nearshore shelf facies.

The sand-flat facies is not commonly found in the St. Peter Sandstone of southeastern Minnesota, except in the middle cave unit of the Battle Creek section. This sand flat was a broad (10-30 miles) slightly inclined surface dissected by numerous tidal creeks and estuaries. Sand was transported to this sand flat by eolian processes (e.g., Shinn, 1977) and to a lesser extent by braided streams, and was subsequently reworked by strong tidal currents and molded into channel bars (with herringbone cross-strata), sand waves and megaripples (with tabular and trough cross-beds), ripples, and the like.

The shoreface facies is more common to the St. Peter Sandstone of southeastern Minnesota. It is represented by the upper part of the Cannon Falls section and the upper and lower massive units of the Battle Creek section. This shoreface was a narrow (1-3 miles), seaward-dipping surface exposed to strong wave action, which was the site of deposition of horizontal to sub-horizontal laminated sand. The macrofauna that are present in the St. Peter Sandstone are generally found within the sediment of this facies (Sloan, this chapter).

The nearshore shelf facies is apparently most common to the St. Peter Sandstone of southeastern Minnesota; it is represented by the massive, thick-bedded sandstone of the Mounds Park section. The nearshore shelf was probably supplied with sand by (1) storm processes (e.g., turbidity currents, geostrophic currents) which eroded the shoreface (e.g., Hayes, 1967); (2) strong storm winds (shamals) which transported sand directly from the continent (e.g., Emery, 1956); and (3) fluvial currents (e.g., Wright, 1977). The shelf facies was apparently below the fair-weather wave base, and was populated by burrowing organisms which destroyed all evidence for the types of processes which transported sand to the open shelf (e.g., graded beds, ripples). However, the shapes of quartz sand grains indicate that shamals and storm erosion of the tidal flat and shoreface (which were rich in wind-blown sand) were greater contributors of sand to the shelf than rivers.

The modern coastal and open-shelf sand deposits on the North Sea tidal flats, which are our modern analog for the depositional environment of the St. Peter Sandstone, are generally 10 to 30 feet thick. However, the St. Peter Sandstone of southeastern Minnesota is between 80 and 160 feet thick. Therefore it is obvious that the formation is composed of numerous stacked sequences of these coastal and shelf sand deposits—that is, it is a composite of multiple regressive and transgressive deposits. The Battle Creek and Cannon Falls sections provide our evidence for this type of cyclic sedimentation.

In this working hypothesis, the regressive phases would begin at

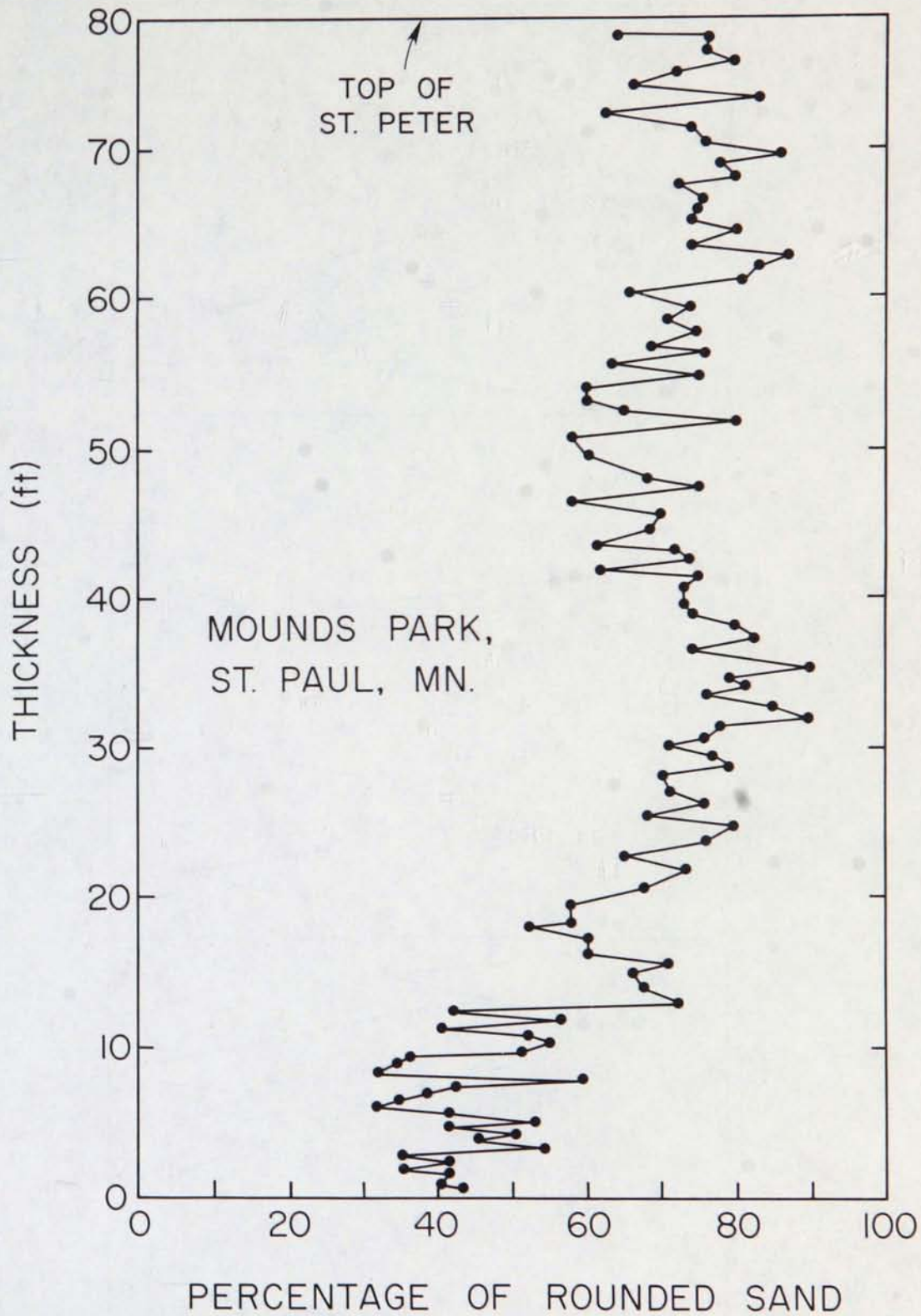


Figure 6.2. Shapes of quartz sand grains in the Mounds Park section.

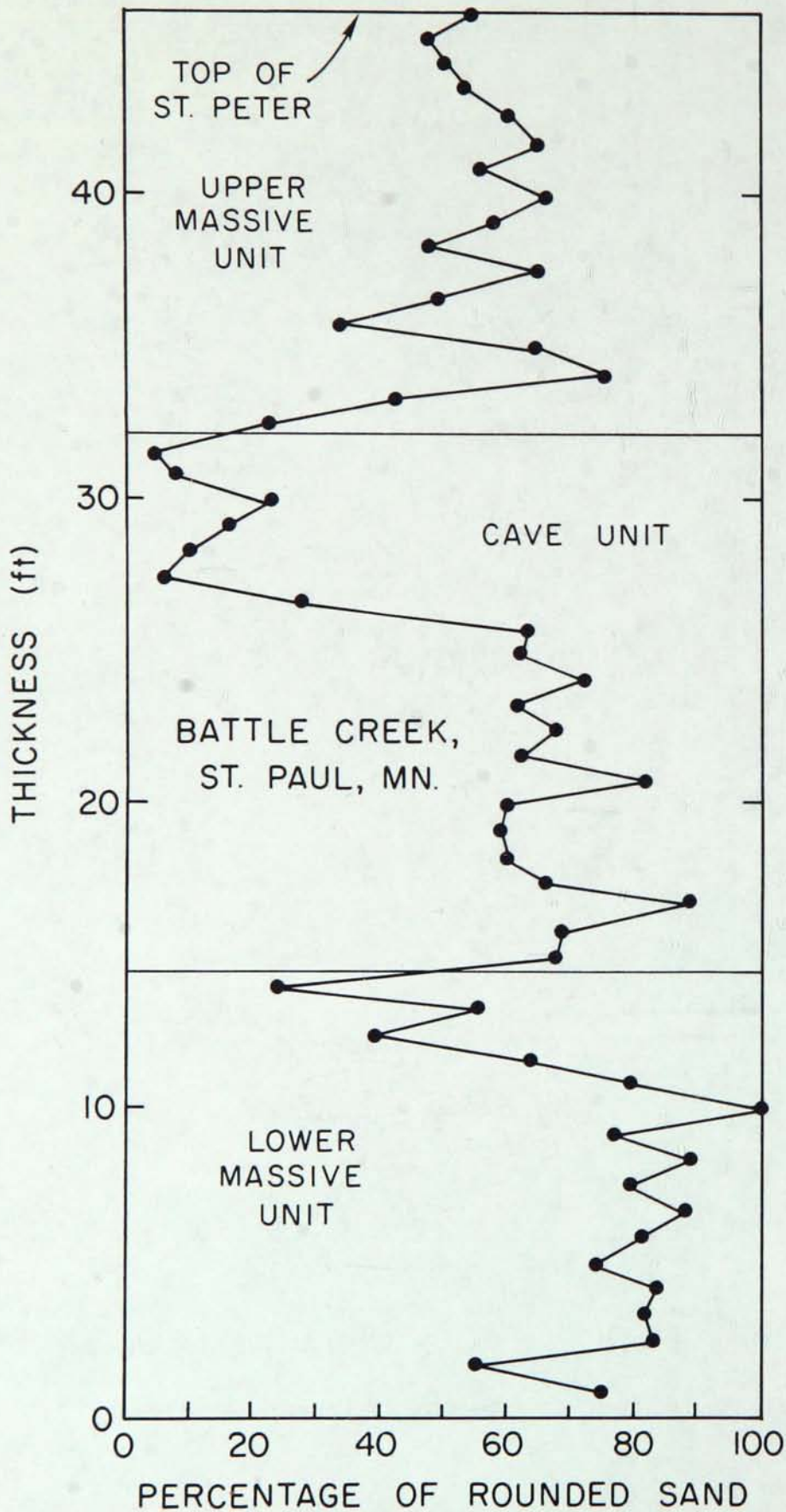


Figure 6.3. Shapes of quartz sand grains in the Battle Creek section.

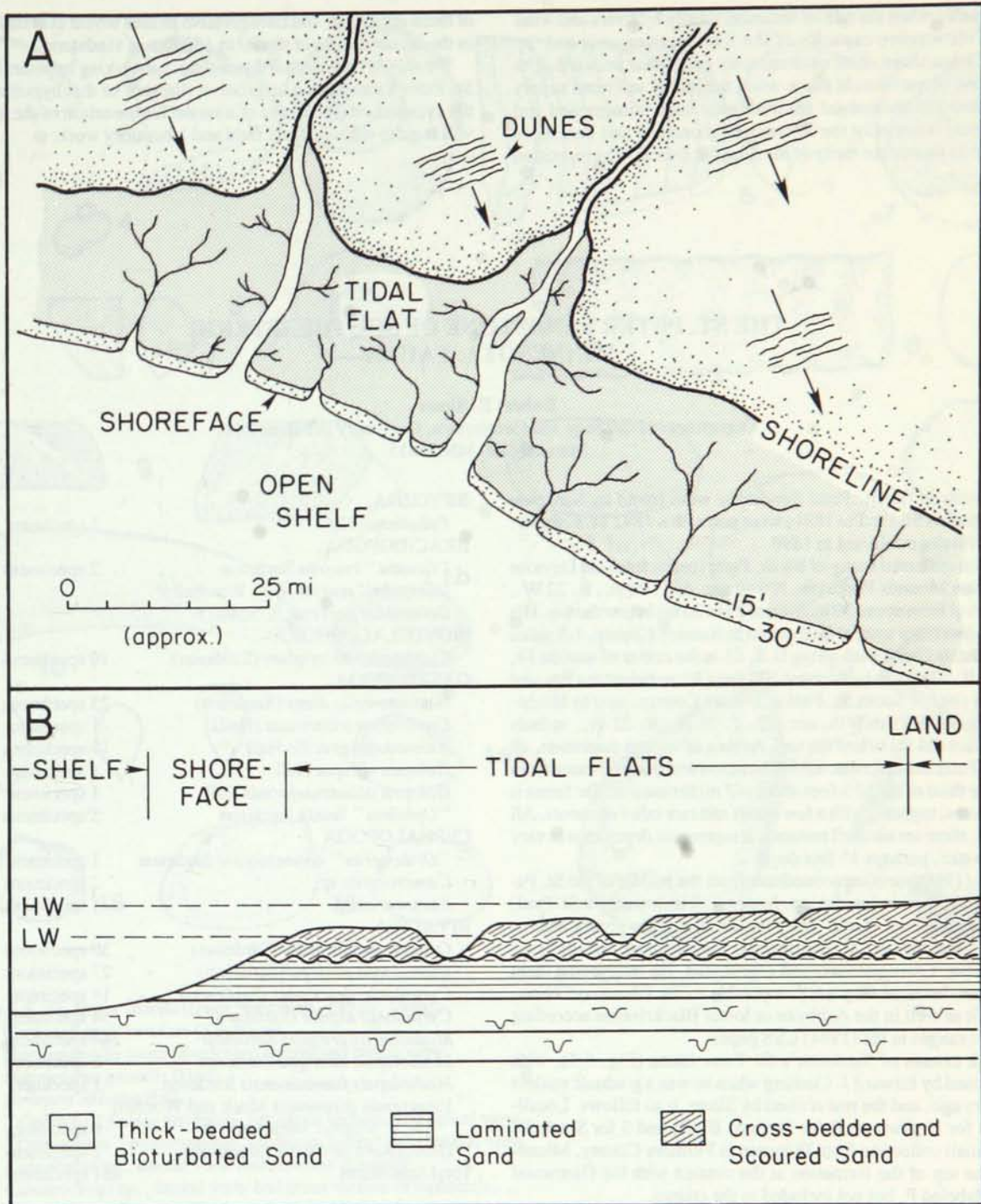


Figure 6.4. Depositional model for the St. Peter Sandstone of southeastern Minnesota.

any depocenter when the rate of sediment supply by rivers and wind exceeded the erosive capacity of the transgressing sea, and the coastal and nearshore shelf environments prograded seaward. The transgressive phases would begin when the rate of sediment supply was lessened and the coastal environments were transgressed and eroded, preserving only the lowermost shoreface and nearshore shelf deposits (hence the rarity of the tidal flat facies). The repetition

of these regressive and transgressive phases would eventually result in the accumulation of the 80 to 160 feet of sandstone.

We should caution that this is simply a working hypothesis for the St. Peter Sandstone. The proof or disproof of this hypothesis, and the eventual establishment of a model for the origin of the St. Peter, will require more diligent field and laboratory work.

THE ST. PETER SANDSTONE OF SOUTHEASTERN MINNESOTA: FAUNA

Robert E. Sloan

Department of Geology and Geophysics, University of Minnesota
Minneapolis, MN 55455

The fossils in the St. Peter Sandstone were found by Sardeson near downtown St. Paul in 1891, were part of his 1892 M.S. thesis, and were finally published in 1896.

Sardeson collected many of his St. Peter fossils from the Daytons Bluff-Indian Mounds Park area, NW¹/₄ sec. 4, T. 28 N., R. 22 W., in an interval from about 50 to 70 feet (15 to 20 m) below the top. His other two localities were at Highwood in Ramsey County, 1.5 miles south of Battle Creek Park along U.S. 61 in the center of section 14, T. 28 N., R. 22 W., in beds about 100 feet (30 m) below the top; and across the river in South St. Paul in Dakota County, next to Minnesota 56, in the SW¹/₄NW¹/₄, sec. 22, T. 28 N., R. 22 W., in beds about 80 feet (24 m) below the top. As best as we can determine, all of the St. Peter fossils collected by Sardeson and Stauffer came from the middle third of the 155-foot-thick (47 m) formation. The fauna is chiefly clams, together with a few snails and rare other elements. All are molds; there are no shell remains. It represents deposition in very shallow water, perhaps 15 feet deep.

Witzke (1980) mentions conodonts from the middle of the St. Peter at 68 feet (20 m) below the top, from a well in downtown St. Paul, close to the St. Paul Hotel. They include the form-genera *Microcoelodus*, *Ptiloconus*, *Multioistodus*, *Stereoconus*, *Mixocoelus*, *Neocoleodus*, *Chirognathus*, and *Oneotodus*. He interpreted them as Chazyan, because they are comparable to the Glenwood fauna, but they fit as well in the Ashbyan or lower Blackriveran according to Sweet's ranges in his (1984) CSS paper.

A quick census of Sardeson's St. Peter fauna (Fig. 6.5), with clams revised by Edward J. Cushing when he was a graduate student some years ago, and the rest revised by Sloan, is as follows. Localities are H for Highwood, D for Daytons Bluff, and S for South St. Paul. A small collection from Fountain in Fillmore County, Minnesota, at the top of the formation at the contact with the Glenwood Shale, is labeled F, but not included in the counts.

There are comparable molluscs in the Rock Elm shale, a basin-fill unit in the Rock Elm disturbance (Cordua, 1985) near the town of Rock Elm in Pierce County, Wisconsin. I suspect the Rock Elm shale and Washington Road sandstone are local facies of the St. Peter Sandstone within the crater.

BRYOZOA:			
<i>Ptilodictya?</i> sp.	1 specimen		H
BRACHIOPODA:			
" <i>Crania</i> " <i>reversa</i> Sardeson	2 specimens		H
" <i>Lingula</i> " <i>morsei</i> N.H. Winchell F			
<i>Doleroides pervetus</i> (Conrad) F			
MONOPLACOPHORA:			
<i>Cyrtoneilopsis vetulum</i> (Sardeson)	10 specimens		S
GASTROPODA:			
<i>Horiotomella aiens</i> (Sardeson)	23 specimens		S
<i>Lophospira tricarinata</i> (Hall)	1 specimen		H, F
<i>Hormotoma gracilis</i> Hall	17 specimens		H, F
<i>Holopea obliqua</i> Hall	1 specimen		S, F
<i>Holopea paludinaeformis</i> Hall	1 specimen		S, F
" <i>Ophileta</i> " <i>fausta</i> Sardeson	5 specimens		H, S
CEPHALOPODA			
" <i>Orthoceras</i> " <i>minnesotense</i> Sardeson	1 specimen		S
<i>Cameroceras</i> sp.	2 specimens		H, S
<i>Kionoceras</i> sp.	1 specimen		H
BIVALVIA			
<i>Orthodesma litoralis</i> (Sardeson)	30 specimens		D, S
<i>Ctenodonta novicea</i> (Sardeson)	27 specimens		D, S
<i>Cyrtodonta descriptus</i> (Sardeson)	14 specimens		D, S
<i>Cyrtodonta dignus</i> (Sardeson)	34 specimens		D, S
<i>Modiolopsis gregalis</i> Sardeson	244 specimens		D, S
<i>Modiolopsis contigua</i> Sardeson	6 specimens		S
<i>Modiolopsis fountainensis</i> Sardeson	1 specimen		H
<i>Vanuxemia dixonensis</i> Meek and Worthen			
(= <i>V. fragosa</i> Sardeson)	8 specimens		H
<i>Goniophora absimilis</i> (Sardeson)	2 specimens		H
Total Specimens	431 specimens		

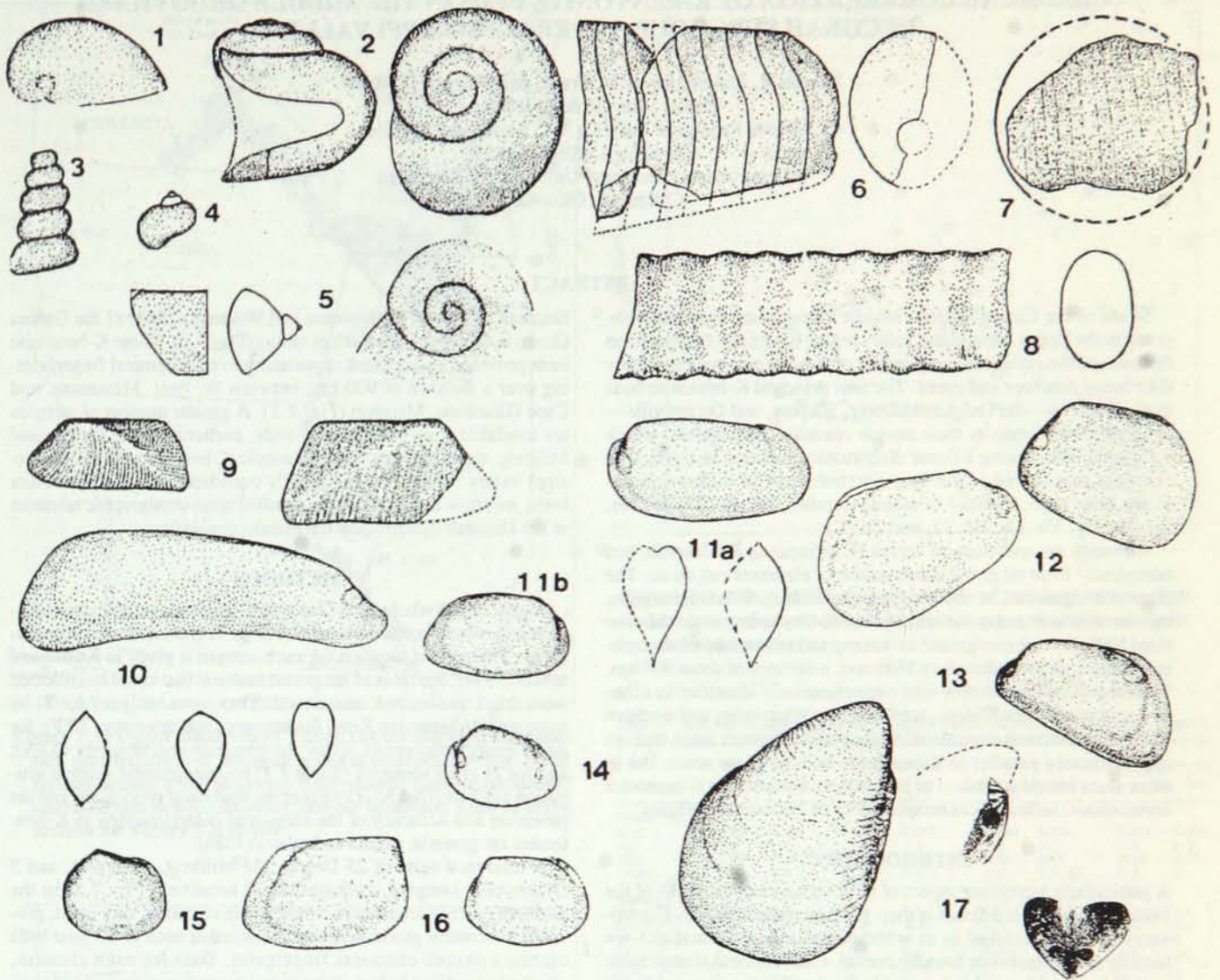


Figure 6.5. St. Peter fossils (from Sardeson, 1892a, 1896).

1. *Cyrtoneilopsis vetulum* (Sardeson).
2. *Horiostomella aiens* (Sardeson) lateral and apical view.
3. *Hormotoma gracilis* (Hall).
4. *Holopea obliqua* Hall.
5. "*Ophileta*" *fausta* Sardeson, lip, cross section, and apical view.
6. "*Orthoceras*" *minnesotense* Sardeson, lateral and cameral view.
7. *Kionoceras* sp., lateral view and restored diameter.
8. *Cameroceras* sp., lateral view and cross section of siphuncle.
9. *Goniophora absimilis* (Sardeson), two individuals.
10. *Orthodesma litoralis* (Sardeson), lateral view and three cross sections.
11. *Modiolopsis gregalis* Sardeson; a, type lateral view and two cross sections; b, a second specimen, type of *M. affinis*.
12. *Modiolopsis fountainensis* Sardeson, type on left.
13. *Modiolopsis contigua* Sardeson.
14. *Ctenodonta novicia* (Sardeson).
15. *Cyrtodonta descriptus* (Sardeson).
16. *Cyrtodonta dignus* (Sardeson).
17. *Vanuxemia dixonensis* Meek and Worthen, lateral view and two views of teeth.

CHEMICAL CORRELATION OF K-BENTONITE BEDS IN THE MIDDLE ORDOVICIAN DECORAH SUBGROUP, UPPER MISSISSIPPI VALLEY

Dennis R. Kolata, Joyce K. Frost, and Warren D. Huff*

Illinois State Geological Survey
Natural Resources Building, 615 East Peabody Drive
Champaign, Illinois 61820

*Department of Geology, University of Cincinnati
Cincinnati, Ohio 45221

ABSTRACT

Strata of the Champlainian (Middle Ordovician) Decorah Subgroup in the Upper Mississippi valley region have been correlated on the basis of the chemical composition of K-bentonite beds in widely distributed outcrops and cores. The four principal K-bentonite beds in the Decorah—the Deicke, Millbrig, Elkport, and Dickeyville—can be differentiated by their unique chemical fingerprints, which were established using a linear discriminant function analysis. The elements that served as the best discriminators of differences between beds were, in order of atomic number, Na, Sc, Ti, Zr, Sm, Eu, Tb, Dy, Yb, Lu, Hf, Ta, and Th.

Although no one element serves to delineate a K-bentonite bed completely from others, a combination of elements can do so. The chemical signatures of the Deicke and Millbrig K-bentonite beds, the two thickest and most widespread K-bentonites in the Mississippi Valley, were recognized in outcrop and subsurface from southern Minnesota to southeastern Missouri, a distance of about 900 km. The Elkport and the Dickeyville were chemically identified in a limited area in northern Illinois, southwestern Wisconsin, and northern Iowa. The Decorah consists of widespread lithologic units that are approximately parallel to K-bentonite beds in some areas, but in other areas lateral gradation of lithologies, as shown by K-bentonite correlations, indicates contemporaneity of Decorah lithofacies.

INTRODUCTION

A particularly intriguing aspect of Ordovician cratonal rocks of the Midcontinent United States is their great lateral continuity. Controversy has long existed as to whether individual formations are broadly transgressive or broadly coeval. Conventional stratigraphic studies have not been able to provide the detailed time control that is necessary to establish contemporaneity of paleoenvironments over wide areas. K-bentonite beds (altered volcanic ash beds), which are abundant in Middle and Upper Ordovician rocks, offer an excellent opportunity to understand the temporal and spatial relations during deposition of certain formations.

The ash falls occurred in very brief intervals of time over wide areas (covering 1.3×10^6 km² of eastern North America); therefore, the K-bentonite beds are essentially isochronous units that are potentially very useful time lines. This potential has been recognized for many years, but because the beds are mineralogically and petrologically indistinguishable, there has been a great deal of uncertainty in identifying individual beds over long distances. Recently, Ordovician (Blackriveran and Rocklandian) K-bentonite beds have been correlated in parts of Ohio, Kentucky, and Tennessee by using methods based on differences in chemical composition (Huff, 1983). The rationale for these methods is the fact that the volcanic ashes from which the K-bentonites formed differ in minor- and trace-element composition, from one layer (i.e., volcano or magma source) to another, as described, for example, in Randle and others (1971).

In this paper, we expand upon the methods of Huff (1983) to chemically correlate the Deicke, Millbrig, Elkport, and Dickeyville K-bentonite Beds (Willman and Kolata, 1978) of the Rocklandian

Decorah Subgroup (Templeton and Willman, 1963) of the Galena Group in the Upper Mississippi valley (Fig. 7.1). These K-bentonite beds provided an excellent opportunity to test chemical fingerprinting over a distance of 900 km, between St. Paul, Minnesota, and Cape Girardeau, Missouri (Fig. 7.1). A greater number of samples are available from the Decorah beds, particularly the Deicke and Millbrig, than from any other Paleozoic K-bentonites in the Mississippi valley region. By chemically correlating these K-bentonite beds, we show in this paper the detailed time-stratigraphic relations of the Decorah Subgroup in the Mississippi valley.

METHODS

A total of 108 whole-rock Decorah K-bentonite samples from outcrop and subsurface at 66 localities (Fig. 7.1) were chemically analyzed. The precise location for each sample is given in Kolata and others (1986). Samples of the purest material that could be collected were dried, pulverized, and sieved. They were analyzed for Ti by wavelength-dispersive X-ray fluorescence spectroscopy (XRF); for Zr by energy-dispersive X-ray fluorescence spectroscopy (XES); and for 24 other elements (Table 7.1) by instrumental neutron activation analysis (INAA). Details of the analytical procedures and the precision and accuracy of the elemental determinations in K-bentonites are given in Kolata and others (1986).

A reference suite of 25 Deicke, 24 Millbrig, 6 Elkport, and 5 Dickeyville samples, collected at 39 localities (Fig. 7.1) in the northern outcrop area where stratigraphic control is very good, provided the control group to determine whether each of the four beds carries a unique chemical fingerprint. Data for each element, grouped according to bed, were tested by one-way analysis of variance to determine whether the mean concentrations were different between the beds. The F value, the ratio of the mean between-group variance to the mean within-group variance, was used as a basis for ranking the elements in apparent order of decreasing discriminating power: Yb, Dy, Sc, Lu, Zr, Na, Ti, Hf, Tb, Eu, Co, Fe, Ta, As, Th, Sb, Sm, Mn, K, La, Rb, Ce, Cs, Ga, Cr, and Zn.

The lowest nine elements in the list were dismissed from further statistical testing for the following reasons. Zinc, which is a highly mobile element, was apparently randomly distributed (Table 7.1), and concentrations of chromium and gallium were not different between beds at the 95-percent confidence level of significance. Among the rare earth elements, the lightest—lanthanum and cerium—are the most mobile (Haskin and Schmitt, 1967), and so are likely to be the most affected in transformation of volcanic ash to K-bentonite. Cesium and rubidium substitute for potassium, and a variable amount of potassium can be introduced in the transformation from volcanic ash to K-bentonite. Furthermore, manganese levels in the K-bentonites are influenced by the presence of trace calcite, because manganese is concentrated in limestone (Goldschmidt, 1954). Data on the remaining 17 elements were subjected to stepwise discriminant analysis using a Statistical Package for the Social Sciences (SPSS) program.

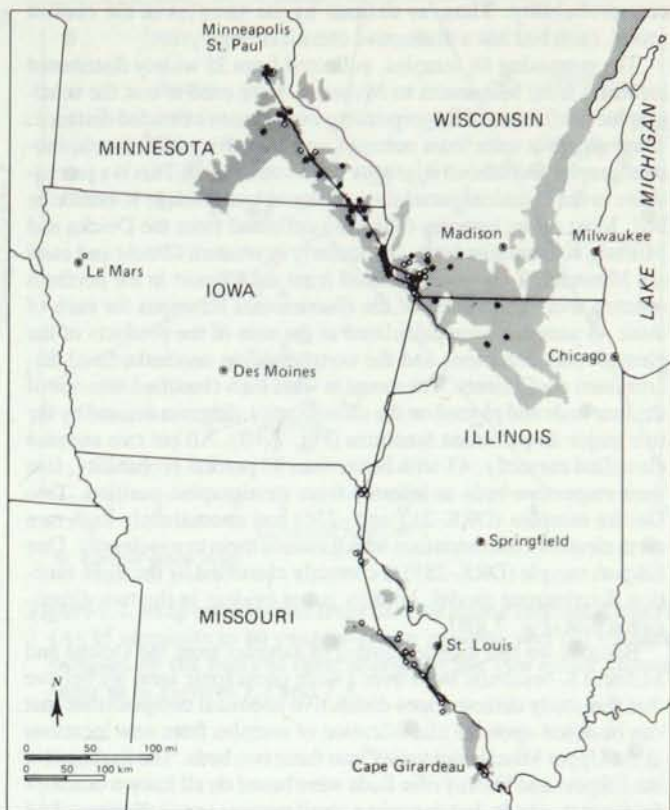


Figure 7.1. Upper Mississippi Valley region showing distribution (shaded area) of Decorah K-bentonite at bedrock surface. Solid circles denote control-group K-bentonite sample localities; open circles denote all other sample localities. Line of cross section for Figure 5 is shown.

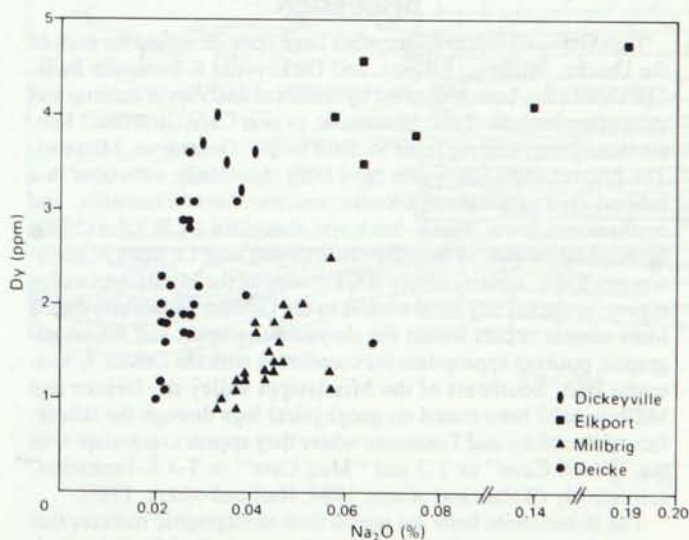


Figure 7.2. Distribution by bed of sodium and dysprosium in control-group samples of Decorah K-bentonites.

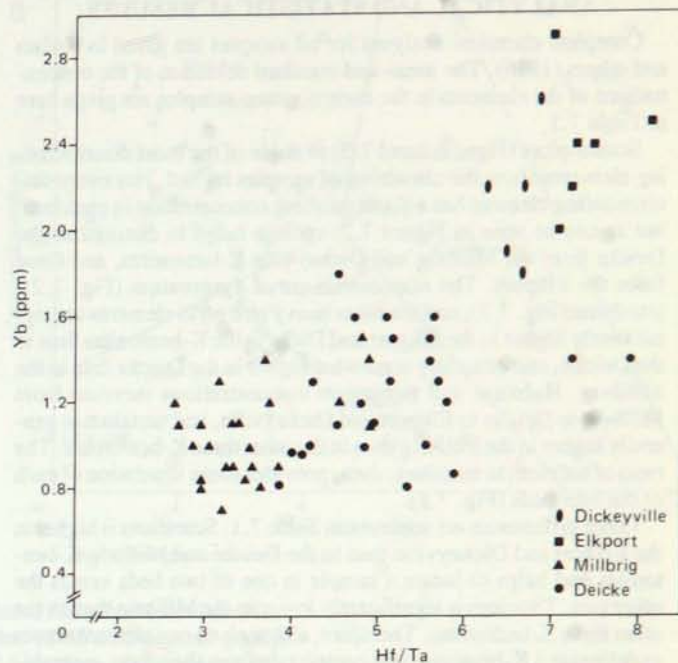


Figure 7.3. Distribution by bed of ratio of hafnium to tantalum contents and of ytterbium in control-group samples of Decorah K-bentonites.

TABLE 1. MEAN AND STANDARD DEVIATION OF ELEMENT CONCENTRATIONS IN CONTROL GROUP SAMPLES

	Dicke (25)		Millbrig (24)		Elkport (6)		Dickeyville (5)	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Oxides (%)								
Na ₂ O	0.027	0.009	0.044	0.007	0.100	0.055	0.035	0.005
K ₂ O	11.0	2.9	9.4	2.0	9.2	0.7	7.3	0.4
TiO ₂	0.46	0.14	0.22	0.06	0.52	0.06	0.43	0.15
Fe ₂ O ₃	2.2	1.4	1.4	0.4	3.9	0.6	2.1	1.1
Elements (ppm)								
Sc	6.2	1.9	7.9	1.1	14.0	1.7	12.1	2.0
Cr	7.1	3.9	7.2	5.9	12.3	5.1	11.3	18.9
Mn	57	57	54	36	141	82	59	50
Co	3.1	2.5	4.0	2.5	12.2	5.7	4.2	5.7
Zn	144	157 (18)	110	176 (11)	137	101 (5)	81	(1)
Ga	20	6	21	4	21	2	26	3
As	6.8	3.4	4.5	2.4	11.3	4.4	8.6	4.8
Rb	76	12	85	12	90	5	85	10
Zr	237	68	161	33	355	25	354	45
Sb	<0.3	0.1	<0.3	0.3	0.6	0.1	0.6	0.3
Cs	3.6	2.0	4.6	1.6	4.7	0.3	5.9	2.1
La	9.0	4.8	5.1	3.8	6.7	1.9	5.1	4.6
Ce	16.8	9.6	10.0	7.0	12.8	3.7	10.0	8.0
Sm	1.8	0.7	1.3	0.4	2.0	0.5	1.9	0.4
Eu	0.26	0.12	0.20	0.10	0.49	0.08	0.41	0.07
Tb	0.28	0.09	0.21	0.08	0.45	0.10	0.43	0.08
Dy	2.1	0.7	1.4	0.4	4.1	0.5	3.6	0.3
Yb	1.2	0.3	1.1	0.2	2.4	0.3	2.1	0.3
Lu	0.22	0.04	0.20	0.07	0.47	0.06	0.42	0.07
Hf	8.8	2.5	7.1	1.2	12.7	1.0	11.6	1.1
Ta	1.7	0.3	2.0	0.2	1.7	0.2	1.8	0.1
Th	20	5	16	4	21	1	21	2

Note: Number of samples in parentheses.

Table 7.1. Mean and standard deviation of element concentrations in control group samples.

ANALYTICAL AND STATISTICAL RESULTS

Complete chemical analyses for all samples are given in Kolata and others (1986). The mean and standard deviation of the concentrations of the elements in the control group samples are given here in Table 7.1.

Scatter plots (Figs. 7.2 and 7.3) of some of the most discriminating elements show the clustering of samples by bed. Not every discriminating element has a distinguishing concentration in each bed, but as can be seen in Figure 7.2, sodium helps to distinguish the Deicke from the Millbrig and Dickeyville K-bentonites, and these from the Elkport. The concentrations of dysprosium (Fig. 7.2), ytterbium (Fig. 7.3), and the other heavy rare earth elements are significantly higher in the Elkport and Dickeyville K-bentonites than in the Deicke, and generally somewhat higher in the Deicke than in the Millbrig. Hafnium and zirconium concentrations increase from Millbrig to Deicke to Elkport and Dickeyville, and tantalum is generally higher in the Millbrig than in the other three K-bentonites. The ratio of hafnium to tantalum, then, provides some separation of each of the four beds (Fig. 7.3).

Other differences are apparent in Table 7.1. Scandium is higher in the Elkport and Dickeyville than in the Deicke and Millbrig K-bentonites and helps to locate a sample in one of two beds versus the other two. Titanium is significantly lower in the Millbrig than in the other three K-bentonites. Therefore, although no one element serves to delineate a K-bentonite bed completely from the others, a combination of elements can do so.

The discriminant analysis program sequentially selected elements into a group that effected the best separation among the group centroids (highest overall multivariate F ratio or minimum Wilks' lambda). The discriminant model used 15 elements, deriving three functions of the form $f = a_1x_1 + a_2x_2 + \dots + a_ix_i + \dots + a_{15}x_{15}$, where a_i is a coefficient and x_i is the concentration of element i in a K-bentonite sample. The canonical correlation coefficients associated with the functions ($r = 0.97, 0.95, \text{ and } 0.72$ for functions 1, 2, and 3, respectively) show that the first two discriminant functions are each very highly correlated with the groups (or K-bentonite beds) and the third is somewhat less correlated. The correlations indicate that the functions, especially the first two, are very effective at separating the four beds. Different elements were important in each of the three functions, but the approximate order of importance of the elements to the discriminant model (i.e., all elements taken as a group) was Eu, Sm, Sc, Ti, Zr, Th, Hf, Lu, Ta, and Dy, followed by Tb (redundant of other heavy rare earth elements), and Fe, Co, Na, and Sb with small coefficients. The values of each function calculated using mean elemental concentrations for each group may be visualized as defining point coordinates within a three-dimensional orthogonal grid. The four groups have significantly different values (scores) for function 1, which may be equated to the x-axis direction. The Millbrig is separated from the other three in function 2 (y-axis direction). This is shown in the plot (Fig. 7.4A) of the first two discriminant functions (third function set to zero). The lines of equidistance between group means shown represent the boundaries for classification of a sample into a bed.

The mean discriminant scores on canonical function 3 (Z-axis) were 0.06, Deicke; 0.07, Millbrig; 1.59, Elkport; and -3.05, Dickeyville. The two-dimensional plot is sufficient to illustrate most of the results because only Elkport and Dickeyville have significant value in the third dimension, and samples of Elkport and Dickeyville were a small fraction of the total number of samples.

The 60 control-group samples were all correctly back-classified by the discriminant functions into their respective groups, as illustrated in Figure 7.4A. That would not necessarily have been the case if the separation of the groups achieved by the model was so insufficient that the cluster of control-group samples for one bed still overlapped that of another. Fifty-nine of the samples fell within their groups with better than 99 percent probability and one with 88 per-

cent probability. Thus, as defined by the samples in the control group, each bed has a distinctive chemical fingerprint.

The remaining 48 samples, collected from 35 widely distributed localities from Minnesota to Missouri, were used to test the stratigraphic usefulness of fingerprinting over a more extended distance. These samples were from outcrops and cores for which the chronostratigraphy and lithostratigraphy were established. This is a prerequisite to the chemical correlation of any volcanic ash or K-bentonite bed. Most of the samples (46) were collected from the Deicke and Millbrig K-bentonite beds, particularly in western Illinois and eastern Missouri. Two were collected from the Elkport in the northern outcrop area. The values of the discriminant functions for each of these 48 samples were calculated as the sum of the products of the element concentrations and the corresponding unstandardized discriminant coefficients. The samples were then classified into one of the four beds and plotted on the classification diagram defined by the two major discriminant functions (Fig. 7.4B). All but two samples classified correctly, 43 with better than 99 percent probability, into their respective beds as inferred from stratigraphic position. Two Deicke samples (DRK-213 and -236) had anomalously high rare earth element concentrations which caused them to misclassify. One Elkport sample (DRK-285) is correctly classified by the three function discriminant model, but this is not evident in the two-dimensional plot (Fig. 7.4B).

Because we had a large number of samples from the Deicke and Millbrig K-bentonite Beds over a wide geographic area, we believe that this study demonstrates distinctive chemical compositions that can be relied upon for classification of samples from new locations in the Upper Mississippi valley into these two beds. The findings for the Elkport and Dickeyville Beds were based on all known outcrops for these two beds, but that was a small number over a distance of 64 km for the Elkport and over 112 km for the Dickeyville bed in the northern outcrop area. For each of these two beds we assert only that the available samples demonstrate consistent chemical composition and that the beds are differentiable from each other and from the Deicke and Millbrig. We currently are seeking new localities for these two beds in order to test our results more extensively.

DISCUSSION

Distinctive chemical fingerprints have been identified for each of the Deicke, Millbrig, Elkport, and Dickeyville K-bentonite Beds. The Deicke has been identified by chemical analyses in outcrop and subsurface from St. Paul, Minnesota, to near Cape Girardeau, Missouri, and the Millbrig from St. Paul to Ste. Genevieve, Missouri. The Elkport and Dickeyville have been chemically correlated in a limited area of northern Illinois, southwestern Wisconsin, and northeastern Iowa. The K-bentonite described by Witzke (1980) from the upper part of the Platteville Group near Le Mars in northwestern Iowa, approximately 300 km west of the Mississippi valley region, is chemically most similar to the Deicke. Moreover, the Le Mars sample occurs within the chronostratigraphic and lithostratigraphic position appropriate for correlation with the Deicke K-bentonite Bed. Southeast of the Mississippi valley the Deicke and Millbrig have been traced on geophysical logs through the subsurface of Kentucky and Tennessee where they appear to correlate with the "Pencil Cave" or T-3 and "Mud Cave" or T-4 K-bentonites, respectively (Kolata and others, 1984; Huff and others, 1986).

The K-bentonite beds are useful time-stratigraphic markers that greatly facilitate correlation of Decorah strata in the Mississippi valley (Fig. 7.5), and make it possible to reconstruct a more comprehensive picture of paleoenvironments and paleogeography during a part of Middle Ordovician (Rocklandian) time. The time lines established by the K-bentonites show that the Decorah members and formations are not stacked in layer-cake fashion with each unit being "essentially isochronous" as suggested by Templeton and Willman (1963). It is true that the Decorah consists of widespread lithologic

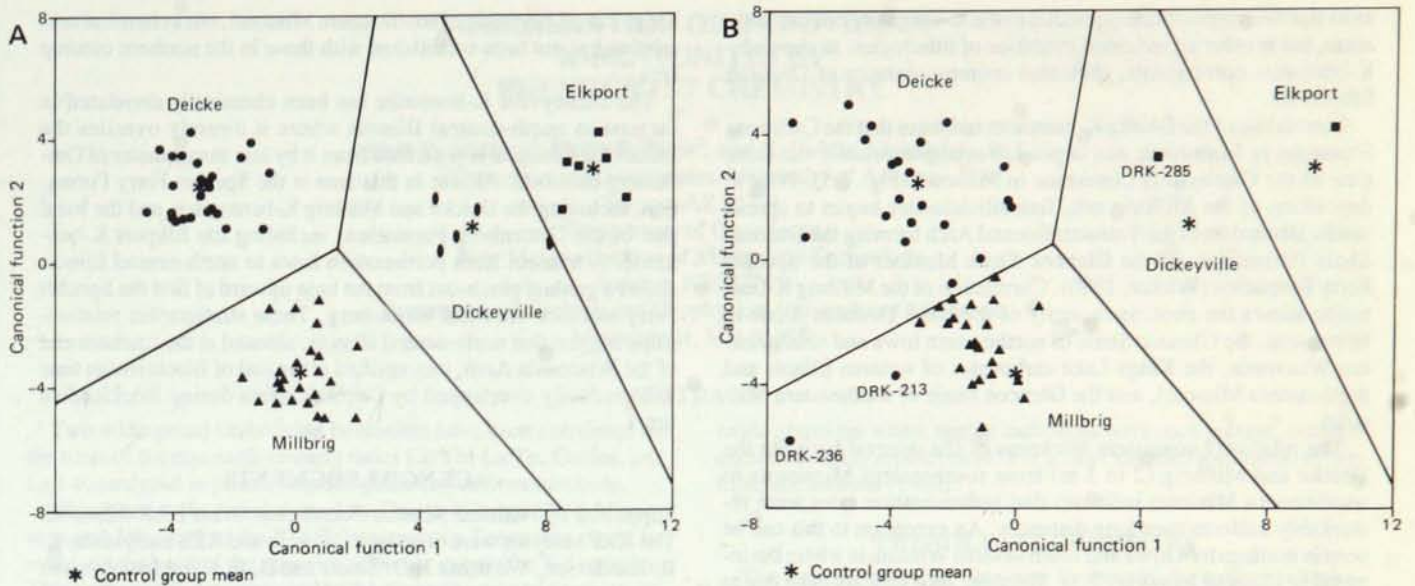


Figure 7.4. Map constructed from the two major canonical discriminant functions calculated for (A) 15 elements in 60 control-group samples and (B) classification of 48 non-control-group samples on the basis of their scores for the two major canonical functions. Symbols are the same as in Figures 7.2 and 7.3.

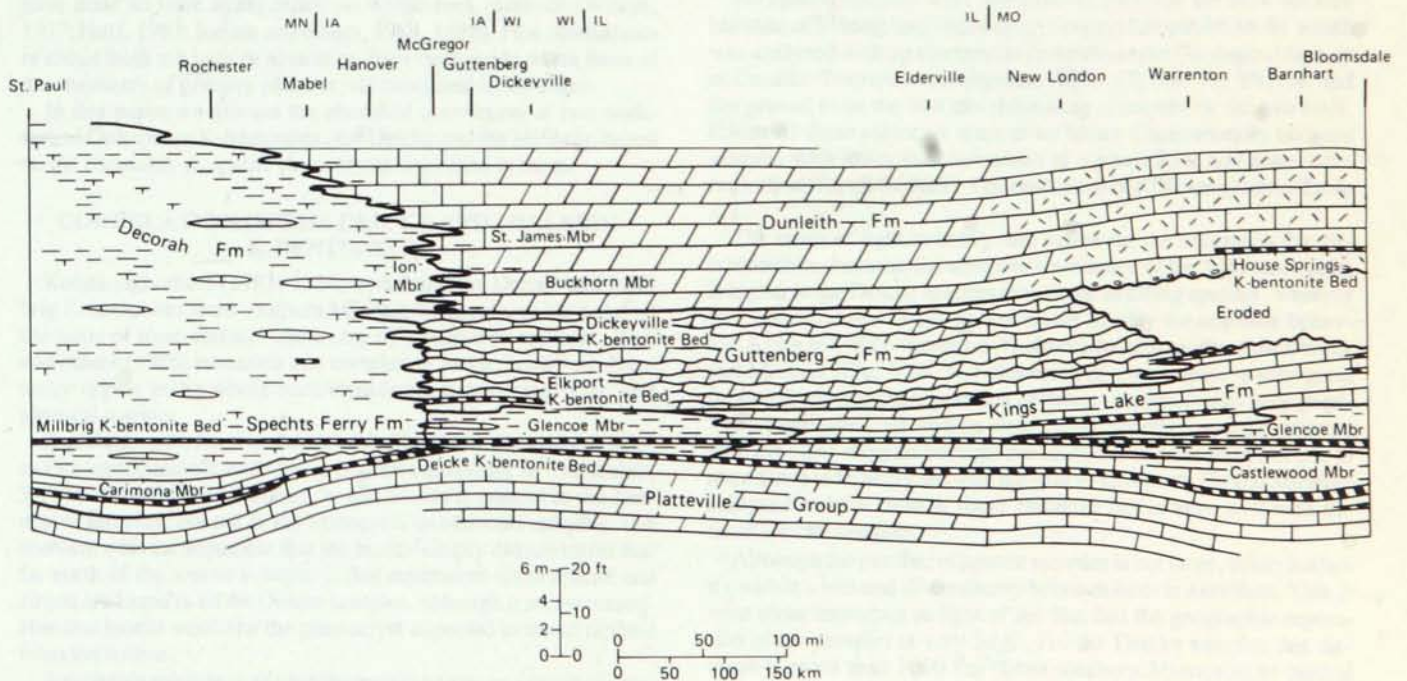


Figure 7.5. Diagrammatic cross section of Decorah and adjacent strata from St. Paul, Minnesota, to Bloomsdale, Missouri; see Figure 7.1 for location.

units that are approximately parallel to the K-bentonite beds in some areas, but in other areas lateral gradation of lithologies, as shown by K-bentonite correlations, indicates contemporaneity of Decorah lithofacies.

Correlation of the Deicke K-bentonite indicates that the Carimona limestone in Minnesota was deposited at approximately the same time as the Castlewood Limestone in Missouri (Fig. 7.5). Prior to deposition of the Millbrig ash, fine siliciclastics began to spread southeastward from the Transcontinental Arch forming the Decorah Shale Formation and the Glencoe Shale Member of the Spechts Ferry Formation (Witzke, 1980). Correlation of the Millbrig K-bentonite shows the contemporaneity of the basal Decorah Shale in Minnesota, the Glencoe Shale of northeastern Iowa and southwestern Wisconsin, the Kings Lake carbonates of western Illinois and northeastern Missouri, and the Glencoe Shale of southeastern Missouri.

The relatively consistent thickness of the interval between the Deicke and Millbrig (2 to 3 m) from southeastern Minnesota to southeastern Missouri indicates that sedimentation rates were remarkably uniform over long distances. An exception to this can be seen in northeastern Iowa and southwestern Wisconsin where the interval is 10 cm or less (Fig. 7.5). Thinning here appears to be due to erosion caused by local uplift after deposition of the Deicke and prior to deposition of the Millbrig ash.

The Elkport and Dickeyville K-bentonites are known only from the Guttenberg Limestone in the northern outcrop area. Several unnamed K-bentonites occur above the Millbrig K-bentonite in the

Kings Lake Limestone of southeastern Missouri, but a chemical correlation has not been established with those in the northern outcrop area.

The Dickeyville K-bentonite has been chemically correlated as far east as north-central Illinois where it directly overlies the Platteville Group or is separated from it by less than a meter of Guttenberg dolomite. Absent in this area is the Spechts Ferry Formation, including the Deicke and Millbrig K-bentonites, and the basal part of the Guttenberg Formation, including the Elkport K-bentonite. A transect from northeastern Iowa to north-central Illinois shows a gradual pinch-out from the base upward of first the Spechts Ferry and then the basal Guttenberg. These stratigraphic relationships suggest that north-central Illinois, situated at the southern end of the Wisconsin Arch, was uplifted at the end of Blackriveran time and gradually overlapped by Decorah strata during Rocklandian time.

ACKNOWLEDGMENTS

Supported by National Science Foundation Grant EAR-8208480. The XRF analyses were done by E. I. Fruth and XES analyses by L. R. Henderson. We thank J. D. Steele and B. R. Cline for computer compilation and statistical tests and for graphs of the chemical data. We also thank W. E. Parham and J. H. Mossler for some samples and field notes from southeastern Minnesota, and B. J. Witzke for the sample from Le Mars, Iowa. Helpful reviews were provided by L. Summa and J. I. Drever.

CORRELATION OF ORDOVICIAN K-BENTONITES BY PHENOCRYST CHEMISTRY

Scott D. Samson¹, Philip R. Kyle², and E. Calvin Alexander, Jr.³

¹Department of Geosciences, University of Arizona
Tucson, AZ 85721

²Department of Geoscience
New Mexico Institute of Mining and Technology
Socorro, NM 87801

³Department of Geology and Geophysics, University of Minnesota
Minneapolis, MN 55455

ABSTRACT

Two widespread Ordovician bentonites have been correlated on the basis of the rare earth element ratios Ce/Yb, La/Tb, Ce/Sm, and La/Lu, analyzed in primary apatite phenocrysts from two beds.

Objections to the correlation of the Deicke K-bentonite in Minnesota and Missouri to the T-3 K-bentonite in Tennessee could be made, on the basis of the presence of biotite in only the T-3 samples. These objections are overcome by the demonstration of titanium oxide minerals replacing the biotite in the Deicke from the northern localities.

INTRODUCTION

The past 2 decades have seen a wealth of studies involving the chemical correlation of Quaternary volcanic ash layers. These correlations relied primarily on whole-rock geochemistry. In contrast, very few chemical correlation studies have involved K-bentonites (altered volcanic ash). The chemical correlation investigations that have done so have again relied on whole-rock methods (Winter, 1977; Huff, 1983; Kolata and others, 1983, 1986). Few correlations of either fresh ash beds or bentonites have been made on the basis of the chemistry of primary phenocrysts contained in the ashes.

In this paper we discuss the chemical correlation of two widespread Ordovician K-bentonites, the Deicke and the Millbrig, based on the chemistry of apatite phenocrysts contained in them.

CORRELATION OF THE DEICKE AND MILLBRIG K-BENTONITES

Kolata and others (1983, 1986) correlated the Deicke and Millbrig K-bentonites from southern Minnesota to southern Missouri on the basis of trace element chemistry of whole-rock samples. Huff and others (1986) extended this correlation to the Tennessee-Kentucky region using whole-rock chemistry, geophysical logs, and physical tracing.

A problem with the correlation of the Deicke K-bentonite in Minnesota and Missouri with the proposed equivalent in Tennessee, Wilson's (1949) T-3 bentonite, is that biotite is present in the Tennessee samples, but not in the Minnesota or Missouri samples. The problem with the argument that the biotite simply did not travel that far north of the source volcano is that equivalent-sized apatite and zircon are found in all the Deicke samples, although it seems reasonable that biotite would be the phenocryst expected to travel farthest from the source.

A probable solution to the biotite problem arose as a result of identifying authigenic minerals in the Deicke samples from Missouri. Titanium oxide minerals are present in the Deicke samples from both Tennessee and Missouri. Many of these have pseudo-hexagonal shapes very similar to the morphology of the biotite grains. It is likely that the biotite was replaced by these titanium oxide minerals. Further evidence for this is that many of the titanium oxide grains have rodlike grooves on their surface. Because the biotite grains from the Tennessee Deicke samples contain abundant apatite inclusions, it is probable that the grooves on the surface of the titanium

oxide grains are where apatite inclusions were once present, but then excluded during replacement. For a more detailed discussion of this topic see Samson (1986).

PHENOCRYST CHEMISTRY

The original research plan was to chemically analyze all phenocrysts found in a given bentonite sample. Unfortunately, apatite separates are extremely difficult to purify in suitable quantities for analysis, and biotite was not present in bentonite samples from Minnesota and Missouri.

The apatite phenocryst chemistry produces a very good separation of the Deicke and Millbrig K-bentonites. Unfortunately, the chemistry of zircon phenocrysts could not distinguish the two bentonites, and this is attributed to the presence of variable amounts of Precambrian cores in the zircons (Samson, 1986).

All apatite samples were analyzed by INAA at the New Mexico Institute of Mining and Technology, except sample SK86-01 which was analyzed with an electron microprobe at the Geological Survey of Canada. The rare earth elements (REE) Ce, La, Tb, Yb, Lu, and Sm proved to be the best discriminating elements for the two beds. Ratios of these elements were even better discriminators because samples with lower concentrations of a given REE had lower concentrations for all the REE. The best ratios of REE are given in Table 7.2.

The ratios of light to heavy rare earths are the best ratios for discrimination, because the absolute abundance of the light rare earths is higher in the Deicke apatites than in the Millbrig apatites, whereas the concentrations of heavy rare earths display the opposite behavior. A plot of Ce/Yb versus La/Tb shows the separation of the Deicke and Millbrig (Fig. 7.6). The clustering of the samples is very good for both beds and the separation between clusters is also very good. The sample analyzed with an electron microprobe cannot be plotted with the other samples because the heavy rare earths were too low in abundance to be analyzed with the probe. However, Ce and Sm were analyzed and the ratio of these elements fits in very well with the other Deicke samples.

Although the number of apatite samples is not large, their similarity within a bed and dissimilarity between beds is excellent. This is even more important in light of the fact that the geographic separation of the samples is very large. For the Deicke samples this distance is more than 1000 km (from southern Minnesota to central Tennessee), and the distance between Millbrig samples is more than 775 km (southern Minnesota to southern Missouri).

CONCLUSIONS

The presence of biotite in the Deicke only in Tennessee can be explained by the replacement of biotite with titanium oxide minerals in the northern localities of the Deicke. This removes a serious objection to the correlation of the Deicke K-bentonite with the T-3 bentonite.

The chemistry of primary apatite phenocrysts produces a very good correlation of the Ordovician Deicke and Millbrig K-bentonites even over a large distance with few samples. This is a new technique for correlation of Paleozoic bentonites, and although only in its preliminary stage, its potential as a very powerful tool in stratigraphy and paleontology is clear.

ACKNOWLEDGMENTS

Samson would like to thank the University of Minnesota, the Minnesota Geological Survey, and Sigma Xi for partial funding of this project.

Table 7.2. Rare earth element ratios producing the best separation of the Deicke and Millbrig K-bentonites.

Sample	La / Tb	Ce / Yb	La / Lu	Ce / Sm
S85-03 (Millbrig)	8.83 ± 0.33	20.7 ± 0.7	49.6 ± 1.6	4.30 ± 0.14
SK86-03 (Millbrig)	9.26 ± 0.37	21.7 ± 0.7	53.3 ± 1.7	4.51 ± 0.14
S85-04 (Deicke)	20.2 ± 0.9	40.0 ± 1.4	105.1 ± 4.4	7.29 ± 0.22
SK86-04 (Deicke)	19.7 ± 0.9	41.2 ± 1.4	107.7 ± 4.0	7.00 ± 0.20
SK86-08 (Deicke)	19.6 ± 0.7	39.4 ± 1.1	108.8 ± 3.0	7.15 ± 0.20
SK86-01 (Deicke)				7.45 ± 1.75

Uncertainties listed are from quadratically compounding the errors for each element. Detailed locations for these samples are given in Samson (1986).

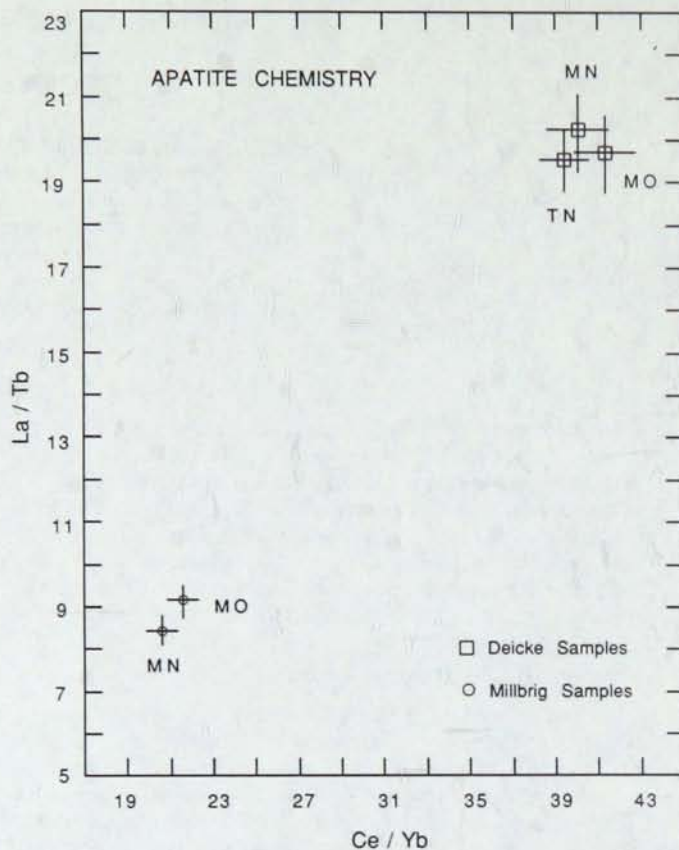


Figure 7.6. Plot of the REE ratios producing the best separation of the Deicke and Millbrig K-bentonite.

CORROSION SURFACES IN THE PLATTEVILLE AND GALENA STRATA OF SOUTHEASTERN MINNESOTA

David Dathe

Department of Geology, Northern Illinois University
DeKalb, IL 60115

Corrosion surfaces are the form of discontinuity surfaces typical in the Platteville-Galena stratigraphic interval in southeastern Minnesota.

DEFINITIONS

Discontinuity surfaces are "minor breaks in the sedimentary column, chiefly intraformational but including interformational junctions that have not involved large-scale erosion" (Bromley, 1975). Thus, discontinuity surfaces are homologous to, but lower in rank than, disconformities. Discontinuity surfaces include special bedding surfaces that have been named abraded surfaces, corrosion surfaces, and omission surfaces.

Two types of discontinuity surfaces—abraded surfaces and corrosion surfaces—depend on the development of a hardground. **Hardgrounds** (Hartgrunde) are synsedimentary lithified seafloors. The term hardground has occasionally been used in reference to discontinuities, although the term discontinuity refers to a surface, whereas the term hardground refers to the state of lithification (in this case, either partial or complete lithification) of the subjacent sediment.

Once a seafloor has been partially or completely lithified, it may be subject to erosion. The type of erosion determines the type of discontinuity surface. Either of two distinct end members may be formed, depending on whether mechanical erosion or chemical corrosion predominates. A variety of intermediate surfaces may be produced by a combination of the two processes. The two end members are described as follows:

(1) **Abraded surfaces**—surfaces in which some sediment was removed (eroded) by traction-current loads. In reference to erosion on seafloors, if the seafloor was hard, it was eroded; if the seafloor was soft, it was scoured.

(2) **Corrosion surfaces**—surfaces in which chemical corrosion of the surface was the dominant process.

An important distinction is made between a corrosion surface, which refers only to the corroded surface itself, and a **corrosion zone**, which refers to "the interval of rock in which the corrosion surface occurs, together with mineral and textural abnormalities related to the corrosion surface" (Weiss, 1958). The term corrosion zone may refer, therefore, both to an actual surface and to the subjacent sediment.

The third type of discontinuity surface does not depend on the development of a hardground and does not involve erosion but rather nondeposition. The surfaces formed are termed (3) **omission surfaces**—surfaces that result from breaks in deposition, not from erosion of a lithified seafloor. If a break in deposition is long enough, a hardground may develop and erosion may occur, producing one of the surfaces mentioned above.

Six separate terms have been introduced. Are all six necessary? Yes, because each addresses a particular and distinct aspect of these bedding surfaces. While numerous authors have been inconsistent in their use of terms, these distinctions should be kept in mind.

FIELD CRITERIA FOR RECOGNIZING CORROSION SURFACES

Corrosion surfaces in outcrops may be prominent or faint, depending on the degree of mineralization, diagenetic history of the

rock, and freshness of the exposure. The following criteria are useful for identifying a corrosion surface in an outcrop.

(1) Smooth to highly irregular, dovetailed and/or pitted surface.

(2) Mineralization (by pyrite and its weathering products) which is most intense at the surface and decreases in intensity downward into the subjacent rock. This is the criterion most commonly seen.

(3) Pits extending downward from the surface and burrows in the subjacent rock immediately below the surface.

Criteria 4-7 are typical of corrosion surfaces in Fillmore County, Minnesota.

(4) Change in rock type from limestone to sandy limestone representing an increase of detrital material—well shown at Mabel Quarry, locality F-160 of Weiss (1954a, p. 291).

(5) Presence of abundant colophane above the corrosion surface.

(6) Corroded pebbles of the subjacent rock apparently suspended in the superjacent matrix (= corrosion conglomerate with hardground intraclasts).

(7) Presence of brassy oolites immediately above the corrosion surface.

Field work indicates that some corrosion surfaces occur as lateral equivalents of a (1) bedding surface, that is, the corrosion surface disappears; these corrosion surfaces may represent topographic highs on the seafloor; (2) shaly bed; (3) chert layer or nodules; (4) sparry calcarenite layer (fossil hash layer). Thus, when examining these features, it is worthwhile to trace them laterally to see if they become corrosion surfaces.

FIELD CRITERIA FOR INFERENCES ON THE ORIGIN OF CORROSION SURFACES

Field evidence used by many authors in making inferences about the nature and origin of hardgrounds is summarized as follows:

Evidence of a submarine origin:

(1) Marine strata above and below the corrosion surface.

(2) Diverse marine fauna on a few of the surfaces.

(3) Vertical pits (borings) which occur on many of the surfaces.

(4) Limited areal extent of some hardgrounds.

Evidence of synsedimentary lithification:

(1) Corrosion surface is sharply defined and irregular.

(2) Intense mineralization at the surface.

(3) Undercut hummocks and dovetailing.

(4) Synsedimentary calcite-filled cracks that cut bioclasts.

(5) Bioclasts truncated at the surface.

(6) Presence of encrusting epifauna.

(7) Borings (*Trypanites*).

Evidence of erosion and scour (see Palmer and Palmer, 1977):

(1) Truncated fossils at the surface.

(2) Presence of quartz sand in burrows.

(3) Fossil hash overlying the surface.

ACKNOWLEDGMENTS

This report is based on research and field work for a dissertation at Northern Illinois University. I would particularly like to thank Dr. Malcolm P. Weiss, Dr. Dennis R. Kolata, David J. Delgado, Calvin O. Levorson, and Arthur J. Gerk for their valuable insights.

THE WAGNER QUARRY CYSTOID BED: A STUDY IN PROSSER (SHERWOOD) PALEOECOLOGY

Robert E. Sloan and David A. DesAutels*

Department of Geology and Geophysics, University of Minnesota
Minneapolis, MN 55455

*(14802 Hoya Court, Houston, TX 77070)

This study is based on the unpublished M.S. thesis of DesAutels (1978), which was supervised by Sloan. The Wagner Quarry cystoid bed is a distinctive mass kill layer about 3 cm thick that occurs 3.43 m (11'3") above the base of the Prosser Limestone and the base of the Sherwood equivalent. The quarries and roadcuts are in sections 5 and 8, T. 111 N., R. 17 W., Leon township, 4 miles south of Cannon Falls, Goodhue County, Minnesota on and near the property of Mr. Lawrence Wagner. The kill resulted from a rapid mass burial in carbonate mud to a depth of 3 cm, perhaps as a result of a storm wave elsewhere reaching bottom. DesAutels identified, measured and counted the total macrofossil assemblage of 1596 individuals of 33 species from a total of 6.86 sq m (74 sq ft) of this bed. The slabs were the property of amateurs and professional collectors, and were sold commercially after analysis. Preparation was by an S.S. White Air-brasive machine. This represents the largest unbiased sample of a Prosser fauna known to the writers, although it clearly does not show the full diversity of the Prosser fauna. The Prosser and Cummingsville fauna is the richest known Middle or Late Ordovician fauna in Minnesota; some 330 species are known (Webers, 1972). The present fauna is in the *Ischadites iowensis* zone and consists of 55% brachiopods, 15% bryozoa, 10% echinoderms, 7% gastropods, 6% trilobites, 2% cephalopods and 3% corals. The benthic species are slightly dwarfed, reaching on the average about 60% of their maximum size elsewhere. Bivalves are totally absent and no conodonts were found. The rank ordered species list (Table 9.1) shows the expected rarification curve (Ager, 1963).

The fossils were collected in the more eastern of Mr. Wagner's two quarries, in the NE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 8 (Figs. 9.1, 9.2). Levorson and Gerk have measured a detailed section (Fig. 9.3), their M-110, the Wagner Hill section, along U.S. 52, in the nearby SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 5. The Decorah Shale in the vicinity of Cannon Falls is about 18.5 m (61 ft) thick, and the lower part of the type Cummingsville Formation has increased in mud content to become the upper part of the Decorah Shale. Similarly the lower part of the type Prosser Limestone, the equivalent of the Rivoli Member of the Illinois and Iowa classification, has greatly increased in mud content and must be classed as part of the Cummingsville Formation here. The horizon of the contact has shifted upward about 6 m (20 ft). These exposures are the most northern outcrops yet studied of the Prosser Limestone, which does not extend more than 2 miles north of here. The horizon is high in the Shermanian stage; the estimated age is 450.0 Ma, and it is part of Levorson and Gerk's (1972) crinoid horizon no. 2. The CSS number in Sweet's (1984) Composite Ordovician Standard is 1038.2.

The chlorophyte (green) alga *Ischadites iowensis* is represented by 10 specimens of the usual 2.5 to 4 cm diameter. Whether it is assigned with *Fisherites* (= *Receptaculites*, Finney and Nitecki, 1979) to the Dasycladaceae or to a separate Receptaculitaceae, it is uniformly regarded as a green alga and as such must have been restricted to very shallow water. Modern green algae are restricted to water less than 50 m in depth by the rapid extinction with depth of the red light they use for photosynthesis (Ginsburg and others, 1972). The density is 1.4 individuals per square meter, suggesting a depth at the deeper end of the range.

The only coral known is *Streptelasma corniculum*. It is known from 54 individuals, representing a population of 7.9 individuals per

square meter. The mean calyx diameter is only 12 mm, about half the usual size.

The bryozoans are represented by 3 species. The moundlike *Prasopora insularis* is the most common with 182 colonies averaging 12 mm in diameter, about half the usual size. It is the third most common species, with a density of 26.5 per square meter. *Stictopora mutabilis* is next in abundance with 33 colonies, all lying loose on the substrate, for a density of 4.8 per square meter. *Nematopora conferta* is the other bryozoan, with 21 colonies or fragments for a density of 3.1 per square meter.

The brachiopods are represented by seven articulate species. The most common species in the community is *Platystrophia biforata*, with 384 individuals for a density of 56.0 per square meter. One third were found with the pedicle valve down; all other brachiopods

Table 9.1. Species list rank ordered by abundance and density.

Species	Number of Individuals	Density per m ²
<i>Platystrophia</i> "biforata"	384	56.0
<i>Zygospira recurvirostris</i>	257	37.5
<i>Prasopora insularis</i>	182	26.5
<i>Pleurocystites squamosus</i>	94	13.7
<i>Strophomena trilobata</i>	84	12.2
<i>Plaesiomys subquadrata</i>	61	8.9
<i>Scalenocystites strimplei</i>	58	8.5
<i>Streptelasma corniculum</i>	54	7.9
<i>Dolichoharpes ottawaensis</i>	52	7.6
<i>Strophomena</i> "incurvata"	41	6.0
<i>Stictopora mutabilis</i>	33	4.8
<i>Illaenus americanus</i>	32	4.7
<i>Maclurites crassa</i>	32	4.7
<i>Fusispira inflata</i>	28	4.1
<i>Nematopora conferta</i>	21	3.1
<i>Raphistomina lapicida</i>	20	2.9
<i>Eomonorachus intermedius</i>	19	2.8
<i>Trochonema umbilicatum</i>	19	2.8
<i>Michelinoceras beltrami</i>	19	2.8
<i>Paucicrura rogata</i>	18	2.6
" <i>Spyroceras</i> " <i>lesueuri</i>	14	2.0
<i>Hormotoma gracilis</i>	13	1.9
<i>Zygospira modesta</i>	11	1.6
<i>Ischadites iowensis</i>	10	1.4
<i>Hudsonaster narrawayi</i>	10	1.4
<i>Ceraurus pleurexanthemus</i>	10	1.4
<i>Isotelus gigas</i>	5	0.7
<i>Glyptocrinus</i> sp.	5	0.7
<i>Cremacrinus</i> sp.	4	0.6
<i>Ophiletina angularis</i>	3	0.4
<i>Ceraurus</i> cf. <i>icarus</i>	1	0.2
<i>Hormotoma subangulata</i>	1	0.2
<i>Cyclocystoides halli</i>	1	0.2
TOTAL 33 species	1596	232.7

were found pedicle valve up. Larger species were buried as much as 1 cm below the surface of the bed; the smaller species were at the surface. The size of *P. biforata* ranged from 2 to 20 mm width with a mean of 6.3 mm, the modal size was from 3 to 4 mm in width, with a size distribution strongly skewed to the smaller sizes. Second in abundance among all species is *Zygospira recurvirostris* with 257 individuals, for a density of 37.5 per square meter. Width ranged from 1 to 6 mm, the mean was 3.2 mm, with a nearly normal size distribution. The related *Zygospira modesta* was represented by 11 individuals. *Strophomena trilobata* was the fifth most common species with 84 specimens for a density of 12.2 per square meter. Width ranged from 8 to 26 mm, with a mean of 17.4 mm. The flatter *S. incurvata* is known from 41 individuals, 6 per square meter. Width ranged from 6 to 25 mm, with a mean of 13.2 mm. Both species had normal size distributions. *Plaesiomys subquadrata* was represented by 61 individuals, for a density of 8.9 per square meter. Width ranged normally from 4 to 13 mm, with a mean of 7.8 mm. The final species of brachiopod is *Paucicrura* (formerly *Resserella*) *rogata* with 18 specimens, ranging in width from 3.2 to 6.4 mm, for a density of 2.6 per square meter.

Echinoderms are represented by 6 species. The rhombiferan *Pleurocystites squamosus* is the fifth most abundant species with 94 individuals and a density of 13.7 per square meter; 16 were found rhomb side up and 8 inverted. Calyx length averaged 13 mm, about 65% of normal size. Next in abundance is the iowacystid solutan *Scalenocystites strimplei* Kolata (1973), for which this is the type locality, represented by 58 individuals and a density of 8.5 per square meter. Only two small specimens were inverted. Calyx length varies from 6 to 13.7 mm; the mean is 10.5 mm. Ten specimens of *Hudsonaster narrawayi* were found for a density of 1.3 per square meter. The arm length was 5 to 11 mm, conspicuously smaller than those known from the Platteville Formation which average about 25 mm. All were right side up except for the largest individual. The calceocrinid inadunate *Cremaerinus* sp. is known from 4 individuals and the camerate *Glyptocrinus* sp. is known from 5 individuals. The rarest species is *Cyclocystoides halli*, known from one individual 13 mm in diameter.

Gastropods are represented by 7 species. *Maclurites crassa* is the most common with 32 individuals, density of 4.7 per square meter. All are conspicuously smaller than in the Stewartville Formation with diameter ranging from 2 to 16.2 mm, and a mean of 9.4 mm. Next in abundance is the possibly carnivorous subulitid neogastropod *Fusispira inflata* with 28 specimens; density is 4.1 per square meter. Height ranges from 16 to 34 mm, with a mean of 22.0 mm. *Raphistomina lapicida* is known from 20 individuals; density is 2.9

per square meter. Smaller than usual, the mean diameter is 13 mm. The pleurotomariacean *Trochonema umbilicatum* is known from 19 specimens, 2.8 per square meter. Height is about 7 mm, half the usual size. The murchisoniid *Hormotoma gracilis* is known from 13 specimens, with a mean height of 14 mm, and a density of 1.9 per square meter. The related *H. subangulata* is known from a single specimen, 35 mm high. *Ophiletina angularis* is the smallest snail, 5 mm in diameter; three are known.

Two cephalopods are known. *Michelinoceras beltrami* has an average diameter of 8 mm, and is known from 19 specimens, for a density of 2.8 per square meter. "*Spyroceras*" *lesueuri*, a larger orthocerid from 1 to 3 cm in diameter, is known from 14 individuals. Large *Endoceras proteiforme* and a giant slightly convolute nautilid 60 cm in diameter with a nearly circular whorl cross section are present in the quarry below the *Scalenocystites* bed. As mentioned above, clams are totally absent from this community.

Trilobites are relatively abundant compared to Sloan's experience collecting them in the Decorah Shale. Most are known only from molts. The mud-plowing *Dolichoharpes ottawaensis* is richest in abundance; this is the lowest horizon at which it occurs in Minnesota, so far as we know. Fifty two individuals are known from complete individuals and cephalons; the density is 7.6 per square meter. Length averages 20 mm. The next most common species is *Illaeus americanus*, known from 121 parts, including 32 pygidia and 31 cephalons, 2.1 individuals per square meter. Pygidial width ranges from 5 to 29 mm, with a mean of 15 mm. *Isotelus gigas* is known from 42 parts of about 5 individuals; the maximum length is about 100 mm. *Ceraurus pleurexanthemus* is known from 42 parts, including 3 pygidia, and 10 cephalons, and this suggests a density of about 1.4 per square meter. *Eomonorachus intermedius* is known from 22 parts, including 19 pygidia; the density was 2.8 per square meter. A single pygidium of a *Ceraurus* cf. *icarus* was found. On the basis of the trilobite depth zones of Chatterton and Ludvigsen (1976), this bed represents the deeper part of the third of his four increasingly deeper depth zones. It clearly represents the deepest part of the Caradocian transgression, and represents the deepest facies recorded in the Middle and Late Ordovician strata of Minnesota.

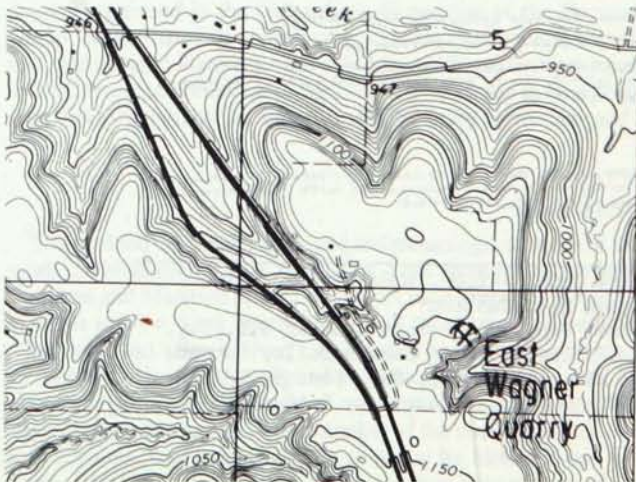


Figure 9.1. Topographic map of the Wagner Hill section and the Wagner Quarry.



Figure 9.2. The Lawrence Wagner east quarry where the *Scalenocystites* bed was collected. The horizon is about 3/4 of the way up the quarry faces shown.

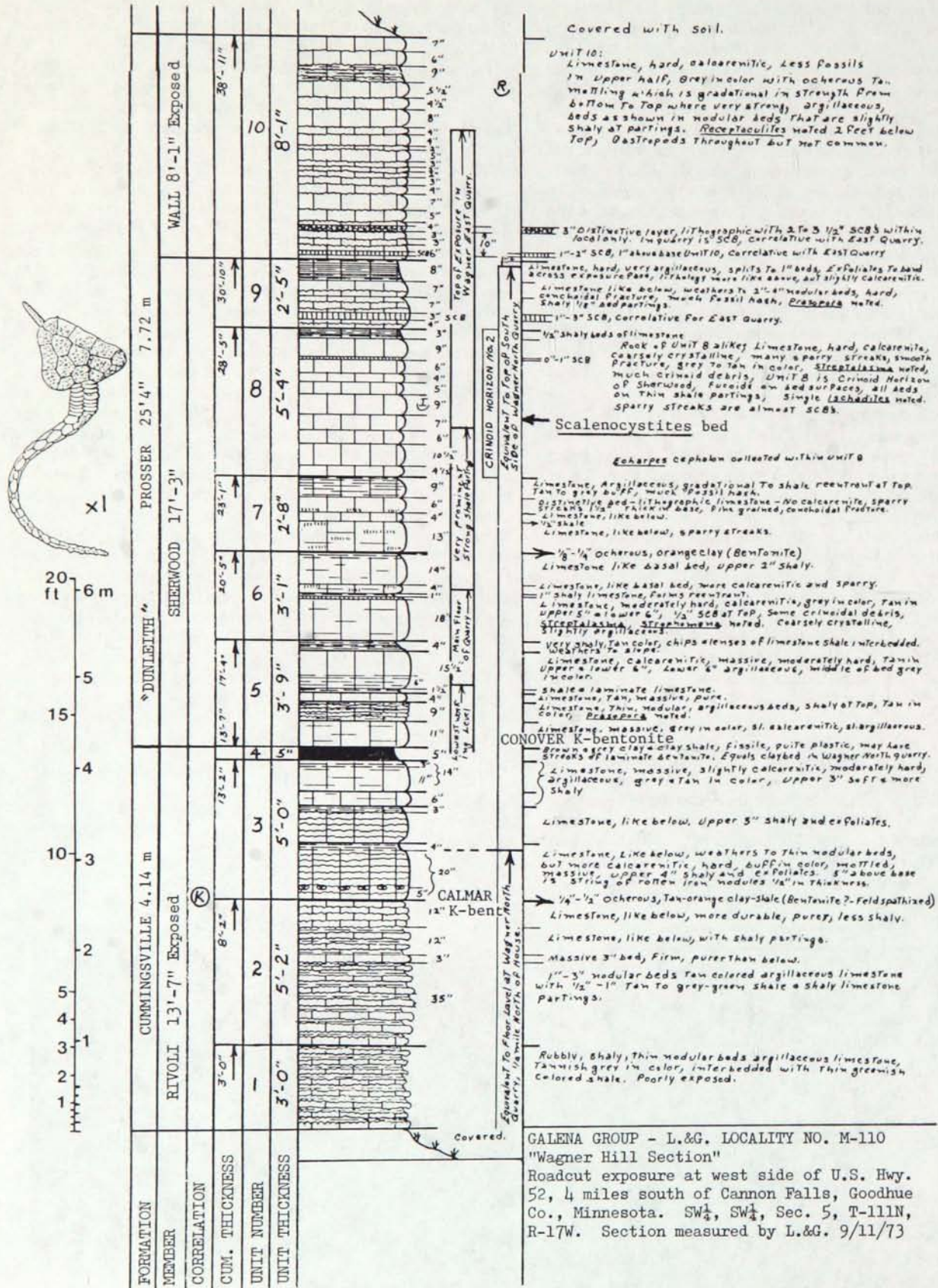


Figure 9.3. The Wagner Hill section of Levorson and Gerks, with minor additions by Sloan.

PLATTEVILLE AND DECORAH TRILOBITES FROM ILLINOIS AND WISCONSIN

Lawrence Lynch DeMott

1922-1986

Edited by Robert E. Sloan¹, Frederick C. Shaw², and Ronald P. Tripp³

¹Department of Geology and Geophysics, University of Minnesota

²Herbert H. Lehman College, CUNY

Bronx, NY 10468

³41 Kirk Drive

Thornhill, Ontario L3T 3K8

Larry DeMott died after a long illness, in 1986. Toward the end of that illness, Sloan with DeMott's permission invited Shaw and Tripp to revise the paleontology of DeMott's original Harvard dissertation (1963). The three of us dedicate this effort to a bright and genial friend who was unable to bring his labors to publication. We hope he would be pleased with this effort. Except where made clear, this text is distilled from DeMott's original manuscript.

Lawrence Lynch DeMott was born January 16, 1922 in Kearney, New Jersey. He took a bachelor's degree in English at Oberlin College in 1943, and a master's degree in English from the University of Chicago in 1947. During 1944-45 he served in the Army Air Corps in Chengdu in Sichuan Province, China, where he first met Harry B. Whittington. After graduating from Chicago, he then taught English at Washington State University in Pullman, Washington, until 1951. On December 26th 1949 he married Helen Sawyer. In 1951 he began work in Geology under Professor Harry B. Whittington at Harvard, working on Platteville and Decorah trilobite collections made by Whittington and J.S. Templeton in 1952. He added to these collections in 1955. He also collected trilobites from critical sections

in New York to improve the level of correlation with the Upper Mississippi valley. He taught geology at Oberlin from 1954 to 1962. He submitted his Ph.D. thesis dissertation "Middle Ordovician Trilobites of the Upper Mississippi Valley" and was granted his degree in August 1963. His thesis has been widely quoted in trilobite literature, but for reasons of teaching pressure was never published. He taught geology at Knox College, in Galesburg, Illinois, beginning in 1962, retiring as head of the department in 1983 for reasons of ill health after two heart attacks.

On reading DeMott's thesis in May 1985, Sloan was impressed with the need for publication, because these trilobites occur in rocks from Minnesota to Missouri, and offered to assist. Larry was happy to accept and turned the thesis over to Sloan. Frederick C. Shaw, also a student of Whittington's, and Ronald P. Tripp agreed to upgrade and revise the taxonomic parts of the thesis for publication. On July 23, 1985, Larry had a heart bypass operation and a pacemaker was inserted. On August 21, he had a stroke, from which he never regained consciousness. He died on February 6, 1986 in Galesburg. He is survived by his widow Helen and a daughter, Margaret.

ABSTRACT

A total of 480 specimens of trilobites belonging to 34 species were collected from the Platteville and Decorah Groups at 15 localities in northern Illinois, 13 localities in southwestern Wisconsin, and a locality in eastern Iowa. Five species and 15 specimens were from the Pecatonica Formation, 20 species and 138 specimens were from the Mifflin Formation, 19 species and 38 specimens were from the Grand Detour Formation, none were found in the Nachusa, and 9 species and 89 specimens were found in the Quimbys Mill Formation of the Platteville Group. Four species and 12 specimens were found in the Spechts Ferry Formation, and 12 species and 188 specimens were found in the Guttenberg Formation of the Decorah Group. Eight Platteville species were found in the Lowville Formation, and 6 Platteville species but only 1 Decorah species were found in the Chaumont Formation of the Black River Group in New York state. Six Decorah species were found in the Selby Formation, and 7

were found in the Napanee Formation of the type Rocklandian. Three Decorah species were found in the Hull Formation, and 2 additional species from post-Decorah rocks ranged through the Selby to Hull of the type Trenton of New York state. Two Decorah trilobite species were found in the Sherman Falls Formation, as were 9 additional trilobite species of post-Decorah distribution. This suggests strongly that the local disconformity between the Quimbys Mill and the Spechts Ferry Formations in northern Illinois and adjacent Wisconsin correlates precisely with the Black River-Trenton boundary. A major extinction of trilobite species took place at this boundary. 9 of 10 known terminal Platteville species (90%) becoming extinct. *Anapliomera shirlandensis* new genus and new species, and new species *Gabriceraurus mifflinensis* and *Ceraurina templetoni* are described.

EDITORS' INTRODUCTION

Sloan edited the stratigraphic and sedimentologic sections of this work. DeMott used Kay's 1937 New York stratigraphic system. Cameron and Mangion (1977) and others have proposed numerous changes in New York terminology, but the distinction between "Trenton" and "Black River" is preserved basically as understood by DeMott. Most of the original paleontological text and all the plates are printed here. However, synonymies were updated and slightly altered in format, and a number of the remarks and discussion sections have been rewritten or recast by Sloan, Shaw, and Tripp. Some systematic changes were made in light of more recent papers, and several of DeMott's proposed species and genera rearranged. These changes are discernible in the synonymies. When ex-

pressing opinions in the paleontology section, Shaw and Tripp have used "we," DeMott's opinions use "I." DeMott used "plane of the margins" to describe the orientation of illaenids. The term is left in the descriptions and has, we think, some merits. We do not, however, advocate its widespread adoption.

The Museum of Comparative Zoology (MCZ) is the repository of many of these specimens. The material of *Sceptaspis* and *Eomonorachus* regrettably was stolen several years ago while on loan. Those specimens are figured as a matter of record. DeMott is the author of record. Remarks or changes clearly attributable to the editors should be referred to by "Sloan" or "Shaw and Tripp in DeMott."

INTRODUCTION

The primary objectives of this work are to give modern descriptions of the trilobites of the Platteville and Decorah Groups of the Upper Mississippi valley, to relate these trilobites to modern rock-stratigraphic units, and to present implications that these trilobites have for regional stratigraphy and for inter-regional correlations.

Credit for the inception of this project belongs to Harry B. Whittington, then of Harvard University, now of the Sedgwick Museum of Cambridge University, and the late J.S. Templeton of the Illinois Geological Survey, who made a large collection of trilobites in 1952. In 1955, after Dr. Templeton's death, I was invited by Dr. Whittington to study the Whittington-Templeton collection. I spent the summer field season of 1955, with student assistance, collecting more trilobites from the same area. Financial aid was received from Harvard University, the Illinois Geological Survey, and the Danforth Foundation. I thank my wife and family for living with this research project for a great many years. I thank Dr. Fred Foreman and Dr. Reuel Frost of Oberlin College, Dr. H. B. Willman of the Illinois Geological Survey, and Dr. Marland P. Billings, Dr. Bernhard Kummel, and especially Dr. H. B. Whittington of Harvard University for their guidance and assistance.

Within this field area there is a short unconformity between the Platteville and Decorah Groups [now dated as about 0.8 m.y. in duration. The stratigraphic column in this study is that of Willman and Kolata (1978) and Kolata (this volume). R.E.S.] All my own observations on these strata and the compatibility of the trilobite data with these lithologic criteria convince me that, as they suggested, Templeton and Willman's formations are time rock units which do not transgress time lines. Figure 10.1 and Table 10.1 show the localities in northern Illinois and southern Wisconsin which were productive of the trilobites of this report.

THE STRATIGRAPHIC RECORD OF THE TRILOBITES

The percentages of the various species found in the Platteville and Decorah Groups are shown in Figure 10.2. The ranges of the species of trilobites found in the Platteville and Decorah Groups are charted in Figure 10.3. One conclusion stands out from these data. There is but one major break in the trilobite faunas in this area. It occurs at the local unconformity between the Quimbys Mill Formation (Platteville Group) and the Spechts Ferry Formation (Decorah Subgroup, Galena Group). [Sardeson (1926), and Sloan (this volume) find that in Minnesota this break occurs at the Deicke K-bentonite which is locally missing in DeMott's field area due to the local unconformity (R.E.S.)]

The trilobites are not evenly distributed within the formations. They are notably absent from or sparse in the dolomite formations, the Pecatonica, and the Nachusa. They are also limited to small portions of the formations, with the exception of the Guttenberg Formation. Table 10.2 shows the number of localities per formation searched for trilobites and the number of localities per formation in which trilobites were found at the 29 localities.

The Nachusa and Pecatonica Formations were barren and nearly barren of many invertebrate groups besides trilobites; this is a direct reflection of the fact that these two formations are the purest dolomites of the interval studied, and their fossils have undergone the most destruction due to dolomitization.

The Spechts Ferry Formation is not poor in fossils. It includes slabs of limestone that are true brachiopod coquinas, within which many other kinds of invertebrate skeletons are preserved.

These differences are in part preservational (whether or not the rocks were dolomitized), and in part biofacial. [For example, Sloan is of the opinion that the Mifflin fauna of DeMott's area, from the presence of *Cybeloides*, *Dolichoharpes*, *Sceptaspis* and *Ceraurinella* represents deeper water than the Mifflin of the Twin Cities. Absence of many Platteville taxa from the Quimbys Mill may be due to the same shallowing that produced the Magnolia and Carimona faunas (below the Deicke K-bentonite) in Minnesota.]

Twenty species occur only in the Platteville Group, and eleven species occur only in the Decorah strata. Only one species, *Sceptaspis lincolnsis*, appears to maintain its identity across the boundary, and only two species, *Hypodicranotus* sp. and *Hemiarges* aff. *paulianus*, are closely allied to species whose holotypes come from higher stratigraphic levels than the present occurrences.

Care was exercised throughout this study to collect with a precision that would permit each formation to be annotated with distinguishing characteristics based upon trilobites. Collecting was done with the aid of detailed graphic lithologic logs drawn by Templeton and Willman at a scale of 1:48. Indeed, it was hoped that some of the Templeton-Willman members would be distinctive as well. Instead, the central finding of this study is that care and precision reveal but the one faunal division.

The trilobites of the Platteville Group constitute a discrete and homogeneous faunal interval. No evolutionary gradations occur within this interval. The trilobite fauna encountered in the Spechts Ferry and Guttenberg Formations of the Decorah Subgroup should not be viewed as a similar discrete entity. Following the extinction produced by the fall of the Deicke K-bentonite, new species migrated in from elsewhere, and not all at the same time. The upper boundary of the Guttenberg was an arbitrary stopping point, chosen because it represents the upper limit of plentiful trilobite preservation in Illinois. To the northwest, in Iowa and Minnesota, the overlying Ion, Cummingsville and Prosser Formations have limestone facies that yield trilobites which can extend the record. cursory examination of sections and collections in these higher strata suggests that the species of trilobites which characterize the Spechts Ferry and Guttenberg Formations disappear at random intervals upsection, and new species come in at a variety of levels. [DeMott concluded that the fauna of the Decorah formations shown in figure 10.2 belongs only to the beginning of a considerably longer period of sedimentation than the Platteville time-rock interval—long enough so that evolutionary changes can be detected, and constant enough so that these changes are not markedly concentrated at any one diastem. R.E.S.]



Figure 10.1. DeMott's trilobite localities in Illinois, Wisconsin, and Iowa, and the geographic localities after which the formations of the region are named.

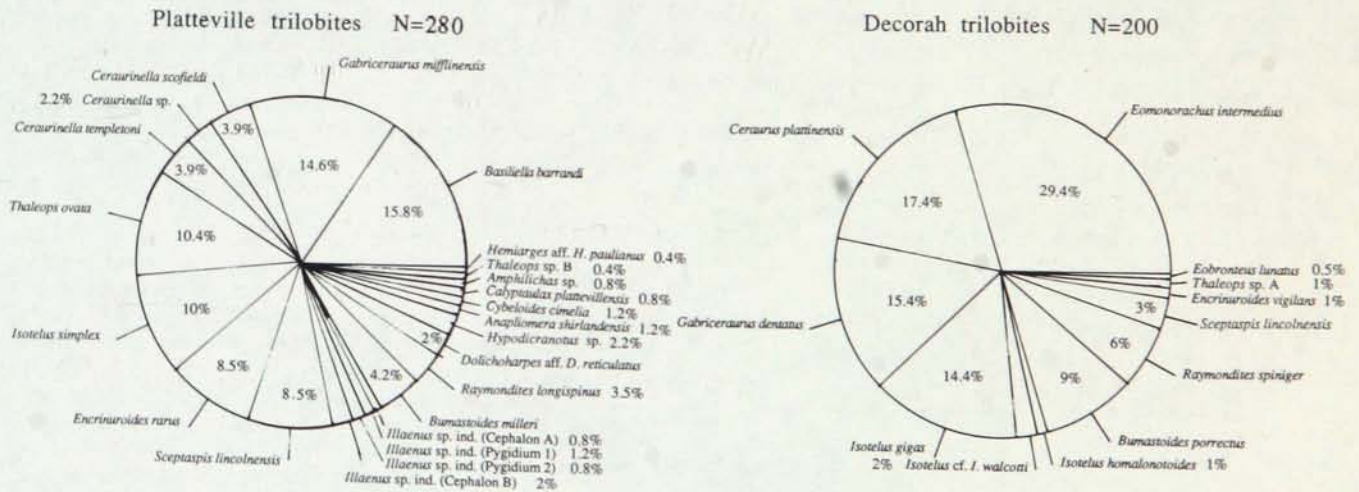


Figure 10.2. Percentage distribution of trilobites in Platteville and Decorah strata.

Table 10.1 Demott's trilobite localities.

[Listed in order from southeast to northwest. Dg, Guttenberg; Ds, Spechts Ferry; Pq, Quimbys Mill; Pn, Nachusa; Pg, Grand Detour; Pm, Mifflin; Pp, Pecatonica.]

Locality	Type	Section	T.	R.	Unit	County, State
1 Medusa	Quarry	NW NW NE 27	22N	9E	Pm	Lee, Ill.
2 Lowell Park	Quarry	SE NE NE 28	22N	9E	Pg	Lee, Ill.
3 Dixon North	Quarry	SW SW NW 22	22N	9E	Pm	Lee, Ill.
4 Dixon Ravine	Creek	NW NW NW 22	22N	9E	Pm	Lee, Ill.
5 Harmony Hill	Creek	SE SE NE 24	23N	9E	Pp	Ogle, Ill.
6 Wooleys Spring	Roadcut & quarry	NE SW NW 2	23N	10E	Pg	Ogle, Ill.
7 Blackhawk	Roadcut & quarry	SW NE SW 34	24N	10E	Pg	Ogle, Ill.
8 Byron South	Quarry	NE NE NW 5	24N	9E	Pg,Pq	Ogle, Ill.
9 Adeline SE.	Railroad cut	NE NE NE 33	25N	9E	Pm	Ogle, Ill.
10 Shirland E.	Quarry	SE NE NE 12	28N	11E	Pg	Winnebago, Ill.
11 Davis S.	Quarry	W SW NE 35	28N	9E	Pg	Stephenson, Ill.
12 Rock City S.	Quarry	NW NW NE 34	28N	9E	Pg	Stephenson, Ill.
13 St. James W.	Quarry	NW SW NW 15	28N	9E	Dg	Stephenson, Ill.
14 Furnace Lead Mill	Bluff	SW NW SW 2	28N	1E	Dg	Jo Davies, Ill.
15 Tuttles Mill	Bluff	SE SE SW 34	29N	1E	Pq	Jo Davies, Ill.
16 Buncombe	Roadcut & creek	W SW NW 32	1N	1E	Dg	Lafayette, Wis.
17 Quimbys Mill	Quarry	SE SE 11	1N	1E	Pg,Dg	Lafayette, Wis.
18 Dickeyville NE.	Roadcut	SE SW SE 1	2N	2W	Pm	Grant, Wis.
19 Dickeyville NW.	Roadcut	NE NE SW 7	2N	2W	Dg	Grant, Wis.
20 Potosi Station	Quarry	SW 4	2N	3W	Pm	Grant, Wis.
21 Platteville N.	Quarry & roadcut	NE SW SE 4	3N	1W	Dg	Grant, Wis.
22 Mifflin Type	Creek	NE NE NE 34	5N	1E	Pm,Pg	Iowa, Wis.
23 Cassville	Creek	NE NW SW 18	3N	5W	Dg	Grant, Wis.
24 Bloomington	Quarries	NE 25	5N	5W	Pm	Grant, Wis.
25 Patch Grove	Quarry & creek	N SE 29	6N	5W	Pm,Dg	Grant, Wis.
26 Mt. Ida E.	Roadcut	NW NW SE 21	6N	3W	Pm	Grant, Wis.
27 Fennimore W.	Roadcut	SE SE NE 21	6N	3W	Pm,Ds,Dg	Grant, Wis.
28 McGregor Type	Creek	E SE NE 29	95N	3W	Pm,Ds,Dg	Clayton, Iowa
29 Liberty Pole	Quarry	NE NE NW 30	12N	4W	Ds	Vernon, Wis.

Table 10.2. Trilobite localities found.

Formation	Localities searched	Trilobite localities	
		found	Percent
Guttenberg	10	10	100
Spechts Ferry	9	3	33
Quimbys Mill	10	3	30
Nachusa	11	0	0
Grand Detour	18	8	44
Mifflin	15	11	73
Pecatonica	10	1	10
Glenwood	6	0	0

Platteville						Galena		GROUP	
Plattin						Decorah		SUB-GROUP	
18-35'	16-20'	20-45'	Grand Detour	15-25'	Nochusa	10-15'	Quimbys Mill	FORMATION	
Pecatonica	Mifflin	Cohen	Sullivan	Furston	Eldora	Elm	Everett	MEMBER	
Hennepin	Ogish	Cohen	Sullivan	Furston	Eldora	Elm	Everett	THICKNESS (ft)	
0-5	0-16	6-18	0-8	6-18	5-10	1-4	5-10	(ft)	
									LOCALITY
									13, 14, 16, 17, 21, 23
									19, 25
									27, 28, 29
									15
									8, 12
									17
									31
									30
									7
									2
									6
									1
									12
									34
									31
									8
									2
									54
									6
									1
									1
15	138	38	0	89	12	188	480		

Figure 10.3. Stratigraphic distribution and numbers of trilobites of the Platteville and Decorah Groups of Illinois and Wisconsin.

My (DeMott's) present knowledge of the trilobite record above the Guttenberg Formation suggests that, of the prevalent Guttenberg species, *Raymondites spiniger*, *Ceraurus plattinensis*, *Gabriceraurus dentatus*, and *Sceptaspis lincolniensis* do not range above the Guttenberg Formation. *Bumastoides porrectus* and *Eomonorachus intermedius* do not range above the Ion Formation, although *Isotelus gigas*, *I. cf. walcotti* and *Encrinuroides vigilans* continue as high as trilobites are seen in the Prosser Limestone. Meanwhile new appearances of species include *Ceraurus pleurexanthemus* and *Flexicalymene senaria*, which make their first appearance in the upper Ion and continue through into the Prosser, and several species—*Iliaenus americanus*, *Bumastoides billingsi*, *Dolichoharpes ottawaensis*, and unnamed species of *Calyptaulax* and *Ceraurinus* make their first appearance in the Prosser.

CORRELATION WITH THE BLACK RIVER AND TRENTON GROUPS IN NEW YORK STATE

When the trilobites of the Upper Mississippi valley are compared with those in western New York and adjacent Ontario, Platteville species are found in the Chaumont Formation at the top of the Black River Group, and Decorah species are found in the lower beds of the Trenton Group. There appears to be fully as large a break between Black River and Trenton trilobite species in New York as there is between Platteville and Decorah species in the area studied. I base these statements upon a study of the literature, upon my observations of museum collections, and on my observations made during 3 weeks spent in the field investigating New York and Ontario sections.

The Black River Group includes, in ascending order, the Pamela, Lowville, and Chaumont Formations. In my field work (re-examining sections as detailed in Young, 1943), I could find no trilobites in the Pamela Formation, and in the Lowville Formation, I collected only the species *Bathyurus extans* (Hall, 1847), which is not present anywhere in my field area [but is present in the Platteville Limestone below the Deicke K-bentonite at Minneapolis and Faribault, Minnesota. R.E.S.]. In the Chaumont Formation, however, there occur *Basiliella barrandi*, *Raymondites longispinus*, *Bumastoides milleri*, *Isotelus simplex*, and *Thaleops ovata*. Fragments of these species were seen at Young's locality 1, Crow River at Crow Bridge, Ontario; locality 3, Napanee, Ontario; and locality 9, quarries 2 miles south of Napanee, Ontario. In addition, these species were found in abundance at Bucks Quarry, near Poland, Herkimer County, New York, which is a Chaumont locality that was particularly sought out in this study to bolster the correlations between New York and the Upper Mississippi valley. (See below for a description of the Bucks Quarry section.) The named species, all abundant in the Midwest, were the only prominent species in the east, so that I consider the Chaumont trilobite fauna essentially identical with the Platteville fauna. Presumably some of the rarer Platteville species occur also in New York and might be found with a more protracted search. Collections in the Museum of Comparative Zoology add one of the rarer species, *Ceraurina scofieldi* from Bucks Quarry. The only anomaly between east and Midwest of which I am aware exists in a specimen from what I suppose to be the Chaumont Formation at Crow Bridge—a bathyurid pygidium with an unusually large axial spine. I do not distinguish it with certainty from *Raymondites spiniger*, a Guttenberg species.

Seven species of trilobites that are prevalent in the Decorah Subgroup occur in the standard sections of the Trenton Group in the east. Moreover, the Decorah species are most typical of the lowest Trenton formations. *Isotelus gigas*, *I. cf. walcotti*, *Bumastoides porrectus*, *Raymondites spiniger*, *Gabriceraurus dentatus*, *Encrinuroides vigilans* and *Eomonorachus intermedius* all occur in the east. Four of these species are based on holotypes which came from "low Trenton" horizons in the east, and all but the *Isotelus* species appear prevalent only in the lower part of the Trenton Group. With

the possible exception of *Raymondites spiniger*, these species do not range downward into Black River formations, and I conclude that the abrupt faunal change that occurs between Platteville and Decorah species of trilobites in my region is also present between the Black River Group and the Trenton Group of New York. (This area in New York and Ontario is included within the area of fall of the Deicke K-bentonite. Restudy of New York bentonites should locate the Deicke and give a firm correlation. R.E.S.)

The exact correlation of lower Trenton formations with Decorah formations is difficult to discern. It has been brought out that the Spechts Ferry-Guttenberg assemblage of trilobites stands at the beginning of a faunal sequence that shows a gradual change when traced upward through the overlying formations. Similar gradual change governs the trilobites of the Trenton Group. How do these two evolving records match?

The literature and my collections from sections described by Kay (1937) along the Trenton outcrop belt between Ingham Mills, New York, and Napanee, Ontario, yield the following data: *Sceptaspis lincolniensis* and *Ceraurus plattinensis*, which terminate in the Guttenberg, are not seen in the east. *Raymondites spiniger*, which terminates in the Guttenberg, was collected from the basal 6 feet of Trenton (Rockland Formation—Selby Member?) at Roaring Brook, East Martinsburg, New York. *Gabriceraurus dentatus*, which terminates in the Guttenberg, was found in the basal 6 feet of Trenton (Rockland Formation—Napanee Member?) at Sugar River, Denley, New York. *Bumastoides porrectus* and *Eomonorachus intermedius*, which range throughout the Ion in the Midwest, were not collected, but both are reported in previous studies from "low Trenton" (probably Rockland) horizons. *Encrinuroides vigilans*, which is long ranging in the Midwest, was frequently collected in the Hull Formation at City Brook, southeast of Newport, New York; in the Rockland Formation (Selby Member?) and in the Hull Formation at Roaring Brook; in the Rockland Formation (Napanee Member) at the Napanee type section, north of Napanee, Ontario. *Isotelus gigas*, long ranging and common in the Midwest, was long ranging and common throughout the Trenton. *Ceraurus pleurexanthemus* and *Flexicalymene senaria*, which first appear in the Ion, were abundant everywhere in the east, appearing at the base of the Trenton sections in all of the Rockland exposures examined, and ranging throughout the Trenton. Other post-Decorah trilobites apparently do not appear in the east until Sherman Falls time.

BUCKS QUARRY SECTION, HERKIMER COUNTY, NEW YORK

Bucks Quarry (Walcott, 1876, 1877) was relocated by recourse to Herkimer County Court records. It is an abandoned small working in the center of a small draw that heads approximately at Buck Hill Road, 0.44 mile north of the junction of Buck Hill Road and New York State Route 8, north of the town of Poland. The quarry is 400 feet west of Buck Hill Road, just within a wood and over the crest of a hill, out of sight from the road. It is more or less semicircular in plan, 70 by 100 feet large, with an 8- to 10-foot face on the high side to the east. The quarry is heavily overgrown, but a small brook flowing down the draw drops over the east face and crosses the quarry floor and keeps open a nearly continuous section.

From this place, Walcott collected more and better Black River trilobites than have come from any other locality in New York State. They include *Basiliella barrandi*, *Isotelus simplex*, *Raymondites longispinus*, *Bumastoides milleri*, *Thaleops ovata*, and *Ceraurina scofieldi*, and associated with these trilobite species occur many specimens of the problematical fossil *Buthograptus laxus* Hall, and the gastropod *Pterotheca expansa* (Emmons). This fauna appears so like the fauna of certain rich Quimby's Mill pockets—and like the assemblages that occur at Pointau Gravier, St. Joseph Island, Lake Huron—that there is a suggestion here, not only of good correlation, but perhaps a single epibolic or peak zone of wide geographic spread and very precise identity.

Section at Bucks Quarry, 0.4 mile north of Poland, Herkimer County, New York

Exposure and measurements commence at a 3 foot natural cascade 40 feet upstream from the quarry rim. The top of the measured section is believed to lie near the top of the Chaumont Formation. Above the cascade, all float is slabby fossiliferous Trenton material of Hull aspect.

Chaumont Formation:

Black, dense, fine-grained crystalline to sublithographic limestone, with scattered sugary seams and patches of medium-grained black calcite, fracturing hackly, weathering light-gray. The lowest Chaumont constitutes the stream bed adjacent to the quarry rim and yields: *Basiliella barrandi*, *Raymondites longispinus*, *Isotelus simplex*, *Thaleops ovata* and *Bumastoides milleri* accompanied by *Buthograptus laxus* and *Pterotheca expansa*, and with gastropods and ostracods.

Total measured Chaumont ca. 11 feet

Lowville Formation:

Medium-gray, dense, sublithographic limestone with phytopsis tubules, fracturing conchoidally, weathering light-gray; plus lower units with light-gray, coarse, conglomeratic limestone composed of whole or broken rounded pebbles $\frac{1}{16}$ to $\frac{1}{2}$ -inch in size of lithographic limestone in a matrix of fine-grained, sugary, crystalline calcite and coarse-grained, white calcite seams and patches.

Total measured Lowville. ca. 11 feet

Total section ca. 22 feet

The section could be extended through additional Lowville exposures downstream from the front edge of the quarry.

The passage in the Bucks Quarry Section from dense, conchoidally fracturing, dove-gray, phytopsis-bearing limestone below to fine-grained, hackly fracturing, black limestone above appears to me entirely similar to other Lowville-Chaumont contacts that I have examined at Sugar River, Roaring Brook, Mill Creek, and in the Watertown area farther to the north. The fossiliferous bed at Bucks Quarry occurs just above this contact, and I identify this fossiliferous horizon as Chaumont with considerable certainty. [Ed. note: As used by DeMott, "Chaumont" probably equals the Watertown Limestone of Cameron and Mangion (1977).]

SUMMARY AND CONCLUSIONS

Trilobite Biofacies and Lithofacies

The described trilobites come from a relatively few and restricted parts of the column studied (Fig. 10.3). For example, in the Pecatonica Formation there is only one locality, in shaly limestones near the middle of the formation. The Mifflin, most productive of any formation, yields trilobites from only a few feet of section at the bottom and the top. The Quimbys Mill is similar. Most of the Grand Detour and all of the Nachusa lack trilobites. The Decorah picture is less clear, although the middle of the Guttenberg, like the Mifflin, is barren of trilobites. In short, most of the column does not record good living and/or preservation conditions for trilobites. The reason is not clear. A number of authors (Shaw and Fortey, 1977; Chatterton and Ludvigsen, 1976; Ludvigsen, 1978b; Shaw, 1980; Titus, 1986; and references therein) note distinguishable trilobite biofacies in a number of lithologies of this approximate age. There is not, for example, an obvious bathyurid biofacies in spite of the nearshore character of much of the sediment. Also, the rubbly-bedded limestones (lenticular bedding of Willman and Kolata, 1978), which are barren in the midparts of the Mifflin and Guttenberg, might have been expected to display reasonably diverse offshore trilobite faunas. As a group, the sizeable collections described here appear vaguely correlative to the

Calyptaulax biofacies of Chatterton and Ludvigsen (1976) and the *Encrinurus* community of Titus (1986), but the real pattern, if any, is not obvious.

Correlation

As DeMott noted, the specific (and to a lesser degree, the generic) character of the trilobite faunas changes from the Platteville to the Decorah (Figs. 10.2, 10.3). DeMott interpreted this as time-significant. In Illinois and surrounding areas this may be true, as the rock types throughout the section are all of shallow shelf type and the change is not an obvious result of sequentially differing trilobite biofacies.

Kolata and others (1986) note that the Deicke K-bentonite bed at the base of the Decorah is a persistent, easily correlated unit over a vast area of the Upper Mississippi valley. Sloan (this volume) shows that this unit represents an important biostratigraphic and ecological (regional? extinction) event in the Midwest. In Minnesota where there is no unconformity, DeMott's Platteville fauna occurs up to the Deicke K-bentonite, and DeMott's Spechts Ferry fauna occurs in the Carimona Member of the Platteville Formation above the Deicke K-bentonite, with *Isotelus gigas* and *Eomonorachus intermedius* each appearing for the first time within 2 inches above the Deicke (Weiss, 1953).

DeMott was convinced that the Platteville-Decorah break corresponded to the Black River-Trenton break in New York and Ontario. His correlation was based largely on the occurrence of Platteville trilobites in the upper Black River (now probably Watertown Limestone of Cameron and Mangion (1977) at Bucks Quarry near Poland, New York. However, comparison to Ludvigsen's (1978a) proposed trilobite zonation for Ontario shows that the stratigraphic order of species seen in the Midwest is not clearly repeated in the east. Indeed, Ludvigsen (1978a, p. 75) claimed that parts of fauna E (deemed typical of the Rockland and Leray and thus high Black River and low Trenton) were rather similar to that of the mid-Platteville. Data published so far cannot resolve the problem. A better understanding of local biogeography, regional extinctions, and subtle differences in paleoecology is needed. Current work on conodonts and graptolites (Sweet, 1984; Bergstrom, 1986; Finney, 1986) will probably provide greater resolution for correlation, but is not discussed here.

PALEONTOLOGY OF THE TRILOBITES

Trilobites in the formations studied typically occur as a minor element in shelly faunas; that is, they are found here and there in rocks filled with brachiopods, bryozoans, anthozoans, gastropods, and the debris of echinoderms. Other minor elements in these same rocks are sponges, pelecypods, and nautiloids.

The modes of preservation of the trilobites include: (1) nearly unaltered exoskeletons with chitinous sheen and original crystalline fabric apparent, seemingly permineralized only, (2) highly recrystallized exoskeletons with chitinous gloss destroyed (and all tendency to crack out of matrix destroyed), (3) natural molds in dolomites, and (4) coarse granular dolomite replacements in dolomite matrices.

Silicification of brachiopods and anthozoans has been found at Mifflin and Guttenberg horizons in the area under study, but no silicification of trilobites is known. Fossils figured from the Pecatonica, Mifflin, Spechts Ferry, and Guttenberg Formations are mostly preparations made on slab surfaces.

Other preparations are trilobites cracked out from where they were entirely embedded in fresh matrix, and subsequently excavated with a vibratool and needle. This method was used particularly for the massively bedded aphanitic limestones of the Quimbys Mill Formation and for the similar "glass rock" beds of the Guttenberg Formation.

Fossils of the Grand Detour Formation are mostly known from dolomite layers, but dolomitized specimens on bedding planes were also excavated mechanically. Replacement tends to weld contacts between these fossils and the matrix. Hand needle work was required, together with the use of aromatic oils as wetting agents that discriminate between fossil and matrix.

A few specimens are known only as molds in dolomite. Artificial positives were made of these with latex, Geon resin, and Dow Permamol compounds.

Terminology

DeMott used morphological terms given preference by Harrington and others (*in* Moore, 1959, p. O117-O126). The following of his practices represent departures or additions to Treatise terminology or are at variance with current usage:

- (1) The terms cheek, fixed cheek, and free cheek are used.
- (2) The term surface ornamentation refers to pits, punctae, scrobiculae, tubercles, granules, terrace lines, etc., which give textures to exoskeletal surfaces but do not determine the shape.
- (3) Lateral glabellar lobes are designated as lobe 1p, 2p, etc., numbering the preoccipital lobe as first and continuing forward and the same 1p, 2p, etc., annotation is used in designating lateral glabellar furrows ahead of the occipital furrow.
- (4) The term glabella does not include the occipital ring.
- (5) Paired symmetrical features are described in the singular wherever clarity permits.
- (6) Cephalon and cranidia of all except the illaenid trilobites are oriented in the manner of Whittington and Evitt (1954, p. 11), accepting the plane of the posterior margin of the occipital ring as an arbitrary vertical plane.
- (7) Isolated pygidia are oriented by assuming that the plane of the pleural margins is an arbitrary horizontal plane.
- (8) In describing and photographing illaenids, instead of employing the plane of the occipital ring—or the plane of the posterior margin of the cephalon in the absence of an occipital ring—DeMott oriented cephalon and cranidia so that: "the mid-points of the anterior and posterior margins both lie in a vertical transverse reference plane, designated plane of the margins." This orientation facilitates quantitative comparisons of inflations and curvatures of the smooth illaenid cephalon. The terms anterior margin and posterior margin are retained in describing the illaenid cephalon even though the orientation places both margins in the same transverse plane. Where clarification seems needed, these margins are referred to by their position as well; thus, "upper (posterior) margin" or "lower (anterior) margin." In discussing illaenids, he also restricted the adjectives anterior and posterior to the designation of position on the cephalon measured sagittally or exsagittally around the curvature of the cephalic surfaces. Distances measured from the plane of the margins are referred to as "in front of" the plane of the margin or "behind" the plane of the margins, never as "anterior" or "posterior" to that plane.

Systematic Paleontology

Family REMOPLEURIDIDAE Hawley and Corda, 1847
Subfamily HYPODICRANOTIDAE Přibyl and Vanek, 1972
Genus *Hypodicranotus* Whittington, 1952

Type species: *Remopleurides striatulus* Walcott, 1875
Hypodicranotus sp.

Plate 1, figs. 1-2, text fig. 9

Material: one cranidium and five hypostoma, total six specimens.

Occurrence: Platteville Group, Mifflin Formation, localities 24, 25, 26, 27.

Description: Glabella smooth; lateral glabellar furrows as dark line only, not impressed. Lateral glabellar furrows convex forward, subequally spaced, distributed over more than half of glabella (a line tangent to the arcs of the 3p furrows crosses sagittal line at four-sevenths the distance from occipital furrow to anterior margin). 3p furrow shortest, gently convex. 2p fur-

row longest, extended distally, gently convex, subparallel to 3p furrow. 1p furrow distally subparallel with 3p and 2p, bowed strongly backward and terminating proximally on a course 60° from transverse. Occipital ring broad, flat, convex forward, apparently without median occipital tubercle. Glabella apparently smooth with no lunate granules.

Hypostome long and deeply forked; strong terrace lines on outer surface of fork. Middle body not distinguishable in exterior view; no circular outline visible; no posterolateral furrow visible; radial depressions shallow, not isolating ovoid bodies.

Remarks: The above material most closely resembles the type species, *H. striatulus* (Walcott, 1875; see Whittington, 1952, pl. 1, figs. 1-10; Ludvigsen, 1979b, fig. 31A,B), but differs in the following features. (1) The occipital tubercle is absent. (2) The lateral glabellar furrows are shorter and not impressed. (3) The surface of the cranidium is smooth, whereas the majority of specimens from Trenton Falls are granular, independent of size. (4) The middle body of the hypostome is featureless, lacking the anterior and lateral lobes of many hypostomes from the type material in which the lobes are variably developed.

The cranidium differs markedly from that of *H. missouriensis* Foerste, 1920, in the forward curvature of the occipital ring, and the more forward positions of the lateral glabellar furrows. Incompletely known species of this genus also are present in the Copenhagen (Ross and Shaw, 1972) and Whittaker Formations (Ludvigsen, 1979a) of the Cordillera. Viola Formation hypostomes now being described by Shaw are identical to those of *H. striatulus*.

Family ASAPHIDAE Burmeister, 1843
Subfamily ASAPHINAE Burmeister, 1843
Genus *Basiliella* Kobayashi, 1934

Type species: *Asaphus barrandi* Hall, 1851

Remarks: *Basiliella* has been reviewed by Ludvigsen (1979b) and later Přibyl and Vanek (1980). We avoid further subdivision into subgenera at this time, contrary to the arrangement of the second authors above. In addition, we follow the recommendations of Hughes (1971), in avoiding the use of the terms isoteliform and niobiform for sutures.

Basiliella barrandi (Hall, 1851)
(Plate 1, figs. 3-18; Plate 2, figs. 1-12)

1851. *Asaphus barrandi* Hall, 1851, in Foster and Whitney, p. 210, pl. 27, figs. 1a-d, pl. 28.

1876. *Asaphus romingeri* Walcott, p. 96.

1876. *Asaphus wisconsinensis* Walcott, p. 97.

1894. *Ptychopyge ulrichi* Clarke, p. 709, text-figs. 12, 13.

1910. *Basilicus romingeri*, Raymond and Narraway, p. 49, pl. 15, figs. 9, 10, pl. 16, figs. 1-4.

1913. *Basilicus barrandei*, Raymond, p. 42.

1934. *Basiliella barrandei*, Kobayashi, 1934, p. 469.

1963. *Basiliella barrandei*, DeMott, p. 61, pl. 1, figs. 3-18, pl. 2, figs. 1-12.

1979. *Basiliella barrandei*, Ludvigsen, fig. 20A, B.

Type: Not selected.

Material: cranidia, free cheeks, hypostomata, thoracic segments and pygidia, totalling over 100 specimens.

Occurrence: Platteville Group, Mifflin Formation, localities 1, 3, 4, 9, 25, 27; Grand Detour Formation locality 10a; Quimbys Mill Formation locality 17.

Description: Large oval asaphinae (largest fragments seen belong to individuals estimated to have been 25 cm long; average specimens represent individuals about 15 cm long). Cephalon semicircular with wide concave peripheral field bounded by a sharply raised, flat, narrow border, and with large genal spine which extends the length of the thorax. Glabella divided by deep oblique 1p furrows into an inflated, pyriform fronto-median lobe, and flanking posterior triangular, nodular 1p lobes. Fronto-median lobe highest one-third its length from the front, divided by a shallow swale into a convex anterior portion and a prominent tuberculoid posterior point. Under oblique illumination, molds of the internal surfaces of the fronto-median lobe show a faint median carina running the length of the glabella and two oblique pairs of faint arcuate ridges, convex forward, immediately anterior to the swale—indicative of the positions of the 2p and 3p lobes. Glabella anterior to the 1p furrow rising abruptly from the cheek surfaces and clearly outlined. Posterior portion of glabella dominated by the oblique 1p furrow; shallow posterior portion of the axial furrow runs directly backward outside the 1p lobe and then turns outward at occipital furrow to cross occipital ring at 45°. Occipital furrow shallow, and occipital ring low, gently convex, without tubercle. Eye

large, semicircular, nearly one-fourth the length of cephalon in diameter, located with anterior corner adjacent to axial furrow opposite distal end of 1p furrow, posterior corner separated from the axial furrow by conspicuous cheek ridge, which commences opposite midpoint of palpebral lobe and runs backward beside axial furrow to become confluent with posterior border ridge; posterior border furrow obscure where cheek ridge crosses. Palpebral lobe with flat border, indented by palpebral furrow, which is prominent posteriorly adjacent to cheek ridge. Posterior section of facial suture runs outward on nearly transverse course, crosses posterior border furrow at low angles, then curves sharply across posterior border to reach margin midway between palpebral lobe and lateral margin. Fixigenal process narrow and scimitar shaped. Anterior section of facial suture swings wide across broad cheek field, equidistant to extension of posterior suture, and then curves forward into raised border. Remainder of anterior suture course is along the inner edge of the raised border to the midpoint, where it is turned forward across the border and outlines a small ogival point, produced the width of the border. Preglabellar field varying in width from a narrow convex trough to a fully flat, moderately wide field, and preglabellar field divided by a medial ridge, an extension of the glabellar carina, visible externally and prominently impressed on the internal surfaces of the exoskeleton. Cheek field divided into broad central platform and a concave peripheral tract adjacent to the raised border. Concave tract widest midway along the side of the cephalon and narrowing forward to where it becomes the pre-glabellar field, and narrowing to the rear where it is extended onto the genal spine as a sharp trough. Raised border narrowest at the front of the cephalon and widening gradually to its termination at the genal spine. Posterior border, sharply ridged between junction with cheek ridge and posterior suture crossing, becomes broad and evenly convex approaching the genal spine. Posterior margin of cephalon swept back to join the spine in a smooth curve. Posterior border and lateral border merge at midlength of spine, terminating the spinal trough, behind which point the spine is flat.

Cephalic doublure convex ventrally, broad, underlying border and concave tracts in cheek fields and entire beneath spine, notched and inflected ventrally beneath glabella to receive hypostome.

Hypostome middle body with sub-quadrate anterior lobe and narrow (sag.) depressed posterior lobe bearing large maculae. Hypostome borders broad, divided posteriorly by a rounded notch into two broad lancet-shaped forks.

Thoracic axis one-third width of thorax. Outer ends of axial rings swept slightly forward. Strong diagonal pleural furrows on inner halves of pleurae. Pleurae strongly deflected beyond fulcra, faceted, and terminated in blunt, squared ends.

Pygidium semicircular with wide, smooth, gently concave border. Axis flared slightly at first ring, evenly tapering posteriorly to one-third anterior width, terminated at crest of posterior slope in a distinct, elevated nub. Axis bears 13 annulations in small and medium sized specimens; annulations are less distinct with an increase in size, with as few as 8 annulations observable in well preserved, very large specimens. Pleural fields with 8 pleural furrows visible in all specimens, not becoming indistinct with an increase in size. Anterior pleural furrow extended out at least half way across otherwise smooth border. Pleural ribs flat, without trace of interpleural furrows. Anterior half-segment raised and flexed opposite thoracic fulcra.

Entire outer surface of dorsal exoskeleton covered by fine anastomosing terrace lines. Outer surfaces of ventral exoskeleton and articulating facets with prominent subparallel terrace lines. Inner exoskeletal surfaces smooth.

Discussion: Walcott (1876) distinguished two species of *Basiliella* in materials from the Quimbys Mill Formation of Wisconsin and in specimens from the congruent horizon at Bucks Quarry, Poland, N.Y. He named his two species *B. romingeri* and *B. wisconsinensis*. Raymond (in Raymond and Narraway, 1910) adjudged the two species to be one, and subsequently (1913) placed all of Walcott's specimens under the older specific name *B. barrandei* (validly but incorrectly named *barrandi* by Hall, the original describer; *barrandei* is an invalid emendation). I have restudied the Walcott specimens in the collections of the MCZ and decide, with Raymond, that there is but one species present. Walcott was correct in stating that there is a variation in the length (sag.) of the pre-glabellar field. My measurements on the 15 specimens of cranidia that I have available show random variations of this preglabellar length. I do not find two discrete groups, nor that the preglabellar lengths are proportional to size (as Raymond contended) or related to any other distinguishing features of shape. I conclude that for unknown reasons this trilobite was unusually plastic in this feature. The originals of Pl. 1, fig. 3 and Pl. 1, fig. 8, show extremes of this variation.

Subfamily ISOTELINAE Angelin, 1854

Genus *Isotelus* DeKay, 1824

Type species: *Isotelus gigas* DeKay, 1824

Isotelus gigas DeKay, 1824

Plate 3, figs. 1-11.

1824. *Isotelus gigas* DeKay, p. 178, pl. 12, figs. 1-2, pl. 13, fig. 1.

1824. *Isotelus planus* DeKay, p. 178, pl. 13, fig. 2.

1894. *Isotelus canalis* Clarke p. 707, text-fig. 9.

1914. *Isotelus gigas*, Raymond, p. 247, pl. 1, figs. 1, 2, pl. 2, figs. 2-5, pl. 3, fig. 3.

1963. *Isotelus gigas* DeMott, p. 68, pl. 3, figs. 1-11.

Neotype MCZ 41 (dorsal shield, figured Raymond, 1914, pl. 3, fig. 3; Whittington, 1950, pl. 73, figs. 1-3; Ludvigsen, 1979b, fig. 12H; Rudkin and Tripp (in prep., pl. 1, figs. 1, 2, 5, 6). Rust Member (Edenian), Russia Member (Shermanian), Denley Formation, Rust Quarry, near Trenton Falls, New York, U.S.A.

Material: 5 cranidia, 5 librigenae, 4 hypostomes, 9 pygidia studied; total 23 specimens.

Occurrence: Decorah Group. Spechts Ferry Formation, localities 27, 29; Guttenberg Formation, localities 13, 16, 18, 21, 25, 27, 28.

Description: Subtriangular cephalon with gently concave borders. Glabella faintly visible anterior to eyes, clearly bounded posterior to eyes, expanded anteriorly and posteriorly to 1.5 times width between eyes. Minute median glabellar tubercle present opposite posterior corner of eye. Median line of glabella slightly carinate in one specimen. Median angle of anterior sutures prominent: 125° and 135° (seen in two small specimens). Genal angle of specimens estimated to have been 30, 45, 55, and 60 mm in length bearing small spinule, presumed to have extended only to the first or possibly the second thoracic segment. Posterior margin of cephalon not swept back to strengthen spinule base. Spinule absent from cheek of specimen estimated to have been a 90-mm individual. Lateral concave border tapers toward genal angle and concavity disappears anterior to the genal spinule.

Hypostome with anterior body occupying one-third total length, and notch between forks penetrating over 0.4 of total length.

Pygidium sub-triangular, hyperbolic (not quite as triangular as in Trenton Falls topotypes) with concave borders. Axis in low relief, clearly discernible. Axial tip distinctly forward from crest of posterior slope. Crest of axis straight in lateral profile; and profile of axial tip and posterior slope in two distinct steps. Anterior ridge adjacent to articulating facet, thin. Anterior pleural furrow relatively shallow, narrow and long. Articulating facet facing obliquely forward and sharply inflected at junction with lateral border. Axial annulations and pleural ribs not seen or very faint. Border concavity of constant width posteriorly and laterally; continuous almost to anterior corners.

Remarks: The material referred to this species resembles *I. gigas*, though the retention of genal spines to 60 mm cephalic length is slightly larger than is the case in topotype *I. gigas*. Additional material might justify the recognition of a distinct population.

Isotelus cf. *walcotti* Walcott, 1918

Plate 3, figs. 12-20

1894. *Isotelus jacobus* Clarke, p. 706, footnote.

1914. *Isotelus iowensis* Raymond, pl. 2, fig. 6, pl. 3, figs. 1, 2.

1918. *Isotelus walcotti* Walcott, p. 133, footnote, pl. 24, fig. 1.

1925. *Isotelus walcotti*, Raymond, 1925, p. 98.

1963. *Isotelus planus*, DeMott, p. 70, pl. 3, figs. 12-20.

Material: 5 pygidia.

Occurrence: Decorah Group. Spechts Ferry Formation, locality 29; Guttenberg Formation, localities, 14, 23, 28.

Description: Pygidial pleural field sub-triangular but border widened laterally so pygidial profile is rounded. Axis in low relief, clearly discernible. Axial tip extended very close to crest of posterior slope. Axis in lateral profile sway-backed, and posterior outline of axis merged with posterior slope. Anterior ridge adjacent to articulating facet, stout. Anterior pleural furrow broad and deep. Articulating facet with an approximately longitudinal strike, and inflected at a low angle with lateral border. Fifteen axial annulations and pleural ribs clearly visible in oblique illumination. Border concavity strong posteriorly, dying out at mid-length of borders.

Remarks: DeMott referred five pygidia to the "second" species at Trenton Falls for which he used DeKays's name *planus*; Rudkin and Tripp (in prep.) argue that *I. planus* is almost certainly a junior synonym of *I. gigas*, and follow Raymond (1925) in the use of *I. walcotti* for this species. Because the anterior margin of the doublure in two of DeMott's pygidia (including his pl. 3, figs. 14-16) is embayed and this is not the case in *I. walcotti* topotype

material, the editors compare this limited material with that species under open nomenclature.

Isotelus simplex (Raymond and Narraway, 1910)

Plate 4, figs. 1-22

1910. *Onchometopus simplex* Raymond and Narraway, p. 51, pl. 16, figs. 6-8.

1920. *Homotelus simplex*, Raymond, p. 285.

1925. *Homotelus simplex*, Raymond, p. 86.

1963. *Isotelus simplex*, DeMott, p. 77, pl. 4, figs. 1-22.

Holotype: Carnegie Museum 1441, collected by E. W. Greiner (dorsal shield, figured Raymond and Narraway, 1910, pl. 16, fig. 8) Franklin Forge Railway Station, near Canister, Woodbury Township, Blair Co., Pennsylvania.

Material: cranidia, free cheeks, and pygidia abundant; total probably over 100 specimens.

Occurrence: Platteville Group. Pecatonica Formation, locality 5; Mifflin Formation, localities 1, 3, 18, 24, 25, 26, 27; Grand Detour Formation, locality 22; Quimbys Mill Formation, localities 10a, 17.

Description: Shields short, rounded, and vaulted, less elongate and less triangular than *I. gigas* and its kin, and uniformly convex, without the concave borders of *I. gigas* and kin. Glabella obsolete anterior to eyes. Shallow axial furrow, discernible adjacent and posterior to palpebral lobe, swings wide laterally behind the eye and reaches posterior margin at a low angle. Glabella at posterior margin twice glabellar width between eyes. Minute glabellar tubercle on line with posterior corners of eyes. Anterior section of facial suture swings wide ahead of eye—to width of glabella on posterior margin—and then follows a straight course beside anterior margin to an angular junction of 130°. Posterior course of facial suture flares wide, meeting posterior margin two-thirds the distance from center to genal corner. Eyes styloform, average for the genus. Genal corner rounded in mature specimens—rounded in a specimen 40 mm in length (Plate 4, figs. 8-9). Small and slender genal spinule known in a specimen 15 mm in length, attached at right angles to posterior margin and extended to second thoracic segment (Plate 4, figs. 10-11).

Hypostome as in *I. gigas* with these differences: (1) body anterior to maculae less constricted, (2) central depression less pronounced, (3) forks more tapering, more sharply pointed.

Thorax with axis wider than in *I. gigas* and axial furrows less sharply incised. Pleural furrows faint and very short.

Pygidium notable for smoothness and regular convexity. Axis, visible only by color change or by very slight furrows seen in oblique illumination, tapers rapidly, posterior half narrow; posterior tip scarcely discernible and with no prominence.

Entire dorsal surface of the animal stippled with very fine pits. Ventral surfaces and articulating facets bearing terrace lines.

Remarks: This is a distinctive, small, and neat isotelid, easily distinguished from the isotelids with concave borders in the overlying formations. Raymond and Narraway described it originally from the Quimbys Mill Formation, where it is abundant.

Several species of isotelinids including *I. simplex* display a lack of concave cephalic and pygidial borders together with relatively anterior placement of the eyes. Raymond (1920) proposed *Homotelus* for these forms, but selected a type species (*H. ulrichi*) with the critical border characteristics poorly represented. Numerous authors (Whittington, 1950, DeMott, 1963, Shaw, 1968, 1974) have noted this and either avoided the use of *Homotelus* or suggested assigning the several species to another genus (e.g. *Vogdesia*). The editors currently suggest leaving most of these species as a distinct group within *Isotelus*.

Isotelus homalonotooides (Walcott, 1877)

Plate 3, figs. 21-26

1877. *Asaphus homalonotooides* Walcott, p. 71.

1880. *Asaphus triangulatus* Whitfield, p. 59.

non 1910. *Isoteloides homalonotooides* (sic) Raymond and Narraway, p. 52, pl. 16, figs. 9-11.

1913. *Isoteloides homalonotooides*, Raymond, pl. 4, fig. 5.

1925. *Ectenaspis homalonotooides*, Raymond, p. 102, pl. 4, figs. 9-10.

1930. *Isoteloides homalonotooides*, Bradley, p. 249, pl. 27, figs. 5-7.

1963. *Isotelus homalonotooides*, DeMott, p. 81, pl. 3, figs. 21-26.

Syntypes: Field Museum of Natural History 12324a cranidium and 12341b pygidium, James Hall Collection (figured Raymond, 1925, pl. 4, figs. 9-10 (plaster casts), Bradley, 1930, pl. 27, figs. 5-6); also 12326 large pygidium (figured Bradley, 1930, pl. 27, fig. 7, 2 miles north of East Dubuque, Illinois, in Wisconsin Guttenberg Formation).

Material: 1 cranidium, 1 pygidium.

Occurrence: Decorah Group. Guttenberg Formation, locality 28.

Description: Glabella bounded anteriorly by an abrupt flexure between it and long, flat preglabellar field. Forward branch of facial suture less divergent in front of eye than in most isotelids, and covering forward along a straight flank to a prominent central angle of 80°. Cranidium, thus limited, distinctive for its long and tapering snout.

Pygidium sharply triangular. Pleural field triangular, bounded by a narrow sloping border. Axis in prominent relief, narrow at anterior margin. Axis and pleural field faintly segmented, visible in oblique illumination. Border smooth, depressed sharply below pleural fields. Posterior tip obscure, but considered to be slightly produced and sharply pointed.

Remarks: In addition to the pointed extremities, the presence of a well developed occipital ring, first and second lateral glabellar furrows, and posterior border furrows distinguish the species from *I. gigas* and most other species. These features are not so strongly developed in this material from the Guttenberg Formation as they are in the types and are no stronger than they are in some other species, e.g. *I. parvirugosus* Chatterton and Ludvigsen (1976, p. 21, pl. 2, figs. 1-42), from the Esbataoittine Formation, western Canada, a species in which the extremities are not attenuated.

Family STYGINIDAE Vogdes, 1890

Genus *Eobronteus* Reed, 1928

Type Species: *Entomostracites laticauda* Wahlenberg, 1818.

Eobronteus lunatus (Billings, 1857)

Plate 13, fig. 25

1857. *Bronteus lunatus* Billings, p. 338.

1893. *Bronteus lunatus*, Billings, p. 188, text-fig. 187.

1894. *Bronteus lunatus*, Clarke, p. 725, text-fig. 43.

1921. *Goldius lunatus*, Raymond, p. 32, pl. 9, fig. 8.

1944. *Scutellum lunatum*, Shimer and Shrock, p. 653, pl. 269, fig. 15.

1947. *Eobronteus lunatus*, Wilson, p. 38, pl. 8, figs. 10-11.

1949. *Eobronteus lunatus*, Sinclair, p. 52, pl. 14, figs. 1-2, 4, 6.

1963. *Eobronteus lunatus* DeMott, p. 83, pl. 13, fig. 25.

1979. *Eobronteus lunatus*, Ludvigsen, fig. 32B.

Holotype: GSC 1781 (dorsal shield, figured Billings, 1857, text-fig. 187; Wilson, 1947, pl. 38, fig. 10; Sinclair, 1949, pl. 14, fig. 2) from Cobourg Formation (Edenian) locality unspecified but probably Ottawa side of Ottawa River, Ontario.

Material: 1 pygidium.

Occurrence: Decorah Group. Guttenberg Formation, locality 27.

Description: Pygidial axis short, pointed, unsegmented, moderately inflated and conically tapering. Pleural field broad, gently convex, divided by radiating shallow furrows into six pairs of broad, flat unfurrowed subequal ribs and a median posterior rib. First and third ribs disproportionately strong at the axis and displacing and constricting the second rib adaxially. Sixth rib slightly narrower than others. Median rib almost twice the width of lateral rib and unfurrowed upon its inner end. Dorsal surface of pygidium concentrically lined by wavering terrace lines, which are slightly bowed adaxially in crossing each rib and are bowed strongly forward in crossing the axis.

Remarks: The characteristics of the specimen are entirely compatible with the previous descriptions and illustrations of the species. Clarke (1894) found the species at the same horizon.

Family ILLAENIDAE Hawle and Corda, 1847

Subfamily ILLAENINAE Hawle and Corda, 1847

Genus *Thaleops* Conrad, 1843

Type Species: *Thaleops ovata* Conrad, 1843, Middle Ordovician, Mineral Point, Wisconsin.

Remarks: Shaw (1968, p. 49) fully discussed the classification problems centering on the *Illaeus-Nanillaenus-Thaleops* Group, and emphasized the difficulty of distinguishing *Nanillaenus* from *Thaleops*. Chatterton and Ludvigsen (1976, p. 30), whilst using *Nanillaenus*, envisaged the possibility that revision might place all these genera in synonymy with *Illaeus*; the present redescription of material undoubtedly conspecific with topotype *T. ovata* of Conrad serves to amplify the understanding of this species.

Thaleops ovata Conrad, 1843

Plate 5, figs. 1-23

1843. *Thaleops ovata* Conrad, p. 332.

1843. *Thaleops (Illaeus) ovatus*, Hall, p. 259, pl. 67, figs. 6a-6b.

1882. *Thaleops ovatus*, Whitfield, p. 238, pl. 5, figs. 1-2#.

1887. *Illaeus herricki* Foerste, p. 479, fig. 2.

1894. *Thaleops ovata*, Clarke, p. 716, text-figs. 25-28.

- non 1902. *Illaenus ovata*, Raymond, pl. 18, fig. 9 (*Thaleops longispina* Shaw).
- non 1905. *Thaleops ovata*, Raymond, pl. 13, fig. 5 (*Thaleops longispina* Shaw).
1908. *Thaleops ovata*, Raymond and Narraway, p. 247, pl. 60, figs. 11-13, pl. 61, figs. 6-7.
1913. *Thaleops ovatus* (pars), Slocum, p. 56, pl. 14, figs. 7-8. non fig. 6, Maquoketa.
1927. *Thaleops ovata*, Walter, p. 224, pl. 17, figs. 3-5.
- non 1930. *Thaleops ovata*, Bradley, p. 256, pl. 30, figs. 15-16 (Kimm-
swick Limestone).
1937. *Thaleops ovatus*, Shrock and Raasch, p. 578, pl. 10, figs. 2a-e.
1947. *Thaleops ovatus*, Wilson, p. 36, pl. 7, figs. 16a-b.
1963. *Thaleops ovata*, DeMott, p. 85, pl. 5, figs. 1-23.
1979. *Thaleops ovata*, Ludvigsen, fig. 20C.

Type: Not selected.

Material: Dorsal shields, cranidia, free cheeks, thoraces, pygidia; total about 218 specimens.

Occurrence: Platteville Group. Pecatonica Formation, locality 5; Mifflin Formation, localities 1, 3, 4, 22, 24, 25, 26, 27; Grand Detour Formation, localities 2, 10a, 11, 12; and Quimbys Mill Formation, localities 8, 10a, 15, 17. This species is twice as common as any other in the Platteville Group.

Description: Cephalon in front of plane of the margins in the shape of half an ellipsoid. Cheeks produced above and in the plane of the margins into laterally directed, tapering eye stalks, produced below and slightly behind the plane of the margins into stout, laterally directed genal spines. Lateral profile of cephalon nearly a semicircle; forward point of cephalon midway between margins and advanced in front of plane of the margins fully one-half the distance (sag.) between margins; lower half of lateral profile a perfect 90° arc; upper half of lateral profile slightly flattened. Base of glabella two fifths of the width between palpebral lobes. Axial furrows deeply impressed, subparallel, slightly concave inward on top third of cephalon; axial furrows lightly impressed, splayed outward, and becoming obsolete between one-third and one-half the distance around the cephalic front. Occipital furrow distinct, shallow, broad at the center where it indents base of glabella; occipital ring low, straight, and smooth. Internal molds of glabella exhibit paired low platforms which represent paired muscle scar indentations on inner surface of exoskeleton; a large pair close to the occipital furrow and a second pair between points where axial furrows diverge are visible on most molds (at least one subsidiary pair close behind the forward pair has been seen on one specimen). Eyes small; visual surface—distinguished by lighter color, without discernible facets—apparently surrounding three sides of slightly protuberant tip of eye stalk. Palpebral lobes tiny, narrowly rounded, not raised, upon the top near the tip of the eye stalks. Anterior branch of facial suture drops directly down front of eye stalk and down cheek to meet lower margin in line with the parallel portions of the axial furrows. Suture course, thus outlined, lies essentially in the plane of the margins, and cranidium in anterior view is ellipsoidal. Posterior branch of facial suture follows short adaxial course on the back slope of eye stalk and then turns outward to immediately adjacent margin. Cheek without posterior border. Lower (anterior) border of cephalon distinguished by four closely spaced parallel terrace lines. Cheek spine about as long as glabella is wide, laterally directed, curving slightly backward at tip. Cheek spine triangular in section, flat topped, and wedged beneath. Entire cephalic surface above the anterior border pitted; fine and discrete pits near lower border coarsen toward glabella, and about the base of glabella become large and elongate, so that surface between pits is reduced to a network of anastomosing ridges. Cheek spines pitted on their top and front facets; terrace lines of the lower border extend onto the lower edge and posterior facet of spines.

Thorax much wider than long, with a tapering axis and tapering pleural fields, of ten smooth segments. Segments, in lateral view, are raked to the rear. Pleurae strongly inflected at about mid-length into steep outer slopes, vertical at pygidium and slanted at about 70° adjacent to cephalon. Pleural tips slightly recurved forward.

Pygidium short, broad, highly vaulted, rectilinear in most aspects; divided between a horizontal anterior platform surmounted by the inflated axis, and a deep and steep posterior slope which drops to a gently curved posterior margin. Lateral margins consist of large longitudinal, vertical articulating facets. Pygidial axis, narrower than adjacent thoracic axis, tapering slightly to a rounded nub at crest of posterior slope, isolated by a strong continuous furrow. Axis under oblique illumination usually shows five faint annulations and posterior tip slightly bilobed. Pygidium entirely covered by pits similar to those on cephalic surface; pits are small on posterior slope, become large,

elongate, and scrobiculate, and give a prominent texture to the anterior pleural fields and the axis.

Remarks: The species *Thaleops ovata* is remarkable for its consistent, unambiguous position in the literature. Most workers report the species only in Platteville equivalent formations and they find it readily identifiable. Only twice has it been reported as occurring in younger strata. Bradley (1930) figured a specimen of "*T. ovatus*" from a Kimmswick locality. This specimen has only nine thoracic segments. Slocum (1913) reported two cranidia from Maquoketa beds, but this material was so slight that Slocum himself figured and wrote his description from Platteville specimens. I discount both of these identifications. The evidence in the present study agrees with that of the majority of previous workers: *T. ovata* is one of the most abundant, distinctive, and useful guide fossils to the Platteville Group encountered in the Upper Mississippi valley. It is limited to the Platteville and unknown from the overlying Decorah beds.

Thaleops sp. "A"

Plate 6, figs. 1-6

1963. *Thaleops divericata* DeMott, p. 90, pl. 6, figs. 1-6.

Material: Two cranidia from the area studied. MCZ specimen 1318 from "Trenton limestone", Saratoga, Saratoga Co., N.Y., believed conspecific.

Occurrence: Decorah Group. Guttenberg Formation, localities 16, 17.

Description: Like *Thaleops ovata* but distinct in the following several particulars:

(1) Ellipsoidal as in *T. ovata*, but cranidium not as fully inflated forward. Forward point of cephalon, midway between margins, advanced only 0.4 the distance between margins.

(2) Eye stalk produced laterally along upper margin as in *T. ovata*, but smaller, more pinched and more delicate.

(3) Axial furrows deeply impressed as in *T. ovata*, but closer together at base of glabella: 0.23 the distance between palpebral lobes, vs. 0.40 in *T. ovata*.

(4) Axial furrows diverging forward throughout their course, concave outward, instead of subparallel and concave inward as in *T. ovata*; and axial furrows visible well beyond the midline, where the furrows of *T. ovata* become obsolete.

(5) Mold of internal surface of glabella with faint continuous ridges along the lines where *T. ovata* shows isolated paired muscle scars; and mold of glabella with a faint median carina, not seen in *T. ovata*.

(6) Occipital furrow widened laterally rather than centrally, and glabella ahead of occipital furrow rounded rather than indented as in *T. ovata*.

(7) Base of glabella less inflated than in *T. ovata*.

Discussion: This form is extremely rare—known from only two cranidia—in contrast to the abundance of *T. ovata* in beds of the Platteville Group. We (eds.) cannot support a new species on such modest material. Nonetheless, differences from the older *T. ovata* do exist, and these two specimens are here treated separately.

Thaleops sp. "B"

Plate 5, figs. 24-26

Materials: a single pygidium.

Occurrence: Platteville Group. Grand Detour Formation, locality 10a.

Description: This single pygidium is different from any other illaenid species here described. It has the general proportions of a *Thaleops ovata* pygidium, and shows the same kind of scrobiculate pits—best developed on the horizontal fields adjacent to the axis. It has an axis of the width of *T. ovata* at the anterior margin. It is bounded laterally by longitudinal vertical articulating facets. It is unlike *T. ovata* in that the axis lacks annulations and lacks rows of excessively coarse pits, and in that the axis tapers, dwindles, and merges with the shield posteriorly instead of ending in a high isolated nubbins. It is also unlike *T. ovata* in having a steeper posterior slope. If the anterior pleural fields and the plane of the posterior margin are regarded as horizontal, then the posterior slope of this specimen is seen to pass beyond the vertical, the lower edge being rolled under near the posterior margin. The specimen does not appear to have been distorted in preservation.

Remarks: This pygidium, though showing many features in common with *T. ovata*, differs too greatly to be considered a variant of that population. We know of no other pygidium with which this can be closely compared, and its specific identity must remain in doubt.

Genus *Illaenus* (Dalman, 1827)

Type species: *Entomostracites crassicauda* Wahlenberg, 1818

Remarks: All of the specimens of *Illaenus* found in this study are confined to the Platteville Group, and none was collected from the Decorah Group. The genus does reappear, however, in the overlying Galena formations.

Iliaenus sp. (Cephalon A)

Plate 6, figs. 7-12

Material: Two cephalons with free cheeks in place.**Occurrence:** Platteville Group, Grand Detour Formation, locations 10a, 11.

Description: Cephalon in lateral view: thin, anterior profile symmetrical, inflated 0.36 of intermarginal distance; curvature acute near the margins and broad in the middle; lateral profile normal to plane of the margins at the anterior (lower) margin, rolled over slightly beyond normal at the posterior (upper) margin. In anterior view normal to plane of the margins: short and broad (sagittal length 0.46 width); lower profile in a broad arc; upper profile nearly straight between eyes—glabella and adjacent cheeks gently arched and of equal height; axial furrows lightly impressed and just enter this view (furrows occupy approximately one-third of the length following the curvature around the front of the cephalon); facial sutures not discernible. Posterior margin outside eye straight, sloping away from horizontal. Cheeks terminated two-thirds of the way down the sides in broad, rectilinear 80° points, slightly ogee at tips. In dorsal view parallel to plane of margins: thin, forward profile hyperbolic, rounded at the center with flat flanks extended to cheek corners; posterior profile broken by glabella, set back slightly behind adjacent cheeks; axial furrows moderately impressed, separated 0.41 the distance between palpebral lobes at posterior margin, converging quickly to 0.35 the distance between palpebral lobes and becoming shallow, parallel, and dwindling and disappearing near the top of the anterior slope. Eye moderate in size, immediately adjacent to posterior margin, not stalked. Flaring cheek corners terminate in this view slightly behind the plane of the margins.

Entire outer surface of cephalon smooth. Inner surface of exoskeleton not known.

Discussion: The species represented by cephalon A shows similarities to *Iliaenus bayfieldi* Billings (Mingan Formation, Quebec) in general cephalic outline and degree of "glabellar" development. Insufficient material is present for certain assignment.

Cephalon A is not assignable to *Nanillaenus*, which has a wider cephalic axis and greater cephalic inflation.

Iliaenus sp. (Cephalon B)

Plate 6, figs. 13-15

Materials: Known from two cranidia.**Occurrence:** Platteville Group, Mifflin Formation, locality 1; Quimbys Mill Formation, locality 17.

Description: Cranidium in lateral view, moderately inflated, anterior profile ovate, maximum inflation 0.46 of intermarginal distance, and center of inflation above the midpoint of cephalon; profile normal to both margins, curvature broader at upper margin than at lower. In anterior view: lower profile in a very flat arc. Upper profile with cheeks straight between axial furrows and tips of palpebral lobes; glabella arched and standing higher than cheeks. Axial furrows lightly impressed on external surface of exoskeleton, cleanly incised on mold of internal surface, enter this view as parallel lines and stop abruptly, not diverging and not slowly dwindling (termination is one-third of the distance from posterior margin following the curvature, around the front of the cephalon). Forward branch of facial suture traverses three-fourths the distance from the palpebral lobe to the lower margin on longitudinal course. Near the margin, the suture curves sharply inward and joins margin on a line midway between eye and axial furrow. Anterior (lower) profile of cranidium, thus outlined, presents a distinctly rectangular field with narrowly rounded corners. A distinctive tiny tubercle is located at each anterior corner of the cranidium just inside the suture line at the point where the suture begins its abrupt curve to the margin. A thin and slight median carina appears on molds of the inner surface of the exoskeleton. It commences between the anterior ends of the axial furrows and extends nearly to terrace lines at the lower margin. No carina is visible on the external surface of exoskeleton. In dorsal view: forward profile of cranidium arcuate; posterior profile straight behind cheeks and gently concave behind glabella; axial furrows well separated and strongly impressed at posterior margin (separated 0.44 the distance between palpebral lobes), converging through first half of course (to a separation which is 0.29 the distance between palpebral lobes), becoming shallow, parallel, and disappearing just within the edge of this view. A small, sharp median tubercle, expressed on both outer and inner surface of exoskeleton, is located very close to the posterior margin and at about the point at which the median carina on internal molds becomes visible. Eye moderate in size, removed by about one-half its own width from posterior margin, and not stalked. Palpebral lobe semicircular; posterior branch of facial suture curves about in the short distance behind the eye and meets posterior margin on a divergent course.

Entire cephalon smooth to naked eye. Under the microscope, molds of in-

ternal surface show a stippling of minute pits with larger pits widely scattered amongst them. These pits (molds of minute styli which must have given a bristled texture to the inner surface of the exoskeleton) are not visible on external surfaces.

Discussion: These cranidia of cephalon B differ from cephalon A in many minor characters. Cephalon B is more asymmetrically inflated, and has more inflation at the base of the glabella, which is bowed forward rather than set back from the posterior margin (compare Pl. 6, figs. 12 and 15). Cephalon B has a narrower glabella and alone possesses the median tubercle and tubercles at the anterior corners of the cranidium. The antero-lateral tubercles and the rectangular shape of the front of the cranidium are features which are not reported, so far as I am aware, in any previously described North American species of *Iliaenus*. Interestingly enough, the front of the cranidium of the Swedish species *Entomostracites crassicauda* Wahlenberg, 1821, the type species of *Iliaenus*, is rectangular as depicted in Wahlenberg's original illustration.

Pygidia of *Iliaenus*

Two kinds of pygidia of the genus *Iliaenus* are present in Platteville formations. There is no way of proving whether or not they belong with cephalon A or B. These pygidia are distinguished from pygidia of other illaenids by short axes which are wider than long, which are arched strongly only at the anterior margin, and which diminish directly behind the anterior margin to merge with the general surface at poorly defined semicircular furrows. These axes occupy one-third or less of the length of the pygidium. Complementing these short axes, there is an absence of any wide horizontal anterior pygidial field or steep posterior face, such as seen in *Thaleops*. Instead, the pleural surface is broadly curved from the anterior to the posterior margin and slopes throughout most of its extent. No puncta or styli are apparent on the inner or outer surfaces of the exoskeletons of the specimens in hand.

Iliaenus sp. (Pygidium 1)

Plate 6, figs. 16-18

Material: three pygidia.**Occurrence:** Platteville Group, Mifflin Formation, locality 24; Grand Detour Formation, locality 10.

Description: Distinguished from pygidium 2 of *Iliaenus* by a ratio of width to length of 0.68, and by an axis which occupies 0.53 width of the anterior margin. Articulating facets diverge at 82° from the horizontal line of the anterior margin. Doublure is broad and has a median length (sag.) one-half that of the dorsal exoskeleton of the pygidium.

Iliaenus sp. (Pygidium 2)

Plate 6, fig. 19

Material: Two specimens, one with thorax attached.**Occurrence:** Platteville Group, Mifflin Formation, locality 3; Grand Detour Formation, locality 10.

Description: Distinguished from pygidium 1 of *Iliaenus* by a ratio of width to length of 0.39, and by an axis which occupies 0.61 the width of the anterior margin. Articulating facets diverge at 53° from the horizontal line of the anterior margin. Doublure narrows at the center where its median length (sag.) is only 0.3 the median length of the dorsal surface of the pygidium.

A thorax preserved with pygidium 2 has parallel axial furrows and parallel lateral margins and has nine thin plain segments. (It is not certain that this thorax is complete.) The length of the nine segments is exactly equal to the length of the pygidium. The axis occupies 0.42 the width of this thorax.

Bumastoides Whittington, 1954

Type species: *Iliaenus milleri* Billings, 1859, Leray-Rockland Beds (Rocklandian), near L'Original, Ontario, Canada.

Remarks: Lane and Thomas (1983) and Chatterton (1980) have recently discussed classification and ontogeny of this and related genera at length. *Bumastoides* and other genera display consistent differences in rostral plate structure, glabellar outline, and anterior pit development from *Bumastus* and similar genera. Although the rostral plate structure and ontogeny of the Platteville material are not known, the specimens are very close in overall structure to specimens of *B. milleri* from type localities in the east. *B. porrectus*, also from an eastern type locality, likewise lacks proper understanding of either its rostral structures or its ontogeny. It appears closely related in dorsal characters to *B. milleri*, and is compared to that species below. Restudy of type Trenton material will be required to settle where these species fit within the guidelines proposed by Lane and Thomas (1983).

Bumastoides milleri (Billings, 1859)

Plate 6, figs. 20-23

1859. *Iliaenus milleri* Billings, p. 375, text-fig. 10.
 1894. *Bumastus trentonensis* Clarke, p. 728, text-figs. 32-35 (non 30-31 = *Iliaenus trentonensis*).
 1908. *Bumastus milleri*, Raymond and Narraway, p. 249, pl. 61, figs. 9-10, pl. 62, figs. 3-5.
 1927. *Bumastus milleri*, Walter, p. 222, pl. 17, fig. 2.
 1947. *Bumastus milleri*, Wilson, p. 35, pl. 7, figs. 1a-b.
 1954. *Bumastoides milleri*, Whittington, p. 138, pl. 62, figs. 16-18, 20, 25-26, 29.
 1956. *Bumastoides milleri*, Wilson, pl. 4, fig. 11.
 1963. *Bumastoides milleri*, DeMott, p. 104, pl. 6, figs. 20-23.

Holotype: GSC 1319b (partially enrolled dorsal shield, figured Billings, 1959, text-fig. 10; Wilson, 1947, pl. 7, figs. 1a-b; Whittington, 1954, pl. 62, figs. 16-18, 20). Leray-Rockland Beds (Blackriveran/Rocklandian) near L'Original, Ontario, Canada.

Material: 1 dorsal shield, 1 thorax and pygidium, cranidia and pygidia moderately abundant; total at least 11 specimens.

Occurrence: Platteville Group, Pecatonica Formation, locality 5; Mifflin Formation, localities 1, 3, 25; and Grand Detour Formation, localities 11, 12.

Description: A full description has been provided by Whittington (1954, p. 138), and the present material agrees in all particulars with that description. Whittington records that the thorax consists of 8-10 thoracic segments; the holotype and all dorsal shields from Ottawa have 9 segments, as is the case in the one dorsal shield in the present collection. Clarke (1894, p. 720) mentions two specimens from Trenton Falls with ten segments; these were considered by Raymond and Narraway (1908) to show other differences from *B. milleri* in addition. We have been unable to trace the specimen mentioned by Clarke with eight thoracic segments. Anterior outline of pygidial doublure bicuspid in the topotype material.

Remarks: See following species (*B. porrectus*)

Bumastoides porrectus (Raymond, 1925)

Plate 6, figs. 24-31

1897. *Bumastus trentonensis*, Clarke, p. 720, fig. 31 (non 30-31, 33).
 1901. *Bumastus trentonensis*, Grabau and Shimer, p. 298, fig. 1610b.
 1925. *Bumastus porrectus* Raymond, p. 114, pl. 8, figs. 7-8.
 1947. *Bumastus porrectus*, Wilson, p. 35, pl. 7, figs. 7-9.
 1963. *Bumastoides porrectus*, DeMott, p. 108, pl. 6, figs. 24-31.

Holotype: MCZ 728. C. D. Walcott Collection (dorsal shield, figured Raymond, 1925, p. 8, figs. 7-8), upper third of Denley Formation (Shermanian), Trenton Falls, New York.

Material: Cranidia and pygidia; total at least 10 specimens.

Occurrence: Decorah Group, Guttenberg Formation, localities 16, 17, 28.

Description: Cranidium in lateral view: moderately inflated, anterior profile ovate, asymmetrical; maximum inflation in front of the plane of the margins 0.4 sagittal length and occurring about two-thirds the distance between upper and lower margins; profile meets plane of the margins above at 45° and below at 60° in anterior view normal to plane of margins; sagittal length 0.8 cranidial width; forward branch of facial suture straight and converging slightly through first half the distance from eye to margin and then broadly curving to become tangent to margin on line with lunette, outlining a cranidium which is broadly U-shaped ahead of eyes; posterior profile gently arcuate (inflated 0.1 cranidial width); lunette 0.2 cephalic length (sag.) and removed by 1.5 times its length from posterior margin, strongly impressed on internal mold and clearly visible on external surface; axial furrow, visible behind eye on all internal surfaces and faintly visible on external surfaces of most specimens, curves and diverges widely between lunette and posterior margin. In dorsal view parallel to plane of margins: front and rear profiles parabolic and subparallel; palpebral lobe small and narrow (tr.) removed nearly its whole length from posterior margin; posterior branch of facial suture straight and diverging to posterior margin. No median pustule present.

Pygidium externally smooth and regularly rounded: length 0.65 width; anterior margin and articulating facets rounded and joined in nearly smooth curve; articulating facets diverging at 65° in the plane of the facets, terminated at pygidial corners on a line (transverse) at mid-length of the pygidium; postero-lateral margin a 130° arc. Doublure extends to mid-length of pygidium, anterior margin bicuspid, cusps separated by 0.4 of the width of pygidium.

Discussion: *B. milleri* differs from *B. porrectus* in the following several particulars: The *B. milleri* cephalon is more fully and symmetrically inflated, has a smaller eye, weaker lunette, and fainter axial furrow; its posterior pro-

file in dorsal view appears much less curved and is not subparallel to the anterior profile as in *B. porrectus*. *B. milleri* bears a small medial tubercle, missing in *B. porrectus*. The *B. milleri* pygidium has a more angulated anterior profile and articulating facets longer and less divergent so that the postero-lateral corners are set farther back in *B. milleri* than in *B. porrectus*.

Specimens of *B. milleri* in the present study show 9 thoracic segments, in agreement with previous descriptions of this species. *B. porrectus* has been described as having 10 thoracic segments; this thorax was not seen in the present study.

Chatterton and Ludvigsen (1976) and Chatterton (1980) noted additional well preserved species from western Canada which are described as distinct from *B. milleri* and *B. porrectus*.

Family BATHYURIDAE Walcott, 1886

Genus *Raymondites* Sinclair, 1944**Type species:** *Bathyurus ingalli* Raymond, 1913.

Discussion: Sinclair (1944) established the subgenus *Bathyurus* (*Raymondites*) for coarsely tubercular and spinose species of *Bathyurus*. Whittington (1953) elevated the group to genus and distinguished *Raymondites* from *Bathyurus* as having: (1) a less expansive frontal lobe and the glabella more rounded and less inflated; (2) one pair of glabellar furrows (two in *Bathyurus*); (3) eye lobe farther back; (4) wider cephalic and pygidial borders; and (5) deeper pleural furrows. Whittington granted that occipital spines and axial pygidial spines were common in species of *Raymondites* but expressly omitted the criterion of spinosity from his generic diagnosis.

In my consideration of the two species of *Raymondites* which occur in the Upper Mississippi valley, I have restudied types and plastotypes at the Museum of Comparative Zoology of most of the specimens on which Raymond, Sinclair, and Whittington based their remarks. I agree with all of Whittington's criteria except his limitation that *Raymondites* may have but a single pair of lateral glabellar furrows. Materials which I name *Raymondites spiniger*, and which I believe are conspecific with some specimens described as *R. ingalli*, show two pairs of lateral glabellar furrows, and I conclude that species with two pairs of glabellar furrows may properly be included in this genus (a discussion of the status of *R. spiniger* and *R. ingalli* is given below following the description of *R. spiniger*).

Raymondites longispinus (Walcott, 1876)

Plate 7, figs. 1-17

1876. *Bathyurus longispinus* Walcott, 1876, p. 94.
 1910. *Bathyurus longispinus*, Raymond and Narraway, p. 47, pl. 16, figs. 12-14.
 1953. *Raymondites longispinus*, Whittington, p. 654, pl. 65, figs. 10, 14-16, 19, pl. 69, fig. 29.
 1963. *Raymondites longispinus*, DeMott, p. 112, pl. 7, figs. 1-17.

Holotype: MCZ 3767 (dorsal shield, figured Raymond and Narraway, pl. 16, figs. 12-14) Blackriveran, Bucks Quarry, Poland, Herkimer County, New York.

Material: Dorsal shield and other fragments, total 11 specimens.

Occurrence: Platteville Group, Mifflin Formation, locality 3; Grand Detour Formation, locality 10a; and Quimbys Mill Formation, locality 17.

Description: Cephalon highly vaulted, wide-bordered, bearing stout genal spines which sweep back to terminate opposite or slightly behind the posterior edge of the pygidium; outline of cephalon with spines an incomplete ellipse. Glabella subcylindrical, swollen slightly in front half, rounded in front. One glabellar furrow, distinguishable only where tuberculate ornament is subdued along the trace of the furrow, commences at axial furrow opposite anterior edge of eye and curves backward and disappears about one-third the distance across the glabella. Occipital furrow clearly incised, moderately wide, straight. Occipital lobe broad, posterior margin bowed strongly backward without occipital spine. Eye far back; posterior edge of palpebral lobe on line with the posterior edge of occipital furrow and overhanging (dorsal to) posterior border. Palpebral lobe flat and smooth. Anterior branch of facial suture in a smooth curve diverging to maximum width opposite front of glabella and rounding onto margin. Posterior branch of facial suture crosses posterior border furrow immediately beneath (ventral) to eye and runs laterally on the downturned edge of the convex posterior border to outline a small, vertical, splinter-like posterior cheek process, which terminates opposite (exsag.) the outer edge of the eye lobe. Posterior border expands laterally and sweeps back in smooth curve to merge into the inclined facet of the genal spine. Anterior and lateral borders wide and gently concave, losing concavity at genal angles to become the horizontal facet of the genal spine. Glabella and genal field lightly covered with small and low tubercles; tubercles most dense and prominent on occipital lobe and on medial posterior portion of

glabella. Palpebral lobes, borders, furrows and genal spines smooth, with fine anastomosing terrace lines.

Cephalic doublure underlying borders and genal spines exceedingly convex. Connective sutures only slightly separated at anterior margin, convex toward rostrum, obliquely directed, delimiting a small and sub-triangular rostral plate.

Hypostome not seen.

Thoracic axis elevated, subcylindrical. Thoracic pleurae with long, transverse pleural grooves and short depressed blunt tips.

Pygidium very broad (transverse) and short (sag.) (width to length greater than 2:1); pleural fields low and border wide and concave. Axis raised, subcylindrical, faintly annulated; two anterior rings usually visible and a third ring usually vague; posterior half unannulated, with a few faint tubercles visible. Four pleural grooves within pleural fields, clearly incised. Four interpleural grooves in the form of low, terraced creases facing posteriorly, lie close to the anterior edge of each pleural rib and are continued across the wide borders to reach margin. Pleural and interpleural furrows most deeply incised anteriorly. Dorsal surface ornamented with fine imbricate terrace lines; posterior half of axis may show a few faint tubercles.

Remarks: *R. longispinus* differs from other species in its lack of an occipital spine and in the very long genal spines.

Raymondites spiniger (Hall, 1847)

Plate 8, figs. 1-9

1847. *Acidaspis spiniger* Hall, p. 241, pl. 64, fig. 5.
 1894. *Bathyurus spiniger*, Clarke, p. 723, text-figs. 38-40.
 1910. *Bathyurus spiniger*, Raymond and Narraway, p. 48, pl. 15, figs. 4-5 (non fig. 6).
 1937. *Bathyurus spiniger*, Kay, p. 300, pl. 9.
 1944. *Bathyurus (Raymondites) ingalli*, Sinclair, p. 16, pl. 1, figs. 9-10 (non pl. 1, fig. 11).
 1947. *Bathyurus ingalli*, Wilson, p. 19, pl. 2, figs. 15-16 (non fig 17 = *B. ingalli* holotype). [?18]
 1947. *Bathyurus spiniger*, Wilson, p. 20, pl. 2, figs. 3-4.
 1951. *Bathyurus ingalli*, Whittington, p. 654, pl. 69, figs. 16-17, 19-21 (non fig. 18).
 1963. *Raymondites spiniger*, DeMott, p. 115, pl. 8, figs. 1-9.
 1979. *Raymondites spiniger*, Ludvigsen, fig. 22A-C.

Holotype: GSC 4318 (cranium, figured Hall, 1843, pl. 64, fig. 5; Ludvigsen, 1979b, fig. 22B), lower part of crinoid beds, Bobcaygeon Formation (Kirkfieldian), Kirkfield Quarry, north of Kirkfield lift-lock, Ontario, Canada.

Material: 6 cranidia, 2 pygidia.

Occurrence: Decorah Group, Guttenberg Formation, localities 16, 18, 23, 27, 28.

Description: Glabella evenly and strongly inflated, subcylindrical, rounded in front. Glabellar surface thickly set about with coarse tubercles; tubercles slightly smaller and more closely spaced in the front than to the rear. Two faint lateral glabellar furrows discernible (chiefly because of the absence of tubercles along their traces rather than by impression). Trace of 2p furrow just anterior to the forward edge of palpebral lobe and extends up the lateral slope of glabella for approximately one-fourth the glabellar width, curving toward the rear as it becomes obscure. 2p lobe known from a slight swell in glabellar surface as well as by the presence of an isolated cluster of four or five tubercles, lies directly opposite the anterior edge of the palpebral lobe. Trace of 1p furrow opposite the anterior end of palpebral furrow, leaves axial furrow on a course slightly more oblique than 2p furrow, and extends farther and curves more strongly to the rear than 2p furrow, traceable in small specimens to a point about one-third of the way across the glabella and on a course which has curved to turn longitudinally. Eye lobe close to rear of glabella; posterior edge of palpebral lobe opposite occipital furrow and overhanging deflected posterior border of cheek. Palpebral lobe with a thick, rolled outer rim, which stands up almost to height of glabella and with a deep crescentic palpebral furrow which opens into the axial furrow at its anterior end and is somewhat open onto the posterior cheek surface adjacent to the axial furrow at its posterior end. Between the palpebral furrow and the axial furrow, a small area of fixed cheek constitutes a small tumulus also reaching nearly to glabellar height and closely set with about five sharp tubercles. Occipital furrow a wide, straight trough without tubercles. Occipital ring, set below glabellar level, is a tuberculate, sub-triangular plate, produced as a base for an occipital spine. Occipital tubercles are large and tend to form small subsidiary spines about the base of the large hollow medial spine. Occipital spine smooth, thin, tapering narrowly, averaging one-third the length of the glabella ahead of occipital furrow. Anterior section of facial suture

leaves the eye on longitudinal course beside axial furrow, diverging slightly; in preglabellar field it rounds narrowly to margin and there follows broad arc of the frontal margin. Anterior cranial profile, thus outlined, is more rectangular than rounded. Preglabellar field concave, moderately wide, smooth. The narrow slice of the genal field included between the anterior suture and the axial furrow may show a few tubercles. Posterior course of facial suture strongly divergent beneath eye; complete course not known. Posterior field of fixed cheek is bent down, nearly vertical; and posterior border, a stout, convex ridge, lies at the base of the posterior slope.

Pygidium hyperbolic, less than twice as wide as long. Border is smooth, slightly concave, and of moderate width, inflected sharply outward at perimeter of vaulted pleural field. Axis very high and subcylindrical, rounded at posterior tip. Four annular rings and a trace of a fifth occupy a little more than half of the axis and grow progressively narrower and fainter from front to rear. Posterior end of axis plain. Axial rings and posterior segment bear small scattered indistinct tubercles. Break in slope at posterior crest of axis sharp. Crest of axis at position of third, fourth, fifth rings, is produced as stout oval base for erect axial spine. Pleural field scored by four strong pleural furrows, strongest to the front. Interpleural furrows, in the form of low, terraced creases, facing posteriorly, are prominent near the front edge of the first ribs, but are very obscure on the posterior ribs. Interpleural furrows bend forward to become almost coincident to pleural furrows at distal ends; and are continued and all four visible crossing the otherwise smooth border. Ribs of pleural fields are sprinkled with a few small low pustules, most obvious forward. Borders show only anastomosing terrace lines.

Discussion: The species most similar to *R. spiniger* is *R. ingalli* (Raymond, 1913b, p. 57, pl. 7, fig. 7). These two species are reported from approximately the same interval in lower Trenton beds in Ontario, and I believe that considerable confusion exists in the literature regarding the identity of the two.

I tentatively accept that there are two species because there are two distinct cranidia. There are cranidia in New York of *R. spiniger* (e.g. Kay, 1927, pl. 9), and there is the holotype cranidium (GSC 4328, Wilson, 1947, pl. 2, figs. 15-18) upon which Raymond based the species *R. ingalli*. This holotype is a somewhat flattened partial cranidium which bears an unusually large occipital spine. It appears to be less inflated than *R. spiniger*, and it does not show the two pairs of glabellar furrows of *R. spiniger* (although these furrows tend to be indistinct in large specimens). I have measured the spine lengths and the glabellar lengths of *R. spiniger* in the three cranidia with whole spines in the Mississippi valley collection, and I have taken measurements of Kay's (1937) whole specimen:

Miss. valley specimen 1 glabella 6.0 mm: spine 2.0 mm.

Miss. valley specimen 2 glabella 10.0 mm: spine 3.0 mm.

N. Y. specimen (Kay, pl. 9) glabella 11.7 mm: spine 4.1 mm.

Miss. valley specimen 3 glabella 15.0 mm: spine 5.0 mm.

These data suggest that the spines of *R. spiniger* grew in a fixed proportion to other parts of the cephalon (spine one-third glabellar length). The *R. ingalli* holotype measures 17.0 mm: spine 12.5 mm, and is thus unlike *R. spiniger*.

Uncertainties arise because the holotype specimen is the only specimen that I know that can be placed in the species *R. ingalli* with any confidence. It has been figured repeatedly (Raymond, 1913, 1921; Sinclair, 1944; Wilson, 1947), but no worker ever mentions or illustrates any other examples with the distinctive large occipital spine.

I consider the pygidia assigned to *R. ingalli* to be identical to the pygidia of *R. spiniger*. Proportions, profile, vaulting, details of the axial annulations and posterior tubercles, and the position of the spinal base, all appear to be identical (compare the *R. spiniger* pygidium, Pl. 9, figs. 4-6, with the pygidium figured by Sinclair (1944) and Wilson (1947) as *R. ingalli*). The only whole specimen I have seen that links this *R. ingalli-spiniger* kind of pygidium to a particular type of head is an MCZ specimen. It shows the pygidium attached to an *R. spiniger*-type of cephalon. The whole specimen figured by Whittington (1953) as *R. ingalli* also shows a cephalon which is reminiscent of *R. spiniger* in its degree of glabellar inflation; but this cephalon is otherwise too indistinct to settle the issue.

I consider, then, that *R. ingalli* is only known from the single holotype cranidium and that all the pygidia now assigned to *R. ingalli* should be assigned to the older species *R. spiniger*. I think there is good possibility that the *R. ingalli* holotype may be an abnormal individual belonging to an *R. spiniger* population. (It should be noted that Ludvigsen (1979b) considered *R. ingalli* as a junior subjective synonym of *R. spiniger*.)

Two other species of *Raymondites* have been named from lower Trenton horizons of Ontario, and these too are very similar to *R. spiniger*. *R. bandifer* Sinclair, 1944, has been distinguished on the basis of a double occipital

spine; and *R. trispinosus* (Wilson, 1947) has been distinguished on the basis of a triple occipital spine. Like *R. ingalli*, these species are based on single holotype cranidia, and duplicate specimens are not reported. There is a tendency for the large tubercles adjacent to the base of the spine of *R. spiniger* to grow elongate (see Pl. 8, fig. 1). It seems likely that *R. bandifer* and *R. trispinosus* may be other extreme individuals belonging to an *R. spiniger* population.

Family HARPIDAE Hawle and Corda, 1847

Genus *Dolichoharpes* Whittington, 1949

Type species: *Eoharpes uniserialis* Raymond, 1925.

Remarks: DeMott (1963) considered several Trenton age species to be possible synonyms of *D. uniserialis*, but the editors deem the material available inadequate to decide this question at present.

Dolichoharpes aff. *reticulata* Whittington, 1949

Plate 8, figs. 10-14

1963. *Dolichoharpes carinobolatus* DeMott, p. 122, pl. 8, figs. 10-14.

Material: 2 cephalae and 3 or more fragmentary brims.

Occurrence: Platteville Group. Mifflin Formation, localities 3, 31; Grand Detour Formation, locality 10a; and Quimbys Mill Formation, locality 10a.

Description: Cephalon oval in outline: anterior profile semicircular, lateral margins straight and parallel, and tips of prolongations incurved on a radius similar to anterior curvature. Brim of moderate width for the genus anteriorly and narrow for the genus laterally, strongly concave, warped up to one-half the height of the cephalon anteriorly and with a prominent beaded external rim. Glabella subtriangular with strongly demarcated triangular 1p lobe giving a posterior width to glabella equal to its length. 1p lateral furrow straight and deep at angle of 45° to sagittal line through most of course, but proximal tip turned anteriorly and dying out rapidly. 2p and 3p lateral furrows obsolete. Demarcating furrow of the oval area of the 2p lobe obsolete. Ridge upon 1p glabellar lobe sharp, convex forward. Ala bounded at inner edge by sharp creased edge of axial furrow; axial furrow widening behind midpoint of 1p lobe to open into a wedge-shaped low inner alar area. Eye line at 60° to sagittal line, straight and strong. Entire surface of cephalon except for alae and 1p lobes pitted, scrobiculate.

Remarks: The few specimens under description agree closely with *Dolichoharpes* aff. *reticulata* of Chatterton and Ludvigsen (1976, p. 41, pl. 7, figs. 1-36, pl. 22, fig. 5) from the upper Esbataottine Formation, Canada, in gross morphology and particularly in the forwardly convex, transverse ridge on the 1p lobe. They differ only in lacking tubercles on this ridge, and in the slightly upturned anterior brim. Cephalae of these two forms differ from *D. reticulata* Whittington (1949, p. 280, pl. 1, figs. 2.6-7, pl. 2; Evtit, 1951, p. 607, pl. 87, 88) from the Edinburg and lower Lincolnshire Formation, in the presence of this ridge and in the following features listed by Chatterton and Ludvigsen: (1) genal roll and preglabellar field steeper, (2) brim is narrower and more concave, (3) higher external rim, (4) prolongations of cephalon not quite as high posteriorly. *D. reticulata* of Shaw (1974, p. 26, pl. 6, figs. 5-14, 17), from the Bromide Formation, Oklahoma, is extremely close to the type form, but differs in possessing a tuberculate transverse ridge on 1p lobe. We consider the presence of this 1p lobe ridge on these three North American forms to be a reliable indicator of close relationship in populations related to *D. reticulata*.

D. arctica Whittington (1954, p. 146, pl. 63, figs. 17-19), based on 2 specimens from Silliman's Fossil Mount, Baffin Island, was compared with *D. uniserialis* and *D. reticulata* by Whittington, and considered as a possible synonym of *D. reticulata* by Shaw (1974, p. 26). Similarities to the latter are: the deep prominent girder, three prominent ridges on marginal band median highest, tubercles on upper and lower external rim and between pits on outer surface of lower lamella externally. However, in *D. arctica* the prolongations are proportionately shorter and internal portion more rapidly reduced in height posteriorly.

Family CHEIRURIDAE Salter, 1864

Subfamily CHEIRURINAE Salter, 1864

Genus *Ceraurus* Green, 1832

Type species: *Ceraurus pleurexanthemus* Green, 1832.

DeMott (1963) summarized the distinctive characters of the American species of *Ceraurus* known at that time, concluding that species of *Ceraurus* may be excellent zone fossils, of very short range vertically and of wide distribution. Table 10.3 is a summary of his conclusions. He regarded eye position as of primary importance, as did Ludvigsen (1979a, b).

Table 10.3. Glabellar features of ceraurids.

Species	Preoccip. glabella (percent)	Ant. margin conv'ty	Eye pos'n	Eye line	Preoccip. sculpt.	Max. glab. convexity	Flare exp's'n
Blackriveran							
<i>gabrielsi</i>	78	strong	L2	nil	uniform	even	mod.
<i>blussoni</i>	81	strong	L2	mod.	uniform	even	mod.
<i>ruodus</i>	83	mod.	L3	v. weak	uniform	mid. L	mod.
<i>mifflinensis</i>	71	strong	L2	weak	large fwd.	front	mod.
<i>hirsutus</i>	82	strong	L2	mod.	3 pairs	mid.	slight
Rocklandian							
<i>plattinensis</i>	77	strong	L2	strong	6 pairs	post'ly	lobe
Kirkfieldian							
<i>dentatus</i>	78	concave	L1	tub'cle	row small	concave	nil
<i>hermanni</i>					post'ly	ant'ly	
<i>pleurexanthemus</i>	77	strong	L3	strong, transverse	4 pairs	post'ly	nil
<i>globulobatus</i>	63	strong	L3	weak	3 pairs	ant'ly	slight

Ceraurus plattinensis Foerste, 1920

Plate 9, figs. 17-24. Plate 10, figs. 8-10

1920. *Ceraurus plattinensis* Foerste, p. 217, pl. 21, figs. 20A-B, pl. 23, figs. 3a-b.

1963. *Ceraurus (Ceraurus) plattinensis* De Mott, p. 144, pl. 9, figs. 17-24, pl. 10, figs. 8-10.

Holotype: Location unknown.

Material: 1 dorsal shield, 19 cranidia, and fewer hypostomes and pygidia; total 35 specimens.

Occurrence: Decorah Group. Spechts Ferry Formation, locality 27; and Guttenberg Formation, localities 13, 14, 16, 17, 21, 27, 28.

Description: The smallest ceraurid of this study—average cephalon 25 mm wide (tr.) at base of genal spines, 9 mm long (sag.); glabella 6 mm across posterior (1p) lobes. Glabella expanding forward (1 mm in 6 mm to 1 mm in 3 mm). Posterior half of glabella strongly inflated and narrowly arched, raising median glabellar lobe high above lateral lobes (and high above cheeks) and giving a round aspect not present in other ceraurids. Uninflated frontal lobe with a round profile and rounded anterior slopes, being less quadrangular than most ceraurids. Median lobe of glabella bearing two longitudinal rows of large pustules, somewhat isolated on a smooth field with only very small pustules in their near vicinity. Posterior pair of aligned pustules demarcating a short high narrow transverse ridge at posterior end of median lobe. Anterior ends of rows of pustules merging in a field of large pustules scattered thickly and at random on frontal lobe. Occipital ring smooth, of moderate width. Cheek within smooth borders, finely pustulate and pitted overall, with two prominent pustules adaxial and posterior to eye in longitudinal alignment with a third pustule on posterior border. Eye line sharp and continuous. Eye opposite second posterior lateral lobe and situated wide on cheeks (5 mm from axial furrow on average specimens). Eye, situated at high points of moderately convex cheek, rises to approximate height of lateral glabellar lobes, but does not stand as high as the inflated medial lobe of glabella. Palpebral lobe signifies a small semicylindrical eye. Eye stalk and free cheek not known. Anterior course of facial suture in a smooth, semicircular course, visible in dorsal view, bounding a narrow (avg 1 mm) preglabellar border of constant width. Rostral sector of preglabellar suture not distinguishable in dorsal view, and hardly distinguishable (as a faint raised arc) in anterior view. Facial suture posterior to eye parabolic, curving forward to lateral border furrow and backward in crossing margin. Posterior border of cephalon with a marked flare between the outer end of thoracic articulating flange and base of genal spine. Genal spine stout, apparently elliptical in cross section near base, curving backward to terminate about the mid point of thorax.

Hypostome slightly narrower than average ceraurid and middle body less inflated. Middle body without median furrow, but with distinct maculae near posterior tip. Hypostome tapering posteriorly with rounded entire margin. Margin of variable width, narrow opposite maculae and widening in long posterior tip.

Thorax poorly known. Axial lobe in at least some specimens with very faint pairs of tubercles; axis considered smooth in other specimens. Nodes adjacent to the oblique pleural grooves low and grooves lightly impressed. Fulcral nodes rounded and only moderately prominent.

Pygidium typically ceraurid. Paired pustules on axial ring of anterior segment very faint (lacking in some specimens assigned to this species) and paired pustules lacking from axial rings of posterior segments. Impressions of pleural furrows (at base of great spines only) very lightly impressed. First and second segments only with raised axis and axial furrow constrictions. Posterior margin of pygidium slightly convex, scalloped opposite ends of segments.

Remarks: *C. plattinensis* resembles the type species in many respects, but differs as follows: (1) The eyes are backwardly placed—opposite the second lateral lobe. (2) Possession of broad tablike flares on the posterior border of the fixed cheeks.

Genus *Gabriceraurus* Pribyl and Vanek, 1985

Type species. *Ceraurus gabrielsi* Ludvigsen, 1979, upper Esbataottine Formation (Blackriveran/Rocklandian), northwestern Canada.

Gabriceraurus dentatus (Raymond and Barton, 1913)

Plate 9, figs. 1-7, pl. 10, figs. 1-3

1913. *Ceraurus dentatus* Raymond and Barton, p. 534, pl. 1, fig. 2, 4, 5.

1927. *Ceraurus hermanni* Walter, p. 249, pl. 19, figs. 11-15.

1963. *Ceraurus (Ceraurus) dentatus* DeMott, p. 148, pl. 9, figs. 1-7, pl. 10, figs. 1-3.

1979. *Ceraurus dentatus* Ludvigsen, fig. 26C.

Holotype: Dorsal shield, now lost (Bolton, 1966, p. 50; dorsal shield, figured Raymond and Barton, 1913, pl. 1, fig. 2), Leray and Rockland Beds (Blackriveran/Rockland), north of Vankleek Hill, Ontario.

Material: 1 dorsal shield, 24 cranidia, 1 hypostome, 4 pygidia.

Occurrence: [Not specified in DeMott text—from Fig. 6, Illustrations, and specimen labels] Decorah Group, Guttenberg Formation, localities 16, 27, 28.

Description: Unusually large species—average cephalon 50 mm in width at base of genal spines and 16 mm in length (sag.); glabella 10 mm wide across 1p lobes—bits and pieces of much larger individuals known (to cephalon 70 mm in width). (Size range very similar to range of New York State type materials described by Raymond and Barton.) Glabella expanding forward 1 mm in 4 mm or 1 mm in 5 mm. Glabella broad and flat, moderately inflated to rear and very deflated in frontal lobe. Frontal lobe markedly quadrate with deflation accounting for a long frontal slope which is flat, or sagging at the center. Anterior profile of frontal lobe often slightly concave due to deflation. Glabella does not reach frontal margin. Large and small pustules sprinkled with random distribution over all glabellar lobes. Posterior edge of median lobe bearing a sharp transverse ridge, usually with many fine pustules closely aligned. Occipital ring broad and smooth with a single tiny pustule at high point near posterior margin. Cheeks, within smooth borders, covered with a random sprinkling of small pustules and pits. Pustules are thick in the area posterior and adaxial from the eye, but no pair or cluster of pustules are outstanding in this region distinct from rest of cheek surfaces, and no pustules occur on the posterior border opposite this area. Eye line represented by a faint alignment of pustules in a low ridge with cols. Eye line emphasized by one unusually large pustule midway between eye and anterolateral pit. Eye well back, opposite back edge of second posterior lobes (or opposite first posterior furrows) and located well out on cheeks (5 mm from axial furrow on average specimen). Palpebral lobe typically ceraurid, small, round, strongly inflected. Eye stands as high or slightly higher than glabella (reflecting a low glabella rather than excessive cheek inflation). Anterior course of facial suture very angular. Facial suture passes forward from eye in a very straight forward course and then breaks sharply anterior to the anterior border furrows and passes across the front of the cephalon well ahead of frontal lobe. Rostral suture sector is very plainly marked by a large scallop which indents the frontal margin in dorsal view and appears as a strong arc, convex upward, in anterior view. Pre-glabellar border, thus bounded, is wider in front of the glabella and much wider at the anterolateral corners than in any other related species. Facial suture posterior to eye is strongly parabolic, swinging far forward to lateral border furrow where it turns backward across lateral border. Borders of cephalon smooth. Lateral borders of cheek extraor-

dinally wide, much wider than posterior borders. Posterior borders very straight with no flare between the thoracic articulating flange and the base of the genal spine. Genal spine stout, tapering rapidly, elliptical in cross section near base.

Hypostoma with middle body long and narrow. Middle body slightly pinched in opposite shoulders. Posterior end of middle body abruptly diminishing and rounded. No median furrow; faint flexures suggest small maculae are present. Border of constant width, wide in proportion to middle body. Posterior margin entire.

Thorax with very low paired pustules on axis. Diagonal furrows and nodes, and fulcral nodes, distinct and sharp. Distal character of pleurae unknown.

Ceraurid pygidium of four nested segments. Axis high standing, tapering, expressed by arching and axial furrow constrictions on first three segments and by the elevation of the anterior end of the median longitudinal plate. First three segments all bearing low paired axial pustules. Great spines on anterior segment flaring and not strongly curved. Strong diagonal furrows impressed at base of great spines; anterior node large and rounded. Posterior segments without pleural furrows or nodes. All segments without fulcral nodes. Segments beyond axis separated by deep intersegmental furrows which appear as pits inside the pygidial border. Border with deeper intersegmental furrows than in most ceraurids, and second and third segments extended beyond border in short, sharp-pointed teeth (hence specific name *dentatus*). Fourth or central segment may be small tooth as well.

Remarks: Although the holotype is lost, Raymond and Barton's excellent photograph is adequate for the recognition of this species, as supplemented by Ludvigsen's illustration of a cephalon with nine thoracic segments attached. DeMott rightly regarded Walter's species *hermanni* as a junior synonym of *C. dentatus*. Dean (1979) has compared material from the Lourdes Limestone, Long Point Group, southwestern Newfoundland. The holotype of *G. hermanni* Walter (1927) from "Platteville" [actually Guttenberg Formation] beds near McGregor, Iowa, a denticulate pygidium which Walter thought might prove to be different from that of *C. dentatus*, is not with Walter's material (which includes his pl. 19, figs. 12-15) in the University of Iowa Collection and must be presumed lost.

Gabriceraurus mifflinensis n. sp.

Plate 9, figs. 8-16. Plate 10, figs. 4-7

1963. *Ceraurus (Ceraurus) mifflinensis* DeMott, p. 137, pl. p. figs 8-15, pl. 10, figs. 4-7.

Diagnosis: Glabellar subquadrate, frontal lobe inflated, extending to anterior margin. Occipital ring broad. Eye placed opposite 2p lobe. Eye line weak. Posterior border widens little abaxially. Cranidium with scattered tubercles.

Holotype: MCZ 8994 (cranidium, Pl. 9, figs. 8-10), Platteville Group, Mifflin Formation, locality 27.

Material: 2 dorsal shields, 20 cranidia, a number of fragmentary hypostomes and pygidia; total 38 specimens.

Occurrence: Platteville Group, Pecatonica Formation, locality 5; Mifflin Formation, localities 3, 9, 20, 24, 25, 26, 27, 28; and Grand Detour Formation, localities 6, 10a.

Description: *G. mifflinensis* stands close to *C. plattinensis*, but differs in the features noted in the diagnosis. In the main, the same characters distinguish it from the type species; in addition, *G. mifflinensis* has the eyes placed much further back—opposite 2p lobe.

This species was compared with *G. hirsutius* (Ludvigsen, 1979, p. 33, pl. 14, figs. 1-25) from the *Ceraurina longispina* Zone, Upper Esbataottine Formation (Blackriveran/Rocklandian), Sunblood Range, Canada, by Ludvigsen, who commented "Ceraurus hirsutius is most similar to the species group clustered around *C. dentatus* Raymond and Barton, 1913, and including *C. plattinensis* Foerste, 1920 and a manuscript species described by DeMott [*C. mifflinensis*]. These species possess sub-rectangular, slightly to moderately inflated glabellae with relatively wide (transverse) lateral glabellar furrows, eyes located opposite 2p lobe, long stout genal spines and cephalic borders, and pygidium lacking tubercles." This evidence is in conformity with the evidence of the remainder of the fauna; the closest age correlation with the Sunblood Range is with this zone.

Genus *Ceraurina* Cooper, 1953

Type Species: *Ceraurina typa* Cooper, 1953 (Edinburg Formation, Strasburg Junction, Virginia, U.S.A.).

Ceraurina scofieldi (Clarke, 1894)

Plate 10, figs. 11-19

1894. *Cyrtometopus scofieldi* Clarke, p. 735, text-fig. 55.

1963. *Ceraurinus (Alloceraurina) scofieldi*, DeMott, p. 154, pl. 10, figs. 11-19.

Holotype: Location unknown.

Material: 1 dorsal shield, 6 cranidia, 3 hypostomes; total 10 specimens.

Occurrence: Platteville Group. Mifflin Formation, localities 22, 24, 27, 28.

Description: A small *Ceraurina*; cephalon rounded, a little too wide to be exactly semicircular, moderately inflated. Average width of cephalon between tips of genal spines 15 mm, max observed 20 mm; average length 6 mm, max 8 mm; average width of glabella 4.5 mm, max 6 mm. Glabella extending to frontal margin with subparallel sides, rounded frontal lobe, and even, subcylindrical inflation throughout. 1p lobe slightly wider (transverse) than rest of glabella or occipital ring; and axial furrows bulging slightly in passing 1p lateral lobes. 1p glabellar furrow narrow, sharply impressed, straight, and following a strongly oblique course. 2p and 3p furrows very faintly scored, parallel to each other, gently curved convex forward, and trending normal to axis. Occipital furrow bowed strongly forward. First posterior furrow not joining occipital furrow directly, nor connected by longitudinal depression; 1p lobe connecting to median glabellar lobe by narrow neck. A small tubercle, visible in oblique illumination, at posterior center of median lobe; glabella otherwise smooth (minutely granular under the lens). Cheek within smooth border without pustules or pits, also minutely granular. Eye line very faint, continuous. Anterior course of facial suture in a smooth arc; joining front margin of glabella (coincident with preglabellar furrow just anterior to point where it crosses the anterolateral border furrow. Posterior course of suture running straight to lateral border, parallel to posterior border, and then inflected strongly backward in crossing lateral border. Genal spine pointed and short.

Hypostoma as for the genus. Spines at posterolateral corners slight, making posterior margin, more nearly straight than forked.

Thorax with a broad smooth gently arched axis without pustules, narrow inner pleural areas. Distal ends of pleurae not observed in this species.

Pygidium with anterior spines about equal in length to genal spines. Second segment with slender spines one half length of anterior spines. Third segment spineless; and fourth segment, which is not ankylosed into a single plate but doubled upon itself with central furrow, bearing a pair of short spines where its ends reach the pygidial margin. Pygidial axis broad and low, demarcated by slight constrictions on first two segments. Intersegmental grooves shallow over axis, developed as pits in pleural region; pygidial border relatively broad and well fused with intersegmental furrows very lightly impressed.

Remarks: Ludvigsen (1979) briefly commented on *C. scofieldi*. The species, with its distinct 1p glabellar lobe and its well developed second set of pygidial spines, includes a mix of characters between his *Ceraurina kingstoni* and *C. longispina* group. The remaining glabella furrows are quite weak or missing proximally. *C. scofieldi* also has virtually no pitting on the fixed cheeks, unlike most other species of *Ceraurina*. DeMott proposed the subgenus *Alloceraurina*, with *scofieldi* (Clarke, 1894) as type species for this and the succeeding two species. However, these species may fall within the limits of *Arcticeraurina* of Pribyl and Vanek (1985, p. 158). The material available is insufficient to decide this question at present.

Ceraurina sp.
Plate 11, figs 1-4

1963. *Ceraurinus (Alloceraurina) speideli* DeMott, p. 156, pl. 11, figs. 1-4.

Material: 7 cranidia, 1 associated hypostome.

Occurrence: Platteville Group. Mifflin Formation, localities 1, 9; Grand Detour Formation, localities 6, 10b; and Quimbys Mill Formation, locality 10A.

Description: A small *Ceraurina*. Cranidium similar in every respect to *C. scofieldi* except that it is (1) slightly narrower and longer and forms a true semicircle (holotype length 9 mm, width at posterior margin, 18 mm); (2) glabella is inflated slightly more to rear than forward, lacking the hemicylindrical aspect of *C. scofieldi*; and (3) first posterior glabellar furrows are connected to the occipital furrow, isolating 1p lobes. Hypostome not distinguished from *C. scofieldi*. Pygidium unknown.

Ceraurina templetoni n. sp.
Plate 11, figs. 5-12

1963. *Ceraurinus (Alloceraurina) templetoni* DeMott, p. 158, pl. 11, figs. 5-12.

Diagnosis: A "*Ceraurina*" of large size, 1p lobe circumscribed. Postero-medial tubercle on preoccipital glabella. Genae coarsely pitted. Hypostome with long (sag.) posterior border, provided with long lateral spines.

Holotype: MCZ 9017 (cranidium, pl. 11, figs. 5-7), Platteville Group. Quimbys Mill Formation, locality 17.

Material: 1 cephalon and thorax, 8 cranidia, 1 hypostome; total 10 specimens.

Occurrence: Platteville Group. Mifflin Formation, locality 3; Grand Detour Formation, locality 10a; and Quimbys Mill Formation, locality 17.

Description: A large *Ceraurina*—holotype cephalon 31 mm wide at tips of genal spines, 15 mm long (sag.); glabella 11 mm in average width. Cephalon semicircular. Glabella with sub-parallel sides; 1p lobes slightly protruding laterally. Occipital ring narrower than any portion of glabella. First posterior furrow deep, straight, on strongly oblique course, and connecting to occipital furrow by an arcuate constriction, isolating 1p lobe. 2p and 3p furrows narrow, lightly impressed, parallel to each other, gently curved concave posteriorly, and trending normal to axis. Median lobe bearing a prominent tubercle at center of posterior border. Glabella gently inflated to a high point between 2p furrows. Forward from 2p furrows, glabella in a gentle and long slope to frontal margin. Frontal lobe delimited from frontal margin by a very faint pre-glabellar furrow, which is barely discernible, crossing the frontal slope of cephalon approximately 1 mm behind frontal margin. Preglabellar furrow with gentle rise at midpoint of frontal lobe. Glabellar surfaces thickly covered with microscopic granules. Cheeks and borders also microscopically granular. Cheek surfaces thickly covered with visible pits. Palpebral lobes small and strongly flexed, located opposite 2p furrows (and on strike of 1p furrows) moderately close to glabella (2 mm from edge of axial furrow in holotype specimen). Eye line slightly raised and clearly demarcated by an absence of cheek pits along its course, passing forward to a point adjacent to anterolateral pit and ending in a low dimpled tumulus. Anterior course of facial suture smoothly semicircular. Suture approaches frontal lobe just anterior to trough of lateral border furrow, and follows course about 1 mm anterior to preglabellar furrow and duplicates gentle median rise of preglabellar furrow. Posterior course of facial suture commences backwards from eye and turns on an arc of approximately 1-mm radius before swinging on an open parabolic course forward to lateral borders and backwards in borders.

Hypostoma unusually elongate and slightly granular. Posterior lobe of middle body demarcated by clear arcuate furrow. Maculae present. Posterior border trailing and bearing two long spines.

Thorax typical for the subgenus.

Pygidium unknown.

Discussion: Within the material available, *C. templetoni* is consistently about twice as large as *C. scofieldi*. This criterion, though useful, is not diagnostic. *C. templetoni* differs from the other two species in the isolation of the 1p lobes by longitudinal constrictions, in the possession of the posterior median tubercle on the glabella, in having obviously pitted cheek surfaces, and in having the long, trailing posterior border on the hypostoma.

C. templetoni is the one striking trilobite of the Quimbys Mill fauna which is not known to be present at Bucks Quarry, N. Y. The name remembers Dr. J.S. Templeton of the Illinois Survey, whose work was fundamental to the stratigraphy and fossil collection of this paper.

Family PLIOMERIDAE Raymond, 1913
Subfamily PLIOMERINAE Raymond, 1913
Genus *Anapliomera* n. gen.

Type Species: *Anapliomera shirlandensis* n. gen. n. sp., Platteville Group. Grand Detour Formation, locality 10A.

Diagnosis: 1p lobe and furrow obsolete. 2p and 3p lobes narrow and subequal. Palpebral lobe placed far back and close to glabella.

Discussion: *Anapliomera* is distinctive in having only two short pairs of glabellar furrows. This immediately sets *Anapliomera* apart from all pliomereid genera except *Pliomereella*, which also has only two pairs of furrows. *Anapliomera* differs from *Pliomereella* by having short straight glabellar furrows and furrows, subequal lateral lobes, which contrast with the latter's long sinuous furrows and unequal lobes.

The most closely related genus to *Anapliomera* is *Quinquecosta* Tripp (1965, p. 595; 1967, pl. 75; 1979, p. 354), type species *Q. williamsi*, from the Albany Group (Llandeilo), Girvan district, Scotland, in gross morphology and particularly in eye position; *Quinquecosta* is now regarded as a pliomereid, not a cybeline as originally thought. In both genera one lateral glabellar furrow bifurcates within a short distance. In *Q. williamsi* it is the 3p furrow which bifurcates; in *A. shirlandensis*, the 2p furrow. The 1p lobe is much reduced in *Q. williamsi*; the editors believe that it is obsolete in *A. shirlandensis*, and that the first and second lateral lobes and furrows of *Anapliomera* represent the second and third of *Quinquecosta*. The faint,

oblique impression on the anterior glabellar margin of *A. shirlandensis* is present on only the right side of DeMott's pl. 8, fig. 16. DeMott (see description) regarded this as the 3p furrow; the editors consider it a supplementary furrow.

The name *Anapliomera* (without-many-segments) is selected to suggest the reduced segmentation of the glabella and at the same time note the pliomeric relationship. The type species is the only species placed in the new genus.

Anapliomera shirlandensis n. gen., n. sp.

Plate 8, figs. 15-18

1963. *Anapliomera shirlandensis* DeMott, p. 164, pl. 8, figs. 15-18.

Diagnosis: As for genus.

Holotype: MCZ 8987 (cranium, pl. 8, figs. 15-17), Platteville Group, Grand Detour Formation, locality 10a.

Material: 3 crania (1 with a thoracic segment associated).

Occurrence: Platteville Group, Grand Detour Formation, locality 10a.

Description: Cephalon lunate, with width (transverse) almost three times length (sag.). Cephalon gently convex centrally, deflected and dipping steeply near margin. Total height of cephalic vault one-half cephalic length (sag.). Cephalic modelling achieved by sharply incised furrows; border, cheek, and glabellar surfaces continuous in overall convexity. Glabella, subequilateral pentagonal, expanding forward, separated from anterior margin by narrow anterior border. Lateral glabellar furrows 1p and 2p equally spaced between anterolateral corners and occipital furrow. Glabellar furrows incised to the depth of the axial furrows at their distal ends, extending normal to the axial furrows into the glabella a distance equal to the spacing between them. Proximal end of 2p furrow terminating in shallow fork; and proximal end of 1p furrow with a faint suggestion of a similar fork. A shallow indentation on the anterior side of the occipital furrow repeats the modelling caused by these furrows. Glabella, thus furrowed, consists of a large frontomedian lobe flanked by two pairs of small subequal pedunculate lateral lobes. Frontal lobe of glabella with a faint median longitudinal depression one-sixth the length (sag.) of glabella, located just posterior to center; and frontal lobe carrying a faint crease (visible only in oblique illumination) which enters frontal lobe from anterolateral border furrow and extends inward the same distance and direction as 1p and 2p furrows. Axial furrow a straight, deep, and flat-bottomed trough, offset outward in crossing the posterior border. Anterior border furrow one-quarter the gauge of axial furrows, rectilinear, with central angle slightly rounded. Anterior border furrow flaring and deepening at junction with axial furrows. Rectilinear course of anterior border furrow causes it to rise and fall (in anterior view) as it traverses the uniform curvature of the cephalon; and anterior border is of variable width between the rectilinear anterior furrows and the curved anterior margin. Occipital furrow one-half the gauge of the axial furrows, and of the same gauge as adjacent posterior border furrows. Center of the occipital furrow bowed strongly forward, contrasting with approximately straight posterior margin of the occipital ring. Occipital ring, thus bounded, is much broader (sag.) in the center than at its ends. Width (transverse) of the occipital ring equal to the width of the glabella at the 2p lobes. Center of occipital ring flush with the general convexity of the cephalon. Occipital ring bowed downward more steeply than the glabella adjacent to the axial furrow; and the posterior border of the cheek likewise displaced below the general convexity of the cephalon adjacent to the axial furrow. Palpebral lobe close to the axial furrows and opposite the 2p lobes of the glabella. Preservation is poor in the known specimens, but apparently palpebral lobe is small, semicircular, and surmounts a small, high, hemicylindrical eye. Palpebral lobe strongly inflected above the general convexity of the cephalon and bounded by shallow palpebral furrow along the posterior two-thirds of base. Inflection at anterior base of palpebral lobe extends to the edge of the axial furrow, constituting a short ocular ridge. Anterior branch of the facial suture runs forward in a slightly arcuate course, concave outward, to meet the anterior margin opposite the ends of the dorsal furrows. Suture line along the frontal margin of cranium scalloped: a broad suture arc convex dorsally lies on the margin beneath the straight limb of the anterior furrow; a smaller arc constitutes a rostral suture in the center of the anterior margin. Posterior branch of the facial suture runs parallel to the posterior border furrow until it crosses the lateral border furrow. In the lateral border, the suture curves sharply back and out and reaches the margin approximately in the center of the rounded genal corner and in line (transverse) with the posterior border furrow. A sutural ridge fills in the lateral border furrow on the fixed cheek where the suture crosses. Posterior border narrow and ridged behind eye, becoming flat and spatulate toward the lateral margin, accentuating the backward curvature of the fixed cheek and contributing to the

round lobate genal angle. Surfaces of the glabella, palpebral lobes, and borders finely granular. Cheek surfaces, within the borders, covered with pits of moderate size.

Free cheek adduced from the known crania to be small, slender, obtusely triangular, with about equal width border and cheek surface, surmounted by a high hemicylindrical eye.

Thorax adduced from the posterior border of the cephalon to have a strongly arched axial lobe about one-quarter total width. Pleurae with ridges, but not pleural grooves. Distal ends of pleurae strongly deflected downward and to the rear. Tips of pleurae flat and broad. (One isolated thoracic segment of this description occurs on the same slab as the specimens and is presumed to belong to this species.)

Pygidium unknown.

Remarks: *Anapliomera shirlandensis* differs conspicuously from *Quinquecosta williamsi* in the following features: (1) the glabella narrows less rapidly forward, (2) in consequence, the occipital furrow constitutes a much greater proportion of the cephalic width—30% (cf. 25%), (3) accordingly the thoracic axis is 40% the width of the axis (cf. 25%), (4) sculpture differs—the field of the free cheek is more coarsely pitted, lateral border smooth, not granular, (5) front of cephalon flexed less strongly upward.

Family ENCRINURIDAE Angelin, 1854

Subfamily ENCRINURINAE Angelin, 1854

Genus *Encrinuroides* Reed, 1931

Type species: *Cybele sexcostata* Salter, 1848, Shoeshook Limestone (Ashgill), Wales.

Encrinuroides rarus (Walcott, 1877)

Plate 11, figs. 13-25

1877. *Ceraurus rarus* Walcott, p. 68.

1877. *Encrinurus varicostatus* Walcott, p. 69.

1894. *Encrinurus wannulus* Clarke, p. 739, text figures 56-57.

1894. *Encrinurus varicostatus* Clarke, p. 740.

1913. *Encrinurus rarus*. Raymond and Barton, p. 541, pl. 2, fig. 3.

non 1928. *Encrinurus rarus*. Troedsson, p. 59, pl. 16, fig. 4-10.

1963. *Encrinuroides rarus*, DeMott, p. 168, pl. 11, figs. 13-25.

1975. *Encrinuroides* cf. *rarus*, Ludvigsen, pl. 3, figs. 22-23.

1976. *Encrinuroides rarus*, Chatterton and Ludvigsen, p. 74, pl. 15, figs. 1-43.

Holotype: Field Museum of Natural History, Chicago UC 12322 (cranium, figured Raymond and Barton, 1913, pl. 2, fig. 3), Platteville Group, Grand Detour Formation, Beloit, Wisconsin.

Material: 12 crania, 10 pygidia; total 22 specimens.

Occurrence: Platteville Group, Pecatonica Formation, locality 5; Mifflin Formation, localities 3, 20; and Grand Detour Formation, localities 22, 25, 26, 27.

Remarks: *E. rarus* has been fully described by Chatterton and Ludvigsen (1976) based on silicified specimens from the lower Esbataottine Formation (*Ceraurina* *nahanniensis* Zone), Sunblood Range, Canada; Ludvigsen (1979a, p. 45, pl. 21, figs. 42-48) has also illustrated silicified specimens from the upper part of the Esbataottine Formation. Chatterton and Ludvigsen comment that the Platteville Formation material described by DeMott (1963) is identical.

Encrinuroides vigilans (Hall, 1847)

Plate 12, figs. 1-4

1847. *Ceraurus vigilans* Hall, p. 245, pl. 65, figs. 2a-h.

1877. *Encrinurus trentonensis* Walcott, p. 68.

1921. *Encrinurus cybeleformis* Raymond, p. 33, pl. 11, fig. 2.

1963. *Encrinurus vigilans*, DeMott, p. 172, pl. 12, figs. 1-4.

1979. *Encrinuroides vigilans*, Ludvigsen, fig. 27A-C.

Lectotype: (hereby selected). AMNH 36070 (dorsal shield, figured Hall, 1847, pl. 65, figs. 2a, b; Ludvigsen, 1979, fig. 27A), lower shaly beds in Trenton Group, Middleville, New York, U.S.A.

Occurrence: Decorah Group, Guttentberg Formation, locality 19.

Material: 1 cranium, 1 pygidium.

Description: Pygidium width 9 mm, length 9 mm. Axis well arched anteriorly, becoming very low but clearly outlined posteriorly and reaching to within 1 mm of posterior border. Axis with 26 visible annulations. First ring complete and bounded by a strong furrow; next two rings complete but with furrows becoming faint medially; all posterior rings interrupted by smooth tract running the length of the axis. Annulations become too faint to count 1 mm from posterior tip of axis. Median tubercles clearly developed on rings 3 and 6. Faint tubercle located at ring 10. Nine pairs of pleurae bent backward

and downward to form typical encrinuid pygidium, strongly convex. An incipient tenth pair of pleurae represented by a single median posterior plate which appears behind the tapering tip of the axis and extends to posterior margin. Margin rounded. Pleurae without tubercles or other decoration. Four anterior interpleural grooves extend to margin. Posterior five pleurae with ends fused in a very narrow border.

Remarks: This species is also present in faunas E-H of Ontario (Rocklandian/Edenian)(Ludvigsen, 1978a, p. 74).

Subfamily CYBELINAE Holliday, 1942

Genus *Cybeloides* Slocum, 1913

Type species: *Cybeloides iowensis* Slocum, 1913 (lower Maquoketa Group (Richmondian), Iowa, U.S.A.).

Cybeloides cimelia Chatterton and Ludvigsen, 1976

Plate 12, figs. 5, 6.

1963. *Cybeloides platylobus* DeMott, p. 175, pl. 12, figs. 5-6.

1975. *Cybeloides* cf. *prima* Ludvigsen, pl. 3, figs. 18-19, pl. 4, figs. 5-6.

1976. *Cybeloides cimelia* Chatterton and Ludvigsen, p. 69, pl. 14, figs. 1-43, pl. 22, fig. 1.

Holotype: GSC 43545 (figured Chatterton and Ludvigsen, 1976, pl. 14, figs. 7-10), lower Esbataottine Formation (Chazy), Mackenzie Mountains, Canada.

Material: 3 cranidia.

Occurrence: Platteville Group. Mifflin Formation, locality 26.

Remarks: These cranidia were considered as identical with *C. cimelia* by Chatterton and Ludvigsen (1976). Points of particular resemblance are the swollen lateral glabellar lobes without tubercles, and the paired tubercles on the median lobe. These are also features of the closely related *C. virginensis seca* Evitt and Tripp (1977, p. 151, pl. 18, figs. 7-17, pl. 19, figs. 1-6, 12-43, pl. 20) from the lower Lincolnshire Formation of Virginia. The Mifflin Formation material agrees with the former species in the narrow median glabellar lobe. *C. cimelia* ranges throughout the Esbataottine Formation (Chazy/Rocklandian).

Family PTERYGOMETOPIDAE Reed, 1959

Subfamily EOMONORACHINAE Pillet, 1954

Genus *Eomonorachus* Delo, 1935

Type species: *Dalmanites intermedius* Walcott, 1879 ("Trenton Limestone" (probably Decorah Group), of Illinois, Wisconsin, and Minnesota).

Eomonorachus intermedius (Walcott, 1877)

Plate 12, figs. 7-15. Plate 13, figs. 1-6

1877. *Dalmanites intermedius* Walcott, p. 69.

1894. *Pterygometopus intermedius*, Clarke, p. 727, text-figs. 45-47.

1963. *Eomonorachus intermedius*, DeMott, p. 185, pl. 12, figs. 7-15, pl. 13, figs. 1-6.

1979b. *Eomonorachus intermedius*, Ludvigsen, fig. 26E.

1982. *Eomonorachus intermedius*, Ludvigsen and Chatterton, p. 188, pl. 1, figs. 8-9, pl. 2, figs. 4-15.

Full synonymy, selection of neotype, and description in Ludvigsen and Chatterton (1982).

Neotype: USNM 41955 (complete enrolled specimen, figured Clarke, 1899, figs. 45-46) Decorah Shale, Chatfield, Minnesota.

Material: Cranidia and pygidia abundant, total over 100 specimens. By far the most abundant species in the Decorah Group.

Occurrence: Decorah Group. Spechts Ferry Formation, localities 27, 29; and Guttenberg Formation, localities 13, 16, 17, 19, 21, 23, 27, 28.

Remarks: *E. intermedius* occurs also in the Plattin Limestone (Rocklandian, Branson, 1909) and in the Rocklandian and Kirkfieldian of Ontario (Ludvigsen, 1978, p. 74).

Genus *Sceptaspis* Ludvigsen and Chatterton, 1982

Type Species: *Pterygometopus lincolnensis* Branson, 1909 (Plattin Formation, Missouri).

Sceptaspis lincolnensis (Branson, 1909)

Plate 13, figs. 7-22

1894. *Dalmanites achates* Clarke, p. 726, text-fig. 44.

1901. *Pterygometopus lincolnensis* Branson, p. 46, pl. 7, figs. 17-19.

1963. *Calyptaulax lincolnensis*, DeMott, p. 192, pl. 13, figs. 7-13 (cranidia).

1963. *Calyptaulax* aff. *lincolnensis*, DeMott, p. 192, pl. 13, figs. 14-21 (pygidia)

1963. *Calyptaulax* sp. ind., DeMott, p. 198, pl. 13, fig. 22.

1979. *Calyptaulax lincolnensis*, Ludvigsen, figs. 28E, F.

1982. *Sceptaspis lincolnensis* Ludvigsen and Chatterton, p. 2194, pl. 5, figs. 1-16, pl. 2, figs. 1-3.

Full synonymy, selection of lectotype, and description in Ludvigsen and Chatterton (1982).

Lectotype: Field Museum of Natural History, Chicago, UC 1148c (cranidium, figured Branson, 1909, pl. 7, figs. 19; Ludvigsen and Chatterton, 1982, pl. 5, fig. 12), Plattin Formation (Blackriveran?), Auburn, Lincoln County, Missouri.

Material: 15 cranidia, 14 pygidia; total 29 specimens. 23 Platteville Group. 6 Decorah Group.

Occurrence: Platteville Group. Mifflin Formation, localities 3, 22, 24, 25, 26, 27; Grand Detour Formation, locality 10a; and Quimbys Mill Formation, locality 17. Decorah Group. Guttenberg Formation, localities 14, 16, 19, 27.

Remarks: *S. lincolnensis* is the only species to persist from the Platteville to the Decorah Group. As Ludvigsen and Chatterton state, *Sceptaspis* was certainly derived from *Calyptaulax*. The species is recorded widely in North America as follows: Gull River Formation, St. Josephs Island (Blackriveran, Okulitch, 1941); Plattin Limestone (Rocklandian, Branson, 1909); Tyrone Limestone (Rocklandian, Foerste, 1919); Bobcaygeon and Verulam Formations (Rocklandian to Shermanian, Ludvigsen, 1979a); Cobourg Formation, Ottawa (Wilson, 1947); Lower Whittaker Formation (Rocklandian to Edenian, Ludvigsen, 1979).

Genus *Calyptaulax* Cooper, 1930

Type Species: *Calyptaulax glabella* Cooper, 1930 (Matapedia Group (Ashgill), Perce, Gaspé Peninsula, Quebec, Canada).

Calyptaulax plattevilensis (Delo, 1940)

Plate 13, figs. 23-24

1894. *Pterygometopus callicephalus* Clarke, p. 73, fig. 52.

1940. *Calliops plattevilensis* Ulrich and Delo, p. 98, pl. 12, figs. 4-5.

1963. *Calyptaulax* aff. *plattevilensis* DeMott, p. 199, pl. 13, figs. 23-24.

Holotype: USNM 78972 (cephalon, figured Delo, 1940, pl. 12, fig. 4). Platteville Formation, Minneapolis, Minnesota.

Material: 2 pygidia.

Occurrence: Platteville Group. Mifflin Formation, locality 24; Grand Detour Formation, locality 6.

Remarks: The large size immediately distinguishes these pygidia from *S. lincolnensis*; although rare, the material agrees in all respects with *C. plattevilensis*.

Family LICHIDAE Hawle and Corda, 1847

Subfamily TETRALICHINAE Phleger, 1936

Genus *Amphilichas* Raymond, 1905

Type species: *Platymetopus lineatus* Angelin, 1854.

Amphilichas sp.

Plate 8, figs. 19-20

1963. *Amphilichas* sp. indet. DeMott, 1963, p. 200, pl. 8, figs. 10-20.

Material: 1 pygidium, 1 hypostome.

Occurrence: Platteville Group. Mifflin Formation, locality 25; and Grand Detour Formation, locality 6.

Remarks: The pygidium resembles that of *A. conradi* Chatterton and Ludvigsen (1976, p. 80, pl. 18, figs. 36-61, pl. 19, fig. 50?) from the Esbataottine Formation, but differs in the stronger second ring furrow and pleural furrows. The hypostome is also similar, though the middle body is narrower and more finely tuberculate.

Subfamily CERATARGINAE Tripp, 1957

Genus *Hemiarges* Gurich, 1901

Type species: *Lichas wesenbergensis* Schmidt, 1901 (Viru Series, Estonia, USSR).

Hemiarges aff. *paulianus* (Clarke, 1894)

Plate 13, figs. 26-28

Material: 1 cranidium

Occurrence: Platteville Group. Mifflin Formation, locality 3.

Description: Glabella wider than long, dominated by trinodal cluster of median lobe and flanking bi-composite lateral lobes. Each of the three divisions clavate and tumid, of subequal height; medial lobe about 1.5 times the length and width of lateral lobes. Posterior one-third of glabella a depressed field occupied by a poorly defined, depressed and tapering posterior extension of the medial lobes and by poorly defined elongate (tr.) lp lobes.

Axial furrows and glabellar furrows weak in depressed posterior field. Occipital furrow sharp, narrow, and shallow. Occipital ring convex forward, narrow, surface slanting forward. Inner cheek area inflated to height of lat-

eral glabella lobe and standing above sunken posterior glabella field. Cheek rounded posteriorly to low posterior border, lower and narrower than occipital ring.

Surface of cranium covered with tiny tubercles. Coarse tubercles sprinkled at random amongst the smaller tubercles and prominent on the inflated lobes of the glabella and adaxial cheek surfaces. Four large tubercles aligned along the elevated posterior margin of the occipital ring.

Remarks: Chatterton and Ludvigsen (1976), Chatterton (1980), and Tripp and Eviitt (1981) have discussed *Hemiarges* species in North America. Based on extant figures, the present cranium appears assignable to this species.

PLATE 1

Figures 1, 2 *Hypodicranotus* sp.

- (1) hypostome, X2, ventral view. Mifflin Fm. at Mt. Ida East. MCZ no. 8906.
- (2) cranium, X3, dorsal view, photographed under alcohol to emphasize glabella furrows. Mifflin Fm. at Patch Grove. MCZ no. 8907.

Figures 3-18 *Basiliella barrandi* (Hall, 1851).

- (3-7) cranium, X1, an artificial cast in dorsal, anterior-oblique, lateral-oblique, anterior, and lateral views. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8908.
- (8) cranium, X1, dorsal view. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8909.
- (9) left free cheek, X1, dorsal view, missing genal spine, anterior extension of raised border, and adaxial projection anterior to eye. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8910.
- (10) right free cheek, fragmentary, X1, dorsal view, showing doublure and the course of the anterior suture along the raised border. Mifflin Fm. at Patch Grove. MCZ no. 8911.
- (11-12) left free cheek, X1, fragmentary with genal spine, dorsal and anterior-oblique views. Mifflin Fm. at Fennimore West. MCZ no. 8912.
- (13-14) left cephalic doublure, X1, dorsal and oblique-anterior views, showing ventral inflection at hypostomal suture, anterior median course of the grand suture in fig. 13, and the relation of the curvature of the doublure to the concavity of the peripheral field of the dorsal exoskeleton in fig. 14. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8913.
- (15) small cranium, X1, dorsal view. Mifflin Fm. at Fennimore West. MCZ no. 8914.
- (16) small cranium, X1, dorsal view. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8915.
- (17) hypostome, X1, ventral view. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8916.
- (18) fragmentary hypostome X1, ventral view. Mifflin Fm. at Dixon North. MCZ no. 8917.

PLATE 2

Figures 1-12 *Basiliella barrandi* (Hall, 1851).

All figures X1

- (1-3) pygidium, dorsal, lateral, and posterior views. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8918.
- (4) pygidium, dorsal view. Mifflin Fm. at Dixon Ravine. MCZ no. 8919.
- (5-7) pygidium in dorsal, lateral, and posterior views. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8920.
- (8) pygidium in dorsal view, excavated to show mold of exterior surface of right pygidial doublure with terrace lines; excavation is carried to the true inner margin of the doublure at the right; the left boundary of the posterior notch is also true. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8921.
- (9) pygidium, dorsal view. Mifflin Fm. at Fennimore West. MCZ no. 8922.
- (10) pygidium, dorsal view. Mifflin Fm. at Medusa Quarry. MCZ no. 8923.
- (11-12) thoracic segment, dorsal and posterior views. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8924.

PLATE 3

Figures 1-11 *Isotelus gigas* DeKay, 1824.

- (1-2) left free cheek, X1, dorsal and lateral views. Spechts Ferry Fm. at Liberty Pole. MCZ no. 8925.
- (3) partial cranium, X1.3, dorsal view, showing molds of faint median sulcus and paired muscle scars (raised) of the exoskeleton; mold of a median pit—the interior expression of the median tubercle—is also visible. Guttenberg Fm. at Fennimore West. MCZ no. 8926.
- (4) cranium, X2, dorsal view, molds of median sulcus and median tubercle as in fig. 3; molds of muscle callosities very faint compared with specimen in fig. 3. Guttenberg Fm. at Fennimore West. MCZ no. 8927.
- (5) left free cheek, X1.3, ventral view, showing curvature of doublure. Guttenberg Fm. at Fennimore West. MCZ no. 8928.
- (6) right free cheek, X2.2, dorsal view. Guttenberg Fm. at Dick-eyville Northwest. MCZ no. 8929.
- (7-8) hypostome, X1, ventral and oblique-lateral views. Spechts Ferry Fm. at Liberty Pole. MCZ no. 8930.
- (9) pygidium, X1, dorsal view, Guttenberg Fm. at Fennimore West. MCZ no. 8931.
- (10-11) pygidium, X1, dorsal and posterior views. Guttenberg at McGregor type section. MCZ no. 8932.

Figures 12-20 *Isotelus cf. walcottii* Walcott, 1918.

- (12-13) pygidium, X1, dorsal and lateral views. Guttenberg Fm. at Furnace Lead Mine. MCZ no. 8933.
- (14-16) pygidium, X1, dorsal, posterior, and lateral views, excavated to show doublure; inner margin and posterior notch of doublure are true. Spechts Ferry Fm. at Liberty Pole. MCZ no. 8934.
- (17-19) pygidium, X1, dorsal and right and left lateral views. Guttenberg Fm. at McGregor type section. MCZ no. 8935.
- (20) pygidium, X1, dorsal view. Guttenberg Fm. at Cassville Camp ground. MCZ no. 8936.

Figures 21-26 *Isotelus homalonotoides* (Walcott, 1877).

- (21-23) cranium, X1, dorsal, oblique-lateral, and lateral views of an artificial mold of interior surface of exoskeleton. Guttenberg Fm. at McGregor type section. MCZ no. 8937.
- (24-26) pygidium, X2, posterior, lateral, and dorsal views of specimen retaining the exoskeleton. Guttenberg Fm. at McGregor type section. MCZ no. 8938.

PLATE 4

Figures 1-22 *Isotelus simplex* (Raymond and Narraway, 1910).

- (1-2) cranium, X1, dorsal and lateral views. Quimbys Mill Fm. at Shirland East. MCZ no. 8939.
- (3) cranium, X1, dorsal view; the pits of the external surface of the exoskeleton are visible on this large specimen adjacent to the posterior margin. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8940.
- (4-5) cephalon, X1, dorsal and oblique-antero-lateral views showing median tubercle and showing mold of exterior surface of doublure with terrace lines and well-developed vincular notch anterior to rounded genal angle. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8941.
- (6-7) left free cheek, X1, dorsal and oblique-lateral views; genal angle slightly pointed but without spine. Quimbys Mill at Shirland East. MCZ no. 8942.
- (8-9) cephalon and thorax, X1, dorsal and lateral views. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8943.
- (10-11) cephalon and thorax, X1, dorsal and oblique-lateral views, showing a small genal spinule which extends the length of the first thoracic segment. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8944.
- (12) hypostome, X2, ventral view. Mifflin Fm. at Dixon North. MCZ no. 8945.
- (13) hypostome, X1, ventral view. Mifflin Fm. at Dixon North. MCZ no. 8946.
- (14-16) pygidium, X1, dorsal, posterior, and lateral views. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8947.
- (17-18) pygidium, X1, dorsal and oblique-posterior views; deflection of vincular hook visible upon mold of exterior surface of doublure at left antero-lateral corner. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8948.

- (19-21) pygidium, X1, dorsal, posterior, and lateral views. Mifflin Fm. at Mount Ida East. MCZ no. 8949.
 (22) pygidium, X2, dorsal view. Mifflin Fm. at Dixon North. MCZ no. 8950.

PLATE 5

Figures 1-23 *Thaleops ovata* Conrad, 1843.

- (1-4) cranidium, X1.5, dorsal, lateral, anterior, and ventral views. Mifflin Fm. at Dixon North. MCZ no. 8951.
 (5-6) cranidium, X1.5, dorsal and anterior views. Grand Detour Fm. at Davis South. MCZ no. 8952.
 (7-8) free cheek, X1.5, anterior and lateral views (compare figures 10 and 11 for orientation of the spine). Quimbys Mill Fm. at Shirland East. MCZ no. 8953.
 (9-11) cephalon and portion of thorax, enrolled, X2, dorsal, anterior, and lateral views. Mifflin Fm. at Fennimore West. MCZ no. 8954.
 (12-13) cranidium, X3, dorsal and anterior views. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8955.
 (14-16) cranidium, X1.5, dorsal, anterior, and lateral views. Mifflin Fm. at Bloomington. MCZ no. 8956.
 (17-18) thorax and pygidium, X2, dorsal and lateral views. Mifflin Fm. at Dixon North. MCZ no. 8957.
 (19-20) thorax and pygidium, X2, lateral and dorsal views. Grand Detour Fm. at Shirland West. MCZ no. 8958.
 (21-23) pygidium, X2, dorsal, posterior, and lateral views. Mifflin Fm. at Patch Grove. MCZ no. 8959

Figures 24-26 *Thaleops* sp. "B".

- (24-26) pygidium, X2, dorsal, posterior, and lateral views. Grand Detour Fm. at Shirland East. MCZ no. 8960.

PLATE 6

Figures 1-6 *Thaleops* sp. "A".

- (1-3) cranidium, X3, dorsal, anterior, and lateral views. Guttenberg Fm. at Quimbys Mill. MCZ no. 8961.
 (4-6) cranidium, X3, dorsal, anterior and lateral views; median carina on the internal mold visible. Guttenberg Fm. at Buncombe. MCZ no. 8962.

Figures 7-12 *Iliaenus* sp. (Cephalon A).

- (7-9) cephalon, X1.5, anterior, lateral, and dorsal views. Grand Detour Fm. at Shirland East. MCZ no. 8963.
 (10-12) cephalon, X1.5, anterior, lateral, and dorsal views. Grand Detour Fm. at Davis South. MCZ no. 8964.

Figures 13-15 *Iliaenus* sp. (Cephalon B).

- (13-15) cranidium, X1.5, anterior, lateral, and dorsal views. Mifflin Fm. at Medusa Quarry. MCZ no. 8965.

Figures 16-18 *Iliaenus* sp. (Pygidium 1).

- (16) pygidium, X1.5, dorsal view. Grand Detour Fm. at Shirland East. MCZ no. 8966.
 (17-18) pygidium, X1.5, dorsal and lateral views. Mifflin Fm. at Bloomington. MCZ no. 8967.

Figure 19 *Iliaenus* sp. (Pygidium 2).

- (19) thorax and pygidium, X2, dorsal view; exoskeleton of pygidium removed exposing narrow doublure, which contrasts in its narrowness with the doublure of *Iliaenus* sp. (Pygidium 1); compare figure 17 above. Mifflin Fm. at Dixon North. MCZ no. 8968.

Figures 20-23 *Bumastoides milleri* (Billings, 1859).

- (20-21) thorax and pygidium, X1.5, dorsal and lateral views. Mifflin Fm. at Dixon North. MCZ no. 8969.
 (22-23) dorsal shield, X2, slightly oblique-lateral and dorsal views. Grand Detour Fm. at Davis South. MCZ no. 8970.

Figures 24-31 *Bumastoides porrectus* (Raymond, 1925).

- (24-26) cranidium, X2, anterior, dorsal, and lateral views. The strongly bowed posterior margin as seen in dorsal view contrasts with all other cranidia illustrated. This species also shows an unusually wide (sag.) anterior border with terrace lines. Compare Plate 6, fig. 11 and Plate 5, figs. 3-4. Guttenberg Fm. at McGregor type section. MCZ no. 8971.

- (27-28) cranidium, X1.5, anterior and dorsal views: the strong mold of a lunette on the internal mold on the right side may be compared here with the almost smooth surface of the exoskeleton about the left-hand lunette (compare also the specimen in fig. 24). Guttenberg Fm. at Buncombe. MCZ no. 8972.

- (29-31) pygidium, X2, in dorsal, lateral, and posterior views. Guttenberg Fm. at Fennimore West. MCZ no. 8973.

PLATE 7

Figures 1-17 *Raymondites longispinus* (Walcott, 1876).

- (1-7) parts of a disarticulated whole specimen, X1.5: (1-4), artificial cast of cephalon in oblique posterior, dorsal, anterior, and lateral views; (5), excavated area beneath the cephalon of figs. 1-4 showing pygidium in dorsal view, and showing the mold of the external surface of the anterior cephalic doublure and the triangular rostrum (rostrum becomes known from this specimen): (6-7), lateral and posterior views of pygidium of fig. 5. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8974.
 (8) pygidium, X1, mold of dorsal surface in dorsal view. Mifflin Fm. at Dixon North. MCZ no. 8975.
 (9-11) cephalon, X1.5, an artificial cast in dorsal, oblique-anterior, and lateral views. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8976.
 (12-13) cranidium, X1, oblique postero-lateral view and dorsal view. Mifflin Fm. at Dixon North. MCZ no. 8977.
 (14-15) cephalon, X1.5, oblique lateral view and dorsal view. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8978.
 (16-17) cranidium, X1.5, oblique lateral view and dorsal view. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 8979.

PLATE 8

Figures 1-9 *Raymondites spiniger* (Hall, 1847).

- (1-3) cranidium, X1.5, dorsal, lateral and anterior views. Guttenberg Fm. at Fennimore West. MCZ no. 8980.
 (4-6) pygidium, X1.5, dorsal, posterior, and lateral views. Guttenberg Fm. at Fennimore West. MCZ no. 8981.
 (7) cranidium, X2, dorsal. Guttenberg Fm. at Fennimore West. MCZ no. 8982.
 (8-9) cranidium, X1.5, dorsal and lateral views. Guttenberg Fm. at Fennimore West. MCZ no. 8983.

Figures 10-14 *Dolichoharpes* aff. *reticulata* Whittington, 1949.

- (10) cephalon, X2, dorsal view: specimen nowhere retains full width of brim. Grand Detour Fm. at Shirland East. MCZ no. 8984.
 (11-13) cephalon, X2, oblique anterior, lateral and dorsal views. Mifflin Fm. at Dixon North. MCZ no. 8985.

- (14) fragmental cephalon, X2, dorsal view. Grand Detour Fm. at Shirland East. MCZ no. 8986.

Figures 15-18 *Anapliomera shirlandensis* n. gen., n. sp.

- (15-17) holotype cranidium, X2, dorsal, anterior, and lateral views. Grand Detour Fm. at Shirland East. MCZ no. 8987.
 (18) paratype cranidium, X2, dorsal view. Grand Detour Fm. at Shirland East. MCZ no. 8988.

Figures 19-20 *Amphilichas* sp.

- (19) hypostome, X2, ventral view. Mifflin Fm. at Patch Grove. MCZ no. 8989.
 (20) pygidium, X2, dorsal view. Grand Detour Fm. at Wooleys Spring. MCZ no. 8990.

PLATE 9

Figures 1-7 *Gabriceaurus dentatus* (Raymond and Barton, 1913).

- (1-3) cranidium, X1.5, dorsal, anterior, and lateral views. Guttenberg Fm. at Buncombe. MCZ no. 8991.
 (4-6) cranidium, X1.5, anterior, dorsal, and lateral views. Guttenberg Fm. at Fennimore West. MCZ no. 8992.
 (7) cranidium, X1.5, dorsal view. Guttenberg Fm. at McGregor type section. MCZ no. 8993.

Figures 8-16 *Gabriceraurus mifflinensis* n. sp.

- (8-10) holotype cranium, X1.5, dorsal, anterior, and lateral views. Mifflin Fm. at Dixon North. MCZ no. 8994.
 (11-13) paratype cranium, X1.5, lateral, dorsal, and anterior views. Mifflin Fm. at Patch Grove. MCZ no. 8995.
 (14-16) slab with two paratype cranidia, X2, cranidia in dorsal view, smaller specimen in anterior and lateral views. Mifflin Fm. at Fennimore West. MCZ no. 8996.

Figures 17-24 *Ceraurus plattinensis* Foerste, 1920.

- (17-19) slab with two cranidia, X2, cranidia in dorsal view, and the larger specimen in anterior and lateral views. Guttenberg Fm. at Platteville North. MCZ no. 8997.
 (20-21) cranium, X2, dorsal and anterior views. Guttenberg Fm. at Fennimore West. MCZ no. 8998.
 (22-24) cranium, X2, dorsal, anterior, and lateral views. Guttenberg Fm. at Fennimore West. MCZ no. 8999.

PLATE 10**Figures 1-3** *Gabriceraurus dentatus* (Raymond and Barton, 1913).

- (1) pygidium, X1.5, dorsal view and internal mold. Guttenberg Fm. at Fennimore West. MCZ no. 9000.
 (2-3) hypostome, X1.5, ventral and lateral views. Guttenberg Fm. at Dickeyville Northwest. MCZ no. 9001.

Figures 4-7 *Gabriceraurus mifflinensis* n. sp.

- (4) pygidium, X1.5, dorsal view. Grand Detour Fm. at Shirland East. MCZ no. 9002.
 (5) pygidium, X1, dorsal view. Mifflin Fm. at Mifflin type section. MCZ no. 9003.
 (6) hypostome, X2, ventral view. Mifflin Fm. at Mount Ida East. MCZ no. 9004.
 (7) cephalon and thorax, X1; ventral view of inner surface of dorsal exoskeleton. Mifflin Fm. at Bloomington. MCZ no. 9005.

Figures 8-10 *Ceraurus plattinensis* Foerste, 1920.

- (8) pygidium, X2, dorsal view. Guttenberg Fm. at Platteville North. MCZ no. 9006.
 (9) hypostome, X2, ventral view. Guttenberg Fm. at Fennimore West. MCZ no. 9007.
 (10) macerated whole individual. X1.5, Guttenberg Fm. at Platteville North. MCZ no. 9008.

Figures 11-19 *Ceraurinella scofieldi* (Clarke 1894).

- (11-13) cranium, X3, dorsal, oblique anterior, and lateral views. Mifflin Fm. at McGregor type section. MCZ no. 9009.
 (14) whole individual, X3, dorsal view; this specimen yields knowledge of the spine on the second posterior segment of the pygidium. Mifflin Fm. at Mifflin type section. MCZ no. 9010.
 (15) cranium, X3, dorsal view. Mifflin Fm. at Bloomington. MCZ no. 9011.
 (16) hypostome, X4, ventral view. Mifflin Fm. at Mifflin type section. MCZ no. 9012.
 (17-19) hypostome X3, ventral, posterior, and lateral views. Mifflin Fm. at McGregor type section. MCZ no. 9013.

PLATE 11**Figures 1-4** *Ceraurinella* sp. (Clarke, 1894).

- (1-2) cranium, X3, lateral and dorsal views. Grand Detour Fm. at Wooleys Spring. MCZ no. 9014.
 (3) cranium, X3, dorsal view. Grand Detour Fm. at Wooleys Spring. MCZ no. 9015.
 (4) hypostome, X3. Grand Detour Fm. at Wooleys Spring. MCZ no. 9016.

Figures 5-12 *Ceraurinella templetoni* n. sp.

- (5-7) holotype cranium, X1.5, dorsal, oblique lateral, and oblique anterior views. Quimbys Mill Fm. at Quimbys Mill. MCZ no. 9017.
 (8-9) paratype cranium, X1.5, lateral and dorsal views. Quimbys Mill Fm. at Quimbys Mill type section. MCZ no. 9018.
 (10-11) paratype cranium, X1.5, dorsal and lateral views. Grand Detour Fm. at Shirland East. MCZ no. 9019.
 (12) hypostome, X2, ventral. Quimbys Mill Fm. at Quimbys Mill type section. MCZ no. 9020.

Figures 13-25 *Encrinuroides rarus* (Walcott, 1877).

- (13-17) cranium, X3, oblique lateral, dorsal, lateral, oblique anterior, and oblique posterior views. Mifflin Fm. at Mount Ida East. MCZ no. 9021.
 (18-19) cranium, X4, in dorsal and oblique anterior views. Mifflin Fm. at Mount Ida East. MCZ no. 9022.
 (20-22) pygidium, X4, in posterior, dorsal, and lateral views. Mifflin Fm. at Dixon North. MCZ no. 9023.
 (23-25) pygidium, X4, in dorsal, lateral, and low-oblique posterior views. Quimbys Mill at Shirland East. MCZ no. 9024.

PLATE 12**Figures 1-4** *Encrinuroides vigilans* (Hall, 1847).

- (1-2) pygidium, X4, dorsal and posterior views. Guttenberg Fm. at Dickeyville Northwest. MCZ no. 9025.
 (3-4) cranium, X4, dorsal and oblique antero-lateral views. Guttenberg Fm. at Dickeyville Northwest. MCZ no. 9026.

Figures 5-6 *Cybeloides cimelia* Chatterton and Ludvigsen, 1976.

- (5-6) cranium, X4, dorsal and oblique lateral views. Mifflin Fm. at Mount Ida East. MCZ no. 9027.

Figures 7-15 *Eomonorachus intermedius* (Walcott, 1877).

- (7-11) enrolled whole specimen, USNM 41955, X4, cephalic, thoracic, pygidial, lateral, and anterior views. Decorah Shale (Guttenberg equivalent) at Chatfield, Minnesota. (These are reproduced from photographs, courtesy H. B. Whittington.)
 *(12) cranium, X3, dorsal view; figured to show abnormal obsolescence at distal ends of 2p furrows. Guttenberg Fm. at Fennimore West.
 *(13-14) cranium, X3, oblique anterior view showing depression of median glabellar lobe and dorsal view. Guttenberg Fm. at Quimbys Mill type section.
 *(15) Slab with cranium and free cheek, X3, illustrating course of the grand suture relative to cephalic margin and anterior double-lure; eye surfaces also visible. Guttenberg Fm. at Dickeyville Northwest.

*Specimens stolen.

PLATE 13**Figures 1-6** *Eomonorachus intermedius* (Walcott, 1877).

- *(1-4) pygidium, X3, a natural mold of inner surface of dorsal exoskeleton in lateral, posterior, and dorsal views, and a ventral view of the surface which made the mold. Guttenberg Fm. at McGregor type section.
 *(5) pygidium, X3, dorsal view of another mold occurring on same slab with specimen shown in figs. 1-4. Guttenberg Fm. at McGregor type section.
 *(6) pygidium, X3, outer surface of dorsal exoskeleton in dorsal view. Guttenberg Fm. at Dickeyville Northwest.

Figures 7-22 *Sceptaspis lincolnensis* (Branson, 1909).

- *(7) cranium, X3, dorsal view. Mifflin Fm. at Fennimore West.
 *(8) cranium, X3, dorsal view; this specimen shows an extreme impressment of the longitudinal glabellar furrows. (Compare fig. 7 with furrows poorly impressed, and fig. 10 which shows average impressment for the species.) Quimbys Mill Fm. at Quimbys Mill.
 *(9) left-hand posterior process of fixed cheek, X4, dorsal view; showing the near approach of the suture to the posterior border behind the eye, and the expansion of the process to a broadly rounded genal corner. Mifflin Fm. at Patch Grove.
 (10-12) cranium, X3, in dorsal, lateral, and oblique anterior views. Mifflin Fm. at Mount Ida East.
 *(13) cranium, X3, dorsal view. Mifflin Fm. at Mifflin type section.
 *(14) pygidium, X3, outer surface of the exoskeleton. Mifflin Fm. at Mount Ida East.
 *(15) pygidium, X3, outer surface of exoskeleton. Mifflin Fm. at Bloomington.

- *(16) left specimen, pygidium, X3, outer surface of exoskeleton, showing abnormalities in the vicinity of the 7th through 11th axial rings and associated pleurae. Right specimen is a pygidium of *Eomonorachus intermedius*, X3, also showing the outer surface of a dorsal exoskeleton. The broader axis, extended to near posterior border; the greater pitch from front to rear; the wider angle, and stronger pleural furrows of *E. intermedius* may be here compared directly to *Sceptaspis*. Guttenberg Fm. at St. James West.
- *(17) pygidium, X2, outer surface of dorsal exoskeleton. Mifflin Fm. at Mount Ida East.
- *(18-20) pygidium, X3, natural mold of inner surface of exoskeleton in dorsal, posterior, and lateral views, showing well the bilobed axial tip, course of pleural furrows, and horizontality of lateral profile. Guttenberg Fm. at Fennimore West.
- *(21) pygidium, X3, outer surface of dorsal exoskeleton. Mifflin Fm. at Fennimore West.
- *(22) pygidium, X3, outer surface of dorsal exoskeleton. Mifflin Fm. at Dixon North.
- Figures 23-24** *Calyptaulax plattevilensis* (Delo, 1940).
- *(23) pygidium, X2, outer surface of exoskeleton; this specimen and fig. 24 show well the strong scalloping of the axial rings which suggests a species distinct from the others treated on this plate. Mifflin Fm. at Bloomington.
- *(24) pygidium, X2, natural mold of inner surface of exoskeleton. Grand Detour Fm. at Wooleys Spring.
- Figure 25** *Eobronteus lunatus* (Billings, 1857).
- (25) central portion of fragmentary pygidium, X4, Guttenberg Fm. at Fennimore West. MCZ no. 9028.
- Figures 26-28** *Hemiarges* aff. *H. paulianus* (Clarke, 1894).
- (26-28) cranidium, X4, dorsal, oblique lateral, and oblique anterior views. Mifflin Formation at Dixon North. MCZ no. 9029.
- *Specimens stolen.

Plate No. 1

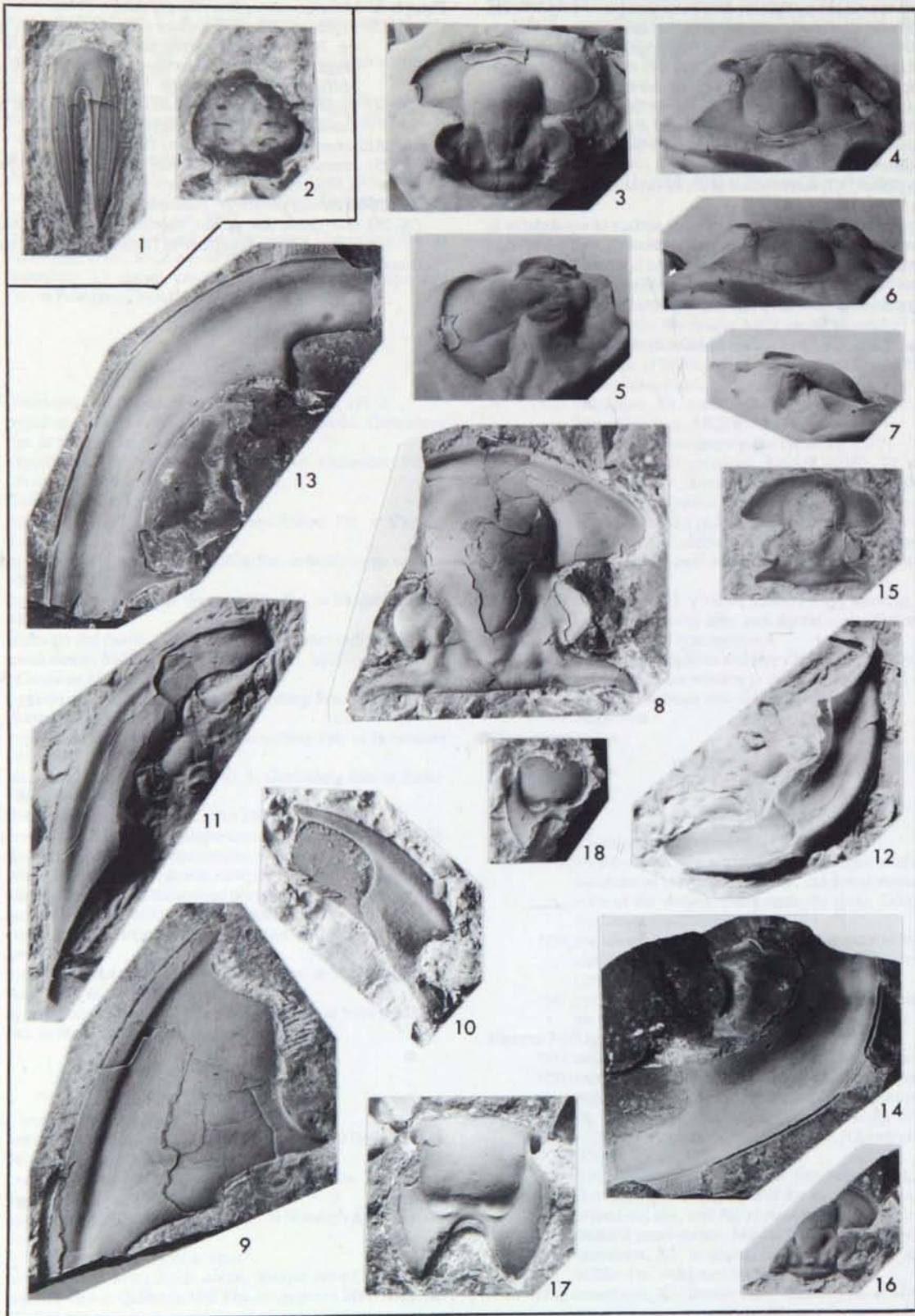


Plate No. 2

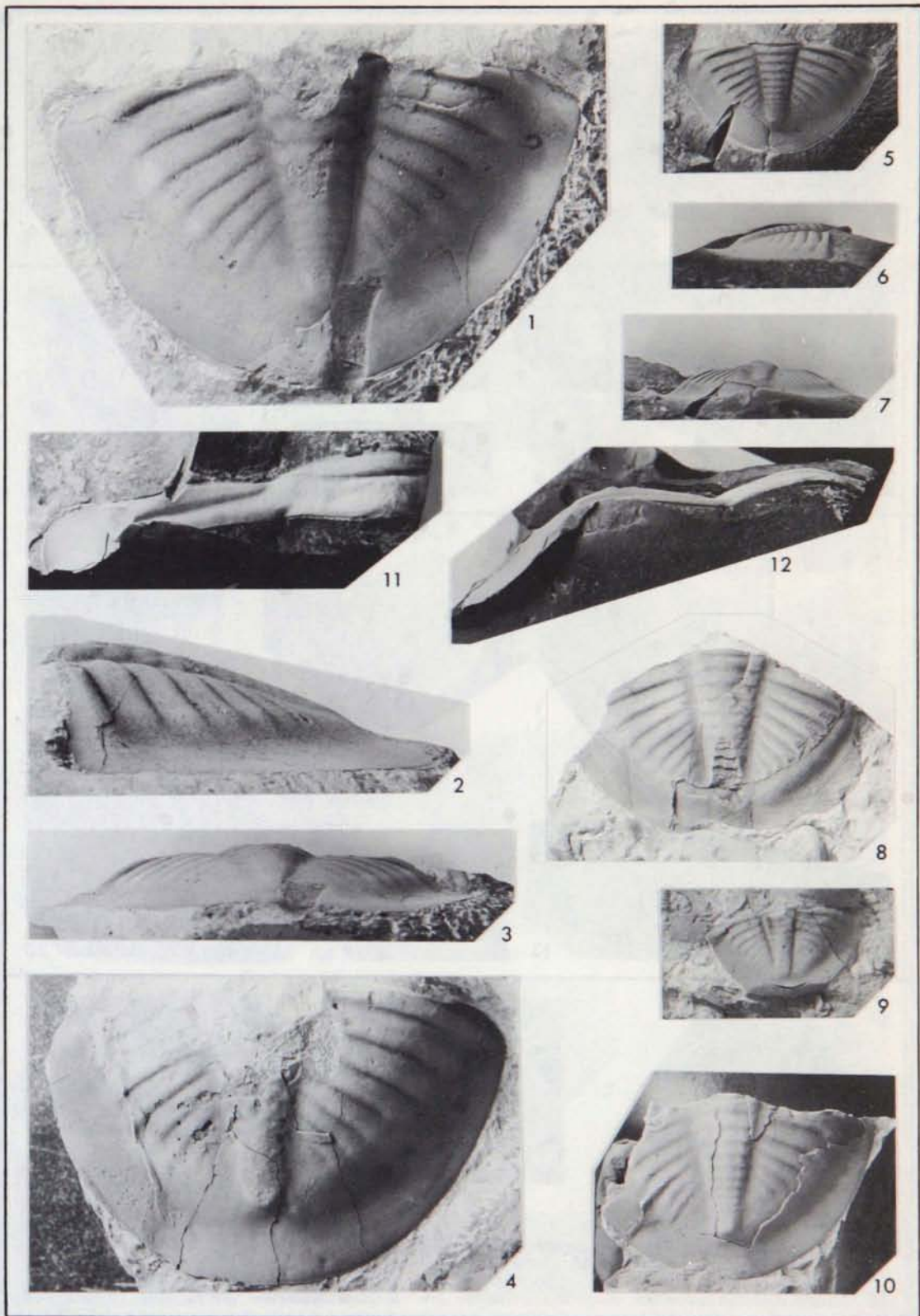


Plate No. 3

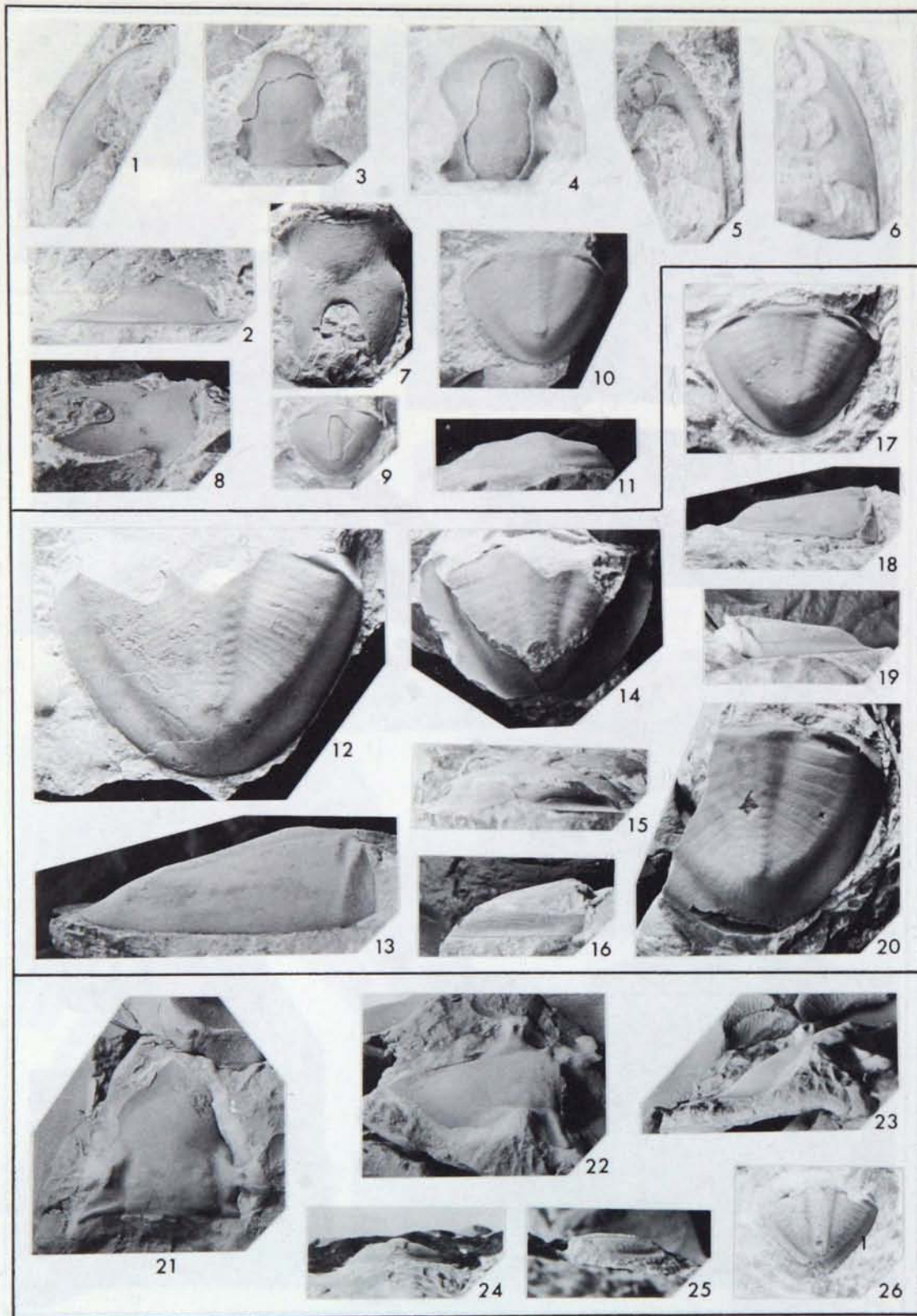


Plate No. 4

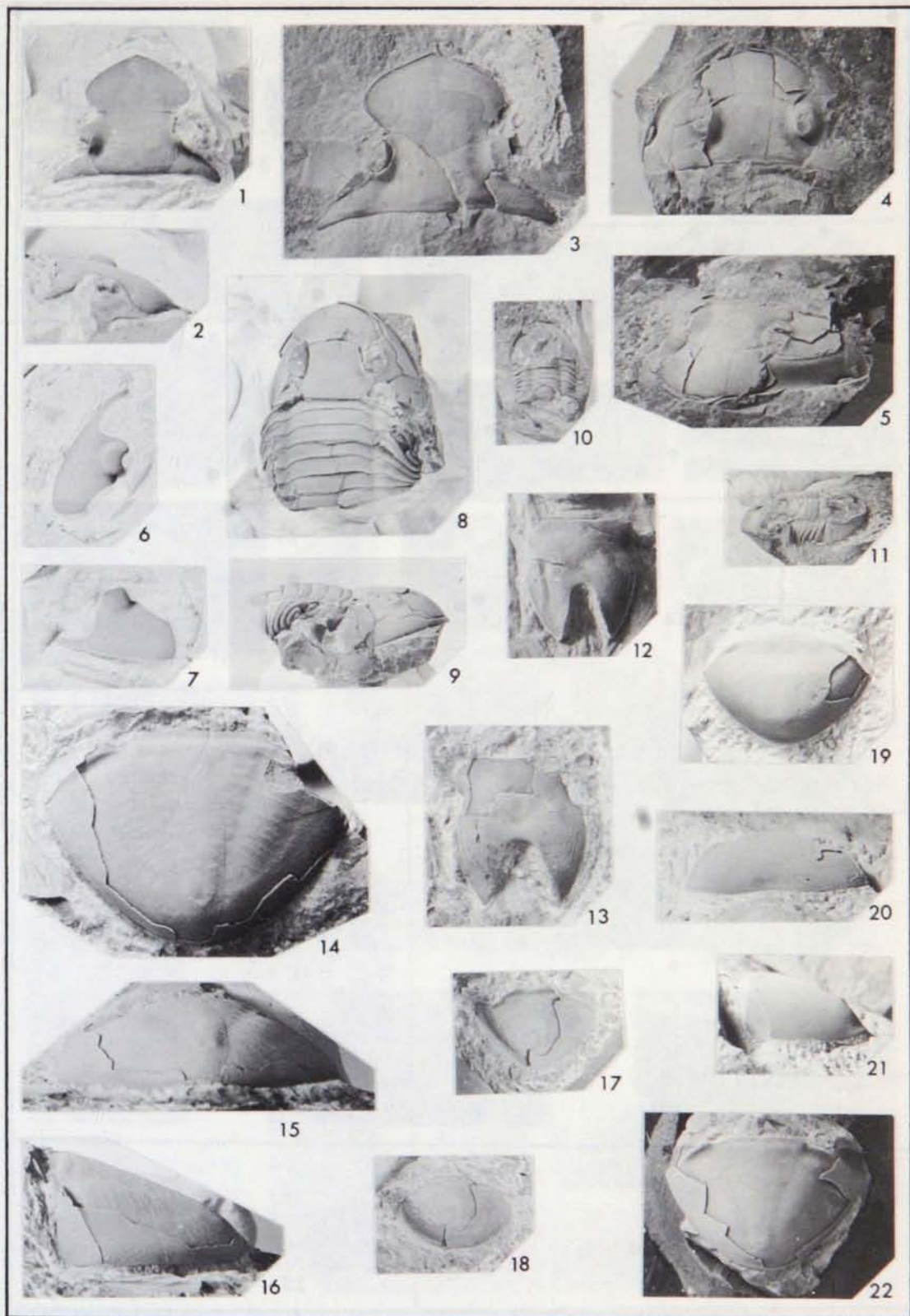


Plate No. 5

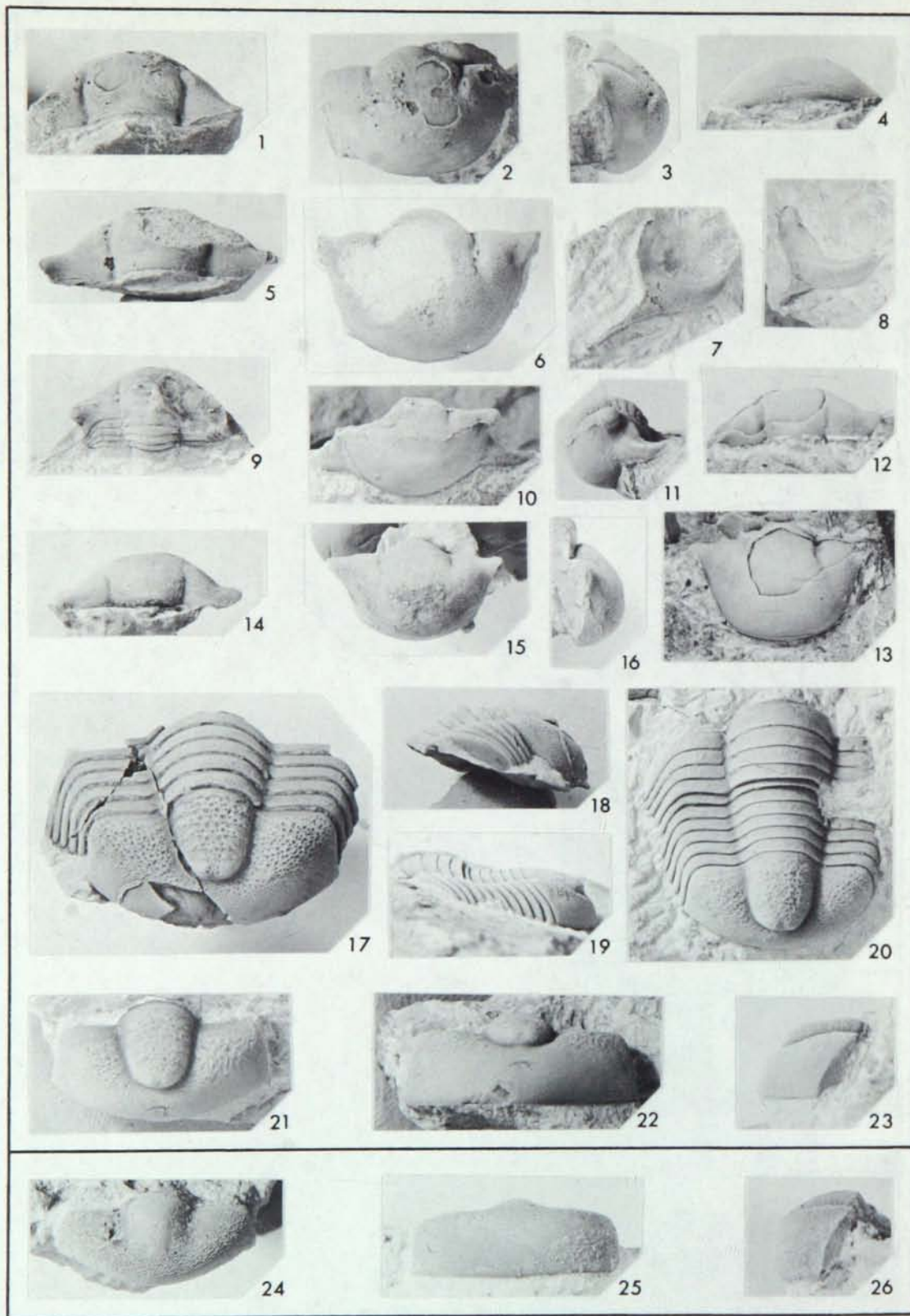


Plate No. 6

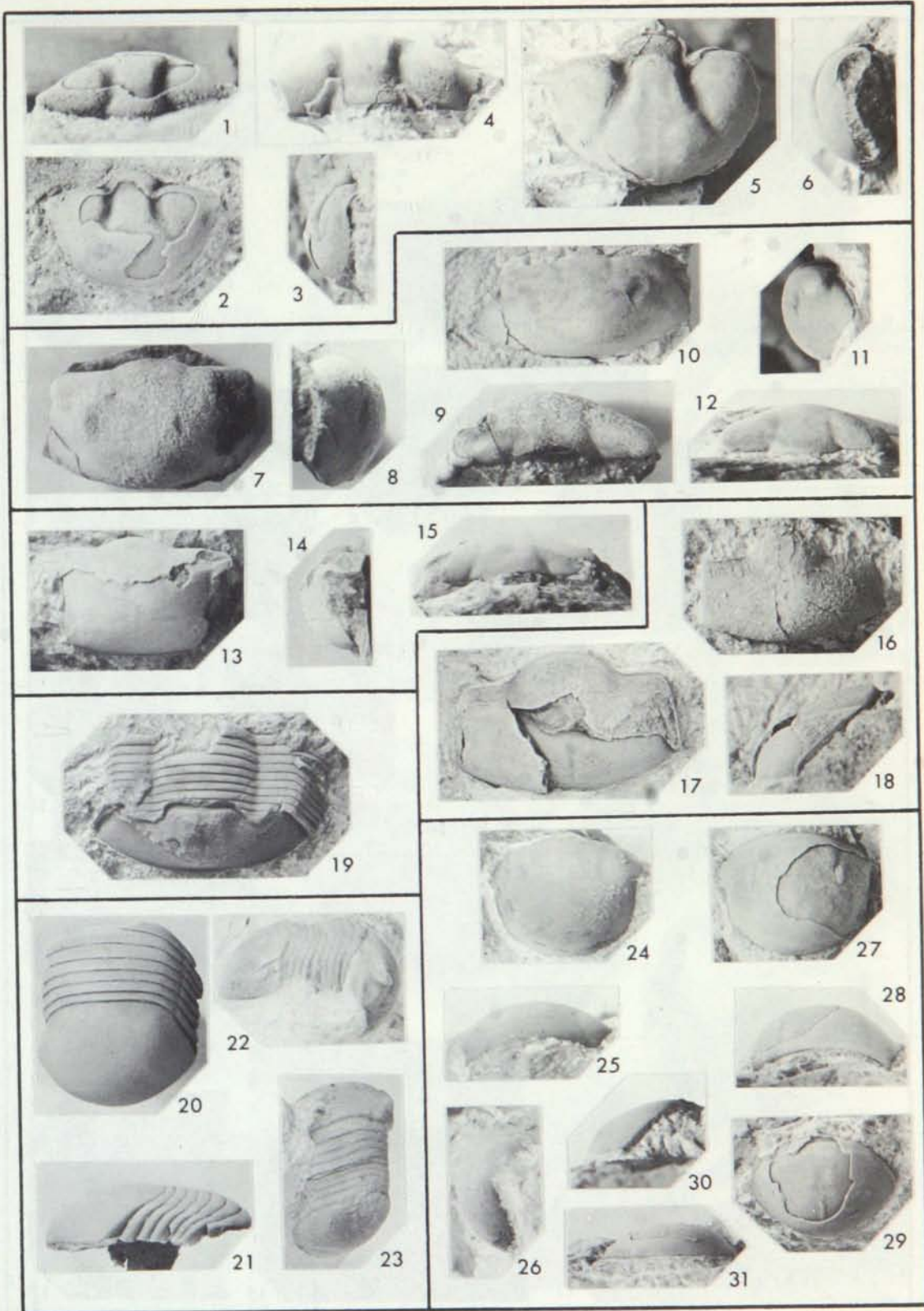


Plate No. 7

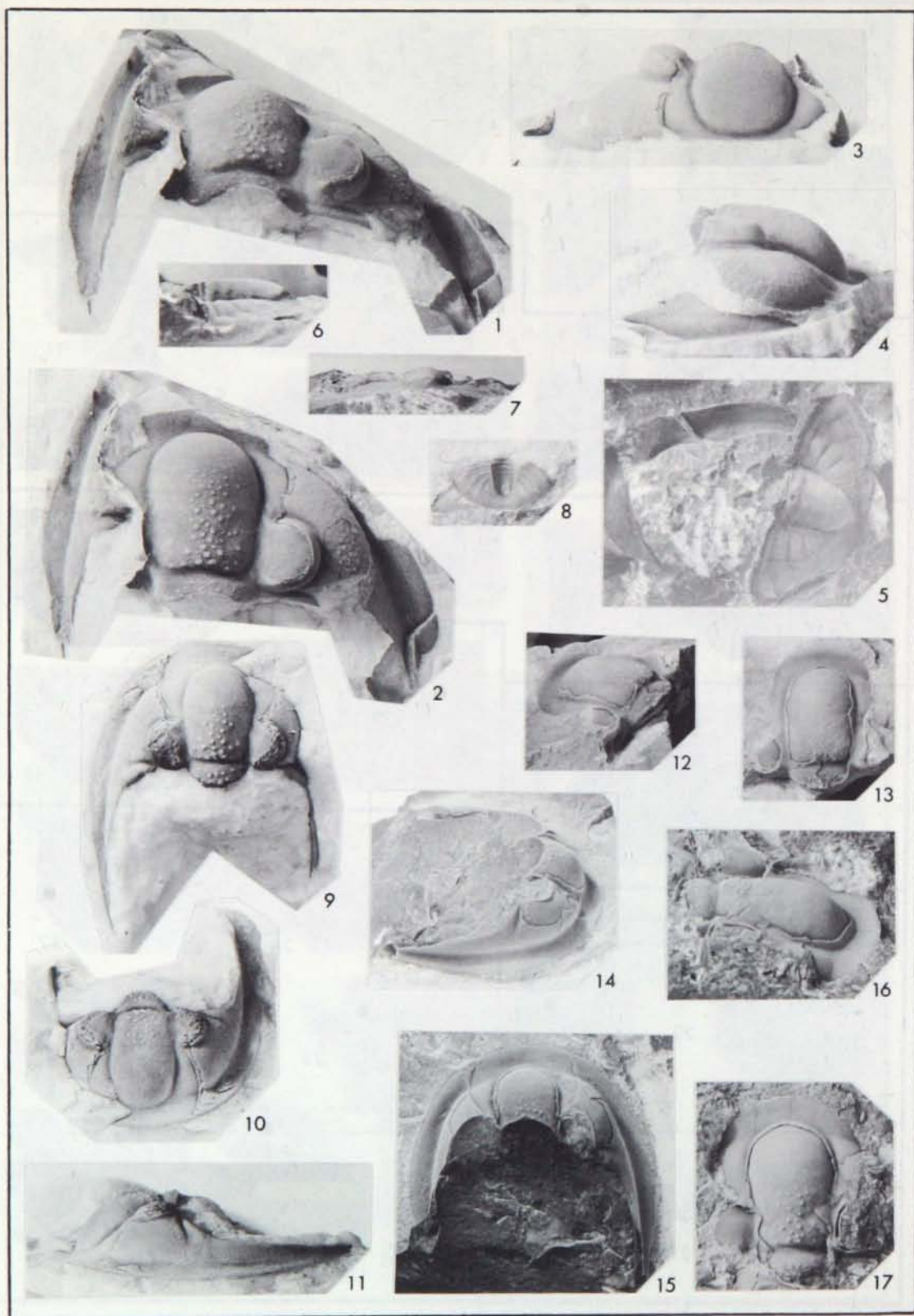


Plate No. 8

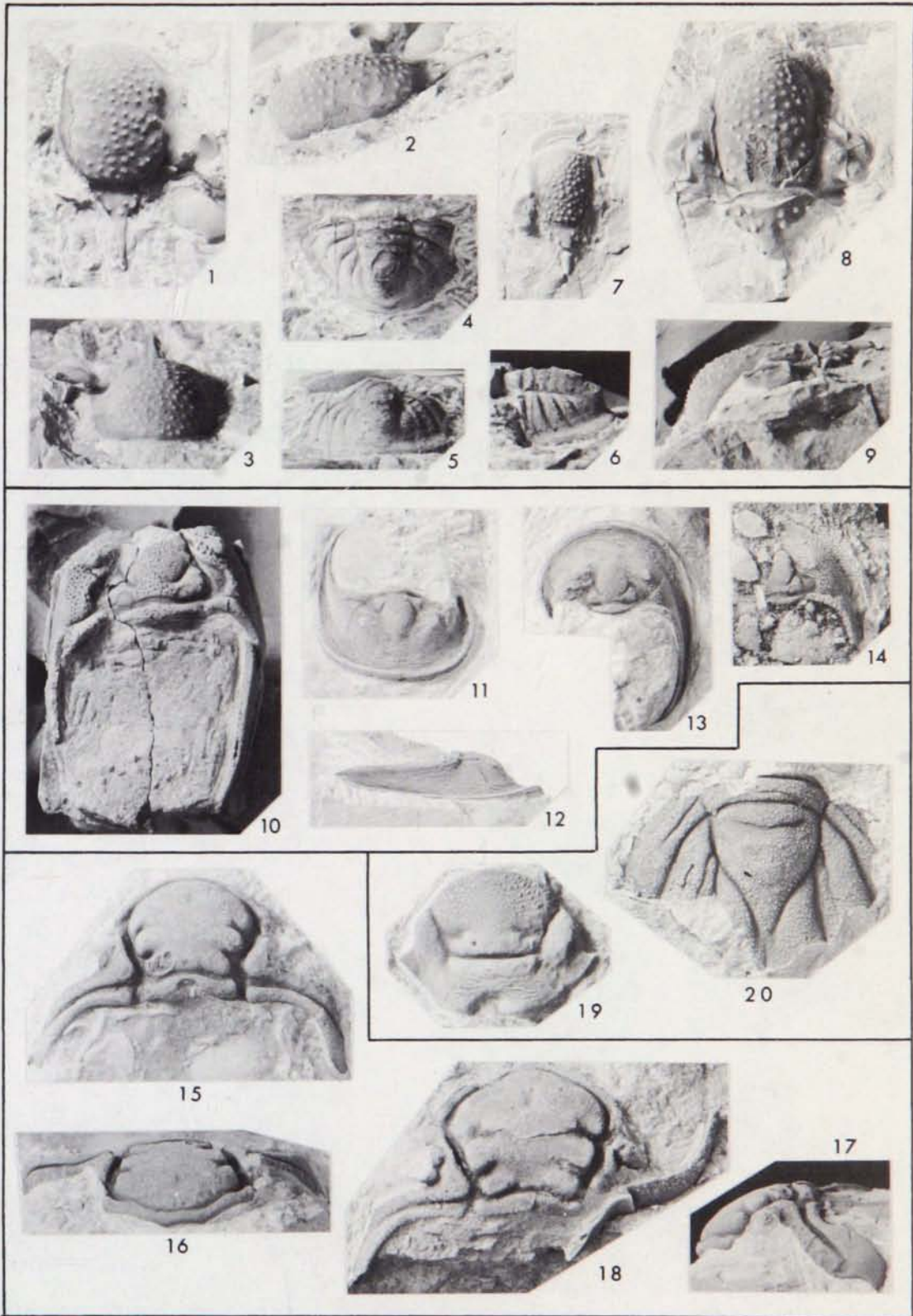


Plate No. 9

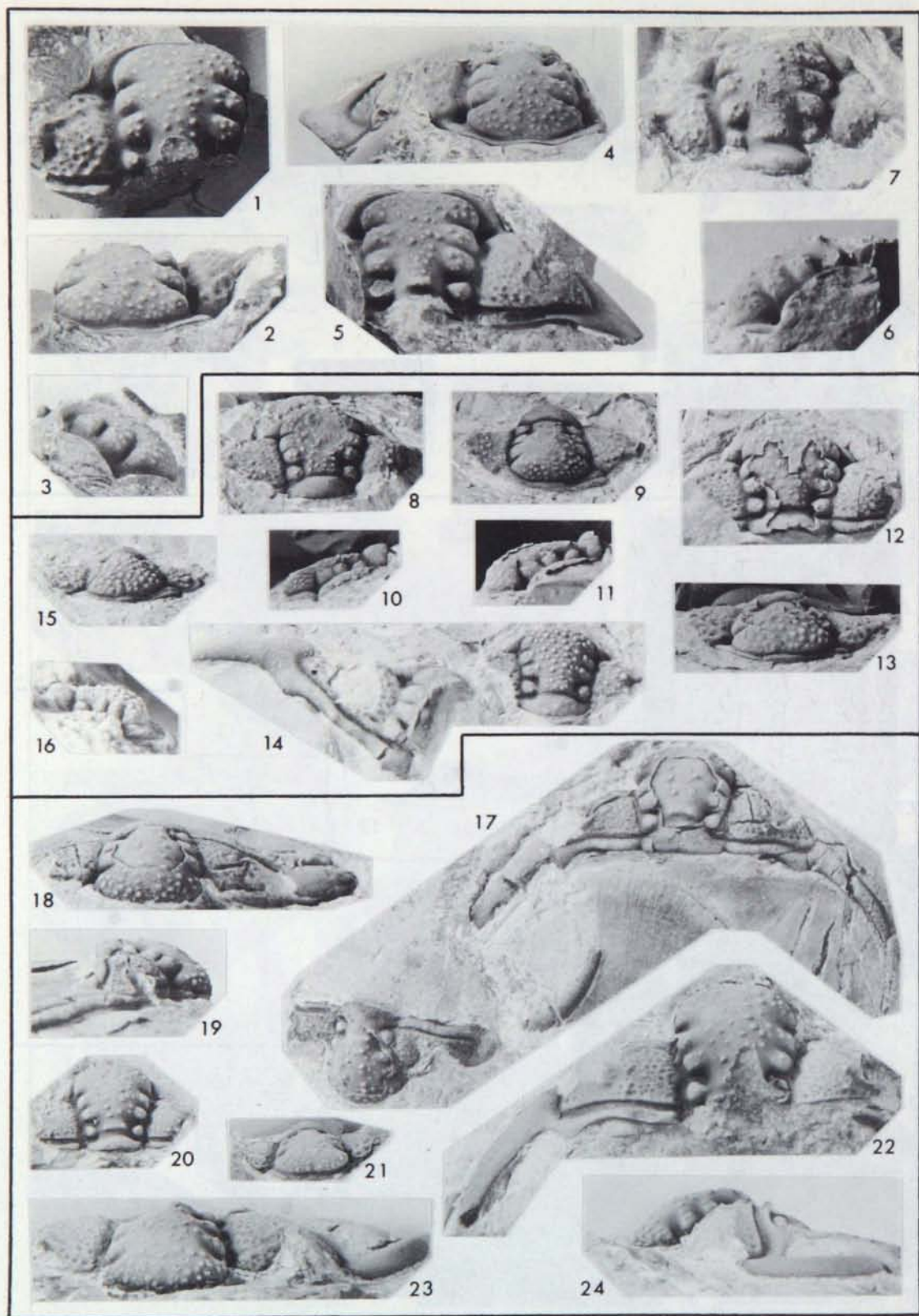


Plate No. 10

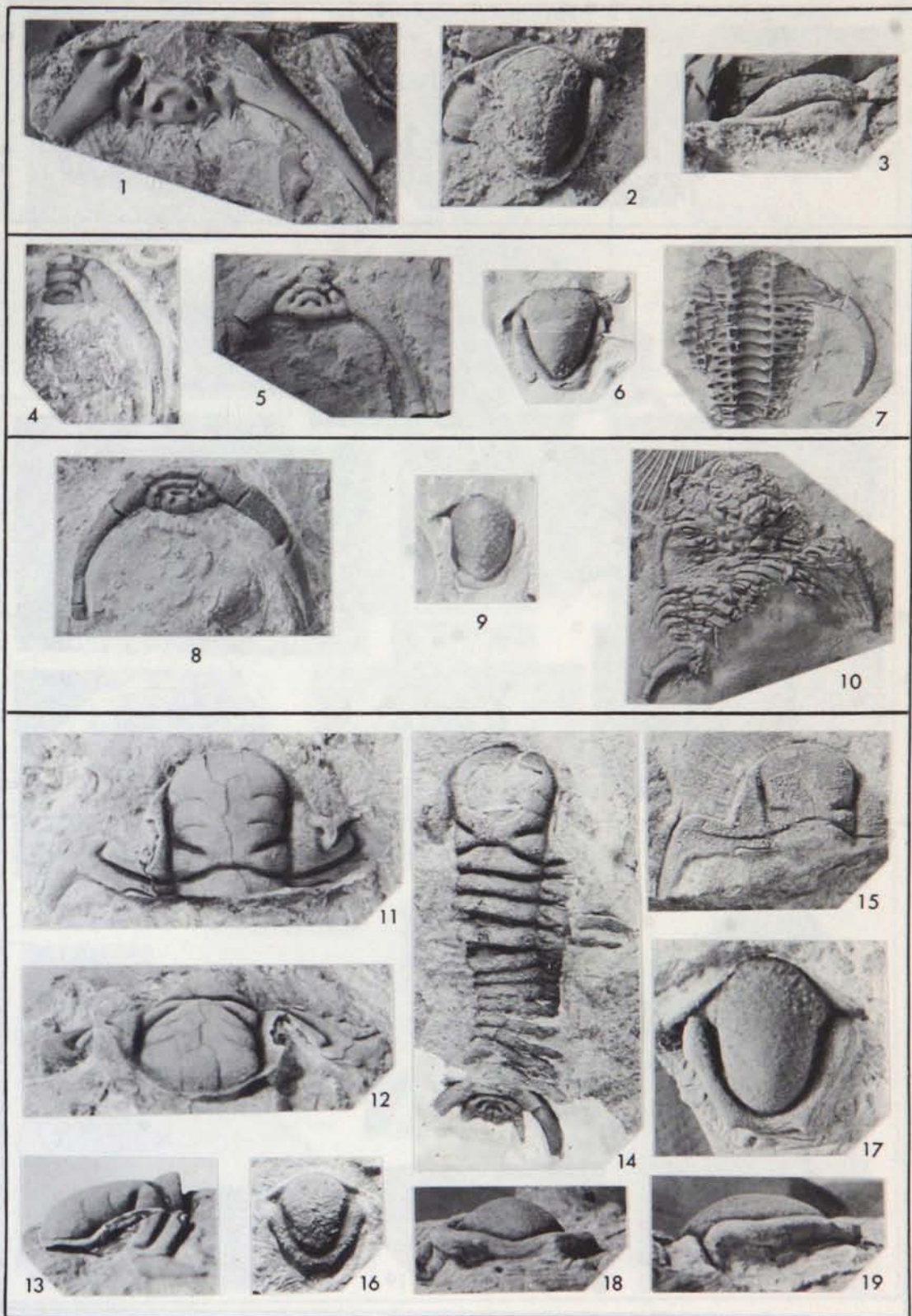


Plate No. 11

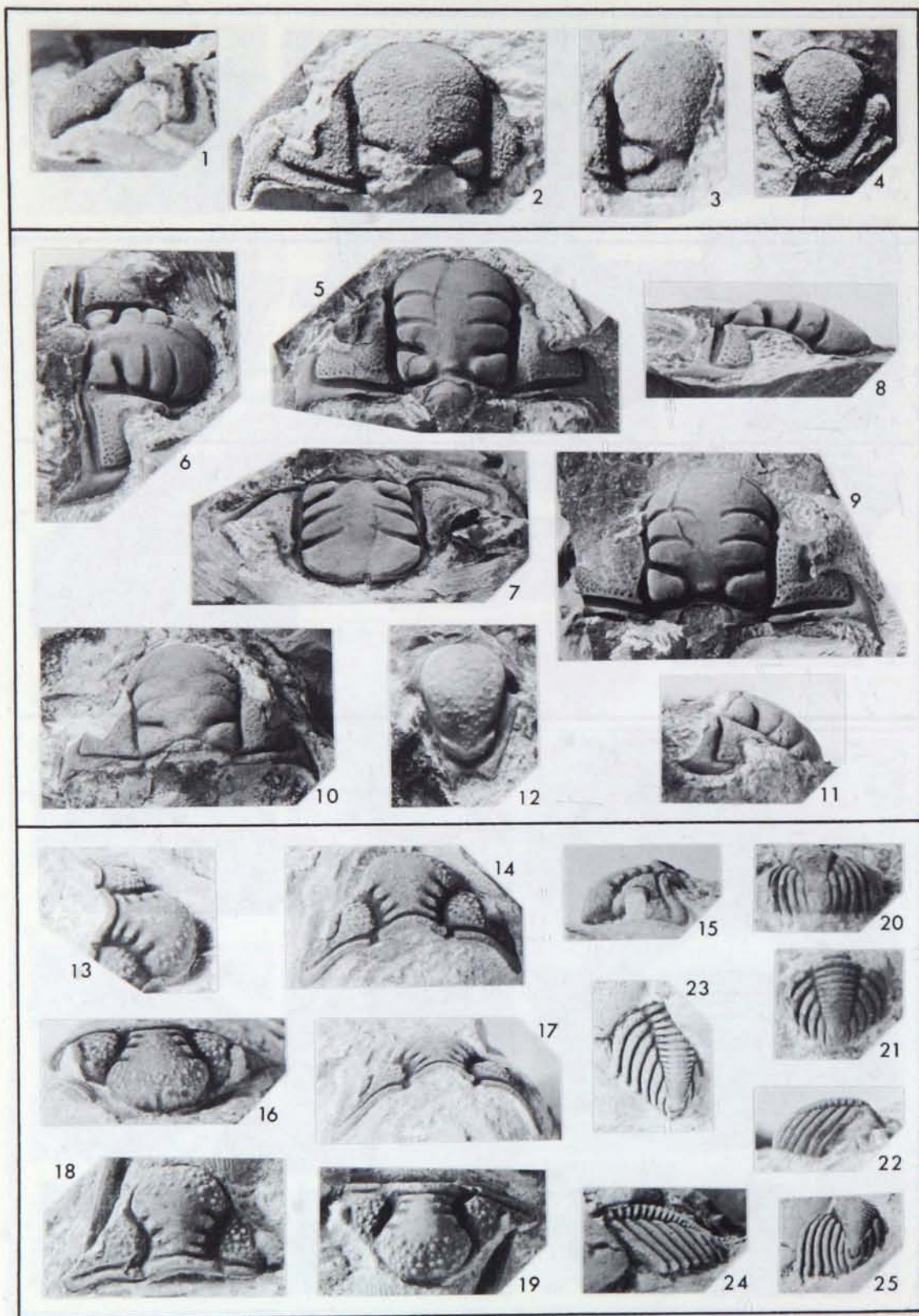


Plate No. 12

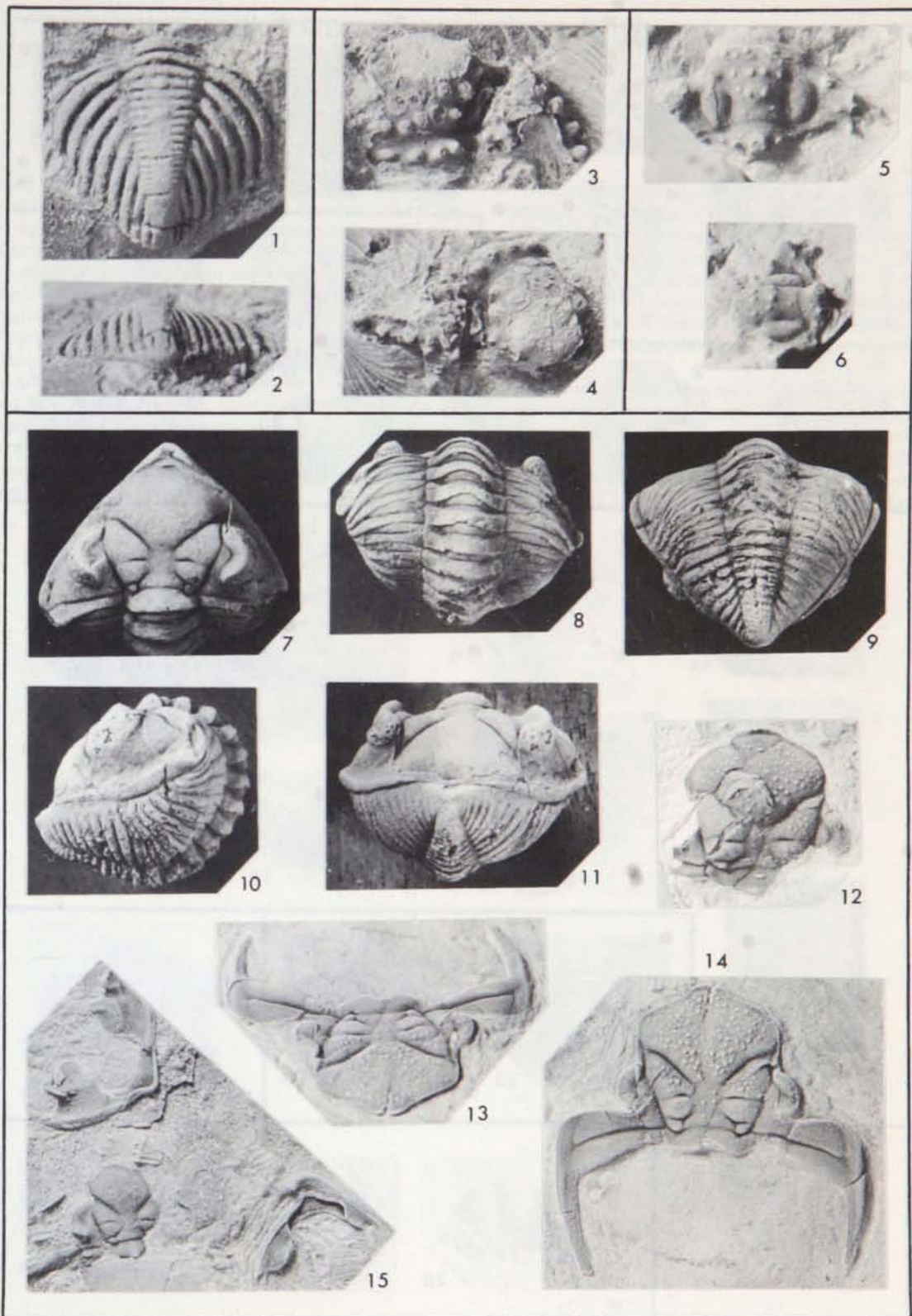
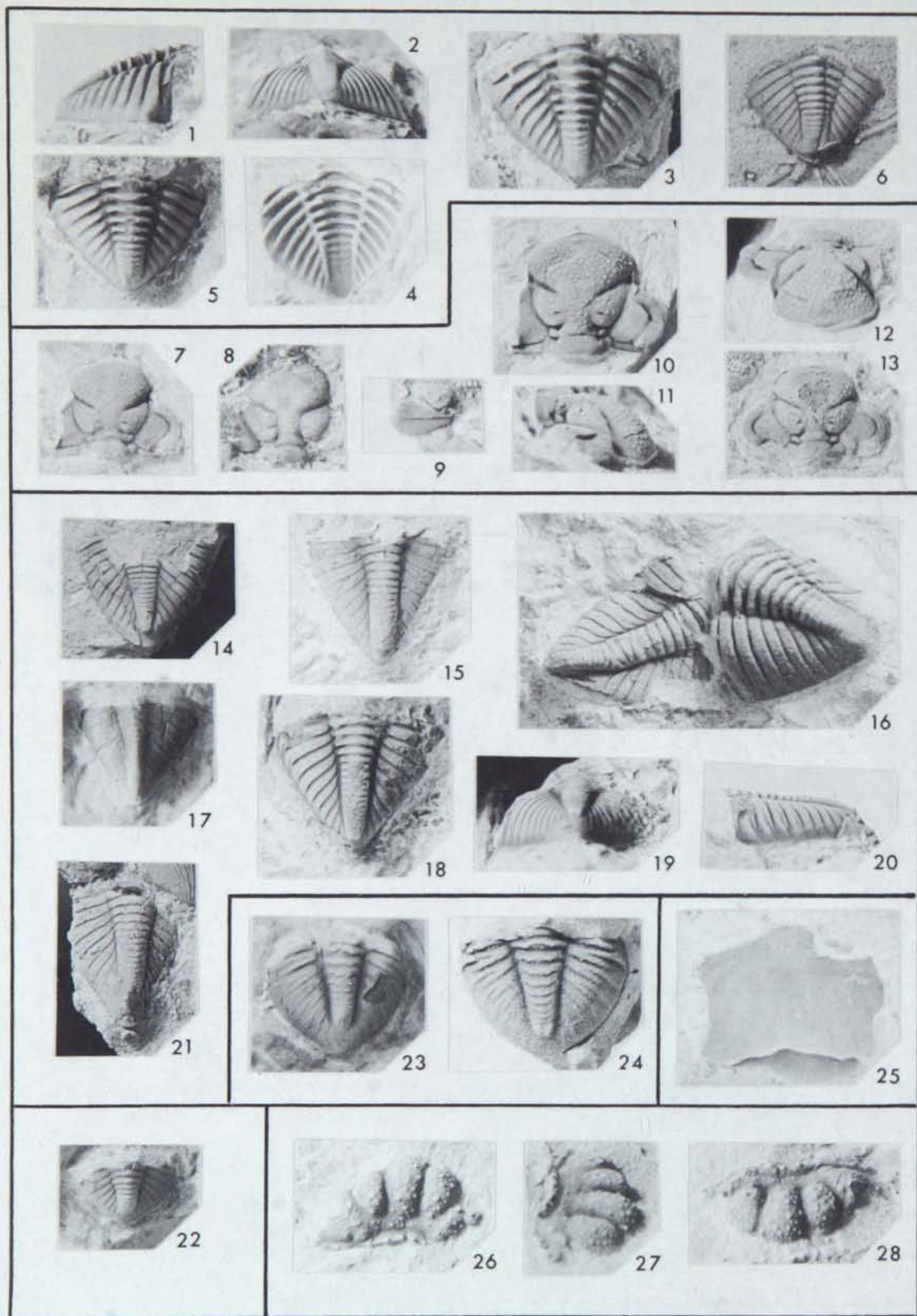


Plate No. 13



MIDDLE AND UPPER ORDOVICIAN OSTRACODA OF MINNESOTA AND IOWA

Frederick M. Swain

Department of Geology and Geophysics, University of Minnesota
Minneapolis, MN 55455

The upper Platteville, the Decorah, and Cummingsville formations (Rocklandian, Kirkfieldian, and early Shermanian) and the Dubuque and lower and middle Maquoketa Formations (Edenian-Maysvillian) have yielded about 150 species of paleocopid and primitive podocopid Ostracoda in southeastern Minnesota and northeastern Iowa (Fig. 11.1). Other parts of the Ordovician in the area contain eoleperditids as well as smaller ostracodes not yet sufficiently studied.

The Decorah Shale and uppermost Platteville limestone contain 64 recorded species, of which 10 are restricted to localities in Minnesota and 34 to localities in Iowa. Several of the Decorah species are represented in the lower Lexington Limestone of central Kentucky, as well as in some Middle Ordovician strata in New York, Pennsylvania, Virginia and Oklahoma and the "late Whittaker-early Barneveld" beds in northern Canada.

The Dubuque Formation (Middle Edenian) yielded only six ostracode species, of which only one is restricted to this formation.

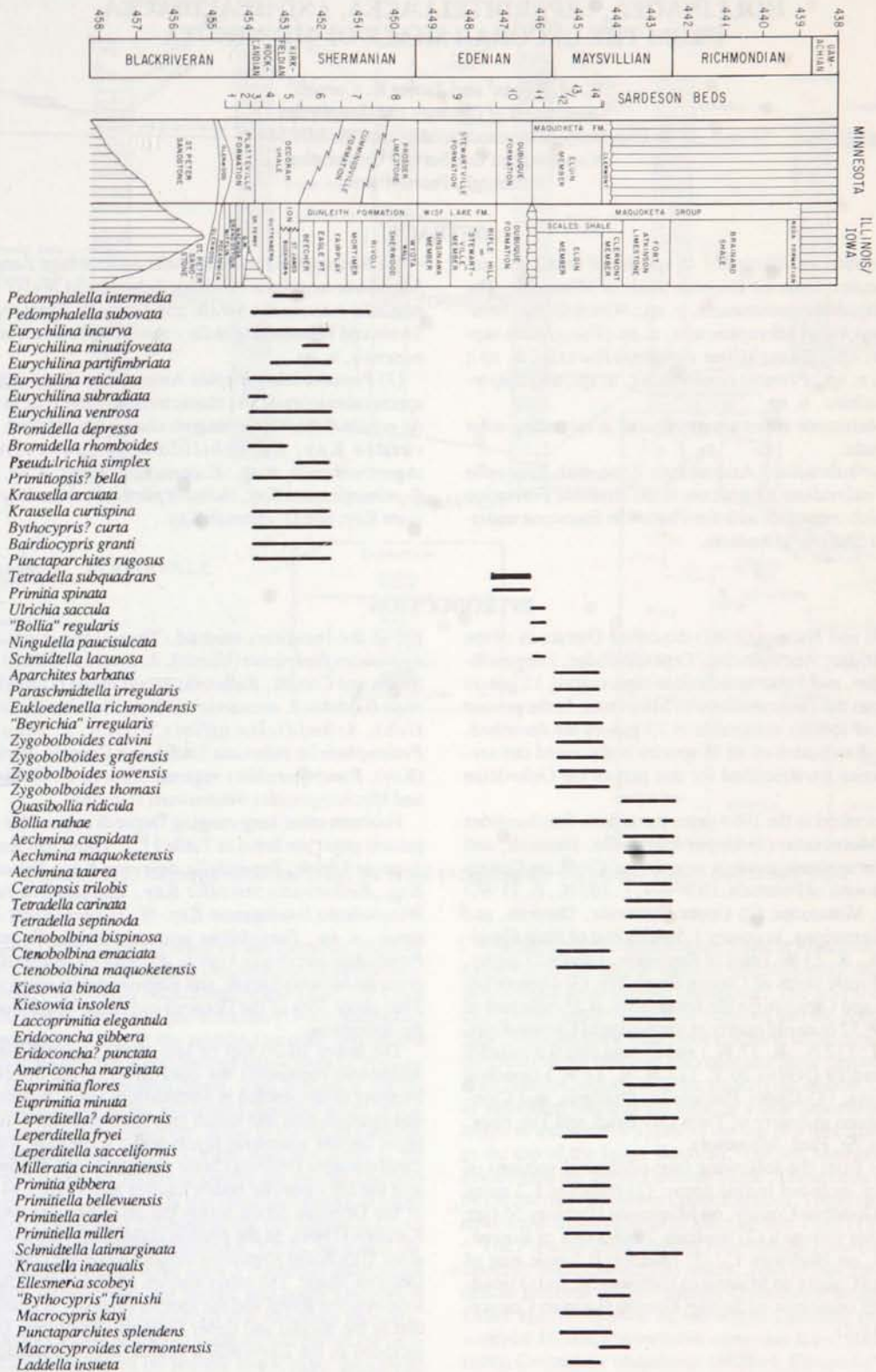
The "depauperate zone" of the lower Maquoketa Formation in northern Iowa has 11 recorded ostracode species, of which four are restricted to this phosphatic and pyritic facies. Elsewhere in Iowa and Missouri, the lower and middle parts of the Maquoketa contain 15 recorded species that have an Upper Ordovician aspect, but for which detailed comparisons with other regions have not yet been made.

Ostracode assemblages appear to represent marine carbonate shelf habitats of normal salinity. The Upper Mississippi valley faunas have been described as follows: Decorah Shale, Kay (1934, 1940), Swain and others (1961), Swain and Cornell (this volume); Dubuque Formation, Burr and Swain (1965); Maquoketa Formation, Burr and Swain (1965), Spivey, (1939) and Keenan (1951).



Figure 11.1. Biozonation chart of the Ostracoda of the Ordovician rocks of Minnesota and Iowa.

Figure 11.1 continued.



OSTRACODA OF THE SUPERFAMILIES DREPANELLEACEA, HOLLINACEA, LEPERDITELLACEA, AND HEALDIACEA FROM THE DECORAH SHALE OF MINNESOTA

F. M. Swain¹ and James R. Cornell²

¹Department of Geology and Geophysics
University of Minnesota, Minneapolis, MN 55455

²Consolidated Gas Service Corporation
Pittsburgh, Pennsylvania

ABSTRACT

This paper describes and illustrates 48 species of Ostracoda, including 8 new species, from the Decorah Shale of Minnesota. The new species are *Rigidella cannonensis*, n. sp.; *Winchellatia? cerasatopea*, n. sp.; *Eurychilina micropunctata*, n. sp.; *Eurychilina sugarcreekensis*, n. sp.; *Eurychilina cannonfallsensis*, n. sp.; *Eurychilina kayi*, n. sp.; *Primitia cannonensis*, n. sp.; and *Elliptocyprites paracylindrica*, n. sp.

The following ostracode zones are recognized in ascending order in the Decorah Shale:

(1) *Eurychilina subradiata* Assemblage Zone with *Krausella variata* Kraft. *E. subradiata* also occurs in the Bromide Formation of Oklahoma, which correlates with the Platteville limestone underlying the Decorah Shale in Minnesota.

(2) *Byrsolopsina planilateralis* Assemblage Zone, together with *Saccolatella angularis* (Ulrich); *Schmidtella brevis* Ulrich; *Pedomphalella intermedia* Swain and Cornell; *Byrsolopsina normeila* Swain and Hansen; *Rigidella cannonensis*, n. sp.; and *Primitia cannonensis*, n. sp.

(3) *Pseudulrichia simplex* Assemblage Zone, with the following species also more or less characteristic of the zone in this area: *Martia micula* (Ulrich); *Ceratopsis chambersi* (Miller); *Kiesowia? verrucosa* Kay; *Eurychilina micropunctata*, n. sp.; *E. sugarcreekensis*, n. sp.; *E. cannonfallsensis*, n. sp.; *E. kayi*, n. sp.; *E. minutifoveata* Kay; *Hallatia particylindrica* Kay; *Opikattia emaciata* Kay; and *O. rotunda* Kay.

INTRODUCTION

Swain, Cornell and Hansen (1961) described Ostracoda of the Families Aparchitidae, Aechminidae, Leperditellidae, Drepanellidae, Eurychilinae, and Punctaparchitidae representing 12 genera and 30 species from the Decorah Shale of Minnesota. In the present paper 48 additional species assignable to 23 genera are described. The stratigraphic distribution of all 78 species is discussed and several ostracodal zones are described for this part of the Ordovician System.

The species described in the 1961 paper came from four localities in southeastern Minnesota: (1) Upper Platteville, Decorah, and Cummingsville formations, roadcut near Sugar Creek on County Road E, 1.5 miles west of Fountain, (NW¹/₄ 9, T. 103 N., R. 11 W.) Fillmore County, Minnesota; (2) Upper Platteville, Decorah, and Cummingsville formations, in quarry 1.5 miles east of State Hospital, (32, T. 107 N., R. 13 W.) east of Rochester, Olmsted County, Minnesota, and 1 mile north of County Road 296; (3) Upper Platteville, Decorah, and Cummingsville formations, 0.25 mile east of Old U.S. Highway 52 in an old quarry at south edge of Cannon Falls, (SW¹/₄ SE¹/₄ 18, T. 112 N., R. 17 W.) and in road cuts 0.8 mile SE along County Road 19 (NW¹/₄ 20 T. 112 N., R. 17 W.) Goodhue County, Minnesota; (4) Upper Platteville, Decorah, and Cummingsville formations in quarry of Twin City Brick and Tile Plant, Cherokee Heights, St. Paul, Minnesota.

The specimens from the following four additional sections of Decorah Shale are included in this paper: (1) roadcuts 1.2 miles north of Wangs, Goodhue County, on Minnesota Highway 56 (see the last chapter, this volume); (2) roadcuts 2 miles east of Roscoe, Goodhue County, on Highway 11; (3) roadcuts 0.5 mile east of Chatfield, Olmsted County on Minnesota Highway 30; and (4) roadside quarry 1 mile southeast of Spring Grove, Houston County, Minnesota (Fig. 11.2).

STRATIGRAPHIC DISTRIBUTION OF THE SPECIES

In the previous paper (Swain and others, 1961), the distribution of Aparchitacea, Leperditellacea, and some of the Beyrichacea and Cytheracea of the Decorah Shale was given as shown in Table 1 of that paper. Thirteen of those 30 species occur throughout the Deco-

rah at the localities studied. These long-ranging species are: *Aparchitites fimbriatus* (Ulrich), *A. macrus* (Ulrich), *A. paratumida* Swain and Cornell, *Bullatella granilabiata* (Ulrich), *Saccolatella arrecta* (Ulrich), *S. arcuamuralis* Kay, *Easchmidtella umbonata* (Ulrich), *Schmidtella affinis* Ulrich, *S. incompta* Ulrich, *Pedomphalella subovata* Swain and Cornell, *Byrsolopsina ovata* (Kay), *Punctaparchitites rugosus* (Jones), *P. multipunctata* (Kay), and *Macrocyproides trentonensis* (Ulrich).

Fourteen other long-ranging Decorah ostracodes described in the present paper are listed in Table 11.1. These species are: *Bollia subaequata* Ulrich, *Bromidella depressa* Kay, *Tetradella ellipsilira* Kay, *Bellornatia tricollis* Kay, *Thomasatia falcicosta* Kay, *Winchellatia lansingensis* Kay, *W. minnesotensis* Kay, *W.? cerasatopea*, n. sp., *Eurychilina ventrosa* Ulrich, *E. reticulata* Ulrich, *Primitiella constricta* Ulrich, *Primitiella plattevilleensis* Kay, *Dicranella bicornis* Ulrich, and *Elliptocyprites paracylindrica*, n. sp. Thus about 35% of the Decorah ostracode species occur throughout the formation.

The lower 10-20 feet or less of the Decorah Shale of southern Minnesota represents the equivalent of the Spechts Ferry Shale Member as recognized in northeastern Iowa. It consists of interbedded greenish gray and bluish gray shale and thin 1- to 6-inch fossiliferous impure limestone layers and a somewhat localized 1-3 inch metabentonite (Milbrig) layer near the base. The lower beds represent the *Stictoporella* beds (Stauffer and Thiel, 1941), and this part of the Decorah Shale forms the *Stictoporella angularis* zone of Karklins (1969). In the present collections only *Eurychilina subradiata* Ulrich and *Krausella variata* Kraft are confined to the lower Decorah Shale. The other species of this part of the formation are long-ranging forms and the species diversity is relatively lower than that in the middle and upper Decorah. The lower Decorah Shale is included in the *Eurychilina subradiata* Assemblage Zone (Swain and others, 1961).

The middle and thickest part of the Decorah Shale of southern Minnesota consists of 20-50 feet or more of greenish gray and bluish gray shale and thin interbeds of coquinoid argillaceous limestone. The latter are generally fewer than in the lower Decorah but there is no definite boundary at either the base or the top of the middle

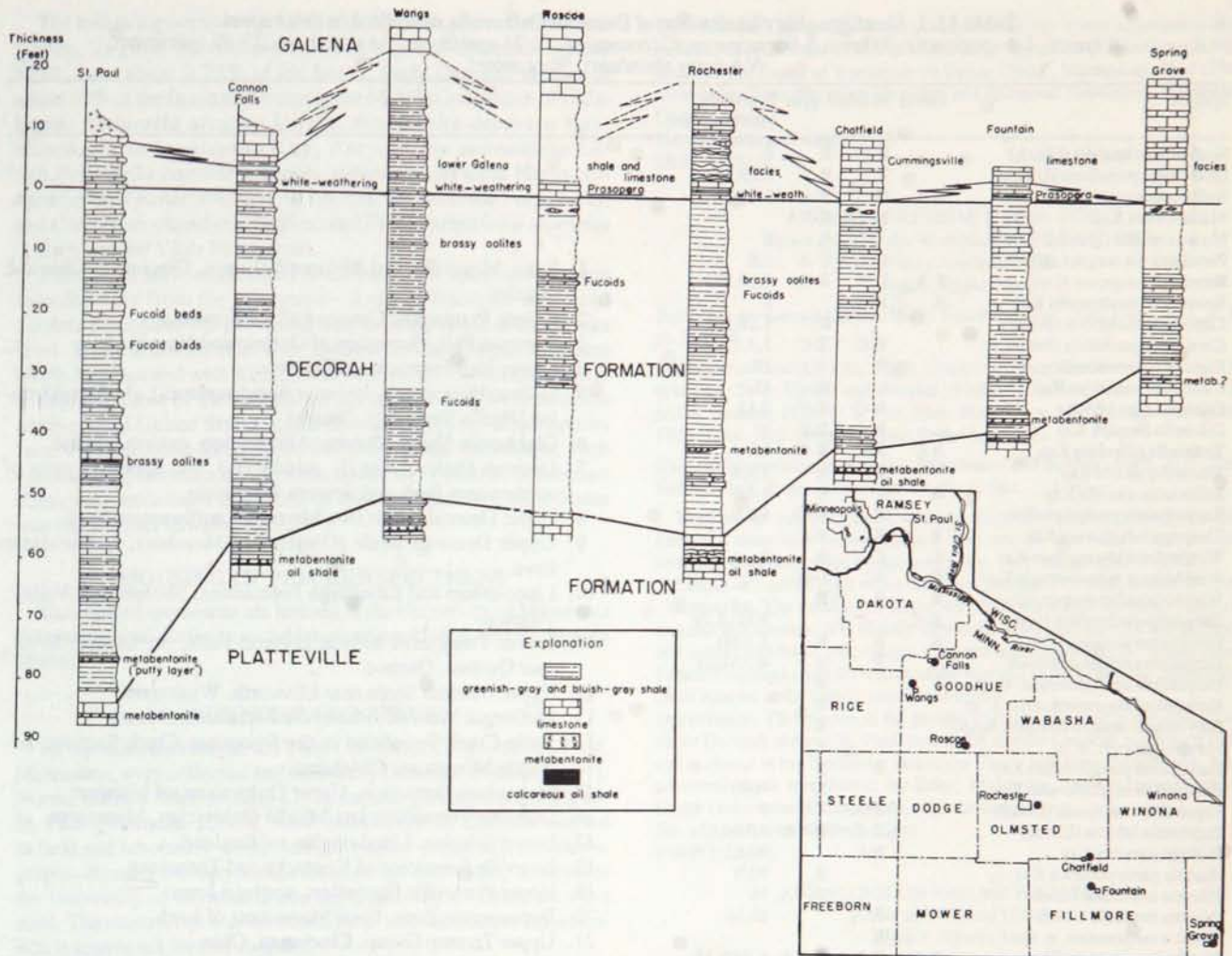


Figure 11.2. Decorah sections from St. Paul to Spring Grove, from which ostracods were collected.

Decorah unit. The Guttenberg Member of the Decorah Shale of northeastern Iowa represents the middle Decorah unit of Minnesota. The *Rhinidictya* and *Ctenodonta* beds (Stauffer and Thiel, 1941) are represented in the middle Decorah, and Karklins (1969) established the *Stictopora mutabilis* Zone in the middle Decorah. Swain and others, (1961) established the *Byrsolopsina planilateralis* Assemblage Zone for the middle Decorah Shale. This species is not restricted to the middle Decorah but apparently does not range below this unit to any extent; it does, however, occur in the upper Decorah Shale. *Nodambichilina symmetrica* (Ulrich) does not occur in the lower Decorah and is rare in the lower part of the middle Decorah (Swain and others, 1961); this species was cited as defining an upper or *Nodambichilina symmetrica* Subzone of the *Byrsolopsina planilateralis* Assemblage Zone (Swain and others, 1961), but it now appears that that species does not have such a restricted distribution and ranges equally well through the middle and upper Decorah at several localities. It is therefore discarded as a sub-zonal indicator. Several ostracode species are restricted to the middle part of the Decorah Shale in Minnesota, based on present knowledge: *Sacclatia angularis* Ulrich (rare), *Schmidtella brevis* Ulrich (rare), *Pedomphalella intermedia* Swain and Cornell (rare), *Byrsolopsina normella* Swain and Hansen (rare), *Hallatia convexa* Kay (rare to common; occurs in middle and upper Decorah of Iowa), *Rigidella cannonensis*, n. sp. (rare) and *Primitia cannonensis*, n. sp. (rare).

The upper part of the Decorah Shale in Minnesota comprises from a few feet to 20 feet or more of greenish-gray shale and blocky to thin-bedded fossiliferous limestone. The so-called fucooid beds that contain many vermicular burrows and the goethitic "brassy oolites" beds are somewhat more common in the upper than in the middle Decorah but that unit also contains these deposits locally. There is no definite contact with the underlying middle Decorah although in individual sections the base of a thin limestone bed may be selected as the top of the lower Decorah. The Ion Member of northeastern Iowa forms the upper Decorah Shale. These beds are characterized by the *Stictopora minima* Zone (Karklins, 1969) and by the *Chasmatorpora* and fucooid beds of Stauffer and Thiel (1941).

The *Pseudulrichia simplex* Assemblage Zone occurs in the upper Decorah Shale (Swain and others, 1961). This species is rare in the middle Decorah but is common to abundant in the upper Decorah. Other species typical of the upper Decorah are: *Macronotella scofieldi* Ulrich; *Parentathia camerata* Kay; *Maratia micula* (Ulrich); *Ceratopsis chambersi* (Miller); *Kiesowia? verrucosa* Kay; *Eurychilina micropunctata*, n. sp.; *E. sugarcreekensis*, n. sp.; *E. cannonfallsensis*, n. sp.; *E. kayi*, n. sp.; *E. minutifoveata* Kay; *Hallatia partycylindrica* Kay; *Primitia mammata* Ulrich (abundant); *Opikatia emaciata* Kay; and *O. rotunda* Kay. Several of the above species range into the Galena Group and into the overlying Dubuque

Table 11.1. Stratigraphic distribution of Decorah Ostracoda described in this report.
 [R (rare), 1-4 specimens; F (few), 5-9 specimens; C (common), 10-24 specimens; A (abundant), 25-49 specimens;
 VA (very abundant), 50 or more]

Species	Lower	Middle	Upper	Elsewhere (see footnotes)
<i>Scofieldia bilateralis</i> (Ulrich)		R-C	R	8
<i>Quasibollia persulcata</i> (Ulrich)		R	R	1,29,30
<i>Bollia subaequata</i> Ulrich	R-C	R	R-A	2,3,4,8
<i>Marattia mara</i> Kay		R-VA	R-VA	
<i>Marattia micula</i> (Ulrich)			R	8
<i>Pseudulrichia simplex</i> (Ulrich)		R	C-A	5,8
<i>Bromidella depressa</i> Kay	F-A	R-A	R-A	7,10,27
<i>Bromidella rhomboides</i> Kay	R	R		8
<i>Ceratopsis chambersi</i> (Miller)			R	1,28,30
<i>Ceratopsis quadrifida</i> (Jones)		R-C	R-C	3,4,7,11
<i>Rigidella cannonensis</i> , n. sp.		R		15
<i>Kiesowia? verrucosa</i> Kay			R	15
<i>Dilobella typa</i> Ulrich		R-C	R-C	8,12
<i>Dilobella simplex</i> Kay		R	R-F	12
<i>Tetradella ellipsilira</i> Kay	R-C	R-C	R-C	8,9
<i>Tetradella ulrichi</i> Kay		R	R-F	3,4,8
<i>Bellornatia tricollis</i> Kay	R	F	R	4,6,8
<i>Raymondatia goniglypta</i> Kay		R	R-C	4,8,9
<i>Thomasatia falcicosta</i> Kay	R	R	R-C	
<i>Winchellatia lansingensis</i> Kay	C	C	R	9
<i>Winchellatia minnesotensis</i> Kay	R	R?	C-R	
<i>Winchellatia? ceratopea</i> , n. sp.	R	R	R	
<i>Eurychilina subradiata</i> Ulrich	R-C			7(M),8,29
<i>Eurychilina ventrosa</i> Ulrich	R	R	R	2,7(M)
<i>Eurychilina reticulata</i> Ulrich	R	R	R	4,7(M,U)
<i>Eurychilina micropunctata</i> , n. sp.			R	
<i>Eurychilina sugarcreekensis</i> , n. sp.			R	
<i>Eurychilina cannonfallsensis</i> , n. sp.			R	
<i>Eurychilina kayi</i> , n. sp.			R	
<i>Eurychilina partifimbriata</i> Kay	R		R	
<i>Eurychilina minutifoveata</i> Kay			R	7(M)
<i>Euprimitia sanctipauli</i> (Ulrich)	R	R-A		7
<i>Euprimitia labiosa</i> (Ulrich)		R-C	F-VA	4,7(M,U)
<i>Hallatia convexa</i> Kay		R-C		7(M,U)
<i>Hallatia partycylindrica</i> Kay			R	7(U)
<i>Primitia mammata</i> Ulrich			A-VA	16
<i>Primitia tumidula</i> Ulrich				15,16
<i>Primitia cannonensis</i> , n. sp.		R		
<i>Primitiella constricta</i> Ulrich	R-VA	R-VA	R-VA	4,7(U),18
<i>Primitiella plattevilensis</i> Kay	R	R	R	19
<i>Pseudoprimitiella unicornis</i> (Ulrich)		R		15,20,21,22, 23?,24?,28
<i>Opikatia emaciata</i> Kay			R	7(M,U)
<i>Opikatia rotunda</i> Kay			R	
<i>Dicranella bicornis</i> Ulrich	R	R	R	9
<i>Dicranella marginata</i> Ulrich		R	R	8,9
<i>Elliptocyprites paracylindrica</i> , n. sp.	R-VA	R-VA	R-VA	2?,7
<i>Krausella variata</i> Kraft	C			10,25
<i>Krausella arcuata</i> Ulrich		R	R	7(M,U),17?,26,27

- Eden, Maysville, and Richmond Groups, Cincinnati, Ohio and vicinity.
- Galena Formation, Cannon Falls, Minnesota.
- Sherman Falls Formation of Ontario and New York.
- Lower Hull Formation of Ontario.
- Liskeard Formation, lower unit, subsurface, Lake Temiskaming, Harris Township, Ontario.
- Glenburnie Shale, Chaumont Formation, eastern Ontario.
- Decorah Shale, lower (l), middle (m), and upper (u) parts of northeastern Iowa and western Wisconsin.
- Upper Decorah Shale (Ion Member), northeastern Iowa.
- Upper Decorah Shale (Guttenberg Member), northeastern Iowa.
- Lincolnshire and Edinburgh Formations, Shenandoah Valley, Virginia.
- Lower Trentonian beds at Lorrette Falls, St. Charles River, near Quebec, Quebec.
- Upper Decorah Shale near Ellsworth, Wisconsin.
- McGregor Member, Platteville Formation of Iowa.
- Tulip Creek Formation in the Sycamore Creek Section, Arbuckle Mountains, Oklahoma.
- Maquoketa Formation, Upper Ordovician, of Missouri
- Dubuque Formation, late Middle Ordovician, Minnesota.
- Lower Silurian, Llandoveryan, of England.
- Lowville Formation of Kentucky and Tennessee.
- Upper Platteville Formation, northern Iowa.
- Depauperate Zone, basal Maquoketa of Iowa.
- Upper Trenton Group, Cincinnati, Ohio.
- Canajoharie and Whetstone Gulf Formations, New York.
- Yeringian Formation, Lilydale, Australia.
- Bola Formation, Montgomeryshire, Wales.
- Crown Point Formation, Middle Chazyan, New York.
- Platteville Formation, Illinois and Wisconsin.
- Bromide Formation, Oklahoma.
- Viola Formation, Oklahoma.
- Lexington Limestone, central Kentucky.
- Clays Ferry Formation, central Kentucky.

Formation and Maquoketa Formation of southern Minnesota and northern Iowa. *C. chambersi* has also been recorded in the Upper Ordovician of southern Ohio, and in the Middle Ordovician of Oklahoma.

Detailed range charts of Decorah ostracode species were prepared by Cornell (1956) for the sections at Rochester, Sugar Creek near Fountain, St. Paul, and Cannon Falls. Copies of these charts are on file at the Minnesota Geological Survey.

Provinciality of the Fauna

In earlier studies of the geographic distribution of Decorah Shale ostracode species, Jones (1891), Kay (1934, 1940), and Copeland (1965) found that the following also occur in the Trenton Group, Middle Ordovician of New York, Quebec and Ontario: *Para-*

parchites rugosus (Jones), *Schmidtella incompta* Ulrich, *Bollia subaequata* Ulrich, *Pseudulrichia simplex* (Ulrich), *Ceratopsis quadrifida* (Jones), *Tetradella ulrichi* Kay, *Bellornatia tricollis* Kay, *Raymondatia goniglypta* Kay, *Eurychilina reticulata* Ulrich, *Euprimitia labiosa* (Ulrich), *Primitiella constricta* Ulrich, and *Pseudoprimitiella unicornis* (Ulrich). They represent about 15% of the ostracode species from the Decorah Shale of Minnesota.

Several of the species have been recorded previously from the Middle Ordovician of Ohio, Tennessee and Kentucky: *Primitiella constricta* Ulrich, *Pseudoprimitiella unicornis* (Ulrich), and *Krausella arcuata* Ulrich. These represent about 6.4% of the Decorah fauna. Two species have been found in the Upper Ordovician near Cincinnati, Ohio: *Quasibollia persulcata* (Ulrich) and *Ceratopsis chambersi* Miller.

The following occur in the Middle Ordovician of the Shenandoah Valley, Virginia: *Bromidella depressa* Kay and *Krausella variata* Kraft, i.e., about 0.25% of the fauna. Eight Decorah species or about 10% of the fauna also occur in the Middle Ordovician of Oklahoma: *Krausella arcuata* Ulrich, *Bromidella depressa* Kay, *Winchellatia longispina* Kay, *Eurychilina subradiata* Ulrich, *Primitiella constricta* Ulrich, *subspecies varicata* Harris, *Elliptocyprites paracylindrica*, n. sp. (in the Bromide Formation), and *Ceratopsis chambersi* (Miller) and *Pseudoprimitiella unicornis* (Ulrich) (in the Viola Formation).

Thus about 68% of Decorah Shale ostracode species have been recorded only from the Minnesota—Iowa—Wisconsin areas, and the data emphasize the provincial nature of the fauna at the species level. While affinities exist with Trentonian assemblages in eastern North America and with Black River and Trentonian assemblages in Oklahoma, most of the species are endemic to the Decorah of the north-central United States. Little or no relationship at the species level with European forms is indicated by present knowledge. Such a relationship between northern European early Middle Ordovician (Chazyan) ostracodes and those of the northeastern United States was cited earlier (Swain, 1962).

HOUSING OF FIGURED SPECIMENS

The figured specimens are housed in the University of Minnesota Paleontological Collections under numbers UMPC 15139 through 15186.

ACKNOWLEDGMENTS

The specimens from the old Twin City Brick Co. plant at St. Paul, Minnesota, were collected and studied by Donald L. Hansen (1951). Norma Hansen (Mrs. Donald L.) assisted in picking and sorting the St. Paul specimens. John C. Kraft and Olgerts L. Karklins assisted in field and laboratory work. Takako Nagase prepared SEM photographs. Beverly Davis typed the manuscript. Laboratory facilities at the University of Minnesota and the University of Delaware were used. The manuscript was reviewed by S. M. Warshauer. Appreciation is expressed for this support.

SYSTEMATIC PALEONTOLOGY

- Class OSTRACODA Latreille 1804
- Order PALAEOCOPIIDA Henningsmoen, 1953
- Suborder BINODICOPINA Schallreuter, 1972
- Superfamily DREPANELLACEA Ulrich and Bassler, 1923
- Family DREPANELLIDAE Ulrich and Bassler, 1923
- Genus SCOFIELDIA Ulrich and Bassler, 1908
- Scofieldia bilateralis* (Ulrich)
- Plate 1, figure 5; plate 2, figure 5

Drepanella bilateralis Ulrich, 1894, Final Report Geol. and Nat. Hist. Survey Minnesota, v. 3, pt. 2, p. 671, pl. 46, figs. 35-38.

Scofieldia bilateralis (Ulrich), Ulrich and Bassler, 1908, U.S. Nat. Mus. Proc., v. 35, p. 314, pl. 41, figs. 16-18. Swartz, 1936, Jour. Paleontology, v. 10, p. 552, pl. 82, figs. 2. Kay, 1940, Jour. Paleontology, v. 14, p. 261.

Shell large, about 3 mm long, subquadrate-subhemispherical, hinge margin about three-fourths of shell length, surface with deep, slightly anteromedian subvertical sulcus in dorsal half which curves anteriorly at midheight; triangular node projects from dorsal margin dorsad of sulcus; anterior to sulcus is a forwardly curved, strongly elevated broad lobe that projects as a blunt point beyond dorsal margin; posterior to sulcus is a backwardly curved, large, broad, strongly-elevated lobe that also projects as a blunt point beyond dorsal margin; this lobe lies closer to valve middle than does anterior lobe; ventral and posterior surface formed into a broad ridge parallel to valve margin; general surface faintly and finely pustulose.

Hingement apparently consists of simple contact of valves.

Length of figured left valve (Pl. 1, fig. 5) 2.68 mm, height 1.86 mm, width 0.53 mm.

Occurrence. The species in the present collection is rare to common in the middle Decorah Shale at St. Paul, rare in the upper Decorah at Cannon Falls, and was not found at Rochester or Sugar Creek, Minnesota. Kay (1940) recorded it from the upper Decorah in Glenwood Township, Winneshiek County, Iowa.

No. of specimens studied. 18

UMPC. 15139

Family BOLLIIDAE Bouček, 1930

Genus *Quasibollia* Warshauer and Berdan, 1982

Quasibollia persulcata (Ulrich)

Plate 1, figures 6a-d

Beyrichia persulcata Ulrich, 1879, Cincinnati Soc. Nat. Hist., v. 2, p. 12, pl. 7, fig. 6

Bollia persulcata (Ulrich), 1890, Cincinnati Soc. Nat. Hist., v. 13, p. 116, text figs. 3a-d; Ulrich and Bassler, 1908, U.S. Nat. Mus. Proc., v. 35, p. 288; Bassler, 1915, U.S. Nat. Mus. Bull. 92, p. 129; Bassler and Kellett, 1934, Geol. Soc. America Spec. Paper 1, p. 218.

Quasibollia persulcata (Ulrich), Warshauer and Berdan, 1982, U.S. Geol. Survey. Prof. Paper 1066-H, p. 20, pl. 1, figs. 2, 4-10.

Shell small, subquadrate. U-shaped ridge interrupted medially on each limb by a transverse furrow; ridge is very narrow and nearly discontinuous ventrally; marginal ridge broad terminally, very narrow mid-ventrally.

Length of figured right valve 0.38 mm, height 0.23 mm, width 0.11 mm.

Remarks. The small size, shape, and furrows across the inner ridge distinguish this species. It is closely similar in shape and form of marginal rim and inner ridge to *B. planojugosa* Swartz and Swain and *B. sagittaformis* Swartz from the Lower Devonian of the Appalachian region, but differs from those species in the details mentioned above.

Occurrence. The species in the present collection is rare in the middle and upper Decorah shale at St. Paul; rare in the middle Decorah at Cannon Falls; and is absent at the Rochester and Sugar Creek localities, Minnesota. It has previously been recorded in the Eden, Maysville, and Richmond Groups, Upper Ordovician of Cincinnati, Ohio and vicinity.

No. of specimens studied. Eight

UMPC. 15140

Genus *BOLLIA* Jones and Holl, 1886

Bollia subaequata Ulrich

Plate 2, figures 1a-h

Bollia subaequata Ulrich, 1894, Final Rept. Geol. and Nat. Hist. Survey Minnesota, v. 3, pt. 2, p. 669, pl. 46, figs. 26-29. Kay, 1934, Jour. Paleontology, v. 8, p. 336, pl. 44, figs. 6-16. Kay, 1940, Jour. Paleontology, v. 14, p. 258, pl. 32. Shimer and Shrock, 1944, Index Fossils of North America, p. 667, pl. 281, figs. 24-26.

Shell subovate-subelliptical, relatively short and high, dorsum sinuous, cardinal angles obtuse; ends rounded, the anterior slightly more extended beyond end of hinge than posterior; broad, smooth marginal rim; U-shaped ridge broad, discontinuous ventrally, ends projecting slightly beyond dorsal margin in most, but not all, specimens; median sulcus between limbs of U-shaped ridge lies slightly anterior to midlength. General surface unornamented. Hinge consists of simple valve contacts. Muscle scar a small elevation near lower end of median interior ridge that represents exterior sulcus.

Length of figured right valve 0.68 mm, height 0.45 mm, width 0.20 mm.

Remarks. The small size and transverse furrow across the base of the U-shaped ridge distinguish this species. *Bollia unguis* (Jones) and related species from the Devonian are similar to *B. subaequata* in shape and major features of ornamentation but generally are large and have the inner ridge more strongly elevated.

Occurrence. In the present collection the species was rare near the base of the Decorah Shale but rare to abundant in the upper Decorah at St. Paul; rare to common four to eight feet above the base of the Decorah at Rochester; rare 20-24 feet above base; and absent at Sugar Creek, Minnesota. It was found previously to be uncommon to very abundant in the upper Decorah of northeastern Iowa, in the Galena Formation at Cannon Falls, Minnesota (Ulrich, 1894; Kay, 1940), the Sherman Falls Formation of Ontario and New York (Kay, 1934), and the Lower Hull Formation of Ontario (Kay, 1934; Copeland, 1965).

No. of specimens studied. 45

UMPC. 15141

Genus *MARATIA* Kay, 1940*Maratia mara* Kay

Plate 1, figures 2a-g

Plate 11, figures 1, 2

Maratia mara Kay, 1940, Jour. Paleontology, v. 14, p. 258, pl. 32, figs. 35, 36; Moore, ed., 1961, Treatise Invert. Paleont., v. Q, p. 129, figs. 62, 7a-c.

Shell subquadrate in side view, highest medially, hinge margin straight, nearly equal to shell length and with slightly obtuse cardinal angles; ventral margin moderately convex; terminal margins broadly and nearly uniformly rounded, the anterior slightly more extended above and truncate below than posterior. Valves nearly equal in size, the right extending slightly beyond left along venter; posteroventral edge of right valve finely spinose; dorsally, left valve extends slightly beyond edge of right; valves more or less compressed, with greatest convexity ventromedian.

Anterior end with a dorsomedian submarginal ridge or lobe (L_1) that fails to reach dorsal margin and dies out at a position venterad of midheight, either abruptly (in males) or by merging gradually with valve surface, as in females; posterojacent to L_1 is a narrow sulcus and then an elongate anteromedian lobe or ridge (L_2) that extends from dorsal margin to midheight, median sulcus lies posterior to L_2 , is open dorsally and extends to venterad of midheight where it gradually becomes shallower and disappears; posterior to median sulcus is a small dorsomedian nodelike lobe (L_3) and behind this, with narrow intervening sulcus, posterior shell surface is inflated as a broad lobe that extends into venter.

Hingement consists of a weak rabbit groove in the edges of both valves, that of left valve fits over right.

Length of figured valve (Pl. 1, fig. 2a) 0.34 mm, height 0.23 mm, width 0.093 mm.

Remarks. The existence of dimorphism in this species is difficult to demonstrate, although *Maratia micula* seems to show it. *M. mara* is higher with respect to length and more equal-ended than *M. micula*. There is considerable variation in the coarseness of the pitting in *M. mara*, although Kay states that pitting is finer in *M. mara* than in *M. micula*. *M. mara* also has a row of posteroventral marginal spines on right valve, not seen in other described species.

Occurrence. The species is rare to very abundant from 11 feet above base to the top of the Decorah at St. Paul; from 15 to 43 feet above base of the Decorah at Cannon Falls; common from 45 to 52 feet above base of Decorah at Wings, Minnesota, in Galena equivalent; 49-51 feet above base of Decorah in section 2 miles east of Roscoe, Minnesota; 40-44 feet above base of Decorah in section on Sugar Creek near Fountain, Minnesota.

No. of specimens studied. 180

UMPC. 15142

Maratia micula (Ulrich)

Plate 1, figures 3a-d

Primitia micula Ulrich, 1894, Final Rept. Geol. and Nat. Hist. Survey Minnesota, v. 3, pt. 2, p. 653, pl. 43, figs. 69-72; Bassler, 1915, U.S. Nat. Mus. Bull. 92, p. 1031; Bassler and Kellett, 1934, Geol. Soc. America Spec. Paper 1, p. 448.

Maratia micula (Ulrich) Kay, 1940, Jour. Paleontology, v. 14, p. 259, pl. 32, figs. 37, 38.

Shell elongate subquadrate in side view, highest about one-third from anterior end; hinge margin straight, about four-fifths of shell length, with only slightly obtuse cardinal angles, of which the posterior is less sharply defined than the anterior; ventral margin moderately convex; posterior margin broadly rounded, anterior margin much narrower, extended above. Valves nearly equal in size, the left may be slightly the larger judged from contact relationships; valve surfaces compressed, with greatest convexity postero-median. Left valve may overlap right ventrally, although complete shells not observed.

A rounded lobate ridge (L_1) lies a little within anterior margin, extending from a position at or near dorsal margin to anteroventral marginal bend where it merges with general valve surface; a second lobe (L_2) lies about one-third from anterior margin, rising near dorsum and dying out near or venterad of midheight; median sulcus occurs approximately at midlength, is open dorsally and merges with valve surface near midheight; a small nodelike lobe (L_3) lies posterior to median sulcus and varies in position from near midheight to near dorsum; posterior one-fourth to one-third of valve more or less inflated (L_4). Dimorphism represented by presumed female forms in which ventral and posterior parts of shell are relatively more inflated, median and anterior lobes merge gradually with shell surface ventrally, in contrast to

males in which lobes are shorter and have more abrupt ventral terminations. General surface except anterior and median lobes coarsely pitted.

Hinge surface consists of simple edges of valves in direct contact; a small notch of uncertain function occurs at anterior cardinal angle of each valve. Muscle scar consists of a small oval scar near ventral end of median sulcus.

Length of figured left valve (Pl. 1, fig. 3b) 0.38 mm, height 0.22 mm, width 0.11 mm.

Remarks. This species is more elongate and less equal-ended than *M. mara* the type species, and it is also more coarsely punctate than that species.

Occurrence. Rare in upper part of Decorah Shale, 67-73 and 77-79 feet above base, St. Paul; rare in upper Decorah, 98-101 feet above base, Wings, Minnesota. Kay originally recorded it from the Ion Member near Church, Iowa. The indications are that the species is restricted to the Ion or upper Decorah, although it is generally rare.

No. of specimens studied. Seven

UMPC. 15143

Family RICHINIDAE Scott, 1961

Genus *PSEUDULRICHIA* Schmidt, 1941*Pseudulrichia simplex* (Ulrich)

Plate 2, figures 3a-e

Dicranella simplex Ulrich, 1894, Final Rept. Geol. and Nat. Hist. Survey Minnesota, v. 3, pt. 2, p. 666, pl. 44, figs. 24, 25, pl. 46, fig. 42.

Bollia simplex (Ulrich) Kay, 1940, Jour. Paleontology, v. 14, p. 258, pl. 32, figs. 33, 34; Swain, and others, 1961, Jour. Paleontology, v. 35, p. 349.

Pseudulrichia simplex (Kay), Scott and Hessland, 1961, in Moore, ed., Treatise Invert. Paleont., v. Q, p. 132, figs. 64, 3e, f; Copeland, 1965, Geol. Surv. Canada Bull. 127, p. 9, pl. 11, figs. 13, 14, 17.

Subovate, short and high, dorsum slightly sinuous, about two-thirds of length, anterior and posterior margins nearly equally and broadly curved, the anterior slightly extended below; anteromedian sulcus gently curved anteriorly in dorsal half; rounded nodes lie on either side of sulcus, the posterior a little more dorsal than the anterior; a short sulcus borders rear node posteriorly. Hinge consists of simple valve edges; adductor muscle scar a small spot on lower part of inner ridge representing median sulcus.

Length of left valve 0.79 mm, height 0.54 mm, width 0.18 mm.

Remarks. Scott (in Moore, 1961) erected the Family Richinidae to include *Bollia*-like genera that lack a marginal rim. Scott and Hessland (1961) assigned Ulrich's species *simplex* to *Pseudulrichia* Schmidt, 1941.

Occurrence. The species is rare in the middle Decorah and common to abundant in the uppermost 12 feet at St. Paul, common in the upper Decorah at Cannon Falls; common in the upper 8 feet at Sugar Creek, Minnesota; and is absent at Rochester. It also occurs in the upper Decorah at Ion, Iowa (Kay, 1940). Copeland (1965) found the species in the Liskeard Formation, lower unit, in a well drilled in Lake Temiskaming, Harris Township, Ontario.

No. of specimens studied. 55

UMPC. 15144

Suborder BEYRICHICOPINA Scott, 1961

Superfamily HOLLINACEA Swartz, 1936

Family PIRETELLIDAE Öpik, 1933

Genus *BROMIDELLA* Harris, 1931*Bromidella depressa* Kay

Plate 9, figure 6; plate 10, figures 1a-g

Plate 11, figures 3, 4, 9, 10

Bromidella depressa Kay, 1940, Jour. Paleontology, v. 14, p. 263, pl. 34, figs. 12-15; Kraft, 1962, Geol. Soc. America Mem. 86, p. 43, pl. 15, figs. 8-17, text fig. 14g,h.

Small, elongate-ovate to subquadrate; dorsum straight to sinuous; venter convex; ends rounded, anterior a little broader than posterior; posterior dorsal cardinal angle varies from slightly obtuse to slightly acute. Shells strongly dimorphic; presumed females bear an elongate rounded frill in anterior-ventral two-thirds; anterodorsal sulcus, anterojacent rounded nodelike lobe; posterodorsal longitudinally elongate lobe; larger posteroventral elongate lobe separated from preceding lobes by furrows; posterior marginal zone compressed; general surface densely pustulose; in ventral view opposing free edges of dimorphic frill do not meet.

Length of figured specimen (Pl. 10, fig. 1a, c) 0.49 mm, height 0.30 mm, width 0.16 mm; length of female specimen (Pl. 10, fig. 1d, g) 0.56 mm, height 0.44 mm, width 0.38 mm.

Occurrence. The species is frequent to abundant throughout the Decorah

Shale at St. Paul; frequent from 5.4 feet above base to the top of the Decorah at Cannon Falls; rare in the middle and upper Decorah at Rochester and at Sugar Creek. Kay (1940, p. 237) found *B. depressa* frequent throughout the Decorah in northeastern Iowa, Minnesota and western Wisconsin. It has also been recorded from the Lincolnshire and Edinburgh Formations near Strasburg, Virginia (Kraft, 1962).

No. of specimens studied. 65

UMPC. 15145

Bromidella rhomboides Kay

Plate 10, figures 2a-g

Plate 11, figures 5, 6

Bromidella rhomboides Kay, 1940, Jour. Paleontology, v. 14, p. 263, pl. 34, figures 16, 17.

Shell small, subrhomboidal in lateral view; dorsum straight, with obtuse anterior cardinal angle and nearly normal to acute posterior cardinal angle; terminal margins truncated, slightly convex, the anterior extended below, the posterior extended above. Short anteriorly curved dorsomedian, slightly anterior sulcus; anteromedian low, rounded dorsal lobe or node; posteromedian low broad dorsal swelling; postero-midventral nodelike posteriorly-projecting elevation; dimorphic mid- and anteroventral elongate curved frill in presumed females, general surface densely pitted; exfoliated surfaces of presumably two-layered walls appear pustulose; in the latter case pores occur in some of the pustules.

Length of figured valve (Pl. 10, fig. 2a, b) 0.59 mm, height 0.44 mm, width 0.12 mm.

Occurrence. The species is rare in the middle Decorah Shale at St. Paul; rare near the base of the Decorah (1.4-3.4 feet above base) at Cannon Falls. It was described as uncommon in the upper Decorah in northeastern Iowa (Kay, 1940, p. 263).

No. of specimens studied. Six

UMPC. 15146

Family QUADRIJUGATORIDAE Kesling and Hussey, 1953

Genus *Ceratopsis* Ulrich, 1894

Family uncertain by Warshauer and Berdan, 1982

Ceratopsis chambersi (Miller)

Plate 3, figure 2

Beyrichia chambersi Miller, 1874, Cincinnati Quart. Jour. Sci. v. 1, p. 234, fig. 27.

Ceratopsis chambersi (Miller), Ulrich, 1894, Final Rept. Geol. and Nat. Hist. Survey Minnesota, v. 3, pt. 2, p. 676, pl. 46, figs. 10-22. Ulrich and Bassler, 1908, U.S. Nat. Mus. Proc., v. 35, pl. 53, figs. 1, 1a; Bassler, 1919, Maryland Geol. Survey, Cambrian-Ordovician vol., p. 169, 182, 364, pl. 55, fig. 34; Ulrich and Bassler, 1923, Maryland Geol. Survey, Silurian vol., p. 310, fig. 20 (fig. 5); Levinson, 1950, Jour. Paleontology, v. 24, p. 69, fig. 7.

Subhemispherical in side view; dorsum straight, except for anterior spine; cardinal angles slightly obtuse; venter convex; ends rounded, anterior broader; greatest height anterior; free margins with narrow flattened border and narrow submarginal ridge; dorsomedian short anteriorly curved sulcus, anterojacent small lobe lying above midheight and anterodorsal small sulcus; anterior to second sulcus is a large dorsally-projecting spine bearing closely-spaced serrations on its posterior side; length of spine two-thirds or more of shell height; general surface smooth; a low obscure oblique lobe lies posterior to dorsomedian sulcus.

Length of left valve 0.83 mm, height exclusive of spine, 0.45 mm, width 0.05 mm.

Occurrence. *C. chambersi* is rare in the upper Decorah Shale at Cannon Falls. It occurs abundantly in the Cincinnati Eden Group at Cincinnati, Waynesville, and Oxford, Ohio, and at Versailles, Indiana. It has also been recorded from the Middle Ordovician Viola Formation of Oklahoma (Harris, 1957).

No. of specimens studied. Three

UMPC. 15147

Ceratopsis quadrifida (Jones)

Plate 3, figures 3a-d

Plate 12, figures 1, 2

Beyrichia quadrifida Jones, 1891, Canadian Geol. Survey Contr. Micropaleontol., pt. 3, p. 66, pl. 66, figs. 9a-b.

Ceratopsis quadrifida (Jones), Ulrich and Bassler, 1908, U.S. Nat. Mus. Proc., v. 35, figs. 21-22; Kay, 1934, Jour. Paleontology, v. 8, p. 340, pl. 44, fig. 27.

Outline subhemispherical, dorsum long and straight, except for anterior projecting spine; venter and ends convex in outline, anterior end broader, greatest height anteromedian; narrow flattened rim along free margins; oblique, anteriorly curved dorsomedian shallow sulcus; weak anteromedian lobe near midheight; anterodorsal shallow oblique sulcus; and anterodorsal large thick, dorsally projecting spine having numerous serrations along posterior slope.

Length of figured left valve (Pl. 3, fig. 3b) 1.43 mm, height 0.87 mm, width 0.37 mm.

Occurrence. The species in the present collections is frequent to common in the middle and upper Decorah Shale at St. Paul; rare in the middle Decorah at Cannon Falls and rare in the upper Decorah at Sugar Creek, Minnesota. It was previously recorded in the upper Decorah of Iowa and Wisconsin; in the Sherman Falls Formation of Trentonian age at Gamebridge, Ontario; in lower Trentonian beds at Lorrette Falls, St. Charles River, near Quebec, Quebec; and in the Hull Formation at Healey Falls, Ontario.

No. of specimens studied. 50

UMPC. 15148

Genus *Rigidella* Öpik, 1937

Rigidella cannonensis Cornell and Swain, n. sp.

Plate 4, figures 3a-f

Shell subelliptical in lateral view, greatest height slightly anterad of median; dorsal margin straight, anterior cardinal angle more obtuse than posterior cardinal angle; ventral margin nearly straight, converging slightly with dorsum posteriorly; anterior margin extended medially and somewhat more narrowly curved than posterior. Valves subequal in size; compressed except for lobate extensions; in edge view valve surfaces rise steeply from margins and lateral slopes are subparallel.

Medially on each valve is a short subvertical sulcus slightly curved toward anterior; posteromedially is a ridge that extends ventro-anteriorly to a position beneath median sulcus where it becomes wider and thicker; a broad ridge or lobe occupies posterior submarginal zone from near cardinal angle to slightly below midheight; anterior to median sulcus is a small dorsomedian lobe, anterior to which lies a broad submarginal ridge or lobe that is highest ventrally; terminal ridge and part of other lobes and dorsal surface rather coarsely pitted; anterior margin of anterior lobe bears a small crest. Internal character of shell not observed.

Length of holotype shell (Pl. 4, fig. 3b) 0.37 mm, height 0.24 mm, width 0.19 mm.

Relationships. *R. cannonensis* is more coarsely pitted than other described species of the genus and has a distinctive ventral thickening of the posteromedian ridge.

Occurrence. The species is rare 25-27 feet above the base of the Decorah Shale at St. Paul; rare 20.4-23.4 feet above the base of the Decorah at Cannon Falls; and rare 16-20 feet above the base of the Decorah at Rochester, Minnesota.

No. of specimens studied. Nine

UMPC. 15149

Genus *KIESOWIA* Ulrich and Bassler, 1908

Kiesowia? verrucosa Kay

Plate 5, figures 4a, b

Kiesowia verrucosa Kay, 1940, Jour. Paleontology, v. 14, p. 260, pl. 32, figs. 39, 40; Keenan, 1951, Jour. Paleontology, v. 25, p. 569, pl. 79, figs. 4-6.

?*Warthinia nodosa* (Kay) (part) Warshauer and Berdan, 1982, U.S. Geol. Survey, Prof. Paper 1066-H, p. 23.

Shell small, subquadrate, dorsum straight, venter gently convex; ends broadly and nearly evenly curved; greatest height slightly anteromedian; free margins with narrow, rounded, low, smooth rim; two small anteromedian nodes, subvertically arranged; posteromedian large rounded node in dorsal half; other smaller scattered nodes, not definitely arranged in a residual lobate pattern; general surface densely pitted.

Length of figured specimen 0.40 mm, height 0.25 mm, width 0.17 mm.

Remarks. The lack of definite residual quadrilobate pattern of the nodes in this species make its generic position uncertain. The present writers would be inclined to place it in the Bolliidae, perhaps related to *Ulrichia*. A closely similar species, found in the Maquoketa Formation of northern Iowa was named *Ulrichia saccula* by Burr and Swain (1965), but this species has since

been transferred to *Warthinia* (Spivey) by Warshauer and Berdan (1982).

Occurrence. The species is rare in the upper Decorah at St. Paul and Cannon Falls. It was recorded by Keenan (1951) from the Upper Ordovician Maquoketa Formation of Missouri, but Keenan's specimens have been transferred to *Warthinia* by Warshauer and Berdan (1982).

No. of specimens studied. Four

UMPC. 15150

Family EURYCHILINIDAE Ulrich and Bassler, 1923
Subfamily EURYCHILININAE Ulrich and Bassler, 1923
Genus *EURYCHILINA* Ulrich, 1889

Eurychilina subradiata Ulrich

Plate 9, figures 4a, b

Plate 13, figure 13

Eurychilina subradiata Ulrich, 1890, Cincinnati Soc. Nat. Hist. Jour., v. 13, p. 126, pl. 9, figs. 1, 2. (See Warshauer & Berdan, 1982 for complete synonymy).

Elongate-subquadrate strongly compressed, straight hinge, venter convex, ends rounded, the anterior slightly broader, cardinal angles slightly obtuse; free margins with broad, smooth, gently convex to nearly flat frill; deep furrow above inner margin of frill; anteromedian dorsal rounded sulcus ends dorsal to midheight; antero-adjacent rounded lobe lies well below midheight; low ridge along dorsum; general surface smooth or with tiny sparse pits; hinge formed by simple contact of valve edges.

Length of left valve 2.28 mm, height 1.17 mm, width 0.32 mm.

Occurrence. Common in the lower middle Decorah at St. Paul; rare in the lower Decorah at Cannon Falls; rare at the base of the Decorah at Rochester and Sugar Creek. Kay (1940) found the species to be rare in the Ion Member, upper Decorah, in Winneshiek County, Iowa, and west of Ellsworth, Wisconsin.

No. of specimens studied. 19

UMPC. 15161

Eurychilina ventrosa Ulrich

Plate 9, figure 1

Eurychilina ventrosa Ulrich, 1894, Final Rept. Geol. and Nat. Hist. Survey Minnesota, v. 3, pt. 2, p. 662, pl. 45, figs. 1-3.

Shell subquadrate to subelliptical-truncate in side view, highest medially; dorsal margin straight, about six-sevenths of shell length, with slightly obtuse, distinct cardinal angles; ventral margin moderately convex; terminal margins broadly curved. Valves subequal, compressed.

Free margins bordered by a broad smooth frill, convex outward and strongly concave on underside, broadest ventrally, becoming progressively narrower terminally and dying out in small ears at cardinal angles; frill bears numerous closely spaced canals perpendicular to margin; a furrow separates inner margin of frill from general surface of valve. A comma-shaped, fairly deep, short sulcus occurs just in front of and dorsal to middle of valve; it does not extend to dorsal margin. Anterior to sulcus is a rounded median node or lobe. Valve surface smooth.

Hinge surface of right valve bears a narrow groove for reception of a small ridgelike extension of edge of left valve.

Length of a figured imperfect right valve (Pl. 9, fig. 1) 1.43 mm, height 0.93 mm, width 0.23 mm.

Remarks. The smooth surface form of shell, and broad frill, gently convex outward, distinguish this species. The anteromedian node is variable in size, and is smaller and less rounded in immature molts than in adult shells.

Occurrence. The species is rare 23-25 feet, 37-39 feet, 45-47 feet, 53-61 feet, 63-67 feet, 69-71 feet, 75-77 feet, 83-85 feet, and 87-89 feet above base of Decorah at St. Paul. At Wangs the species is rare 2-4 feet and 53-57 feet above base of Decorah; at Rochester it is rare 4-8 feet, 16-20 feet, and 24-28 feet above the base; at Chatfield it is rare 29-33 feet above the base; and at Spring Grove it was found in a shale parting in the upper 10 feet of the Platteville Formation. Ulrich originally described the species from the Prosser (lower Galena) limestone at Cannon Falls. Kay recorded it as frequent in the Ion Member of the Decorah in northeastern Iowa.

No. of specimens studied. 40

UMPC. 15162

Eurychilina minutifoveata Kay

Plate 9, figure 7

Plate 12, figures 9, 10

Eurychilina minutifoveata Kay, 1940, Jour. Paleontology, v. 14, p. 251, pl. 31, fig. 9.

The present specimens are only questionably assigned to this species, owing to poor preservation. Shell elongate subquadrate in side view, highest medially; hinge margin straight, nearly equal to shell length, cardinal marginal bends not strongly obtuse, extending slightly beyond dorsal margin; ventral margin moderately extended above. Valves subequal, the left slightly the larger, greatest convexity median.

Free margins of valves bear a sharp-edged narrow velate ridge which extends upward and outward from valve surface at posterior end more than elsewhere. Shallow median sulcus extends from just below dorsal margin nearly to midheight; a small node lies anterior to sulcus.

Length of figured specimen (Pl. 9, fig. 7) 1.03 mm, height 0.53 mm, width 0.37 mm.

Remarks. The surfaces of the valves in the specimens described by Kay are finely reticulate, whereas the present specimens are smooth.

Occurrence. Rare in Decorah Shale, 53-56 feet above base, section 1 mile south of Cannon Falls, Minnesota. The species was originally described from the Ion Member, exposed in Glenwood Township, Winneshiek County, Iowa.

No. of specimens studied. Four

UMPC. 15169

Eurychilina reticulata Ulrich

Plate 8, figures 3a-e; plate 9, figures 5a, b

Plate 13, figures 2-6, 14, 15

Eurychilina reticulata Ulrich, 1889, Canadian Geol. Survey, Contr. Micro-paleontology, pt. 2, p. 52, pl. 9, figs. 9, 9a; Ulrich, 1894, Final Rept. Geol. and Nat. Hist. Survey Minnesota, v. 3, pt. 2, p. 600, pl. 44, fig. 1; Reudemann, 1901-1902, N.Y. State Mus., Bull. 49, p. 76, pl. 5, fig. 3; Ulrich and Bassler, 1908, U.S. Nat. Mus. Proc., v. 35, p. 298, fig. 46; Ulrich and Bassler, 1923, Maryland Geol. Survey, Silurian vol., p. 303, fig. 16-5.

Subquadrate, long straight hinge, highest anteromedially, anterior cardinal angle more obtuse than posterior, venter and ends convex, that of anterior extended below, that of posterior extended above. Antero-median teardrop shaped sulcus extends from dorsal margin to about one-third distance to venter; small smooth rounded node lies anterior to sulcus; free margins bear a broad slightly convex frill that is broadest anteroventrally, and are crossed by closely spaced low ridges and furrows; a groove marks juncture of frill with edge of valve; general surface bears closely spaced large pits.

Length of left valve (Pl. 8, fig. 3a) 1.79 mm, height 0.99 mm, width 0.53 mm.

Occurrence. The species is rare in the middle and upper (21-61 feet above base) Decorah Shale at St. Paul; rare at 23.4-26.4 feet and 36.9-42.9 feet above the base at Cannon Falls; rare at the base and 20-28 feet above the base at Rochester and rare in the upper Decorah at Sugar Creek. It was recorded earlier as frequent in the Ion and Guttenberg Members of northeastern Iowa and in the Hull Formation, Healey Falls, Ontario (Kay, 1934, 1940).

No. of specimens studied. 15

UMPC. 15163

Eurychilina micropunctata Swain and Cornell, n. sp.

Plate 8, figure 2

Plate 13, figure 1

Eurychilina reticulata Ulrich, Cornell, 1956, Unpublished M.S. Thesis, Univ. Minnesota, pl. 10, fig. 4a (not Ulrich, 1889).

Shell subquadrate in side view, highest anteromedially; dorsal margin straight and only a little less than greatest length of shell, anterior cardinal angle obtuse; posterior cardinal angle acute, and with earlike small projections above margin; ventral margin slightly convex; anterior margin broadly rounded; posterior margin also broadly rounded and extended above. Valves compressed.

Rounded, deep, anteromedian, smooth-surfaced sulcus extends from dorsal margin to a position about two-fifths from dorsal margin; small, rounded, smooth node lies anterior to sulcus; free margins bear a narrow rim that is broader terminally than ventrally; an upturned smooth frill broadest ventrally is incompletely developed in holotype specimen; general surface bears medium-sized pits with interspaces equal to or greater than diameter of pits.

Length of holotype left valve 2.70 mm, height 1.40 mm, width 0.43 mm.

Relationships. The species has smaller and more widely spaced pits than *E. reticulata* Ulrich and its frill is smooth and there is a well defined free marginal rim.

Occurrence. The species is rare in the upper Decorah Shale 36-40 feet above base, Sugar Creek section near Fountain, Minnesota.

No. of specimens studied. Three

UMPC. 15164

Eurychilina sugarcreekensis Swain and Cornell, n. sp.
Plate 8, figure 4a, b

Eurychilina reticulata Ulrich, Cornell, 1956, Unpublished M.S. Thesis, Univ. Minnesota, pl. 16, fig. 6b (not Ulrich, 1889).

Shell subquadrate in lateral view, highest at or near midlength; dorsal margin nearly straight, with an upturn at slightly obtuse posterior cardinal angle; ventral margin convex; terminal margins broadly rounded. Valves compressed. Shallow anteromedian short, dorsal sulcus does not reach dorsal margins and terminates ventrally about one-third distance from dorsal to ventral margin; sulcus is concave toward anterior margin and is defined anteriorly by a small rounded node; free margins bear a broad smooth frill that has a convex outer, and a concave inner surface; general surface smooth. Hinge margin marked by faint rabbit grooves; adductor muscle scar a small spot lying near base of prominent anteromedian inner ridge that represents exterior shallow sulcus; a row of small pits extends along inner edge of frill on valve interior.

Length of holotype right valve 2.07 mm, height 1.30 mm, width 0.33 mm.

Relationships. The smooth surface of this species resembles that in *E. ventrosa* Ulrich, *E. partifimbriata* Kay, and *E. subradiata* Ulrich. The first species has a weaker sulcus and the second two species have stronger anteromedian sulci than *E. sugarcreekensis*. The frills of the other three species are differently formed than in the new species.

Occurrence. This species is rare in the upper Decorah Shale 32-36 feet above the base, Sugar Creek section near Fountain, Minnesota.

No. of specimens studied. Three

UMPC. 15165

Eurychilina cannonfallsensis Swain and Cornell, n. sp.
Plate 8, figure 5

Eurychilina reticulata Ulrich, Cornell, 1956, Unpublished M.S. Thesis, Univ. of Minnesota, pl. 10, fig. 9 (not Ulrich, 1889).

Shell subquadrate in side view, highest medially; hinge margin long and straight, the anterior cardinal angle slightly obtuse, the posterior slightly acute; ventral margin gently convex; anterior margin broadly curved; posterior margin also broadly curved, somewhat extended above. Valves compressed.

Anteromedian dorsal sulcus rises at dorsal margin and extends about two-fifths distance to venter from dorsum; sulcus is of moderate depth and nearly parallel-sided, with adjacent low anteromedian lobe; a moderately broad frill adjoins free margin; frill is flat and is traversed by closely spaced ridges and furrows; a narrow, uniform ridge marks inner margin of frill on exterior surface. General surface coarsely and densely pitted.

Length of holotype valve 3.40 mm, height 1.87 mm, width 0.66 mm.

Relationships. The general shape and coarse pitting of this species are similar to features of *E. reticulata* Ulrich, but the low anteromedian node, parallel-sided sulcus, submarginal ridge, and ornamented frill are different from that species.

Occurrence. This species is rare 36-40 feet above the base of the Decorah Shale section at Cannon Falls, Minnesota.

No. of specimens studied. Four

UMPC. 15166

Eurychilina kayi Swain and Cornell, n. sp.
Plate 9, figure 2a-c
Plate 12, figure 13
Plate 13, figures 7, 9

Eurychilina partifimbriata Kay, Cornell, 1956, Unpublished M.S. Thesis, Univ. of Minnesota, pl. 9, fig. 15b (not Kay, 1940)

Shell elongate subquadrate in side view, highest anteriorly; dorsal margin straight except for upturned posterior cardinal angle; both cardinal angles obtuse, the anterior the more so; ventral margin moderately convex; anterior margin broadly curved, posterior margin slightly narrower. Valves much compressed. Anteromedian fairly deep dorsal sulcus, curved anteriorly, extends from dorsal margin to about two-fifths distance to ventral margin; rounded node lies anterior to sulcus; free margins have a very broad upturned frill with faint transverse striations; general surface smooth.

Length of holotype shell 2.90 mm, height 1.56 mm, width 0.27 mm.

Relationships. The sulcation, general shape, and smooth surface of this species are similar to features in *E. subradiata* Ulrich but the frill of that species is much narrower and is downturned.

Occurrence. This species is rare 49-53 feet above the base of the Decorah Shale section at Cannon Falls, Minnesota.

No. of specimens studied. Three

UMPC. 15167

Eurychilina partifimbriata Kay
Plate 9, figures 3a, b
Plate 13, figures 8, 10, 16

Eurychilina partifimbriata Kay, 1940, Jour. Paleontology, v. 14, p. 251, pl. 31, figs. 6-8.

Subrhomboidal, dorsum nearly straight, anterior cardinal angle obtuse, posterior cardinal angle nearly 90°; venter and ends gently convex, anterior extended below; comma-shaped slightly anteromedian sulcus in dorsal third; anterior to sulcus is rounded node and a narrow ridge defines sulcus ventrally; upturned frill borders venter and anterior margins and on its underside forms a compartment closed at each end. General surface finely granulose or pustulose.

Length of left valve (Pl. 9, fig. 3b) 1.61 mm, height 1.1 mm, width 0.23 mm.

Occurrence. The species occurs rarely 49-53 feet above the base of the Decorah Shale at Cannon Falls, Minnesota; in the middle Decorah at St. Paul; and in the upper Decorah at Rochester and Sugar Creek. It was also recorded from the upper Decorah, 6 miles south of Cannon Falls, Minnesota (Kay, 1940).

No. of specimens studied. Seven

UMPC. 15168

Subfamily EUPRIMITIINAE Hessland, 1949
Genus *EUPRIMITIA* Ulrich and Bassler, 1923
Euprimitia sanctipauli (Ulrich)
Plate 6, figures 2a-f

Primitia sanctipauli Ulrich, 1894, Final Rept. Geol. and Nat. Hist. Survey Minnesota, v. 3, pt. 2, p. 652, pl. 43, figs. 73, 74.

Euprimitia sanctipauli (Ulrich), Ulrich and Bassler, 1923, Maryland Geol. Survey, Silurian vol., p. 299, text fig. 15-5; Kay, 1940, Jour. Paleontology, v. 14, p. 252, pl. 31, figs. 11-15; Moore, ed., 1961, Treatise Invert. Paleont., v. Q, p. 144, figure 78, 4a, b.

Shell subovate in lateral view, highest posteromedially; dorsal margin nearly straight, about three-fourths of shell length, with poorly defined cardinal angles, the anterior obtuse, the posterior much less obtuse; anterior margin rounded, extended medially to dorsomedially; posterior margin more broadly curved, slightly extended above. Valves subequal, moderately convex, greatest convexity posteroventral in position.

Anteromedian, weak to moderately strong sulcus occurs in dorsal half of shell; in some specimens it forms a shallow pit that reaches only part way to dorsal margin, in a few specimens sulcus extends nearly to dorsal margin; general surface of valve except border areas finely pitted.

Presumed female dimorphs provided with a narrow submarginal frill beginning near midheight on anterior end and extending to midventral region.

Hinge consists of simple contact of valve edges, each of which is indistinctly grooved. Muscle scar not observed.

Length of figured male valve (Pl. 6, fig. 2d) 0.70 mm, height 0.50 mm, width 0.18 mm; length of figured female right valve (Pl. 6, fig. 2a) 0.76 mm, height 0.55 mm, width 0.16 mm.

Occurrence. At St. Paul, the species is rare 5-7 feet, 21-25 feet, 33-35 feet, 41-47 feet, and 51-61 feet, and abundant 45-47 feet above the base of the Decorah; at Cannon Falls, it is rare 5.5-7.5 feet above the base of the Decorah. At Chatfield, the species is frequent 25-29 feet and abundant 23-25 feet above base of Decorah. Kay recorded the species at a few localities in Iowa and Minnesota.

No. of specimens studied. 77

UMPC. 15170

Euprimitia labiosa (Ulrich)
Plate 5, figure 7; plate 6, figures 1a-d
Plate 13, figure 12

Halliella labiosa Ulrich, 1894, Final Rept. Geol. and Nat. Hist. Survey Minnesota, v. 3, pt. 2, p. 656, pl. 46, figs. 43-46; Grabau and Shimer, 1910, North American Index Fossils, p. 346, text fig. 1658, r, r1; Kay, 1934, Jour.

Paleontology, v. 8, p. 332, pl. 44, figs. 17, 18; Harris, 1936, Okla. City Geol. Soc. Field Conf. Guidebook, p. 7, fig. 25; 1957, Okla. Geol. Surv. Bull. 75, p. 200, pl. 6, figs. 14, 15, 16a, b.

Halliella labiosa Bassler, 1913, 1927, 1937 in Zittel and Eastman, Textbook Paleontology, p. 738, fig. 1425h; Swartz, 1936, Jour. Paleontology, v. 10, pl. 85, fig. 1d (Harris, 1957, p. 200).

Euprimitia labiosa (Ulrich), Kay, 1940, Jour. Paleontology, v. 14, p. 252, pl. 31, figs. 16-18; Moore, ed., 1961, Treatise Invert. Paleont., v. Q, p. 144, fig. 78, 9a-e.

Hallatia healeyensis Kay, 1934, Jour. Paleontology, v. 8, p. 335, pl. 45, figs. 5, 6, *vide* Harris, 1957, Okla. Geol. Surv. Bull. 75, p. 200.

Shell subovate in side view, highest medially; dorsal margin nearly straight but slightly sinuous, with posterior cardinal angle more obtuse than anterior; ventral margin rather strongly convex; terminal margins broadly curved, the anterior somewhat extended above. Valves subequal, compressed, greatest convexity posterodorsal in position.

Posterior marginal area bears a submarginal ridge that extends to mid-venter, and does not quite reach posterior cardinal angle; this ridge rises from inner edge of a border that extends along and is more or less perpendicular to entire free margin; along anterior margin inner edge of border slightly overhangs edge of valve. A pitlike lachrymose sulcus occurs a little anterior and dorsal to middle of valve; valve surface within marginal border formed as a broad U-shaped lobe, highest posterodorsally when it projects slightly beyond edge of valve, separated from posterior ridge by a groove, and merging gradually with anterior overhanging part of border. General surface of valve within border deeply pitted, the pits arranged in gently curving, convex-downward, to nearly straight lines in midportion of valve; anteriorly, rows of pits to some extent converge and merge with marginal border; posterior submarginal ridge is concentrically striated, the resulting grooves are crossed by tiny bars in a pattern that appears to represent stretched-out pits. In some specimens, posterior marginal ridge more pronounced than in other specimens, perhaps a dimorphic feature, although this is not clear.

Hingement consists of a faint notchlike groove in edge of left valve into which fits edge of right valve.

Length of figured possibly female right valve (Pl. 6, fig. 1a) 0.63 mm, height 0.43 mm, width 0.12 mm.

Remarks. Harris (1957, p. 200) continued to refer this species to *Halliella* Ulrich, although Kay after 1940, considered it to be *Euprimitia*. Scott (in Moore, ed., 1961, p. 114) considers *Halliella* to be of questionable status and Levinson (in Moore and others, 1961, p. 144) again assigns *labiosa* to *Euprimitia*.

Occurrence. The species is rare 11-13 feet, 29-31 feet, and 45-49 feet above the base of the Decorah, frequent 55-59 feet, common 25-27 feet, 79-81 feet, and 83-89 feet, at St. Paul. At Cannon Falls it is rare 15.5-17.5 feet, 37-40 feet, and 55-58 feet above the base, frequent 9.5-13.5 feet and 23.5-26.5 feet, common 7.5-9.5 feet, 13.5-15.5 feet, and 46-55 feet above base of Decorah. At Chatfield the species is rare 25-29 feet and common 21-25 feet above base of Decorah. At Rochester it is rare 20-24 feet above the base; at Sugar Creek rare 28-32 feet and frequent 36-41 feet above the base. Kay recorded it as uncommon in the Guttenberg and Ion Members of the Decorah at several localities in Iowa and frequent in the Hull Formation in Ontario.

No. of specimens studied. 141

UMPC. 15171

Family TETRADELLIDAE Swartz, 1936

Genus *DILOBELLA* Ulrich, 1894

Dilobella typa Ulrich

Plate 3, figure 7; plate 4, figures 1a, b

Plate 11, figures 13-15

Dilobella typa Ulrich, 1894, Minnesota Geol. and Nat. Hist. Survey Final Report, v. 3, pt. 2, p. 673, pl. 46, figs. 30-34; Kay, 1940, Jour. Paleontology, v. 14, p. 256, pl. 33, figs. 8-16.

Ctenobolbina fulcrata Ulrich, 1894, Final Rept. Geol. and Nat. Hist. Survey Minnesota, v. 3, pt. 2, p. 674, pl. 44, figs. 8-11.

Ctenobolbina crassa Ulrich, 1894, Final Rept. Geol. and Nat. Hist. Survey Minnesota, v. 3, pt. 2, p. 675, pl. 44, figs. 12-16.

Shell subquadrate-subhemispherical in side view, dorsum straight except where ends of lobes project beyond dorsal margin; venter moderately to strongly convex; ends rounded, the anterior is the broader; greatest height typically anteromedian but may be near midlength; compressed marginal

border absent or very narrow; broad anteromedian sulcus extends from dorsum to well venterad of midheight; large dorsally pointed lobes lie on either side of sulcus; ventral surface swollen in presumed female shells (Pl. 3, fig. 7) and overhangs ventral margin; general exterior surface appears to be smooth. Hinge edge of left valve a ridge that bears closely spaced weak transverse grooves. Interior of valve surface marked by a rippled surface pattern resembling that in modern *Candona*, in which organic matter impregnates shell.

Length of figured valve (Pl. 4, fig. 1b) 0.94 mm, height 0.71 mm, width 0.30 mm.

Occurrence. *D. typa* is common in the middle Decorah Shale at St. Paul; rare in the middle and upper Decorah at Cannon Falls; and rare in the upper four feet of the Decorah at Rochester. It was recorded previously as common in the upper Decorah six miles south of Cannon Falls and near Ellsworth, Wisconsin, and less common in northeastern Iowa in the upper Decorah (Kay, 1940).

No. of specimens studied. 30

UMPC. 15151

Dilobella simplex Kay

Plate 3, figure 6

Plate 11, figures 7, 8

Dilobella simplex Kay, 1940, Jour. Paleontology, v. 14, p. 257, pl. 33, figs. 17-19.

Elongate-subquadrate in side view, dorsum nearly straight except where lobes project slightly beyond margin, anterior cardinal angle more obtuse than posterior, ventral margin strongly convex; terminal margins rounded, that of anterior much broader than posterior, the latter extended above, marginal narrow compressed border; general valve inflated and overhangs ventral margin; slightly anteromedian wide anteriorly-curving sulcus opens on dorsal margin and extends to within one-fourth of valve height from ventral margin; surface on either side of sulcus forms a large lobe; surface of lobes appears slightly granular, perhaps due to recrystallization of surface.

Length of left valve 0.9 mm, height 0.50 mm, width of valve 0.21 mm.

Occurrence. This species is rare in the middle Decorah at St. Paul; rare to frequent in the middle and upper Decorah at Cannon Falls; and rare in the upper Decorah at Sugar Creek, Minnesota. It was originally recorded as rare in the upper Decorah near Ellsworth, Wisconsin.

No. of specimens studied. 11

UMPC. 15152

Genus *TETRADELLA* Ulrich, 1890

Tetradella ellipsilira Kay

Plate 4, figures 4a-i; plate 5, figures 1a, b

Plate 12, figure 4

Beyrichia quadrilirata Hall and Whitfield, 1875, Ohio Geol. Survey, Paleontology, Rept. 2, pt. 2, p. 105, pl. 4, figures 6-7.

Tetradella quadrilirata Ulrich, 1894, Final Rept. Geol. and Nat. Hist. Survey Minnesota, v. 3, pt. 2, p. 679, pl. 46, figures 1-11 (not Hall and Whitfield, 1875).

Tetradella ellipsilira Kay, 1934, Jour. Paleontology, v. 8, p. 339, pl. 45, figures 10-15; *ibid.*, 1940, v. 14, p. 265, pl. 34, figures 18-22.

Shell subelliptical-subquadrate and variable individually in outline; dorsum nearly straight, venter convex, ends rounded but variable; highest anteromedially in typical specimens; free margins with narrow elevated rim; submarginal ridge of frill-less forms with narrow crest; crests appear lacking on frilled forms; anteromedian lobe not reaching dorsal margin; posteromedian lobe and ends of submarginal ridge extend beyond dorsal margin in many specimens; dorsomedian sulcus curves toward anterior and extends to well venterad of midheight; general surface smooth. Hinge margin of right valve bears a furrow. Anteroventral dimorphic frill of presumed females bears 3 large rounded pits.

Length of right valve (Pl. 4, fig. 4a) 0.83 mm, height 0.50 mm, width 0.20 mm.

Occurrence. The species is rare to common in the lower and middle Decorah and common in the upper Decorah Shale at St. Paul; rare from the middle throughout the upper Decorah at Cannon Falls; common in the middle and upper Decorah at Rochester and Sugar Creek, Minnesota. It was recorded earlier as common to abundant in the Guttenberg and Ion Members of the middle and upper Decorah respectively, of Iowa, Minnesota, and Wisconsin (Kay, 1940, p. 237).

No. of specimens studied. 65

UMPC. 15153

Tetradella ulrichi Kay
Plate 5, figures 2a-e

Tetradella lunatifera Ulrich, 1894, Final Rept. Geol. and Nat. Hist. Survey Minnesota, v. 3, pt. 2, p. 680, pl. 46, figs. 12-14, text figs. 51a, b (not *Streptopala lunatifera* Ulrich, 1889).

Tetradella ulrichi Kay, 1934, Jour. Paleontology, v. 8, p. 339, pl. 45, figs. 16-19; *ibid.*, 1940, v. 14, p. 265, pl. 34, fig. 23.

Elongate subovate-subquadrate, dorsum nearly straight except where lobes project beyond margin, cardinal angles obtuse; long median sulcus extends nearly to venter, elongate lobe, bulbous dorsally, lies anterad of sulcus; narrow U-shaped ridge lies within margin and is separated from narrow marginal ridge by a furrow; two subparallel ridges posterior to median sulcus and one ridge anterior to median sulcus rise from ventral submarginal ridge and extend nearly to or slightly beyond dorsal margin.

Length of right valve (Pl. 5, fig. 2d) 0.53 mm, height 0.39 mm, width 0.14 mm.

Occurrence. The species occurs frequently in the upper Decorah Shale at St. Paul; it is rare in the middle Decorah at Cannon Falls; and it is rare in the upper Decorah at Sugar Creek, Minnesota. Kay (1940) found it to be frequent in the upper Decorah Ion Member, in northeastern Iowa, and (1934) recorded it as uncommon in the Hull Formation at Healey Falls, Ontario, and common in the Sherman Falls Formation at Gamebridge, Ontario.

No. of specimens studied. 14

UMPC. 15154

Family BASSLERATIDAE Schmidt, 1941
Genus *BELLORNATIA* Kay, 1934

Remarks. The orientation is reversed from that used by Kay. The genus was based by Kay on "two very similar species" (Kay, 1934, p. 342), although he named only *B. tricollis*. Later Kay (1940, p. 265) treated the unnamed form as a dimorph of *B. tricollis*. Kay's 1934 unnamed form from the Glenburnie Shale of Ontario possesses three inframarginal nodes not present in *B. tricollis* as originally described. The noded forms from Ontario and from the Decorah Shale Kay in 1940 included as dimorphs within *B. tricollis*.

Bellornatia tricollis Kay

Plate 2, figures 4a-f; plate 3, figures 1a-c Plate 13, figure 17

Bellornatia tricollis Kay, 1934, Jour. Paleontology, v. 8, p. 342, pl. 44, figs. 22-26; *ibid.*, 1940, v. 14, p. 265, pl. 34, figs. 24-26; Moore, ed., 1961, Treatise Invert. Paleont., v. Q, p. 140, figs. 2a-d.

Shell subquadrate in side view, highest posteromedially; dorsal margin nearly straight, slightly convex medially with well defined cardinal angles, the anterior slightly obtuse, the posterior varying from a right angle to slightly acute, resulting in a forward swing to shell; ventral margin nearly straight, with median concavity in some specimens; terminal margins broadly curved, extended below anteriorly and extended above posteriorly. Valves subequal, compressed, greatest convexity posteromedian.

Free margins a narrow marginal rim defined on inner side by a shallow groove; within groove, shell surface is outlined by a submarginal ridge that along dorsum projects beyond edge of valve; mid-dorsally a spurlike short lobe extends toward middle of valve and defines the upper end of the median sulcus; the latter occurs medially to anteromedially and is depressed slightly below level of valve surface within submarginal ridge; anterior to median sulcus and approximately across midheight is an oblong, slightly oblique node; posterior to sulcus is a larger node anteroventral to which is a short broad spurlike projection from submarginal ridge.

Hinge surface slightly depressed below outer margin, that of right valve weakly rabbeted below and is overlapped by edge of left. Muscle scar not observed.

Length of figured specimen (Pl. 2, fig. 4c) 0.63 mm, height 0.40 mm, width 0.13 mm.

Remarks. The dimorphism referred to by Kay (1940, p. 265) is believed to be due to variations in the strength of the posteromedian node and the short dorsal and ventral spurs from the inframarginal ridge. Whether this variation is dimorphic or of individual nature is uncertain but the present writers incline toward the latter view.

Occurrence. The species is rare 3-9 feet above base of Decorah at St. Paul; rare 3.5-5.5 feet and frequent 11.5-13.5 feet above base at Cannon Falls; not found at the other localities studied in Minnesota. Kay found it rarely in the Ion Member of the Decorah of northeastern Iowa, in the lower part of the

Hull Formation and in the Glenburnie Shale of the Chaumont Formation, eastern Ontario.

No. of specimens studied. 12

UMPC. 15155

Genus *RAYMONDATIA* Kay, 1934

Raymondatia goniglypta Kay

Plate 4, figures 2a-c

Raymondatia goniglypta Kay, 1934, Jour. Paleontology, v. 8, p. 342, pl. 45, figs. 7-9, *ibid.*, 1940, v. 14, p. 266, pl. 34, figs. 30, 31.

Shell elliptical in side view, highest medially; dorsal margin nearly straight, the anterior cardinal angle somewhat more obtuse than the posterior; ventral margin nearly straight, very slightly concave posteromedially; anterior margin broadly rounded; posterior margin also broadly rounded, but projects less beyond end of hinge than anterior and is slightly extended above. Valves subequal, compressed, with greatest convexity posterior in position.

Entire periphery of each valve bears a broad rounded marginal ridge which is lowest just anteriorad of anterior cardinal angle and highest posteriorly; a prominently elevated broad ridge begins at low point on marginal ridge, extends ventrally to near midheight, then bends abruptly anteroventrally at an angle of 110°-120°; a prominent deep median sulcus which has a narrow curved crossbar at its lower termination, separates anteromedian ridge from a posterior large nodelike swelling; this swelling connected anteriorly to a subvertical ridge that extends dorsally to marginal ridge, and ventrally, by means of the small curved crossbar previously mentioned, to lower part of anterior ridge; a small low nodelike swelling lies adjacent to marginal ridge posteroventrally. Posteriorly marginal ridge strongly elevated and separated from a flange along outer margin by a furrow. Hinge surface indented below outer margin; hinge surface of left valve weakly rabbeted above for reception of edge of right valve.

Length of figured left valve (Pl. 4, fig. 2b) 0.58 mm, height 0.34 mm, width 0.13 mm.

Remarks. This genus is monotypic according to present knowledge. In general shape, sulcation, and other features of surface ornamentation it is prophetic of some Mesozoic Cytheracea.

Occurrence. At St. Paul, the species is rare from 29-31 feet, 43-51 feet, 53-55 feet, 57-59 feet and 63-65 feet, common from 65-67 feet and 81-87 feet above base of Decorah. At Cannon Falls it is rare from 7.5-9.5 feet and 46.5-49.5 feet above base of Decorah; at Wangs it is rare 2-4 feet above base and frequent 59-63 feet above base; at Rochester it is rare 28-32 feet above the base; at Sugar Creek, it is rare 28-32 feet above base. The species was not found at the other localities studied in Minnesota. Kay found it to be frequent in occurrence in the Guttenberg and Ion Members in Iowa and western Wisconsin; also present in shales in the McGregor Member of the Platteville Formation of Iowa and in the Hull Formation of Ontario.

No. of specimens studied. 67

UMPC. 15156

Genus *THOMASATIA* Kay 1934

Thomasatia falcicosta Kay

Plate 5, figures 3a-d

Thomasatia falcicosta Kay, 1934, Jour. Paleontology, v. 8, p. 337, pl. 46, figs. 13-23; *ibid.*, 1940, v. 14, p. 266, pl. 34, fig. 29; Moore, ed., 1961, Treatise on Invert. Paleont., v. Q, p. 142, Text fig. 72, 4a-1.

Shell subquadrate-subelliptical in side view, highest medially; dorsal margin nearly straight about six-sevenths of shell length, with moderately obtuse not sharply defined cardinal angles; ventral margin nearly straight to very slightly concave medially; terminal margins broadly rounded, the anterior typically extended medially and the posterior extended above, but many variations occur. Valves subequal, only moderately convex, greatest convexity posterior in position.

Free margin of shell with narrow rounded marginal rim; a distinct, deep furrow separates rim from remainder of valve; ventral and posterior portions, and in some specimens the anterior part of valve, within furrow, formed into a submarginal ridge, the posterior termination of which forms the most strongly elevated part of valve; dorsal submarginal rounded ridge also terminates posteriorly in a rounded elevation; a prominent median sulcus (S_2) lies at or just anterad of midlength, it lies behind a rounded lobe and is connected dorsally to a second sulcus (S_1) which defines median lobe on the anterior; general surface of valves finely pitted, although pitting is very weak or absent on marginal ridges.

Hinge surface recessed within outer margin, that of right valve consists of a ridge which fits against and perhaps is slightly overlapped by similarly nar-

rowed hinge edge of left valve. Muscle scar not observed in specimens at hand. Ventral selvage extended flange-like, especially in left valve, and curved inward at or posterior to midlength.

Length of figured specimen (Pl. 5, fig. 3d) 0.72 mm, height 0.46 mm, width 0.23 mm.

Remarks. The present specimens are like those originally described by Kay from the Hull Formation of eastern Ontario and the Ion Member of the Decorah except for the anteromedian low gap in the dorsal submarginal rim of Kay's specimens. In the present specimens this gap is absent or very weakly developed.

Occurrence. The species is rare 43-47 feet, 49-51 feet, 59-61 feet, 63-65 feet, and 81-85 feet above base, and common 61-63 and 65-67 feet above base of Decorah at St. Paul. At Cannon Falls it is rare 7.5-9.5 feet, 13.5-15.5 feet and 46.5-58.5 feet above the base of the Decorah. It is common in the Wangs section from 59-63 feet above the base; rare in the upper Decorah at Spring Grove and rare 33-38 feet above base of Decorah at Chatfield.

No. of specimens studied. 64

UMPC. 15157

Family SIGMOOPSIDAE Henningsmoen, 1953

Genus *WINCHELLATIA* Kay 1940

Winchellatia lansingensis Kay

Plate 5, figures 5a-e

Plate 12, figures 3, 5, 6

Winchellatia lansingensis Kay, 1940, Jour. Paleontology, v. 14, p. 254, pl. 32, figures 6-8.

Subquadrate to subelliptical, small-sized, highest antero-medially; dorsum straight, anterior cardinal angle more obtuse than posterior; venter slightly convex with small projection posteriorly; anterior broadly rounded, typically with slight cardinal notch or concavity; posterior narrower, slightly extended above; anteromedian dorsal sulcus curves to define rounded antero-medial node; posterodorsal surface depressed; mid-ventral surface inflated and broad posteriorly as a curved submarginal lobe; general surface smooth to granular, anterior margin and posteroventral margin flattened and rimlike.

Length of left valve (Pl. 5, fig. 5b) 0.66 mm, height 0.41 mm, width 0.17 mm.

Occurrence. This form is common in the lower and middle Decorah Shale at Sugar Creek, Minnesota, and in the Guttenberg Member of northeastern Iowa. It is rare in the upper Decorah at Rochester, Minnesota.

No. of specimens studied. 28

UMPC. 15158

Winchellatia minnesotensis Kay

Plate 5, figures 6a-d

Plate 12, figure 7

Winchellatia minnesotensis Kay, 1940, Jour. Paleontology, v. 14, p. 255, pl. 32, figures 13-19.

Subquadrate to subhemispherical in side view, highest medially to antero-medially, apparently dimorphic, the presumed females more full posteroventrally than males; dorsum straight, with tendency toward earlike small extensions at slightly obtuse cardinal angles; venter and ends slightly convex, fringed with a row of nodes or blunt spines on each valve; narrow marginal ridge; anterodorsal anteriorly curved crescentic sulcus and antero-medial low node; ventromedian backward-projecting large spine; general surface pustulose.

Length of shell (Pl. 5, fig. 6c) 0.73 mm, height 0.46 mm, width, exclusive of ventral spines, 0.36 mm.

Occurrence. The species is rare 9-11 feet above base and common 55-87 feet above base of Decorah Shale at St. Paul. It is rare in the lower and upper Decorah at Cannon Falls and is frequent in the upper Decorah 6 miles south of Cannon Falls, Minnesota (Kay, 1940).

No. of specimens studied. 30

UMPC. 15159

Winchellatia? ceratopea Cornell and Swain, n. sp.

Plate 1, figures 4a-f; plate 4, figures 1a, b

Plate 12, figure 8

Shell subquadrate in lateral view, highest medially; dorsal margin nearly straight; cardinal angles obtuse; anterior cardinal angle about 140°; posterior cardinal angle about 120°; ventral margin smoothly and gently convex; anterior margin broadly rounded, extended medially; posterior margin less broadly rounded, slightly extended above. Valves appear to be subequal but no complete carapaces were found. Valves compressed, greatest convexity

posteromedian; possible female dimorphs are more inflated posteriorly.

General shell surface smooth. A deep wide subvertical sulcus that becomes somewhat wider and shallower ventrally extends from dorsal margin to midheight and near midlength; anterodorsal to sulcus is a small rounded node or lobe, anterior to which is a shallow crescent-shaped depression or sulcus; points of crescent are directed posteriorly; posterodorsal to median sulcus is a large node or lobe that rises abruptly from anterodorsal border; a long pointed spine rises from node and in well-preserved specimens projects well beyond hinge line.

Hinge margin consists of the thin edge of each valve with thickening of valve and a slight notch occurring at each posterocardinal angle, more strongly so at anterior. Hinge edges bear closely spaced weak transverse ridges and grooves.

Length of holotype male? left valve 0.54 mm, height 0.34 mm, width 0.07 mm; length of female? paratype right valve 0.41 mm, height 0.27 mm, width 0.16 mm.

Relationships. *W.? ceratopea* is closely related to *Maratia mara* in outline and in the presence of two dorsal lobes on either side of the median sulcus. The posterior lobe of *W. ceratopea* is much larger (about one-third of valve length) than that of either *M. mara* or *M. micula*. The latter two species also lack the prominent posterodorsal spine of *W.? ceratopea*. *Maratia* typically has the general surface pitted unlike the present species.

Occurrence. The species is rare 1-3 feet above the base of the Decorah Shale at St. Paul, 1.4-7.4, 17.4-20.4 and 49-55 feet above the base of the Decorah at Cannon Falls, Minnesota, and 20-24 feet above the base of the Decorah at Rochester, Minnesota. It was not found in the Sugar Creek or other sections.

No. of specimens studied. 6

UMPC. 15160

Superfamily LEPERDITELLACEA Ulrich and Bassler 1906

Family LEPERDITELLIDAE Ulrich and Bassler 1906

Genus *HALLATIA* Kay, 1934

Hallatia convexa Kay

Plate 6, figures 3a-g

Hallatia convexa Kay, 1940, Jour. Paleontology, v. 14, p. 253, pl. 31, figs. 21-23.

Subquadrate, dorsum nearly straight but with small antero-medial concavity; anterior cardinal angle more obtuse than posterior; venter gently to moderately convex, anterior broadly curved; posterior subtruncate, and marginal zone is compressed; dorsal-antero-medial small pitlike sulcus represented on valve interior by a broad ridge; surface on either side of sulcus flattened and overhangs venter; general surface smooth.

Length of right valve (Pl. 6, fig. 3f) 0.67 mm, height 0.47 mm, width 0.13 mm.

Occurrence. The species is rare 23-29 feet above base of Decorah at St. Paul; common 9.4-13.4 feet above the base at Cannon Falls. It was described as rare to uncommon in the middle and upper Decorah Shale of northeastern Iowa.

No. of specimens studied. 16

UMPC. 15172

Hallatia particylindrica Kay

Plate 6, figure 4; plate 7, figure 2

Hallatia particylindrica Kay, 1934, Jour. Paleontology, v. 8, p. 336, pl. 45, figs. 3, 4; *ibid.*, 1940, v. 14, p. 253, pl. 31, figs. 24, 25.

Subquadrate to subovate, highest antero-medially; dorsum slightly sinuous; venter moderately convex, ends rounded, the posterior broader and more truncated than anterior; narrow rim and inner bordering furrow along free margins; broad anteriorly curving median sulcus in dorsal half; general surface smooth and inflated on either side of, and ventral to, sulcus.

Length of right valve (Pl. 7, fig. 2) 0.64 mm, height 0.41 mm, width 0.13 mm.

Occurrence. This form is rare 36-40 feet above base of Decorah at Sugar Creek, near Fountain, Minnesota. It is rare to uncommon in the upper Decorah of northeastern Iowa.

No. of specimens studied. Three

UMPC. 15173

Genus *PRIMITIA* Jones and Holl

Primitia mammata Ulrich

Plate 6, figures 5a-c; plate 7, figures 1a-c

Primitia mammata Ulrich, 1894, Final Rept. Geol. and Nat. Hist. Survey Minnesota, v. 3, pt. 2, p. 652, pl. 43, figs. 78, 79, 81; Kay, 1940, Jour. Pa-

leontology, v. 14, p. 248, pl. 30, fig. 22; Burr and Swain, 1965, Minn. Geol. Survey Spec. Pub. 3, p. 20, pl. 6, fig. 18.

Subovate, small anterodorsal sulcus, dorsum somewhat umbonate beyond straight hinge which is about three-fourths of length; small swelling on either side of sulcus; surface smooth.

Length of right valve (Pl. 6, fig. 5) 0.51 mm, height 0.35 mm, width 0.09 mm.

Occurrence. The species is abundant to very abundant in the upper Decorah Shale at St. Paul, and is common in the upper Decorah at Cannon Falls. It was recorded also in the Dubuque Formation, late middle Ordovician, of southern Minnesota (Burr and Swain, 1965).

No. of specimens studied. 125

UMPC. 15174

Primitia tumidula Ulrich

Plate 13, figure 11

Primitia tumidula Ulrich, 1894, Final Rept. Geol. and Nat. Hist. Survey Minnesota, v. 3, pt. 2, p. 655, pl. 43, figs. 62-65; Grabau and Shimer, 1910, North American Index Fossils, p. 345, text fig. 1658, m, m1, n; Burr and Swain, 1965, Minn. Geol. Survey, Spec. Pub. 3, p. 21, pt. 4, figs. 1, 6, pl. 6, figs. 25-32, 34.

Subovate, thickest posteriorly, longest and highest medially; strongly convex; anterior margin more broadly rounded than posterior; antero-medial dorsal sulcus curves anteriorly, with small swelling on either side; these extend beyond hinge margin; submarginal furrow may represent site of former edge of retained molt valve; general surface smooth.

Length of a right valve 0.63 mm, height 0.43 mm, width 0.21 mm.

Occurrence. The species is rare in the middle Decorah Shale at St. Paul; and in the middle Decorah at Cannon Falls. It has also been found in the Upper Ordovician Maquoketa Formation of Minnesota, Iowa, and Missouri and in the underlying Dubuque Formation of Minnesota. It was questionably recorded in the Llandoveryan, lower Silurian of England.

No. of specimens studied. Four

UMPC. 15175

Primitia cannonensis Swain and Cornell, n. sp.

Plate 7, figures 4a-d

Shell subovate in side view, dorsal margin nearly straight in posterior two-thirds, deflexed in anterior third; greatest height about one-third from posterior end; ventral margin moderately convex, anterior margin much more narrowly rounded than posterior; both ends slightly extended above. Valves rather strongly convex, greatest convexity about one-fourth from posterior end, which has compressed marginal zone; left valve slightly larger than right.

A narrow marginal lip occurs along venter and lower parts of ends; dorsally and about two-fifths from anterior end is a shallow, broad and rather short sulcus; anterior to sulcus is a low node that is somewhat more elevated in left than in right valve; posterodorsal surface swollen. General surface finely and densely punctate in dorsal half at least.

Length of holotype 0.71 mm, height 0.58 mm, width 0.41 mm.

Relationships. In general shape and type of sulcation the species conforms to *Primitia*. The punctate surface seems to be a unique feature as well as the deflexed nature of the anterior part of the dorsal margin.

Occurrence. The species is rare from 49-53 feet above the base of the Decorah Shale at Cannon Falls, Minnesota.

No. of specimens studied. Three

UMPC. 15176

Genus *PRIMITIELLA* Ulrich, 1894

Primitiella constricta Ulrich

Plate 7, figures 3a-g

Primitiella constricta Ulrich, 1894, Final Rept. Geol. and Nat. Hist. Survey Minnesota, v. 3, pt. 2, p. 647, pl. 43, figs. 48-52; Kay, 1940, Jour. Paleontology, v. 14, p. 262, pl. 33, figs. 22-26.

Subelliptical, dorsum nearly straight to slightly concave, anterior cardinal angle more obtuse than posterior; venter slightly convex, straightened to slightly concave medially, ends rounded, the anterior more extended medially than posterior; left valve slightly larger than right; valves moderately convex; dorsomedian surface depressed, corresponding feature on interior surface a low elevation; general surface bears scattered small pits.

Length of figured right valve (Pl. 7, fig. 3b) 0.67 mm, height 0.59 mm, width 0.24 mm.

Occurrence. The species is very abundant in the basal 11 feet of Decorah Shale and is rare in the middle and upper Decorah at St. Paul; rare to abundant

throughout the Decorah Shale at Cannon Falls; rare throughout the Decorah Shale at Rochester; and rare in the middle and upper Decorah at Sugar Creek, near Fountain, Minnesota. It has previously been recorded in the upper Decorah of northeastern Iowa; in the Hull Formation at Healey Falls, Ontario; in the lower and upper Lowville Formation at High Bridge, Kentucky and Lavergne, Tennessee.

No. of specimens studied. 115

UMPC. 15177

Primitiella plattevillensis Kay

Plate 7, figures 5a-f; plate 8, figure 1

Plate 11, figures 11, 12

Primitiella plattevillensis Kay, 1940, Jour. Paleontology, v. 14, p. 262, pl. 33, figs. 27-30.

Subelliptical, dorsum straight, anterior cardinal angle equal or less obtuse than posterior; ends and venter convex; anterior more extended beyond hinge line than posterior; valves compressed, rising steeply from margins and with main surface flattened; median dorsal surface broadly but only slightly depressed; surface weakly and sparsely punctate.

Length of right valve (Pl. 7, fig. 5b) 0.71 mm, height 0.43 mm, width 0.11 mm.

Occurrence. The species is rare in the lowermost 1-3 feet, and in the middle and upper Decorah at St. Paul. It was recorded in the upper Platteville limestone of Iowa.

No. of specimens studied. Eight

UMPC. 15178

Genus *PSEUDOPRIMITIELLA* Warshauer, 1981

Pseudoprimitiella unicornis (Ulrich)

Plate 7, figure 6

Leperditia unicornis Ulrich, 1879, Cincinnati Soc. Nat. Hist. Jour., v. 2, p. 10, pl. 7, fig. 4.

?*Aparchites unicornis* Ulrich, 1889, Contr. Canadian Micropaleontology, pt. 2, p. 50.

?*Primitia unicornis* Jones, 1890, Geol. Soc. London, Quart. Jour., v. 46, p. 7.

Primitiella unicornis (Ulrich), Ulrich, 1894, Final Rept. Minn. Geol. and Nat. Hist. Survey of, v. 3, pt. 2, p. 649, pl. 43, figs. 75-77; Shimer and Shrock, 1944, Index Fossils of North America, p. 665, pl. 281, figs. 5-7; Keenan, 1951, Jour. Paleontology, v. 25, p. 568, pl. 78, fig. 5, pl. 79, figs. 38, 39; Burr and Swain, 1965, Minn. Geol. Survey, Spec. Pub. 3, p. 22, pl. 2, figs. 21-25, l. 6, figs. 1-10.

Pseudoprimitiella unicornis (Ulrich), Warshauer, 1981, Jour. Paleontology, v. 55, p. 890, pl. 1, figs. 9-12.

Suboblong to subelliptical, convexity greatest postero-medially; hinge long and straight, anterior cardinal angle the more convex; venter and ends gently convex; faint poorly defined broad dorsomedian depression; posterior small short submarginal spine; general surface sparsely pitted.

Length of right valve 0.79 mm, height 0.44 mm, width 0.12 mm.

Occurrence. This easily recognized species is rare 35-37 feet above the base of the Decorah Shale at St. Paul, Minnesota. It has also been found in the "depauperate zone" at the base of the Maquoketa Formation of Iowa, and in the Maquoketa Formation of Missouri, in the upper Trenton Group at Cincinnati, Ohio, in the Canajoharie and Whetstone Gulf Formations of New York; and questionably in the Yeringian Formation, Lilydale, Australia, and the Bola Formation at Montgomeryshire, Wales.

No. of specimens studied. Four

UMPC. 15179

Superfamily and Family Uncertain

Genus *OPIKATIA* Kay, 1940

Remarks. The orientation used here is modified from that of Kay (1940) and Moore (1961) in which the anterior-posterior orientation of the valves was reversed.

Opikatia rotunda Kay
Plate 1, figures 1a-i

Opikatia rotunda Kay, 1940, Jour. Paleontology, v. 14, p. 264, pl. 34, figs. 1-6.

Subquadrate, median circular depression nearly surrounded by broad swelling that terminates anteriorly as a rounded node; general surface smooth. These forms were believed by Kay to be female dimorphs.

Length of male left valve (Pl. 1, fig. 1a) 0.68 mm, height 0.39 mm, width 0.21 mm.

Occurrence. The species was obtained rarely in the upper Decorah Ion Member at Cannon Falls and Sugar Creek, Minnesota, but was not found at Rochester or St. Paul. The species was recorded by Kay (1940) from the Ion Member of the Decorah, 6 miles south of Cannon Falls, Minnesota. *Opikatia emaciata* Kay was also recorded rarely in the upper Decorah at Cannon Falls and Sugar Creek, Minnesota, but is not illustrated separately here. The writers consider it possible that *O. emaciata* is a variant of *O. rotunda*.

No. of specimens studied. Three

UMPC. 15181; *Opikatia emaciata* Kay 1940 is housed under UMPC 15180.

Genus *DICRANELLA* Ulrich, 1894
Dicranella bicornis Ulrich
Plate 3, figures 4a-c
Plate 12, figures 14, 15

Dicranella bicornis Ulrich, 1894, Final Rept. Geol. and Nat. Hist. Survey Minnesota, v. 3, pt. 2, p. 665, pl. 46, figs. 39, 40. Ulrich and Bassler, 1923, Maryland Geol. Survey, Silurian vol., p. 229, 301, fig. 15. Kay, 1940, Jour. Paleontology, v. 14, p. 260, pl. 33, figs. 1-3.

Shell subquadrate to subtriangular, highest anteromedially; dorsum straight, except for median projecting spine; venter moderately convex in males, strongly convex in females; anterior more broadly curved than posterior in females; ends more nearly equal in males; ventral frill extends along posterior two-thirds of margin and is strongly overhanging; outer surface of shell varies from nearly flat with an inner ridge, to somewhat curved and without a ridge. Anteromedian dorsal sulcus extends to near midheight; anteromedian rounded lobe extends to near dorsal margin; posteromedian lobe has spinelike dorsal projection that extends beyond dorsal margin in unbroken specimens; general surface finely granulose; free margins nodose. Granular nature of shell surface suggests some modern forms that have shell impregnated with organic matter.

Length of female left valve (Pl. 3, fig. 4a) 0.78 mm, height 0.47 mm, width 0.23 mm, exclusive of spines.

Occurrence. This species in the present collection is rare in the lower, middle and upper part of the upper Decorah Formation at St. Paul; rare throughout the Decorah at Cannon Falls, and rare in the upper Decorah at Sugar Creek. It has been recorded as rare in the middle Decorah in northeastern Iowa.

No. of specimens studied. 18

UMPC. 15182.

Dicranella marginata Ulrich
Plate 3, figures 5a, b

Dicranella marginata Ulrich, 1894, Final Rept. Geol. and Nat. Hist. Survey Minnesota, v. 3, pt. 2, p. 666, pl. 44, figs. 27, 28; Kay, 1940, Jour. Paleontology, v. 14, p. 260, pl. 33, figs. 1-3.

Shell subquadrate to subtriangular, highest anteromedially; dorsum nearly straight; anterior cardinal angle slightly more obtuse than posterior; venter strongly convex in female dimorphs; anterior margin extended below in females; posterior margin extended above; dorsomedian sulcus extends nearly to midheight, curves anteriorly; anteromedian high bluntly-pointed lobe may extend beyond dorsal margin; anteroventral frill in presumed females lies along anterior two-thirds of venter, and has a narrow ridge along its crest; general surface smooth to sparsely pitted.

Length of right valve (Pl. 3, fig. 5b) 0.80 mm, height exclusive of spines 0.58 mm, width 0.25 mm.

Occurrence. The species is rare in the middle and upper Decorah Shale at St. Paul; rare in the upper Decorah at Cannon Falls. It was previously recorded as rare in the middle and upper Decorah in northeastern Iowa.

No. of specimens studied. Nine

UMPC. 15183

Order PODOCOPIDA Müller, 1884
Suborder METACOPINA Sylvester-Bradley, 1961
Superfamily HEALDIACEA Harlton, 1933
Family BAIRDIOCYPRIDIDAE Shaver, 1961
Genus *ELLIPTOCYPRITES* Swain, 1962
Elliptocyprites paracylindrica Swain and Cornell, n. sp.
Plate 10, figures 3a-e

Shell elliptical in side view, highest medially to postero-medially, dorsum and venter nearly straight to gently convex, ends rounded, the anterior slightly narrower than posterior. Valves rather compressed; left valve larger than right; lateral surfaces nearly subparallel in edge view. Surface smooth. Left valve dorsum bears a groove for reception of edge of right. Midventral edge of left valve slightly intumed.

Length of holotype shell 0.80 mm, height 0.40 mm, convexity of valves 0.13 mm.

Relationships. The species is more elliptical than *Phelobothocypris cylindrica* (Hall, 1871) of the Upper Ordovician which has the venter straighter than the dorsum. It is very close in outline to '*Bythocypris*' *phaseolus elongata* Jones (1889) from the Lower Silurian Llandoveryan but the valves are less convex than that species. As compared to *E. parallela* Swain and *E. longula* Swain from the Middle Ordovician its dorsum and venter are slightly more convex. This species has probably been referred to in the literature as *Bythocypris cylindrica*.

Length of figured shell (Pl. 10, fig. 3a) 0.58 mm, height 0.23 mm, width 0.18 mm.

Occurrence. This form is rare to abundant throughout the Decorah Shale at St. Paul; rare to common throughout the Decorah at Cannon Falls; rare to abundant throughout the Decorah at Sugar Creek. The species possibly occurs also in the Decorah of northeastern Iowa, and in the Galena Group at Cannon Falls, Minnesota, where it was recorded as *Bythocypris cylindrica* in part.

No. of specimens studied. 125

UMPC. 15184

Family KRAUSELLIDAE Berdan, 1961
Genus *KRAUSELLA* Ulrich, 1894
Krausella variata Kraft
Plate 10, figure 4

Krausella variata Kraft, 1962, Geol. Soc. America, Mem. 86, p. 63, pl. 17, figs. 1-23.

Elongate-sublanceolate, right valve larger than left, overlapping and overreaching left dorsally and ventrally, posteroventral spine on right valve varies from thick and blunt to pointed; venter convex, thus differing from *K. arcuata*; surface smooth.

Length of shell 1.55 mm, height 0.74 mm, width 0.85 mm.

Occurrence. The species was obtained in the present collection from 0-1.5 feet above base of Decorah Shale, Cannon Falls, Minnesota. The species also occurs in the Edinburgh and Lincolnshire Formations of Virginia and in the Crown Point Formation of New York.

No. of specimens studied. Three

UMPC. 15185

Krausella arcuata Ulrich
Plate 10, figures 5a-c

Krausella arcuata Ulrich, 1894, Final Rept. Geol. and Nat. Hist. Survey Minnesota, v. 3, pt. 2, p. 692, pl. 44, figs. 47-53.

Elongate-sublanceolate, dorsum moderately arched, venter nearly straight to slightly sinuous; anterior rounded, extended below; posterior end of right bluntly pointed, strongly extended below; pointed end varies in sharpness and valve margin above pointed end is variably straight to concave; left valve narrowly rounded posteriorly. Valves moderately convex, greatest convexity median; right valve larger than left. Surface smooth.

Length of shell (Pl. 10, fig. 5c) 1.83 mm, height 0.79 mm, width 0.70 mm.

Occurrence. The species is rare in the middle and in the uppermost four feet of the Decorah Shale at Rochester, Minnesota. It was recorded as frequent to very abundant in the middle Decorah and rare in the upper Decorah of northeastern Iowa, in the Platteville Formation of Illinois and Wisconsin, the Lowville Formation of Kentucky, the Bromide Formation of Oklahoma, and questionably in the Llandovery beds of Wales.

No. of specimens studied. Five

UMPC. 15186

PLATE 1

- Figures 1a-i.** *Opikatia rotunda* Kay. a. Interior of a male? left valve. b, d. Interior and exterior views of a female? left valve. c. Dorsal view of a left valve. e. Exterior of a female? right valve. f. Exterior of a male right valve. g. Exterior of a male? left valve. h. Exterior of a female? left valve. i. Ventral view of female left valve. 1a, c, e, g, h, and i are from 55-57 feet above base of Decorah Shale, St. Paul, Minnesota; 1b, d and f are from 53-55 feet above base of Decorah Shale, Cannon Falls section, Minnesota. X75.
- Figures 2a-g.** *Marattia mara* Kay. a. Exterior of a male right valve. b. Exterior of a female left valve. c. Exterior of a female left valve. d. Exterior of a male right valve. e. Interior of a female left valve. f. Interior of a female left valve. g. Dorsal view of shell. 2a, b, d, e, f, and g are from 15.5-17.5 feet above base of Decorah at Cannon Falls section, Minnesota; 2c is from 40-44 feet above base of Decorah Shale at Sugar Creek section, Minnesota. X75.
- Figures 3a-d.** *Marattia micula* (Ulrich). a. Exterior of a female? left valve. b. Exterior of female? right valve. c. Exterior of male? right valve. d. Interior of female? left valve. All are from 67-69 feet above base of Decorah Shale at St. Paul section, Minnesota. X75.
- Figures 4a-f.** *Winchellatia? ceratopea* Cornell and Swain, n. sp. a, b. Exterior of holotype and interior of paratype left valves. c, d. Exterior and interior views of paratype right valve. e. Ventral view of paratype right valve. f. Dorsal view of paratype right valve. 4a, e and f are from 1.5-3.5 feet above base of Decorah at Cannon Falls section, Minnesota. 4b, c and d are from 0-1.5 feet above base of Decorah same locality. X75.
- Figure 5.** *Scofieldia bilateralis* (Ulrich). Exterior of a left valve; 48-49 feet above base of Decorah, Cannon Falls section, Minnesota. X33.
- Figure 6a-d.** *Quasibollia persulcata* (Ulrich). a. Exterior of a right valve, broken medially. b. Interior of a left valve. c. Dorsal view of left valve. d. Ventral view of right valve. All are from 46-53 feet above base of Decorah, Cannon Falls section, Minnesota. X75.

PLATE 2

- Figures 1a-h.** *Bollia subaequata* Ulrich. a. Exterior of a left valve. b. Interior of a right valve. c. Dorsal view of a right valve. d. Exterior of a right valve. e. Interior of a left valve. f. Exterior of a left valve. g. Ventral view of a left valve. h. Interior of a right valve. 1a, d and f are from 49-53 feet above base of Decorah at Cannon Falls section, Minnesota; 1b, e and h are from 56.5-60 feet above base of Decorah, Cannon Falls; 1c and g are from 77-79 feet above base of Decorah at St. Paul section, Minnesota. X75.
- Figure 2.** *Bollia subaequata* (Ulrich). Immature; exterior of right valve. 20-24 feet above base. Rochester section, Minnesota. X75.
- Figures 3a-e.** *Pseudulrichia simplex* (Kay). a. Exterior of left valve. b. Interior of right valve. c. Exterior of right valve. d. Ventral view of left valve. e. Dorsal view of shell. All are from 81-83 feet above base of Decorah at St. Paul section, Minnesota. X75.
- Figures 4a-f.** *Bellornatia tricollis* Kay. a. Interior of left valve. b. Exterior of left valve. c. Exterior of right valve. d. Dorsal view of left valve. e. Dorsal view of right valve. f. Exterior of left valve. 4a is from 11.5-13.5 feet above base of Decorah at Cannon Falls section, Minnesota; 4b is from 1-3 feet above base of Decorah at St. Paul section, Minnesota; 4c-f are from 3.5-5.5 feet above base of Decorah at Cannon Falls section, Minnesota. X75.
- Figure 5.** *Scofieldia bilateralis* (Ulrich). Interior of left valve; 48-49 feet above base of Decorah, Cannon Falls section, Minnesota. X33.

PLATE 3

- Figures 1a-c.** *Bellornatia tricollis* Kay. a, c. Exterior and interior of left valves, imperfect posteroventrally. b. Exterior of right valve. 1a and b are from 3.5-5.5 feet above base of Decorah, Cannon Falls section, Minnesota. 1c is from 1-3 feet above base of Decorah at St. Paul section, Minnesota. X75.
- Figure 2.** *Ceratopsis chambersi* (Miller). Exterior of left valve; 47-49 feet above base of Decorah at Cannon Falls section, Minnesota. X75.
- Figures 3a-d.** *Ceratopsis quadrifida* (Jones). a. Ventral view of right valve. b. Interior of left valve in which dorsal spine is broken. c. Exterior of left valve. d. Dorsal view of left valve. All are from 39.5-43 feet above base of Decorah, Cannon Falls section, Minnesota. X45.

Figures 4a-c. *Dicranella bicornis* Ulrich. a. Exterior of a female left valve broken posterodorsally. b. Exterior of a male left valve. c. Ventral view of shell. All are from 36-40 feet above base of Decorah, Sugar Creek section, Minnesota. 4a, b, X 75; 4c, X45.

Figures 5a, b. *Dicranella marginata* Ulrich. a. Exterior of left valve broken posteriorly. b. Exterior of a right valve; 56.5-59 feet above base of Decorah, Cannon Falls section, Minnesota. X75.

Figure 6. *Dilobella simplex* Kay. Exterior of left valve; 56.5-60 feet above base of Decorah, Cannon Falls section, Minnesota. X75.

Figure 7. *Dilobella typa* Ulrich. Interior of right valve; 49-55 feet above base of Decorah, Cannon Falls section, Minnesota. X75.

PLATE 4

- Figures 1a, b.** *Dilobella typa* Ulrich. a. Interior of left valve. b. Exterior of right valve. The specimens are from 49-55 feet above base of Decorah, Cannon Falls section, Minnesota. X75.
- Figures 2a-c.** *Raymondatia goniglypta* Kay. a. Exterior of right valve. b. Exterior of left valve. c. Interior of left valve. The specimens are from 47-49 feet above base of Decorah, Cannon Falls section, Minnesota. X75.
- Figures 3a-f.** *Rigidella cannonensis* Cornell and Swain, n. sp. a. Right side of paratype shell. b. Right side of holotype shell. c. Left side of paratype shell. d. Dorsal view of holotype shell. e. Right side of paratype shell. f. Dorsal view of paratype shell. 3a, c and f are from 16-20 feet above base of Decorah, Rochester section, Minnesota. 3b, d and e are from 52.5-55 feet above base of Decorah, Cannon Falls section, Minnesota. X75.
- Figures 4a-i.** *Tetradella ellipsilira* Kay. a. Interior of right valve. b. Dorsal view of right valve. c. Interior of left valve. d. Exterior of male left valve. e. Exterior of poorly preserved female left valve. f. Exterior of female right valve. g. Ventral view of male left valve. h. Ventral view of female left valve. i. Interior of right valve. 4a and c are from 36-40 feet above base of Decorah, Sugar Creek section, Minnesota. 4b, d, f, h and i are from 52.5-55 feet above base of Decorah, Cannon Falls section, Minnesota. 4e and g are from 23-25 feet above base of Decorah, St. Paul section, Minnesota. X75.

PLATE 5

- Figures 1a, b.** *Tetradella ellipsilira* Kay. a. Exterior of female left valve. b. Exterior of large female left valve questionably representing this species. The specimens are from 23-25 feet above base of Decorah, St. Paul section, Minnesota. X 75.
- Figures 2a-e.** *Tetradella ulrichi* Kay. a. Exterior of right valve. b. Dorsal view of right valve. c. Ventral view of right valve. d. Exterior of right valve. e. Interior of left valve. 2a is from 36-40 feet above base of Decorah, Sugar Creek section, Minnesota. 2b-e are from 42-45 feet above base of Decorah, Cannon Falls section, Minnesota. X75.
- Figures 3a-d.** *Thomasatia falcicosta* Kay. a. Interior of left valve. b. Exterior of right valve broken posterodorsally and with recrystallized surface. c. Exterior of valve that has the anteromedian node broken. d. Exterior of left valve. 3a and b are from 45-47 feet above base of Decorah, Cannon Falls section, Minnesota. 3c is from 42-45 feet above base of Decorah, same locality. 3d is from 39.5-42 feet above base, same locality. X75.
- Figures 4a, b.** *Kiesowia verrucosa* Kay. a. Right side of shell. b. Dorsal view of shell. The specimens are from 60-61 feet above base of Decorah, Cannon Falls section, Minnesota. X75.
- Figures 5a-e.** *Winchellatia lansingensis* Kay. a. Exterior of left valve. b. Interior of left valve. c. Exterior of right valve. d. Interior of right valve. e. Dorsal view of left valve. The specimens are from 20-24 feet above base of Decorah, Sugar Creek section, Minnesota. X75.
- Figures 6a-d.** *Winchellatia minnesotensis* Kay. a. Ventral view of small shell. b. Right side of small shell. c. Right side of mature shell. d. Ventral view of mature shell. 6a and d are from 53-56.5 feet above base of Decorah, Cannon Falls section, Minnesota; 6b and c are from 52.5-55 feet above base, same locality. X75.
- Figure 7.** *Euprimitia labiosa* (Ulrich). Exterior of a left valve; 7.5-9.5 feet above base of Decorah, Cannon Falls section, Minnesota. X75.

PLATE 6

- Figures 1a-d.** *Euprimitia labiosa* (Ulrich). a. Exterior of right valve. b. Dorsal view of right valve. c. Ventral view of right valve. d. Interior of left valve. All are from 7.5-9.5 feet above base of Decorah, Cannon Falls section, Minnesota. X75.
- Figures 2a-f.** *Euprimitia sanctipauli* (Ulrich). a. Exterior of female right valve. b. Dorsal view of right valve. c. Ventral view of left valve. d. Exterior of male left valve. e. Interior of right valve. f. Exterior of left valve. All are from 23-25 feet above base of Decorah, St. Paul section, Minnesota. X75.
- Figures 3a-g.** *Hallatia convexa* Kay. a. Interior of female? left valve. b. Ventral view of right valve. c. Dorsal view of shell. d. Exterior of male? left valve. e. Exterior of female? left valve. f. Exterior of female? right valve. g. Interior of poorly preserved left valve. All are from 55-57 feet above base of Decorah, St. Paul section, Minnesota. X75.
- Figure 4.** *Hallatia particylindrica* Kay. Exterior of right valve; 36-40 feet above base of Decorah, Sugar Creek section, Minnesota. X75.
- Figures 5a-c.** *Primitia mammata* Ulrich. a. Exterior of right valve. b. Dorsal view of right valve. c. Interior of right valve. All are from 85-87 feet above base of Decorah, St. Paul section, Minnesota. X75.

PLATE 7

- Figures 1a-c.** *Primitia mammata* Ulrich. a. Exterior of left valve. b. Dorsal view of left valve. c. Exterior of poorly preserved left valve. All are from 85-87 feet above base of Decorah, St. Paul section, Minnesota. X75.
- Figure 2.** *Hallatia particylindrica* Kay. Exterior of right valve; 43-45 feet above base of Decorah, St. Paul section, Minnesota. X75.
- Figures 3a-g.** *Primitiella constricta* Ulrich. a. Ventral view of immature female? shell. b. Exterior of female? right valve. c. Dorsal view, slightly tilted to the right, of a male? shell. d. Interior of a female? left valve. e. Interior of female? right valve. f. Exterior of male? right valve. g. Right side of immature female? shell. 3a, c and f are from 1.5-3.5 feet above base of Decorah, Cannon Falls section, Minnesota. 3b, d and e are from 0-1.5 feet above base of Decorah, same locality. 3g is from 3.5-5.5 feet above base of Decorah, same locality. X75.
- Figures 4a-d.** *Primitia cannonensis* Swain and Cornell, n. sp. a. Left side of holotype shell. b. Right side of paratype shell. c. Ventral view of holotype shell. d. Dorsal view of holotype shell; 49-53 feet above base of Decorah, Cannon Falls section, Minnesota. X75.
- Figures 5a-f.** *Primitiella plattevillensis* Kay. a. Interior of male? left valve. b. Exterior of right valve. c. Exterior of left valve. d. Interior of female? left valve. e. Dorsal view of right valve. f. Ventral view of left valve. All are from 35-37 feet above base of Decorah, St. Paul section, Minnesota. X75.
- Figure 6.** *Pseudoprimitiella unicornis* (Ulrich). Exterior of right valve; 35-37 feet above base of Decorah, St. Paul section, Minnesota. X75.

PLATE 8

- Figure 1.** *Primitiella plattevillensis* Kay. Interior of right valve; 35-37 feet above base of Decorah, St. Paul section, Minnesota. X75.
- Figure 2.** *Eurychilina micropunctata* Swain and Cornell, n. sp. Exterior of left valve; 4-8 feet above base of Decorah, Rochester section, Minnesota. X45.
- Figures 3a-e.** *Eurychilina reticulata* Ulrich. a. Exterior of left valve. b. Dorsal view of left valve. c. Ventral view of right valve. d. Ventral view of small shell. e. Dorsal view of shell. 3a and d are from 52.5-55.5 feet above base of Decorah, Cannon Falls section, Minnesota. 3b and c are from 32-36 feet above base of Decorah, Sugar Creek section, Minnesota. 3e is from 40-43.5 feet above base of Decorah, Cannon Falls section, Minnesota. All X45 except c which is X36.
- Figures 4a, b.** *Eurychilina sugarcreekensis* Swain and Cornell, n. sp. Exterior and interior views of holotype female? right valve; 32-36 feet above base of Decorah, Sugar Creek section, Minnesota. X36.
- Figure 5.** *Eurychilina cannonfallsensis* Swain and Cornell, n. sp. Exterior of left valve; 36-40 feet above base of Decorah, Cannon Falls section, Minnesota. X36.

PLATE 9

- Figure 1.** *Eurychilina ventrosa* Ulrich. Exterior of a right valve; 23-25 feet above base of Decorah, St. Paul section, Minnesota. X75.
- Figures 2a-c.** *Eurychilina kayi* Swain and Cornell, n. sp. a. Exterior of immature right valve. b. Exterior of large left valve. c. Dorsal view of left valve. All are from 49-53 feet above base of Decorah, Cannon Falls section, Minnesota. a, X75; b, c, X39.
- Figures 3a, b.** *Eurychilina partifimbriata* Kay. a. Interior of left valve. b. Exterior of left valve. 3a and b are from 49-53 feet above base of Decorah, Cannon Falls section, Minnesota. X45.
- Figures 4a, b.** *Eurychilina subradiata* Ulrich. a. Exterior of left valve. b. Dorsal view of left valve. 4a and b are from 7.5-9.5 feet above base of Decorah, Cannon Falls section, Minnesota. X33.
- Figures 5a, b.** *Eurychilina reticulata* Ulrich. a. Exterior of right valve. b. Exterior of left valve. 5a and b are from 7.5-9.5 feet above base of Decorah, Cannon Falls section, Minnesota. a, X30; b, X45.
- Figure 6.** *Bromidella depressa* Kay. Exterior of right valve; 23-25 feet above base of Decorah, St. Paul section, Minnesota. X75.
- Figure 7.** *Eurychilina minutifoveata* Kay. Left side of poorly preserved shell; 53-56 feet above base of Decorah, 1 mile S. of Cannon Falls section, Minnesota. X45.

PLATE 10

- Figures 1a-g.** *Bromidella depressa* Kay. a, b. Exterior views of two male left valves. c. Ventral view of male shell. d. Exterior of female left valve. e. Exterior of female right valve. f. Interior of female right valve. g. Ventral view of female shell. 1a and b are from 23-25 feet above base of Decorah, St. Paul section, Minnesota; 1c is from 45-47 feet above base of Decorah at St. Paul; 1d is from 5.5-7.5 feet above base of Decorah, Cannon Falls section, Minnesota; 1e and f are from 53-56 feet above base of Decorah at Cannon Falls; 1g is from 43-45 feet above base of Decorah at St. Paul. X75.
- Figures 2a-g.** *Bromidella rhomboides* Kay. a. Interior of right valve. b. Ventral view of left valve. c. Exterior view of right valve. d. Ventral view of left valve. e. Interior of left valve. f. Exterior of left valve. g. Dorsal view of right valve. All except 2d are from 51-53 feet above base of Decorah, St. Paul section, Minnesota; 2d is from 53-56.5 feet above base of Decorah, Cannon Falls section, Minnesota. X75.
- Figures 3a-e.** *Elliptocyprites paracylindrica* Swain and Cornell, n. sp. a. Right side of shell. b, c. Ventral views of two shells. d. Right side of shell. e. Interior of left valve. All but 3d are from 3.5-5.5 feet above base of Decorah, Cannon Falls section, Minnesota; 3d is from 0-1.5 feet above base of Decorah, same locality. X75.
- Figure 4.** *Krausella variata* Kraft. a. Exterior of left valve from 0-1.5 feet above base of Decorah, Cannon Falls section, Minnesota. X45.
- Figures 5a-c.** *Krausella arcuata* Ulrich. a. Right side of shell. b. Ventral view of shell. c. Exterior of right valve; a and b are from 3.5-5.5 feet above base of Decorah, Cannon Falls section, Minnesota; c is from 9.5-11.5 feet above base, same locality. X45.

PLATE 11

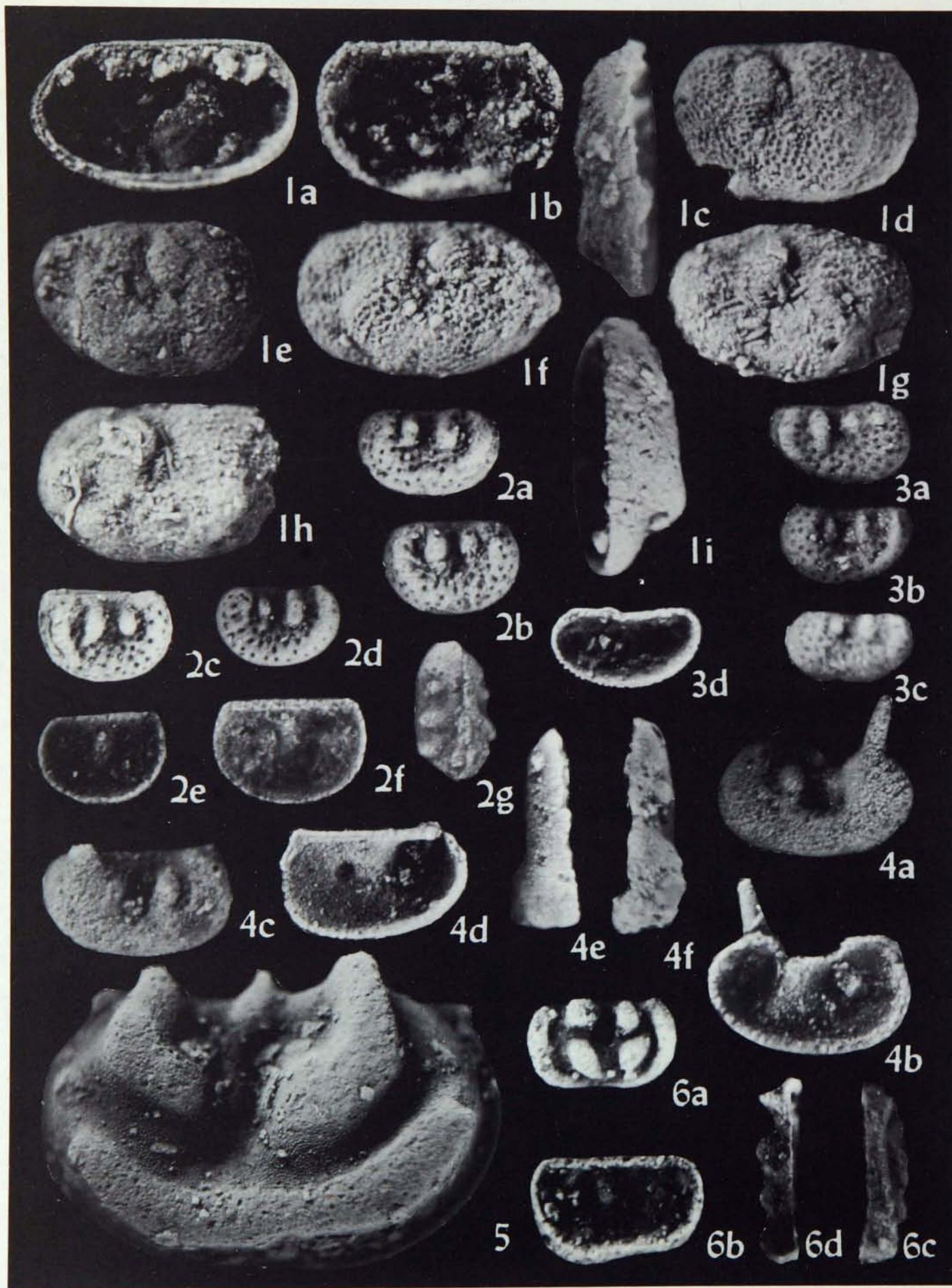
- Figure 1.** *Maratia mara* Kay. Exterior of left valve, X162; 15.5-17.5 feet above base of Decorah Shale, Cannon Falls section, Minnesota.
- Figure 2.** *Maratia mara* Kay. Interior of left valve, X138; same horizon and locality as 1.
- Figures 3, 4.** *Bromidella depressa* Kay. Exterior of male right valve, interior of right valve, X68; 5.5-7.5 feet above base of Decorah Shale, Cannon Falls Section, Minnesota.
- Figures 5, 6.** *Bromidella rhomboides* Kay. Exterior of right valve, X188; dorsal view of shell, X155; 25-27 feet above base of Decorah Shale, St. Paul section, Minnesota.
- Figures 7, 8.** *Dilobella simplex* Kay. Exterior of right valve, X58; dorsal view of shell, X60; 47-49 feet above base of Decorah Shale, St. Paul section, Minnesota.
- Figures 9, 10.** *Bromidella depressa* Kay. Right side of shell, X89; ventral view of shell, X104; 23-25 feet above base of Decorah Shale, St. Paul section, Minnesota.
- Figures 11, 12.** *Primitiella plattevillensis* Kay. Interior of left valve, X54; right side of shell, X72; 35-37 feet above base of Decorah Shale, St. Paul section, Minnesota.
- Figures 13-15.** *Dilobella typa* Ulrich. Right side, X54; interior of left valve, X52; ventral view of shell, X40; 55-57 feet above base of Decorah Shale, St. Paul section, Minnesota.

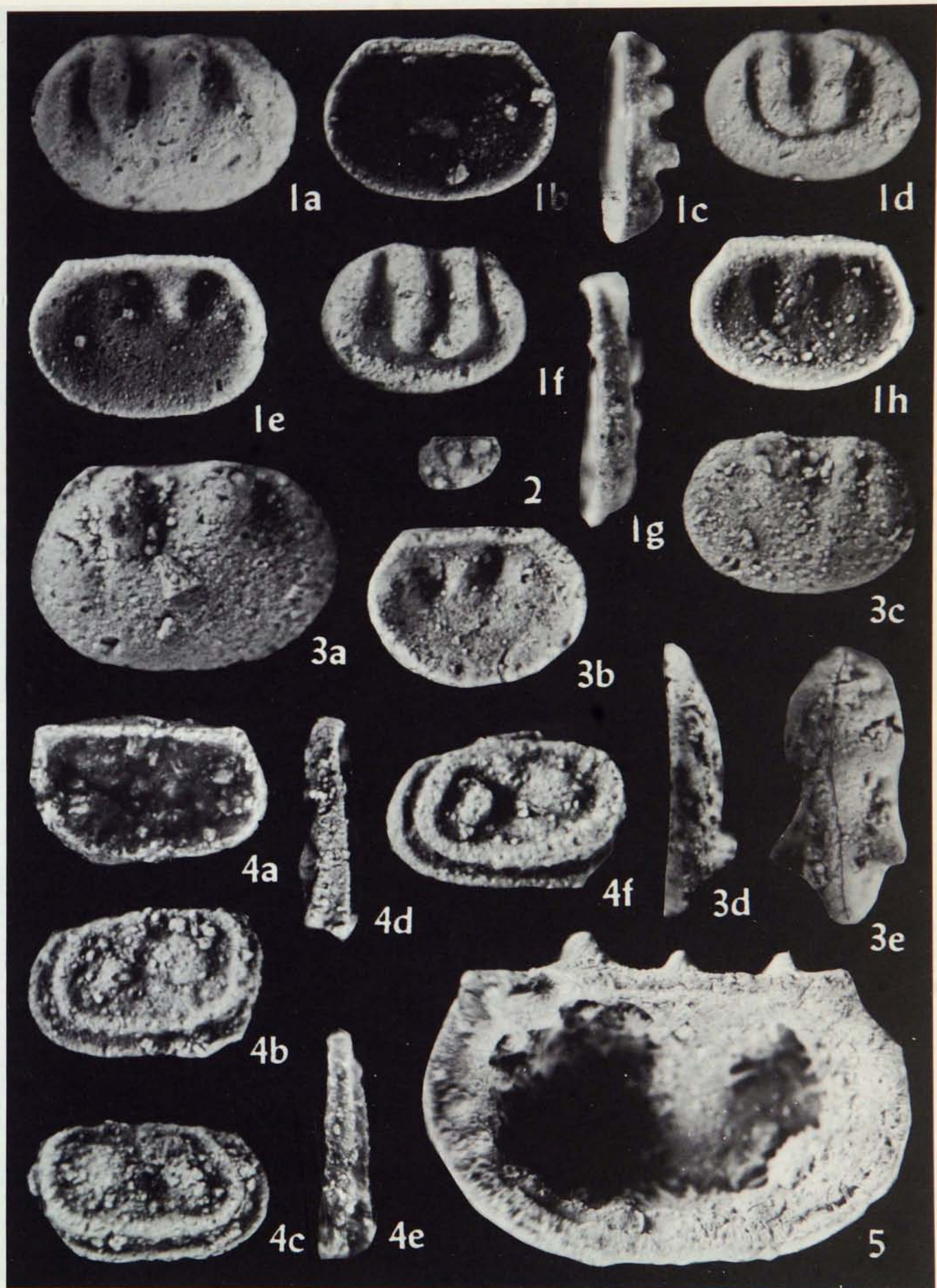
PLATE 12

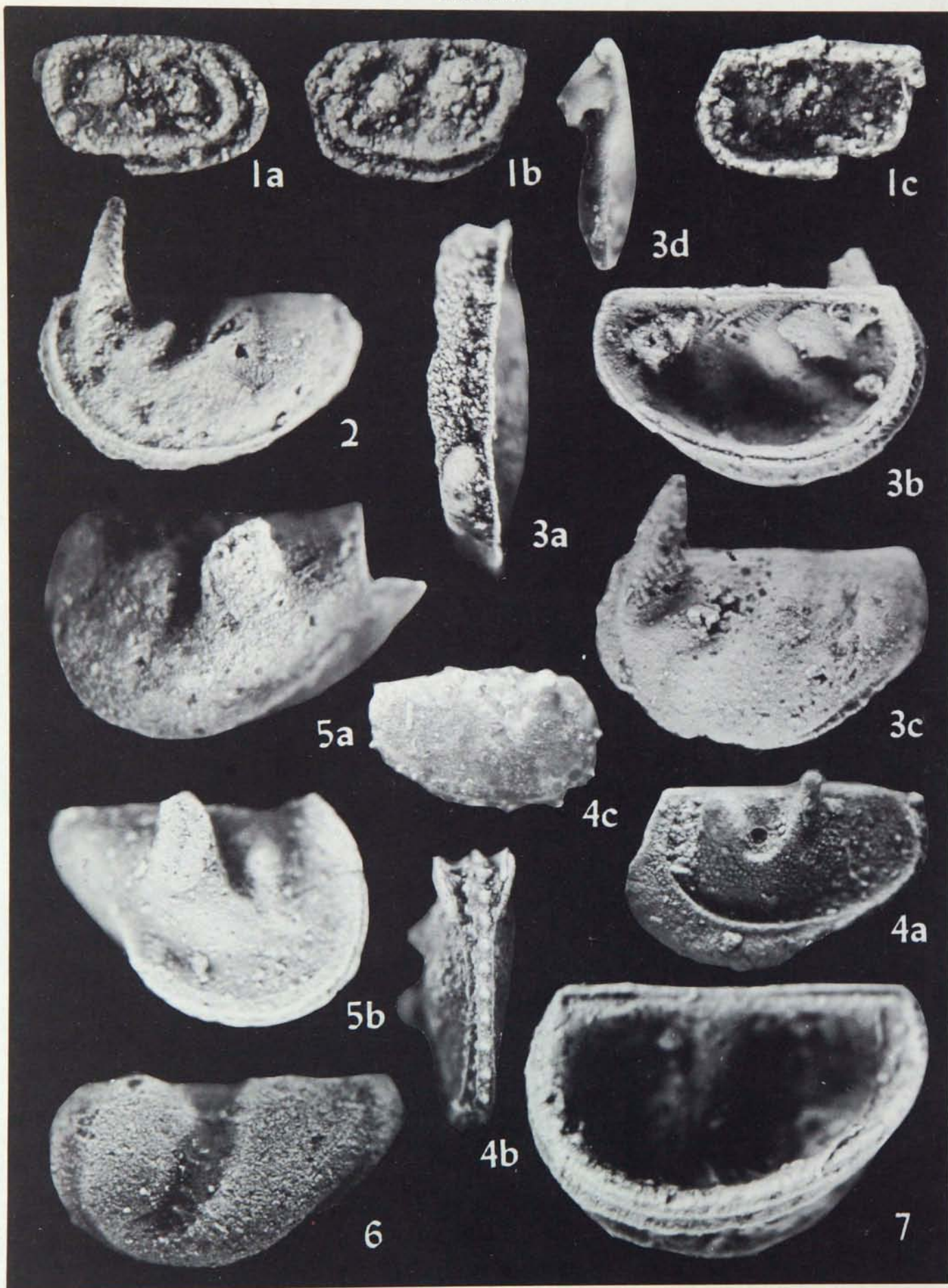
- Figures 1, 2.** *Ceratopsis quadrifida* (Jones). Exterior of left valve, X39; exterior of right valve, X54; 61-63 feet and 47-49 feet above base of Decorah Shale, respectively, St. Paul section, Minnesota.
- Figure 4.** *Tetradella ellipsilira* Kay. Exterior of left valve, X58; 23-25 feet above base of Decorah Shale, St. Paul section, Minnesota.
- Figures 3, 5, 6.** *Winchellatia lansingensis* Kay. Exterior of left valve, X76, somewhat foreshortened owing to tilting of anterior end away from observer; interior of left valve, X78; exterior of left valve, X73; 20-24 feet above base of Decorah Shale, Sugar Creek section near Fountain, Minnesota.
- Figure 7.** *Winchellatia minnesotensis?* Kay. Right side of immature shell, X97; 56.5-59.8 feet above base of Decorah Shale, Cannon Falls section, Minnesota.
- Figure 8.** *Winchellatia? ceratopea*, n. sp. Exterior of paratype right valve, X118; 1-3 feet above base of Decorah Shale, St. Paul section, Minnesota.
- Figures 9, 10.** *Eurychilina minutifoveata* Kay. Right side of shell, X64 and ventral view of shell, X59; 53.2-56.5 feet above base of Decorah Shale, Cannon Falls section, Minnesota.
- Figures 11, 12.** *Eurychilina minutifoveata* Kay? Right side and ventral views of shell, X48; 52.6-55.6 feet above base of Decorah Shale, Cannon Falls section, Minnesota.
- Figure 13.** *Eurychilina kayi*, n. sp. Exterior of a broken left valve paratype, X22; 49-53 feet above base of Decorah Shale, Cannon Falls, Minnesota.
- Figures 14, 15.** *Dicranella bicornis* Ulrich. Right side of shell, X53; ventral view of shell, X47; 36-40 feet above base of Decorah Shale, Sugar Creek section near Fountain, Minnesota.

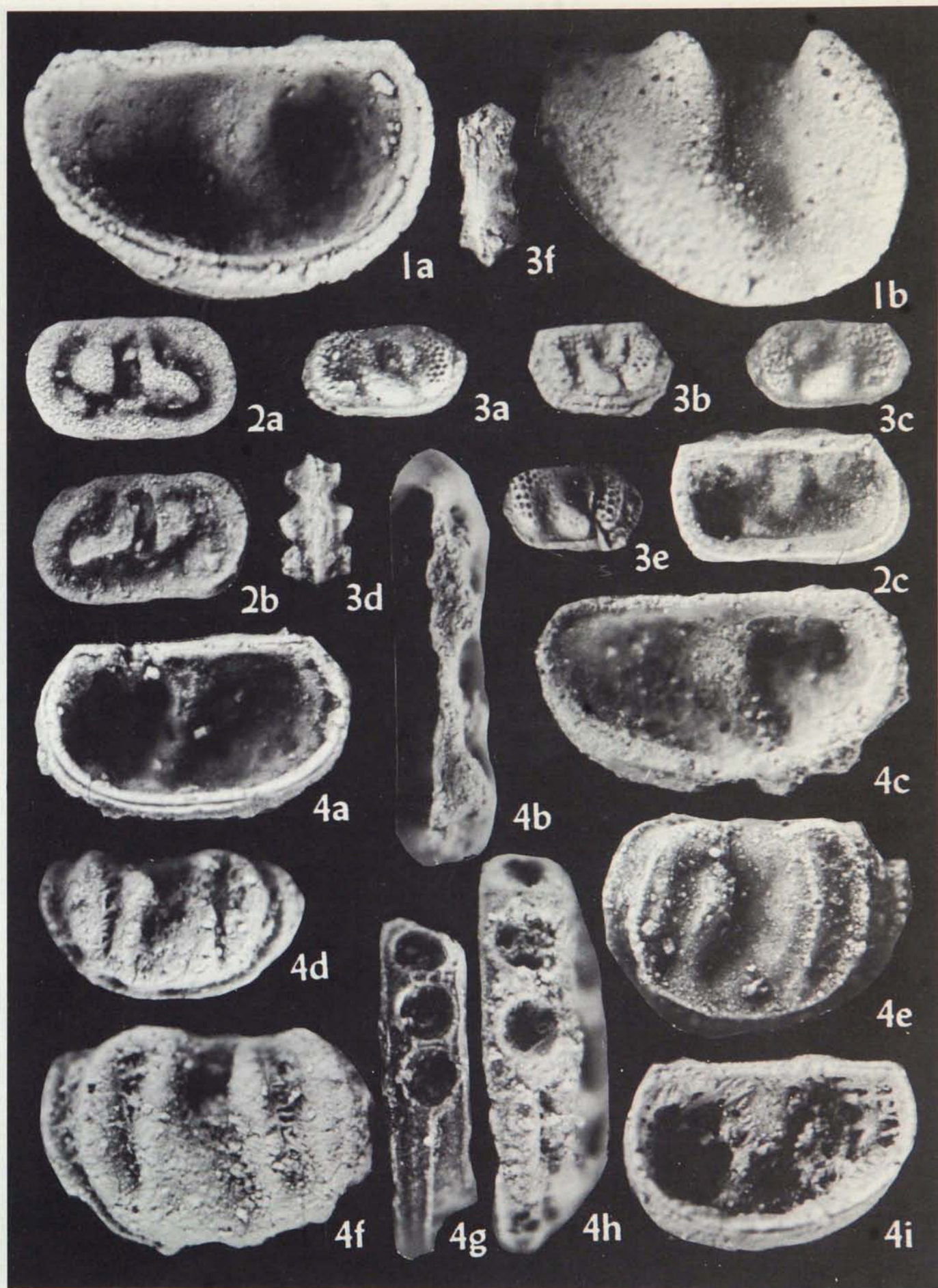
PLATE 13

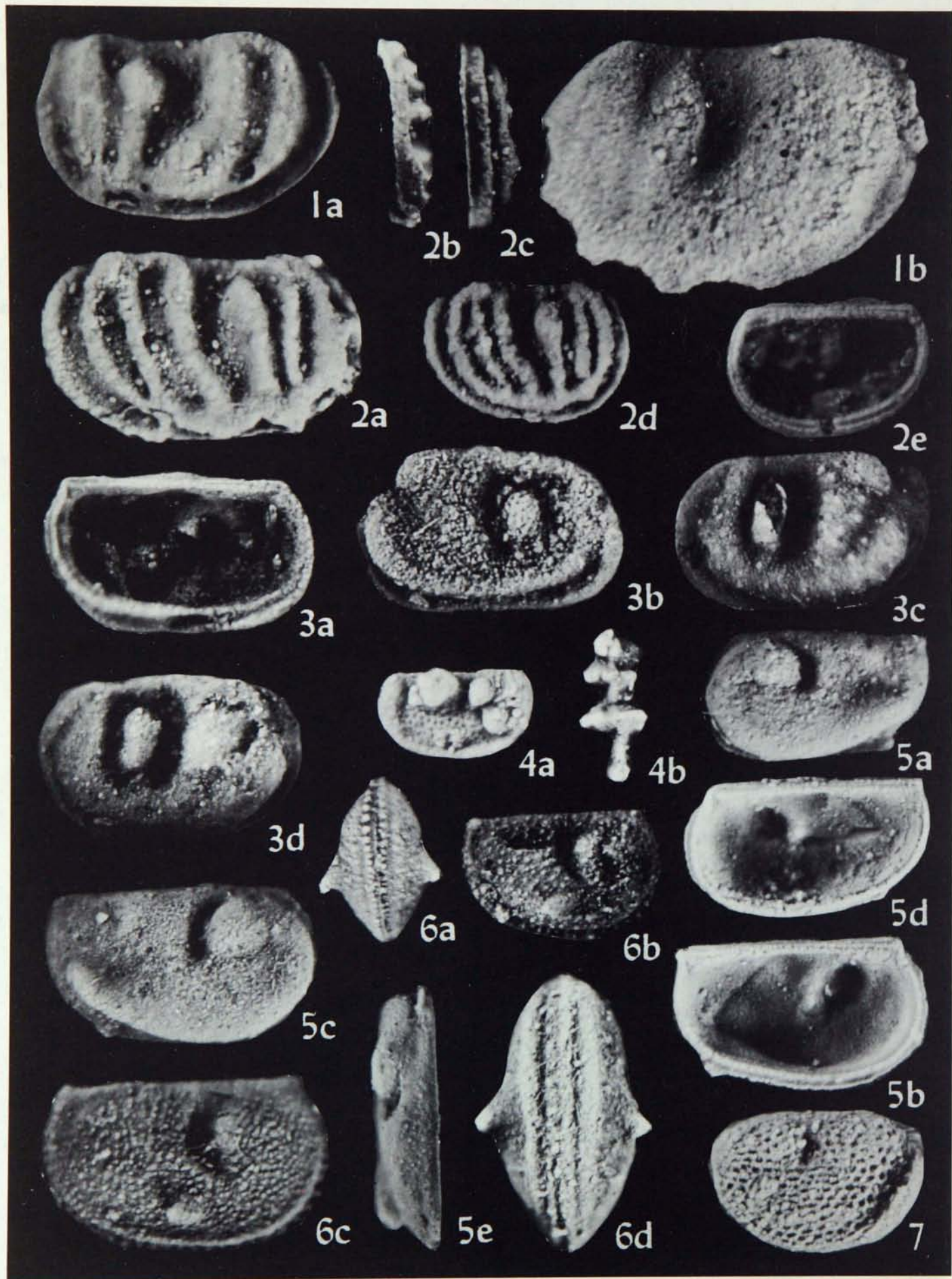
- Figure 1.** *Eurychilina micropunctata*, n. sp. Exterior of holotype right valve, X23; 4-8 feet above base of Decorah Shale, Rochester section, Minnesota.
- Figures 2, 3.** *Eurychilina reticulata* Ulrich. Right side of shell, X35; dorsal view of shell, X36; 40-43.5 feet above base of Decorah Shale, Cannon Falls section, Minnesota.
- Figures 4, 5.** *Eurychilina reticulata* Ulrich. Left side of shell, X37; dorsal view of shell, X35; 7.5-9.5 feet above base of Decorah shale, Cannon Falls section, Minnesota.
- Figure 6.** *Eurychilina reticulata* Ulrich. Left side of shell, X37; 7.5-9.5 feet above base of Decorah Shale, Cannon Falls section, Minnesota.
- Figures 7, 9.** *Eurychilina kayi*, n. sp. Exterior of holotype left valve, X20; interior of paratype left valve, X19; 32-36 feet above base of Decorah Shale, Sugar Creek section near Fountain, Minnesota.
- Figure 8.** *Eurychilina partifimbriata* Kay. Dorsal view of immature shell, X62; 55.2-57.8 feet above base of Decorah Shale, Cannon Falls section, Minnesota.
- Figures 10, 16.** *Eurychilina partifimbriata* Kay. Exterior of left valve, X34; interior of right valve, X32; 40-44 feet above base of Decorah Shale, Sugar Creek section near Fountain, Minnesota.
- Figure 11.** *Primitia tumidula* Ulrich. Exterior of right valve, X71; middle part of Decorah Shale, St. Paul section, Minnesota.
- Figure 12.** *Euprimitia labiosa* (Ulrich). Exterior of left valve, X82; 7.5-9.5 feet above base of Decorah Shale, Cannon Falls section, Minnesota.
- Figure 13.** *Eurychilina subradiata* Ulrich. Exterior of left valve, X26; 7.5-9.5 feet above base of Decorah Shale, Cannon Falls section, Minnesota.
- Figures 14, 15.** *Eurychilina reticulata* Ulrich. Exterior of right valve, X21; interior of right valve, X20; 52.5-55.5 feet above base of Decorah Shale, Cannon Falls section, Minnesota.
- Figure 17.** *Bellornatia tricollis* Kay. Exterior of left valve, X106; 29-31 feet above base of Decorah Shale, Cannon Falls section, Minnesota.

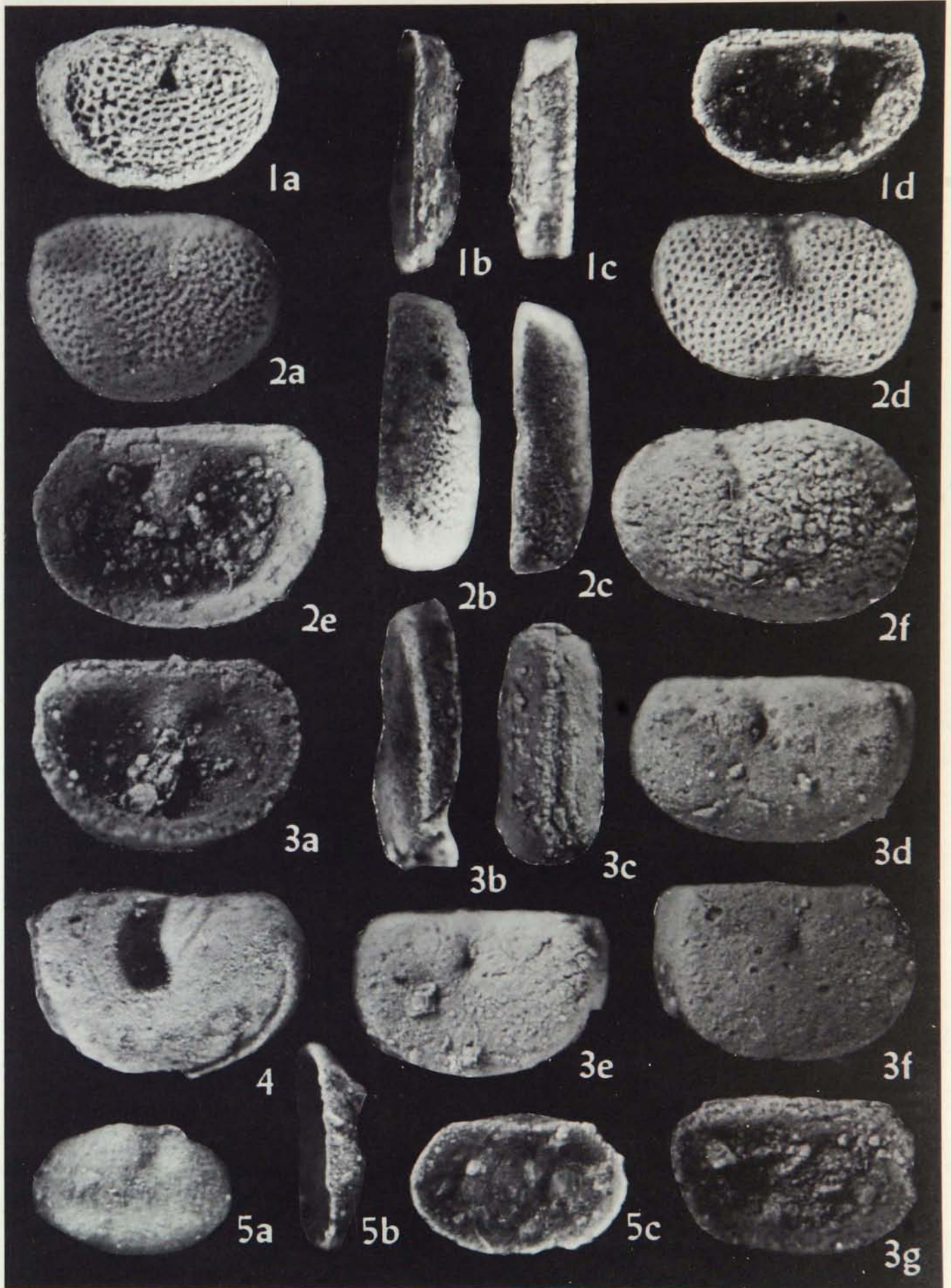


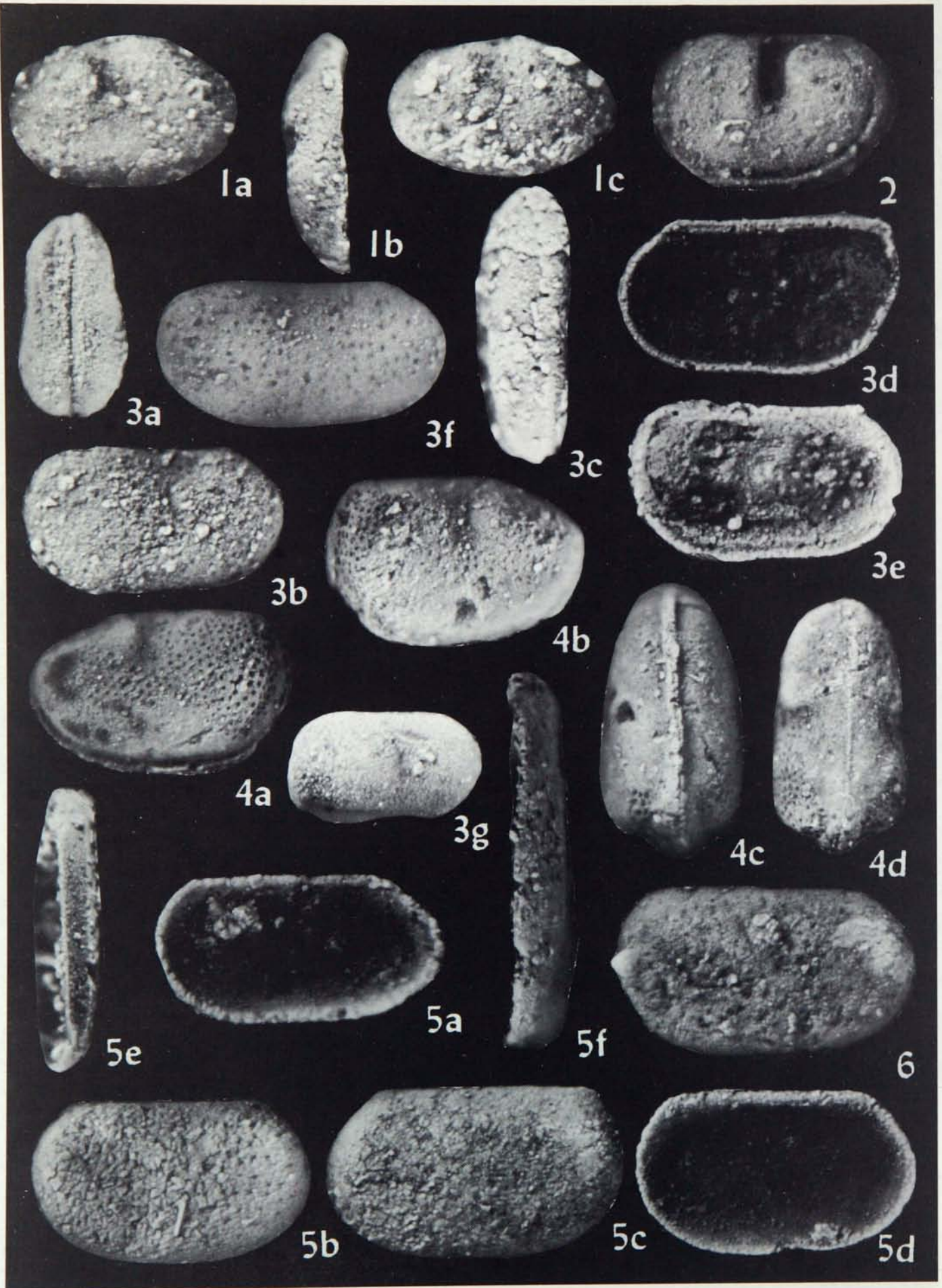


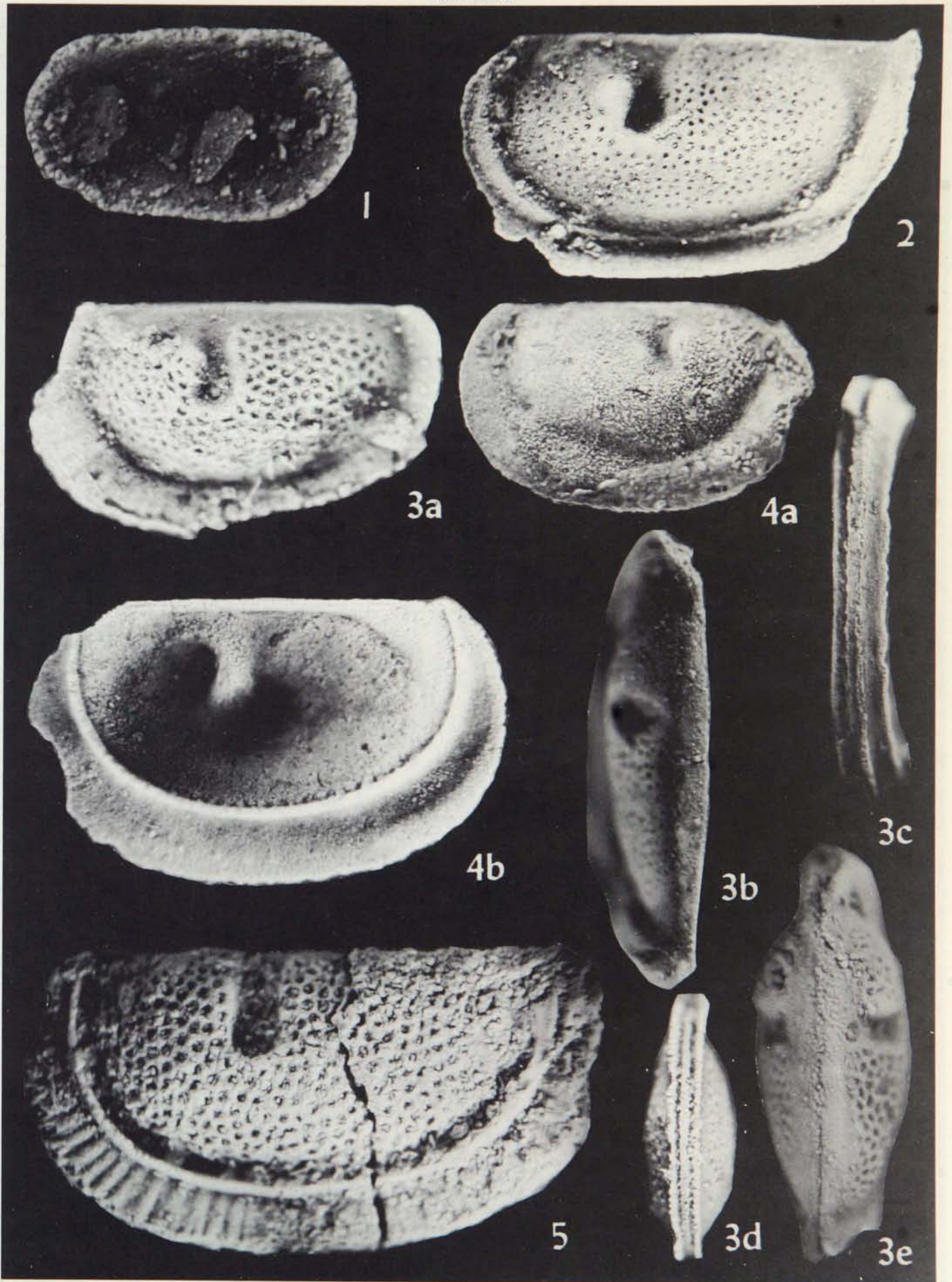


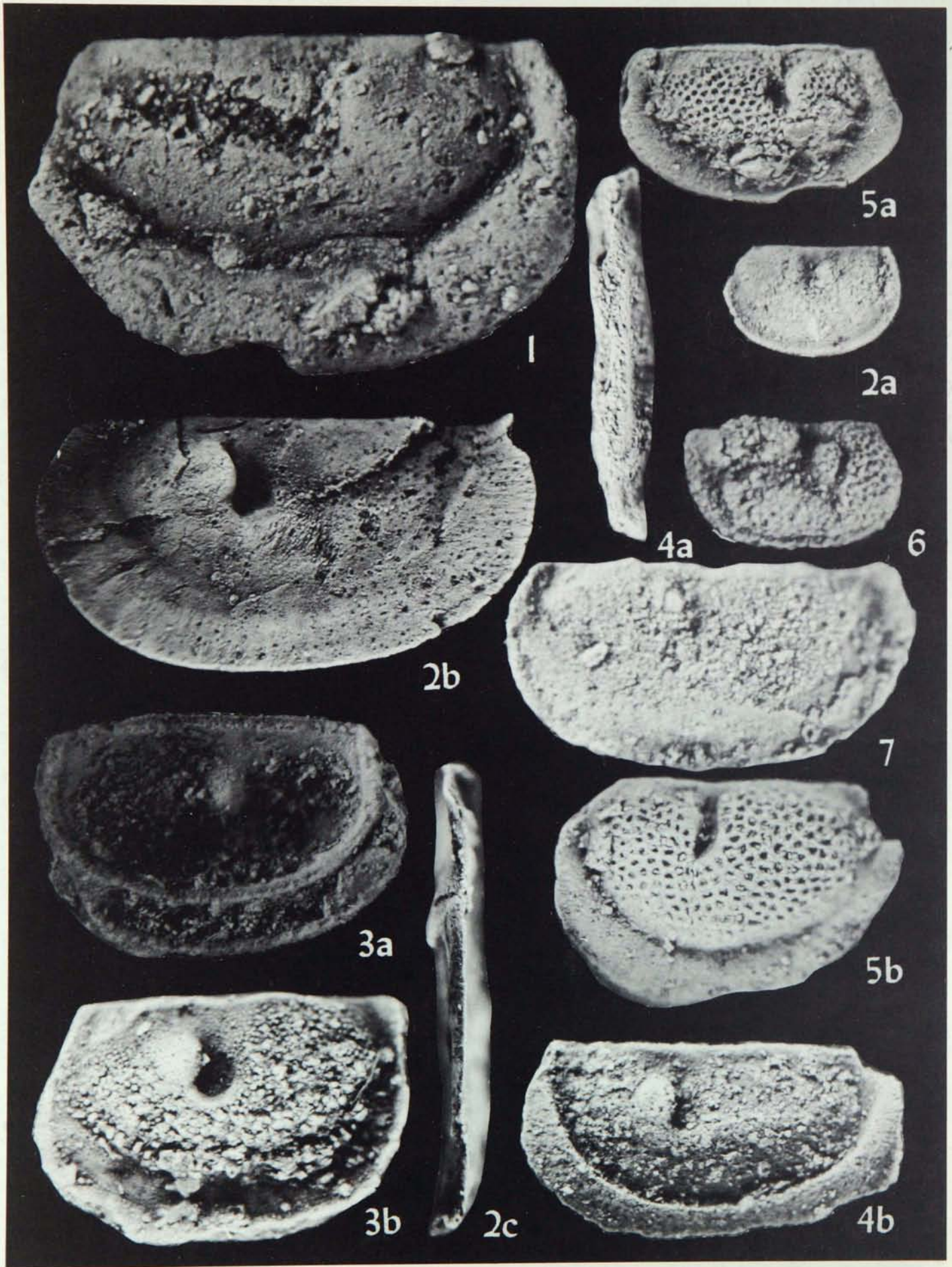


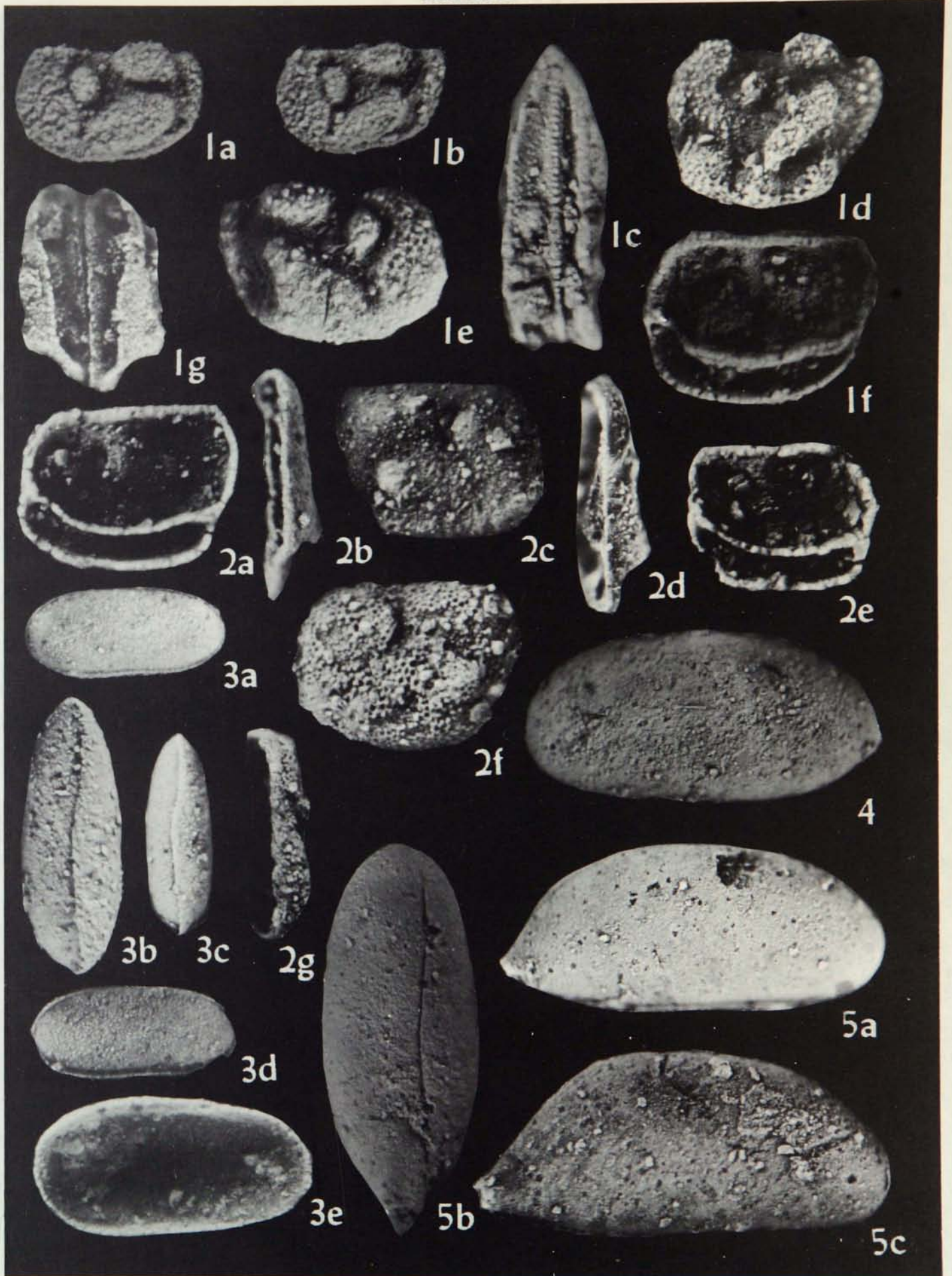




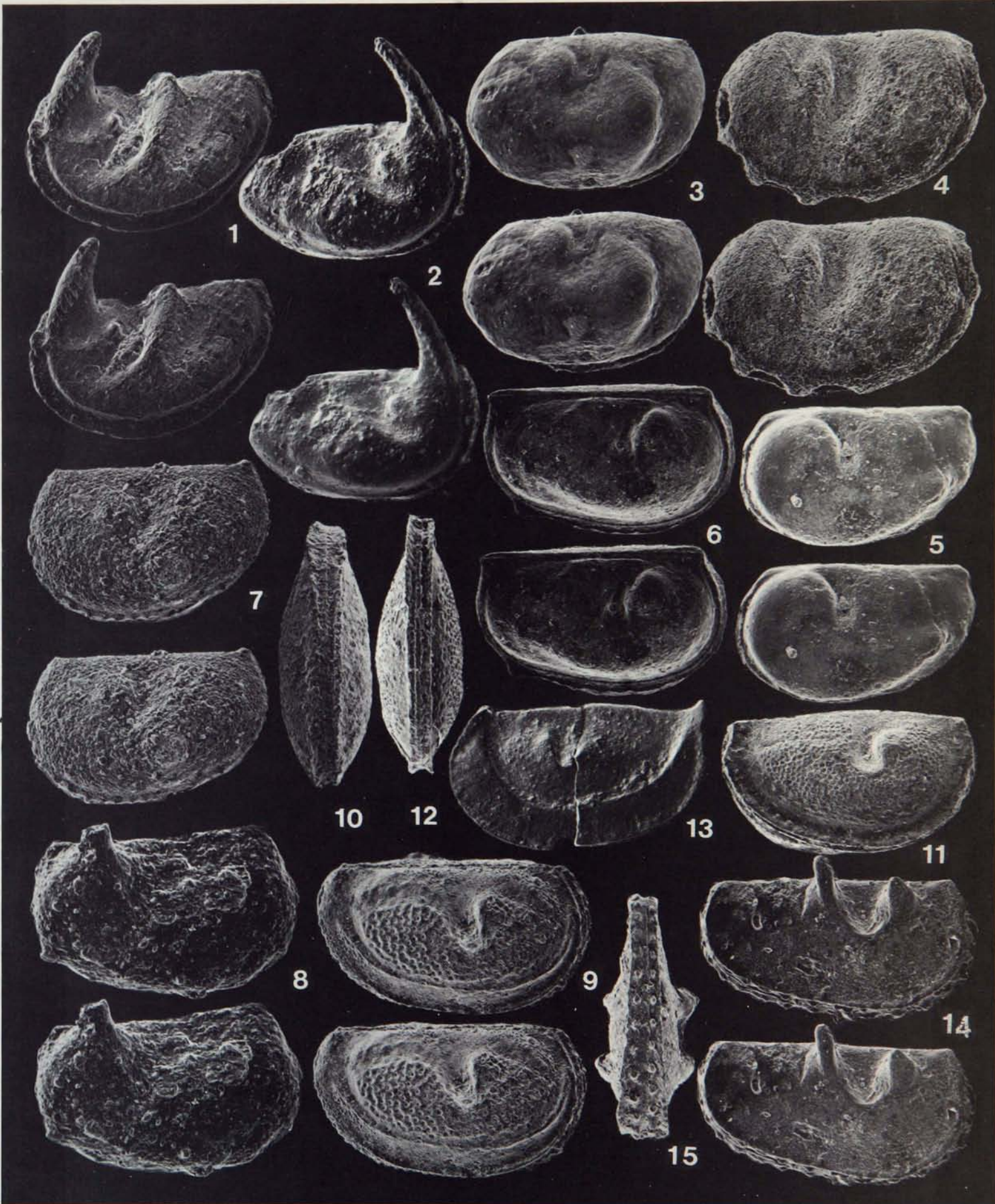














BRACHIOPODS AND TRILOBITES OF THE SARDESON BEDS IN THE TWIN CITIES

William F. Rice and Eric P. Hedblom
 Department of Geology and Geophysics
 University of Minnesota
 Minneapolis, MN 55455

INTRODUCTION

Middle Ordovician strata in the Twin Cities area contain a rich brachiopod fauna and somewhat less rich trilobite fauna. The collection of Frederick W. Sardeson, a pioneer in the study of the Ordovician in Minnesota, contains tens of thousands of specimens representing more than 80 species of brachiopods and 25 species of trilobites (Figs. 12.1 and 12.2). Sardeson organized his collection within a framework of 14 biostratigraphic beds. This paper is a basic guide to collecting the most common brachiopods and trilobites from the first six of Sardeson's beds in the Twin Cities.

SARDESON'S BEDS

Sardeson's beds have been used as a guide for paleontological work in Minnesota for most of a century. Therefore, it is appropriate to outline his system in a historical context.

In the late 19th century, Lower Paleozoic stratigraphy in Minnesota and surrounding states was encumbered with a nomenclatural system derived primarily from rocks found in New York State. Names such as "Black River Limestone," "Trenton Shales," and "Trenton Limestones" were applied to Minnesota rocks even though the rocks bore little or no lithologic resemblance to their New York namesakes. In the early 1890s Sardeson, then a graduate student at the University of Minnesota, proposed a new system for the classification of the Middle and Upper Ordovician rocks of the Upper Mississippi valley (Sardeson, 1892b, 1897a). Beginning at the base of what is now the Glenwood Formation, Sardeson divided the Upper and Middle Ordovician strata into 14 beds. Each bed was characterized by a suite of fossils and given a name (and later a number). Although Sardeson's definitions of each bed are somewhat vague and ambiguous, it is evident that the beds were intended to be biostratigraphic rather than lithologic units. In practice, however, the bed boundaries seem to have corresponded approximately to what are now accepted as formal lithostratigraphic units. Sardeson, himself, seems to have used the beds as little more than convenient collecting intervals.

In Minnesota, beds 1 and 2 include the Glenwood Formation and most of the Platteville Formation; beds 3, 4, and 5 (and in St. Paul, part of bed 6) are now known as the Decorah Shale; beds 6, 7, 8, and 9 constitute the Galena Group; bed 10 is the Dubuque Formation; and beds 11, 12, 13, and 14 constitute the Maquoketa Formation. The bed thicknesses range from about 12 feet to about 75 feet, depending on the locality and horizon.

The imprecision of Sardeson's bed definitions poses particular difficulties for stratigraphers. For example, in his 1892 paper he designated 5 brachiopods and one bryozoan (*Stictopora*) as characteristic of bed 4 but in his 1897 paper he stated that bed 4 is characterized by "the purity of the clay and the absence of certain species of fossils" (1897, p. 28). As a result of this ambiguity and because most beds are not tied to any lithologic markers, the bed boundaries are not very practical for use in the field. Despite its shortcomings (many of which Sardeson himself was aware) Sardeson's bed system was a major improvement over previous biostratigraphic systems. In addition to freeing the Upper Mississippi valley from a New York-based nomenclature, the beds served as the stratigraphic framework for Sardeson's collection of Middle and Upper Ordovician fossils from the Upper Mississippi valley, one of the largest and most representative collections in North America.

Sardeson's bed system eventually became firmly entrenched in

the geologic literature, primarily as a result of having been appropriated (with minor changes and without credit to Sardeson) by Winchell and Ulrich for inclusion in volume III, part 2 of the *Geology of Minnesota, Final Report* (1897) (Fig. 1.1). Other important Ordovician workers who have utilized Sardeson's beds include Kay (1929), Stauffer and Thiel (1941), Cooper (1956), and Brower and Veinus (1978) (Fig. 12.3).

BRACHIOPODS AND TRILOBITES OF THE PLATTEVILLE AND DECORAH FORMATIONS

The lowest stratum included in Sardeson's bed system is the Glenwood Formation. It is almost entirely devoid of macrofossils and, in general, it is not worthwhile hunting in the Glenwood.

Also included in Sardeson's bed 1 are the Pecatonica and Mifflin Members of the Platteville Formation. The Pecatonica is poorly fossiliferous but the Mifflin contains a fair number of fossils. However, collecting *in situ* Mifflin can be tedious and unrewarding because the Mifflin is a cliff-former and the fossils are best exposed on the bedding surfaces. In over 40 years of collecting, Sardeson was able to find hundreds of easily extractable fossils in the shaly partings, but it is probably easiest to collect slabs of the distinctively crinkly-bedded Mifflin in the talus at the foot of the cliff. Common Mifflin brachiopods include *Campylorthis deflecta*, *Oepikina minnesotensis*, *Hesperorthis tricenaria*, and *Rostricellula minnesotensis*, while *Isotelus simplex*, *Bunastoides milleri*, *Iliaenus sp.*, and various ceraurids make up the bulk of the trilobite fauna.

The Hidden Falls and Magnolia Members of the Platteville are included in Sardeson's bed 2. In the fossiliferous Magnolia Member nearly all the fossils are preserved as molds or casts and most have a sugary coating of dolomite crystals. The most common brachiopods in the Magnolia are *Campylorthis deflecta*, *Trigrammaria winchelli*, *Hesperorthis tricenaria*, and *Pionodema conradi*. The trilobite fauna in bed 2 is very similar to that of bed 1; the same illaenids, ceraurids and asaphids are strongly represented. Incidentally, molluscs are probably more common in the Magnolia Member than in any other part of the Twin Cities column.

The Carimona Member of the Platteville and approximately the lowest 2 meters of the Decorah Shale are included in Sardeson's very fossiliferous bed 3. The Carimona contains beautifully preserved (but uncommon) specimens of the lingulid *Pachyglossella eldери* in life position. Farther south, in Fillmore County, Minnesota, many exposures of the Carimona above the Deicke K-bentonite are packed with the atrypaecean *Protozyga nicolleti*. The horizon about 1 m above the base of the Decorah (marked RBY-3 in Fig. 13.2) is particularly fossiliferous. The fossils in this excellent collecting horizon are loose and easily hand-picked from the shale. Especially common brachiopods in this interval are the homeomorphs *Pionodema subaequata* and *Doleroides pervetus*, which are often very difficult to differentiate. Trilobites are nearly absent from bed 3. Two *Eomonorachus intermedius* individuals and one unidentifiable *Bumastus* cranidium represent the entirety of Sardeson's collections in this horizon.

The interval of Decorah Shale from the Millbrig K-bentonite (about 2.1 m above the base of the Decorah) to about 12 m above the base is roughly equivalent to Sardeson's bed 4. Incidentally, the exposure of the Millbrig at the Twin City Brick Company (the brickyard) is one of the best in the state. Shale, calcareous shale, and coquinoid lenses make up the bulk of this interval of Decorah. The

fossils are concentrated in the coquinas and are very sparse in the shale. The most common brachiopods are *Rostricellula minnesotensis*, *Strophomena septata* (near the top), and *Pionodema subaequata*. (*Doleroides pervetus* has not been found above the Millbrig at the brickyard.) The most common trilobites in the Sardeson collection from this zone are *Bumastoides porrectus* (many of the specimens enrolled) and spare parts of *Isotelus gigas*. However, the most commonly found trilobites in the Decorah are Pterygometopidae; most of these specimens are *Eomonorachus intermedius* but a few may be *Sceptaspis lincolnensis*.

Sardeson's bed 5, roughly 12-19 m above the base of the Decorah at the brickyard, is predominantly shale with calcareous interbeds and coquinas. RBY-30, about 12 m above the base of the Decorah has yielded numerous specimens of *Strophomena septata*, *Oepikina inquassa*, *Dalmanella sculpta*, *Rhynchotrema wisconsinense* (which abruptly replaces *Rostricellula minnesotensis*) and *Sowerbyella curdsvillensis* (= *S. punctostriata*). Toward the top of this interval, *Zygospira recurvirostris* and *Sowerbyella minnesotensis* (which abruptly replaces *S. curdsvillensis*) begin to dominate the brachiopod fauna. Sample RBY-35, about 17 m above the base, contains the uncommon orthacean *Skenidioides anthonense*. The trilobite fauna of bed 5 is very similar to that of bed 4, with *Isotelus gigas* the dominant representative in the Sardeson collection. The top of Sardeson's bed 5 is marked by a prominent "brassy" oolite bed. A similar bed is found at the top of the Decorah in Fillmore County.

The interval from 19 m to 27 m (the top of the Decorah in St. Paul)

is dominated by the brachiopods *Sowerbyella minnesotensis*, *Zygospira recurvirostris*, and *Paucicrura rogata*. Preliminary measurements suggest that the median lobe of the cardinal process of *P. rogata* gradually increases in length at a rate of 0.024 mm/100 cm of section between RBY-35 and RBY-63. This gradual change could be used to determine the stratigraphic horizon within the range of *P. rogata* more precisely. Other common brachiopods in bed 6 include the tiny lingulacean *Craniops minor*, fairly abundant on calcareous slabs in the interval RBY-42 to RBY-46, and the strophomenacean *Rafinesquina trentonensis*. The dominant trilobites continue to be *Isotelus gigas* and *Bumastoides porrectus*.

FURTHER INVESTIGATIONS

Sardeson divided the Glenwood, Platteville, and Decorah Formations in the Twin Cities into 6 beds. This coarse division of about 35 m of section presents a somewhat unrealistic picture of faunal succession — one of abrupt extinctions occurring simultaneously with equally abrupt appearances. Sampling at finer intervals would increase the biostratigraphic resolution. Rice has divided the 27.2 m section of Decorah Shale at the brickyard into more than 60 intervals and sampled the brachiopods from each interval. The range chart resulting from this sampling (see Rice, this volume) shows that the brachiopod succession in the brickyard section is gradual rather than abrupt. Hedblom is in the process of sampling the trilobites from the same intervals. We intend to continue this sort of biostratigraphic investigation throughout the rest of the Middle and Upper Ordovician of Minnesota.

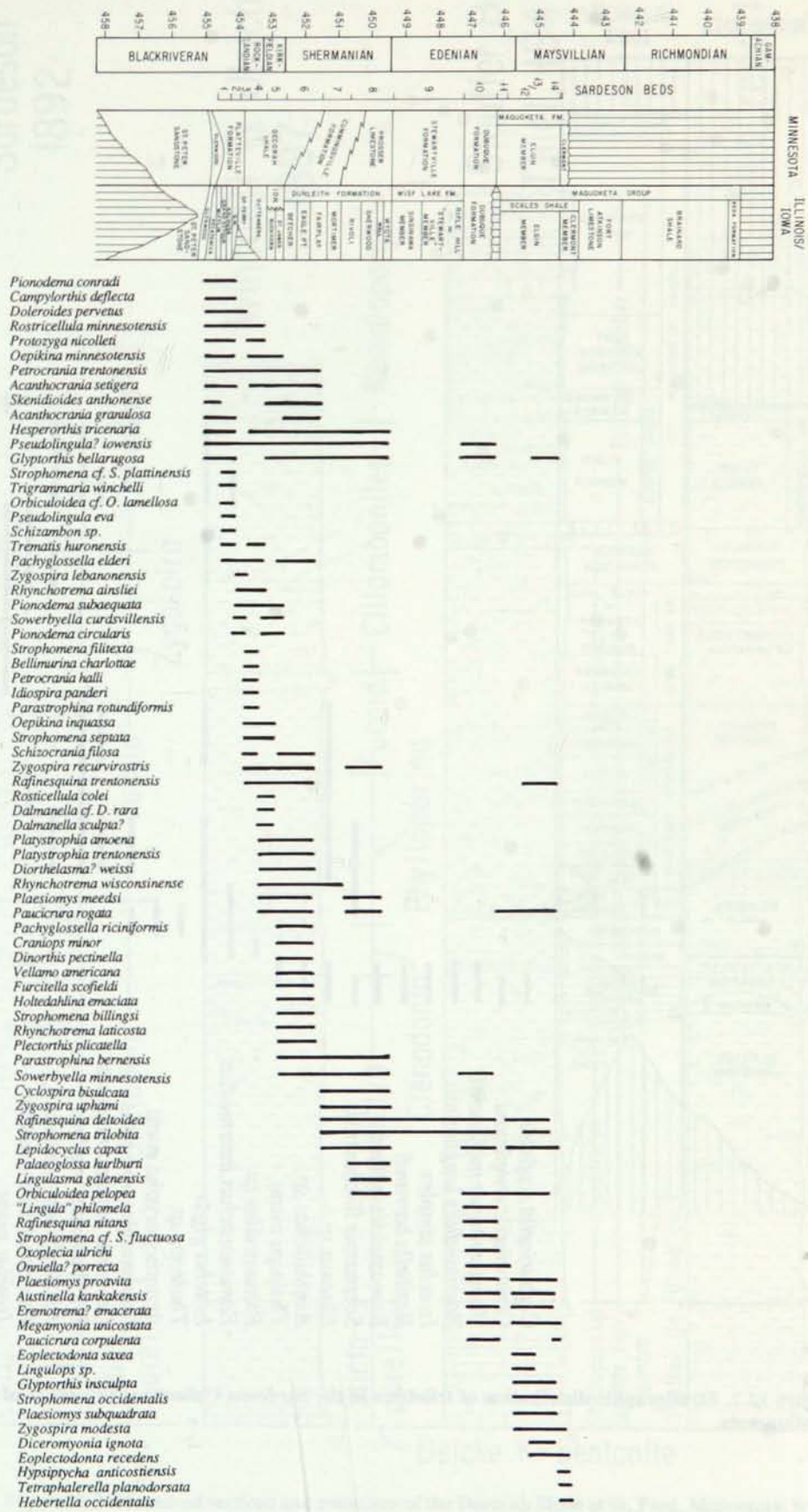


Figure 12.1. Stratigraphic distribution of brachiopods in the Sardeson Collection, University of Minnesota.

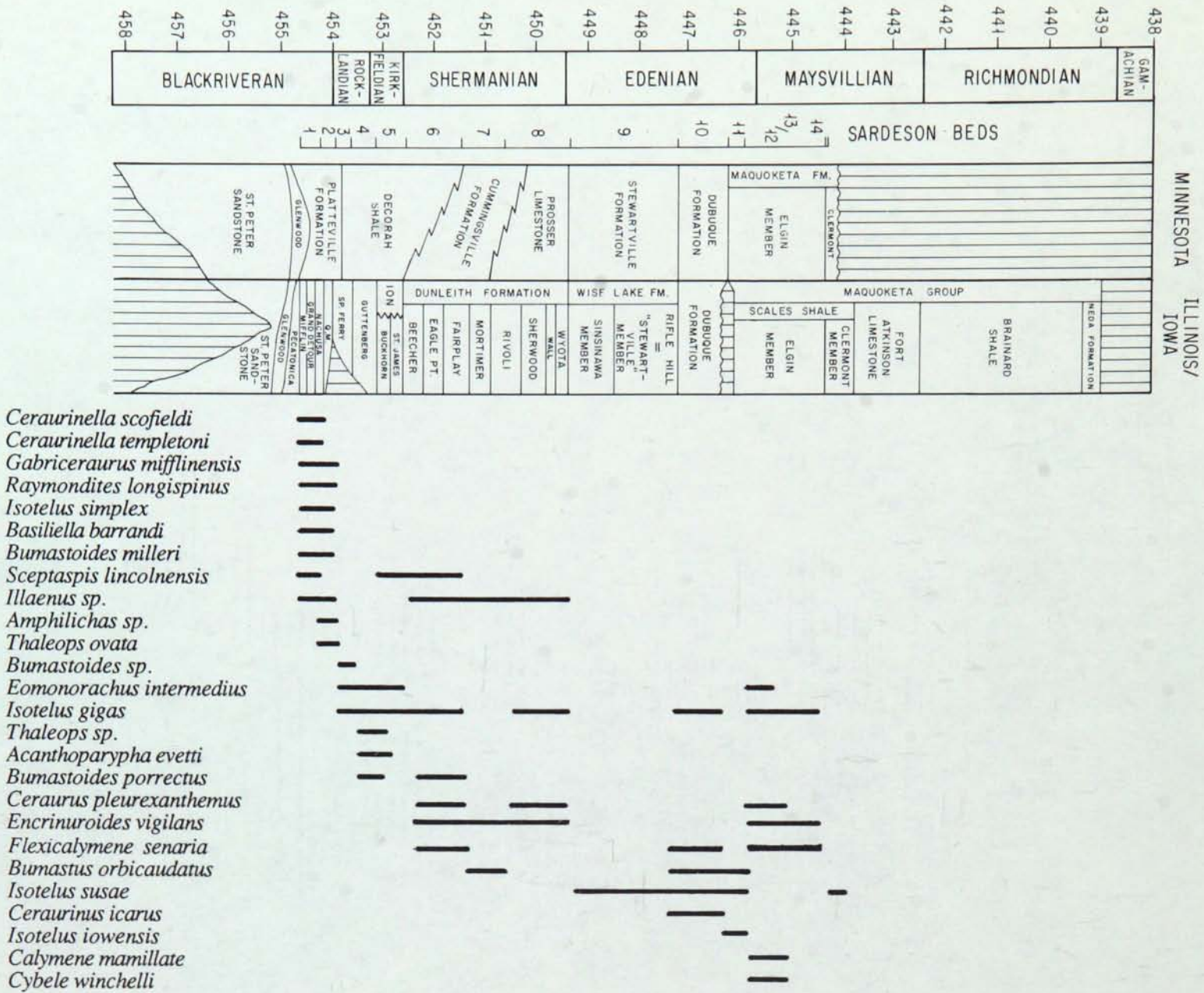
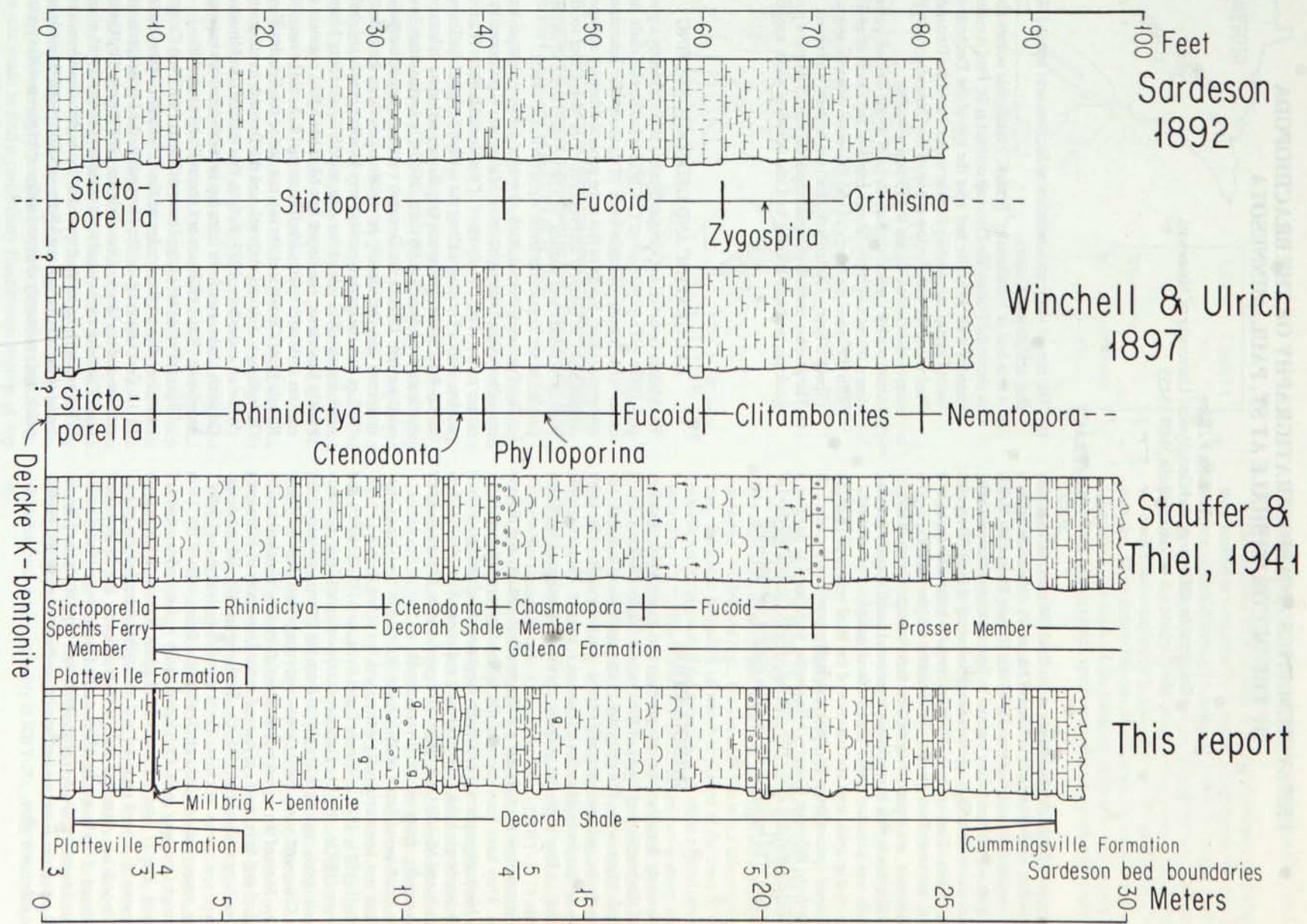


Figure 12.2. Stratigraphic distribution of trilobites in the Sardeson Collection, University of Minnesota.

Figure 12.3. Measured sections and zonations of the Decorah Shale at St. Paul, Minnesota, from various authors.



THE SYSTEMATICS AND BIOSTRATIGRAPHY OF THE BRACHIOPODA OF THE DECORAH SHALE AT ST. PAUL, MINNESOTA

William F. Rice

Department of Geology and Geophysics, University of Minnesota
Minneapolis, MN 55455

ABSTRACT

The Decorah Shale (Mohawkian) at St. Paul, Minnesota, contains an abundant and diverse brachiopod fauna. A collection from a single measured section at the site of the former Twin City Brick Company, supplemented by a small collection from Shadow Falls, contains more than 6000 specimens representing at least 37 species from 6 orders. Two species, *Diorthelasma* ? *weissi* and *Zygospira plinthii*, are new. Two species, *Dalmanella sculpta* ? and *Zygospira lebanonensis*, are reported for the first time from the Decorah Shale. The collection is rich in small specimens and small species because the shale was screened rather than surface picked.

The stratigraphic tops and bottoms of the local ranges of 15 of the brachiopod species from St. Paul and from a previously made collection from Fillmore County, Minnesota, were used to develop a temporal subdivision of the Decorah based on the graphic method of correlation. The results of the analysis suggest the following:

- (1) The rate of shale accumulation at St. Paul was about 1.4 times that at Fillmore County.
- (2) A thin bed of ferriferous ("brassy") ooids that occurs about 19 m above the Platteville-Decorah contact at St. Paul is contemporaneous with a similar bed near the top of the Decorah in Fillmore County, suggesting that the upper 8 m of the Decorah at St. Paul is coeval with the lower part of the Cummingsville Formation of the Galena Group in Fillmore County.
- (3) Attempts by earlier authors to infer a one-to-one correspondence of each of three faunal zones of the Decorah at St. Paul with the three members of the Decorah in northeastern Iowa (Spechts Ferry, Guttenberg, Ion) are probably incorrect.
- (4) The graphic method of biostratigraphic correlation is a powerful geologic problem-solving tool and deserves wider application.

INTRODUCTION

This study describes the composition and stratigraphic distribution of the brachiopod fauna of the Decorah Shale (Mohawkian) at St. Paul, Minnesota. The purposes of this study were to update the nomenclature and taxonomy of Decorah brachiopods from St. Paul; and to lay the foundation for a regional system of biostratigraphic correlation based on the graphic methods developed by Shaw (1964).

Paleozoic brachiopods are a widespread, abundant, and diverse group. They have been successfully utilized as correlative tools by many biostratigraphers, despite the supposed disadvantage of their sessile benthonic habit. The explosive radiation of the phylum during Early and Middle Ordovician time provides the biostratigrapher with a rapidly changing and diverse fauna.

The brachiopod fauna of the Decorah Shale in the Twin Cities area has not been critically examined for more than 80 years. Winchell (1881, 1886), Winchell and Schuchert (1892, 1895) and Sardeson (1892c, 1897b,c) independently collected large numbers of brachiopods (among other phyla) from the Paleozoic rocks of the Twin Cities and surrounding areas and recognized dozens of new species. Most of the type specimens designated by Winchell and by Winchell and Schuchert are housed in the University of Minnesota Paleontology Collection (UMPC). Sardeson usually did not designate type specimens, but his collection is also housed in the UMPC.

The outcrop of the Decorah Shale at the former site of the Twin City Brick Company in St. Paul is especially well suited to a study of this kind. The 27.24m section is the thickest outcrop of Decorah in Minnesota. It is well exposed and accessible from bottom to top. Brachiopods are abundant and, with bryozoans, are the dominant constituent of the fauna. In addition, the fossils are relatively easily extracted from the shale. These conditions have made the "brick-yard" a popular fossil collecting site for both amateur and professional paleontologists.

GEOGRAPHIC AND GEOLOGIC SETTING

The Middle Ordovician Decorah Shale is predominantly a greenish-gray (5GY 6/1) to pale-olive (5Y 6/1) fossiliferous shale or claystone with lenses and thin beds of coquinooidal limestone and calcareous shale. Rocks of this same general lithology and age occur continuously in outcrop and subcrop from Minnesota southwestward to Nebraska and Kansas, in a broad band south of and roughly parallel to the Transcontinental Arch (Witzke, 1980).

The Transcontinental Arch, a major positive feature trending roughly northeast through central Minnesota, is presumed to be the source of the clastic component of the Decorah Shale (Parham and Austin, 1969). The shales along the southern edge of the Transcontinental Arch become progressively thinner and more calcareous in a southeastward direction (Witzke, 1980). In northeastern Iowa and northwestern Illinois the Decorah contains proportionately more limestone and can usually be divided into three members (Kay, 1928, p. 16): the lower Spechts Ferry Member consists of shale with some interbedded limestone; the middle Guttenberg Member is mostly limestone; the upper Ion Member again consists of calcareous shale with interbedded limestone. It should be noted that the Illinois State Geological Survey has raised the Spechts Ferry and Guttenberg to formational rank and the Decorah to subgroup rank (Willman and others, 1975; Kolata, this volume). In Minnesota the Decorah Shale is uniform from top to bottom and consequently the members of Kay (1928) are not generally recognizable.

This study focuses on the Decorah Shale of the Twin Cities basin, located on the northern edge of the Hollandale embayment (Fig. 13.1). Good outcrops of the Decorah in the Minneapolis-St. Paul area are scarce. Much of the shale has been removed by Quaternary glacial activity and most of what remains is covered with glacial till. What outcrops do exist, exposed at the higher elevations along the banks of the Mississippi and Minnesota Rivers and their minor tributaries, are commonly slumped and/or overgrown with vegetation.

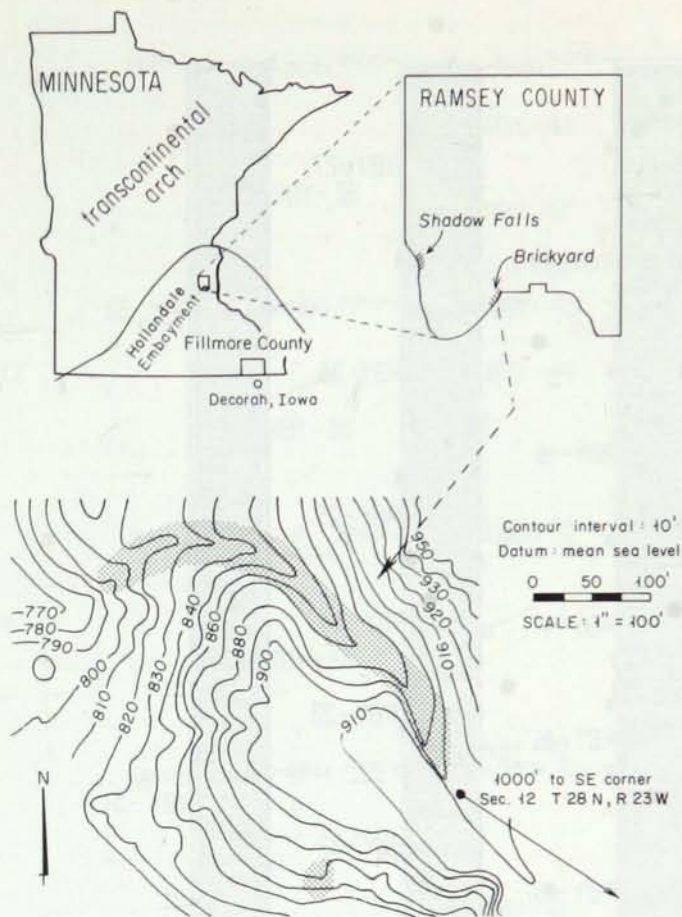


Figure 13.1. Index map of collecting localities (shaded) and major geographic features mentioned in text. Topographic map after Port Authority of the City of St. Paul.

The measured section and principal collecting site for this study is a gully near the southern edge of Ramsey County, Minnesota (NW $\frac{1}{4}$ SW $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 12, T. 28 N., R. 23 W., St. Paul East 7.5-minute quadrangle) (Fig. 13.1). The gully is on the north edge of a series of amphitheater-shaped pits which, from 1890 to 1973, were mined for clay by the Twin City Brick Company. This locality is therefore designated the "brickyard" section. Subsequent to 1973 the brickyard was purchased by Ramsey County for use as a public park, but in December 1983 the park (presently known as Lilydale Park) became the property of the city of St. Paul and since 1984 has been accessible only with the written permission of the St. Paul Superintendent of Parks and Recreation.

Samples were also collected from Shadow Falls, a small city park at the west end of Summit Avenue in St. Paul. This site (Fig. 20.2) includes only the basal 6 or 7 m of the Decorah Shale.

Samples were collected between fall 1979 and summer 1984 and were taken at intervals of no more than 1 m and usually less than 0.5 m (Fig. 13.2). Each sample interval was searched for fossils which were obviously *in situ*. If a fossiliferous horizon was located within any interval, most of the sample was taken from that horizon, with small random samples also taken from the rest of the interval. If no obviously fossiliferous horizon was found, only random samples were taken from the interval. The total bulk sample taken from any single interval ranged from 2 to 4 kg dry weight. Those sample intervals composed mainly of limestone were collected as slabs. No attempt was made to find a particularly fossiliferous section of any limestone bed. Strata equivalent to covered intervals in the gully were located about 100 m south-southeast of the covered section on

the south-facing wall of the northernmost clay pit (Fig. 13.1) and at the Shadow Falls locality.

Dried samples were soaked in Stoddard solvent for 24 hours and then soaked in water for 24 hours to disaggregate the clay fraction and then screened through a series of sieves, the finest of which had a mesh opening of 0.125 mm (3 ϕ). The resulting concentrate was hand picked for brachiopods under a microscope. Limestone slabs were searched completely in a manner similar to that used for loose samples. More than 6000 specimens were collected in this manner. Liberal use was made of the Sardeson collection as a source of measured and photographic specimens when my own collection was deficient.

In order to avoid confusion when using vernacular forms of zoological names, I have followed the suggestion in the footnote by R. C. Moore on page H12 of Williams and Rowell (1965a). The vernacular ending for groups of ordinal rank (e.g. Orthida) is "ides" (e.g. orthides), for subordinal rank (e.g. Orthidina) is "idines" (e.g. orthidines), for superfamily rank (e.g. Orthacea) is "aceans" (e.g. orthaceans), for family rank (e.g. Orthidae) is "ids" (e.g. orthids), and for subfamily rank (e.g. Orthinae) is "ins" (e.g. orthins). Any of the above vernacular nouns may be changed to an adjective by dropping the terminal "s".

LITHOSTRATIGRAPHY

Strata from the upper St. Peter Sandstone through the lowermost Cummingsville Formation are exposed at the brickyard locality. The beds are horizontal and unfaulted, although some slumping has occurred. As defined here, the Decorah Shale is a lithostratigraphic unit, the lower boundary of which is placed at the base of the first significant occurrence of the greenish-gray shale typical of the Decorah (Fig. 13.2). The Platteville-Decorah contact is sharp and is 75 cm above the Deicke K-bentonite in the Carimona Member of the Platteville Formation (the "Carimona" bentonite of earlier authors). The Illinois State Geological Survey places the Black River-Rockland stage boundary at the base of this bentonite (Willman and Kolata, 1978). There is a prominent 17-cm-thick bed of limestone of Platteville lithology (RBY-2), the base of which is 54 cm above the Platteville-Decorah contact. From the base of RBY-3 (71 cm above the Platteville-Decorah contact) the Decorah retains its characteristic lithology with few exceptions.

The Millbrig K-bentonite (RBY-7) (the "Spechts Ferry" bentonite of earlier authors) is 3 cm thick and occurs 2.10 m above the Platteville-Decorah contact. The stratigraphic interval between the Deicke and Millbrig K-bentonites is 2.85 m, which compares to approximately 1.8 m for Fillmore County, Minnesota (Weiss, 1953) and approximately 3.5 m near Rochester, Minnesota (Weiss and Bell, 1956). Two other possible bentonites occur in the brickyard section. Sample RBY-45 is a gray clay, 1 cm thick, situated 20.5 m above the Platteville-Decorah contact. A 4-cm-thick bed (no sample number) of similar gray clay with a slick, greasy texture occurs 25 cm above the Decorah-Galena contact. Neither of these two possible bentonites was chemically or petrographically studied. It is doubtful that either is correlative with the Elkport or Dickeyville bentonites of Willman and Kolata (1978).

A 10- to 12-cm-thick shaly limestone (RBY-40) containing very abundant ferrous ("brassy") ooids occurs approximately 19.0 m above the Platteville-Decorah contact. This bed is quite distinctive and can be traced for at least several hundred meters southward at the brickyard. The presence of a significant concentration of brassy ooids marks the top of the Decorah Shale in some sections in Fillmore County (Weiss, 1957). Fossils in the brassy oolite bed are very scarce. Brassy ooids in much lower concentrations occur in places in the brickyard section, notably in RBY-20, about 10 m below RBY-40.

The top of the Decorah at the brickyard is not nearly so well defined as the base. I placed the upper boundary at the top of the upper-

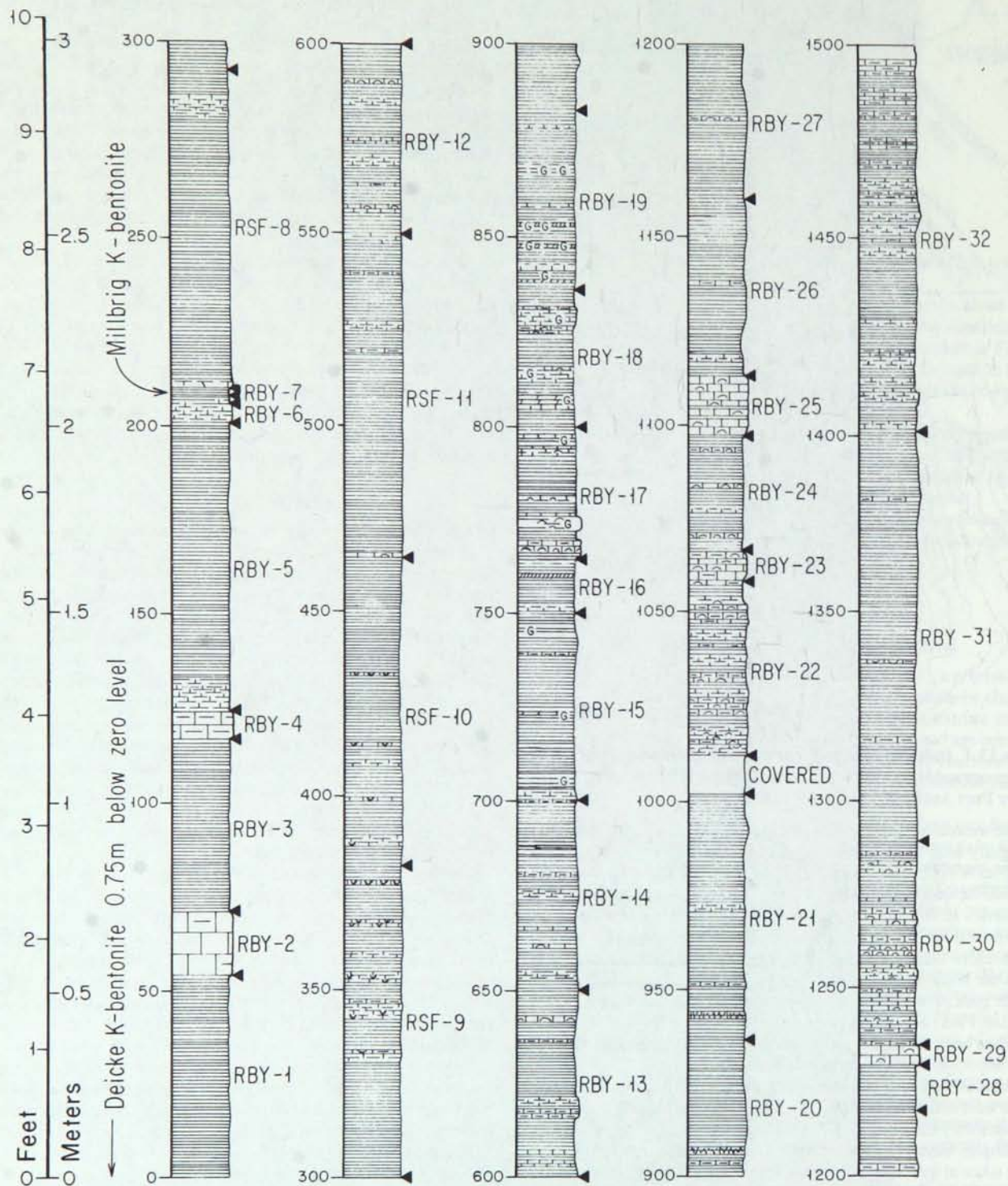


Figure 13.2. Sample register and measured section of the Decorah Shale. Sample number prefix refers to the locality at which the section was measured. Vertical scale is centimeters above the Platteville-Decorah contact.

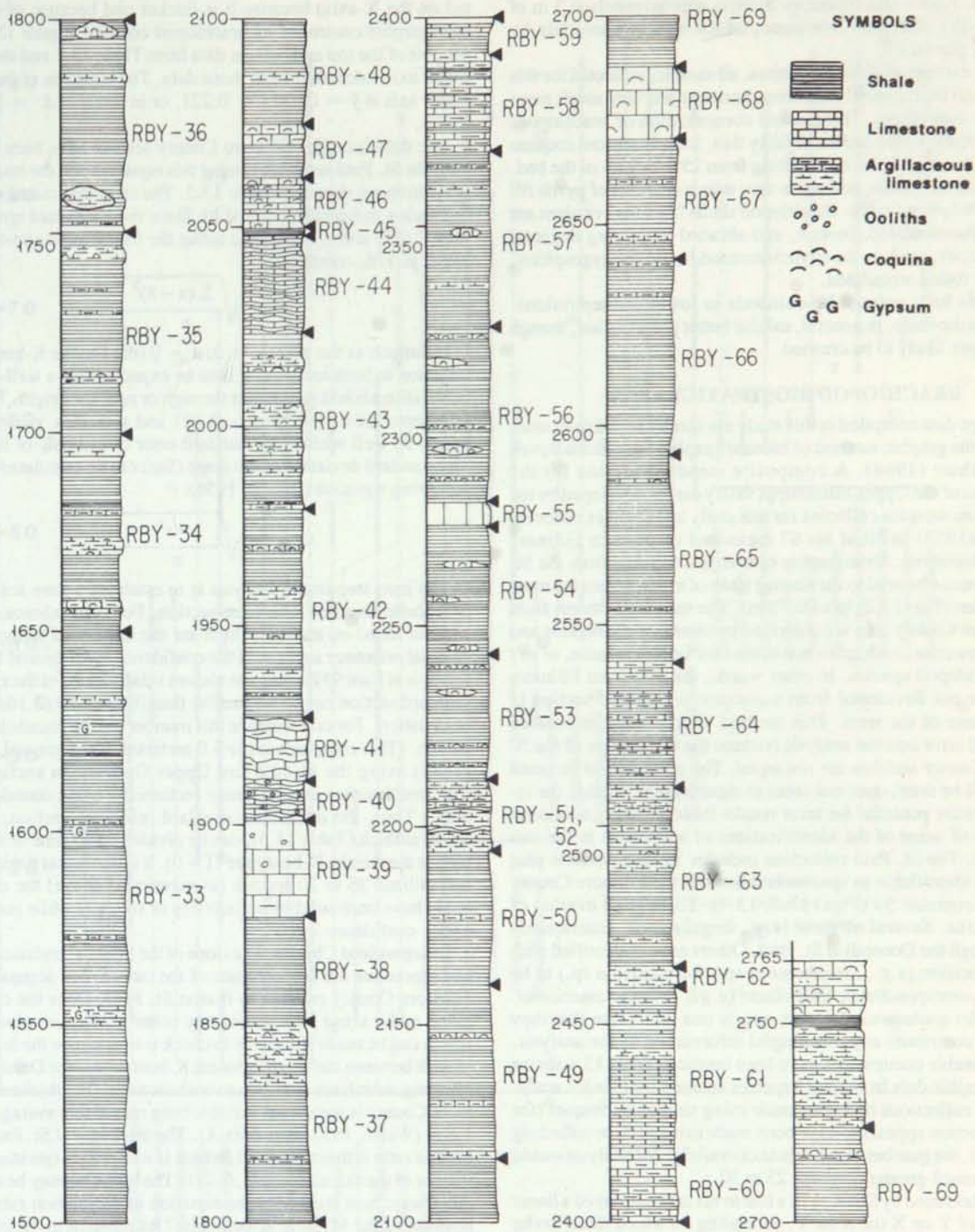


Figure 13.2 continued.

most significant greenish-gray shale bed, 27.24 m above the base (Fig. 13.2). Above this boundary there is approximately 0.5 m of yellowish silty shale and limestone, which is in turn overlain by Quaternary glacial till.

With the exception of the bentonites, all samples collected for this study contain brachiopods, but some horizons are very much more productive than others. The greatest concentration of brachiopods (and most other phyla) occurs in fairly thin, loosely packed coquina beds, with fossil material constituting from 25% to 90% of the bed. Shale, calcareous shale, and some very minor amounts of pyrite fill the spaces between fossils. Brachiopod shells from the coquinas are typically disarticulated, broken, and abraded to varying degrees. Certain species, such as the rhynchotrematids and the zygospirins, are usually found articulated.

The shale beds contain brachiopods in lower concentrations. Shells from the shale, in general, exhibit better preservation, though they are more likely to be crushed.

BRACHIOPOD BIOSTRATIGRAPHY

The range data compiled in this study are ideally suited to an analysis using the graphic method of biostratigraphic correlation developed by Shaw (1964). A composite standard section for the Mohawkian of the Upper Mississippi valley can be developed by using data from samples collected for this study and samples collected by Weiss (1953) in 30 of his 67 measured sections in Fillmore County, Minnesota. Stratigraphic bottom and top data from the St. Paul section can be read to the nearest tenth of a meter from the measured section (Fig. 13.2) (plus 0.75 m). The tops and bottoms from the Fillmore County data were derived by choosing the highest and lowest occurrence, with reference to the Deicke K-bentonite, of any given brachiopod species. In other words, the data from Fillmore County are not developed from a composite standard section in Shaw's sense of the term. This method undoubtedly introduced some slight error into the analysis because the thicknesses of the 30 Fillmore County sections are not equal. The error should be small and, as will be seen, does not seem to significantly degrade the results. A greater potential for error results from the likely noncorrespondence of some of the identifications of specimens in the two collections. The St. Paul collection includes 39 taxa (species plus genera not identifiable to species level) while the Fillmore County collection contains 50 (Figs. 13.3, 13.4). There is an overlap of about 25 taxa. Several of these (e.g., lingulaceans, craniaceans) range through the Decorah at St. Paul. Others are not identified with enough precision (e.g., *Strophomena* sp., *Rafinesquina* sp.) to be certain of correspondence. Still others (e.g., *Vellamo americana*, *Skenidioides anthonense*) are so rare in one collection that they would not contribute any meaningful information to the analysis. All questionable occurrences have been omitted. Table 13.1 shows the stratigraphic data from the 15 species deemed suitable for analysis. If both collections had been made using similar techniques (the Weiss collection appears to have been made using surface collecting techniques), the number of reliable taxa available for analysis would have been much greater, perhaps 25 to 30.

The method used by Shaw to fit a line to his data employed a linear regression of Y on X (or X on Y, depending on which direction he was projecting data points). In my opinion a more appropriate line of correlation is the reduced major axis (Imbrie, 1956). A basic assumption of the linear regression technique is that one of the variables is dependent (graphed on the Y-axis), while the other is independent (graphed on the X-axis): Y is a function of X. Clearly, no such dependence relationship exists between the Fillmore County (Y) and St. Paul (X) sections. The parameters of the reduced major axis (slope m; y-intercept + b) are calculated using the following equations (Imbrie, 1956):

$$m = S_y/S_x \\ b = \bar{y} - \bar{x}m$$

The St. Paul section has been chosen as the reference section (plotted on the X-axis) because it is thicker and because of the better stratigraphic control of its brachiopod content. Figure 13.5 shows the plot of the top and bottom data from Table 13.1 and the reduced major axis calculated from those data. The equation of the reduced major axis is $\hat{y} = 0.721x - 0.221$, or in terms of \hat{x} : $= 1.387y + 0.306$.

The data from the Fillmore County section have been projected onto the St. Paul section by using this equation and the results of the projection are shown in Table 13.2. The error associated with making such a projection is called by Shaw the "standard error of estimate" (S_x) and is calculated using the following equation (Shaw, 1964, p. 176, corrected):

$$S_x = \sqrt{\frac{\sum (x - \hat{x})^2}{n}}$$

Inasmuch as the point $y = 0, x = 0$ (the Deicke K-bentonite) is common to both sections, it is to be expected that a well-fit line of correlation should pass either through or near the origin. The actual intercepts are $x = 0, y = -0.221$ and $y = 0, x = 0.306$; both points lie well within one standard error of estimate of the origin. The standard deviation of the slope (S_m) can be calculated using the following equation (Imbrie, 1956):

$$S_m = m \sqrt{\frac{1 - r^2}{n}}$$

The next step in the analysis is to establish a time scale for the composite standard reference section. For convenience, the time scale is based on meters, which are the units used to measure the original reference section. If the confidence level desired for the interval is at least 95%, then the chosen subdivisions of the composite standard section can be no smaller than $(t_{95\%})(S_x) \equiv (2.16)(4.05) = 8.75$ meters. For convenience this number will be rounded up to 9.0 meters. (This compares to the 6.0 meters/unit determined by Sweet (1984) using the Middle and Upper Ordovician section of the Cincinnati region as a reference section and using conodont range data.) Thus, the composite standard reference section, which is 27.99 m thick (Table 13.3), can be divided into 3 time units, beginning at the Deicke K-bentonite ($T = 0$). It is likely that if this analysis had utilized 25 to 30 species (as mentioned above) the composite could have been subdivided into five or six units while maintaining a 95% confidence level.

Independent Checks: The slope of the line of correlation is 0.721 and represents the best estimate of the rate of rock accumulation at Fillmore County relative to that at St. Paul. Does the calculated slope make sense in terms of any other geological observations which can be made? One way to check is to compare the thicknesses of rock between the two prominent K-bentonites, the Deicke and the Millbrig, which are common to both sections. The thickness in Fillmore County is somewhat variable but a reasonable average is about 1.8 m (Weiss, 1953, appendix A). The thickness at St. Paul is 2.85 m. The ratio is therefore 0.63, which is well within one standard deviation of the calculated rate, 0.721. The question may be asked another way: how well does the equation of correlation estimate the position of the Millbrig K-bentonite? Its position in the composite standard section is known (2.85 m), so by using the above equation the predicted position in Fillmore County is calculated to be 1.83 m, i.e., very nearly the same as that observed in the field.

Applications: As mentioned in a previous section, the top of the Decorah in some parts of Fillmore County is marked by a high concentration of brassy ooids (Weiss, 1957). This horizon occurs approximately 13.5 m above the Deicke K-bentonite (Weiss, 1953, appendix A). A similar distinctive bed of brassy ooids at the brickyard is located approximately 19.9 m (about 2.2 Decorah time units) above the Deicke K-bentonite. Using the equations above, the equivalent time in the Fillmore County section is found to occur at

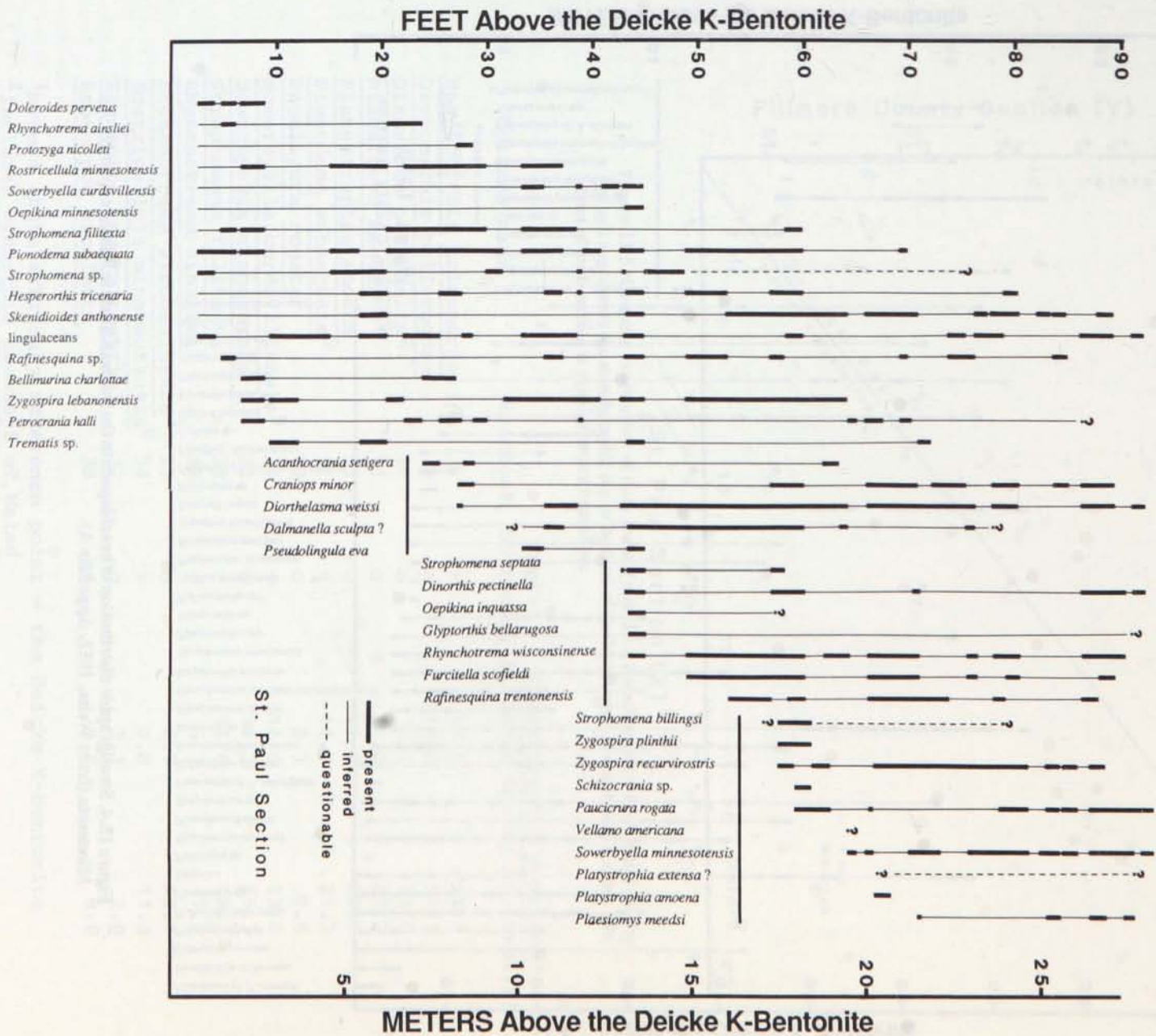


Figure 13.3. Stratigraphic distribution of brachiopods in the Decorah Shale at St. Paul, Minnesota.

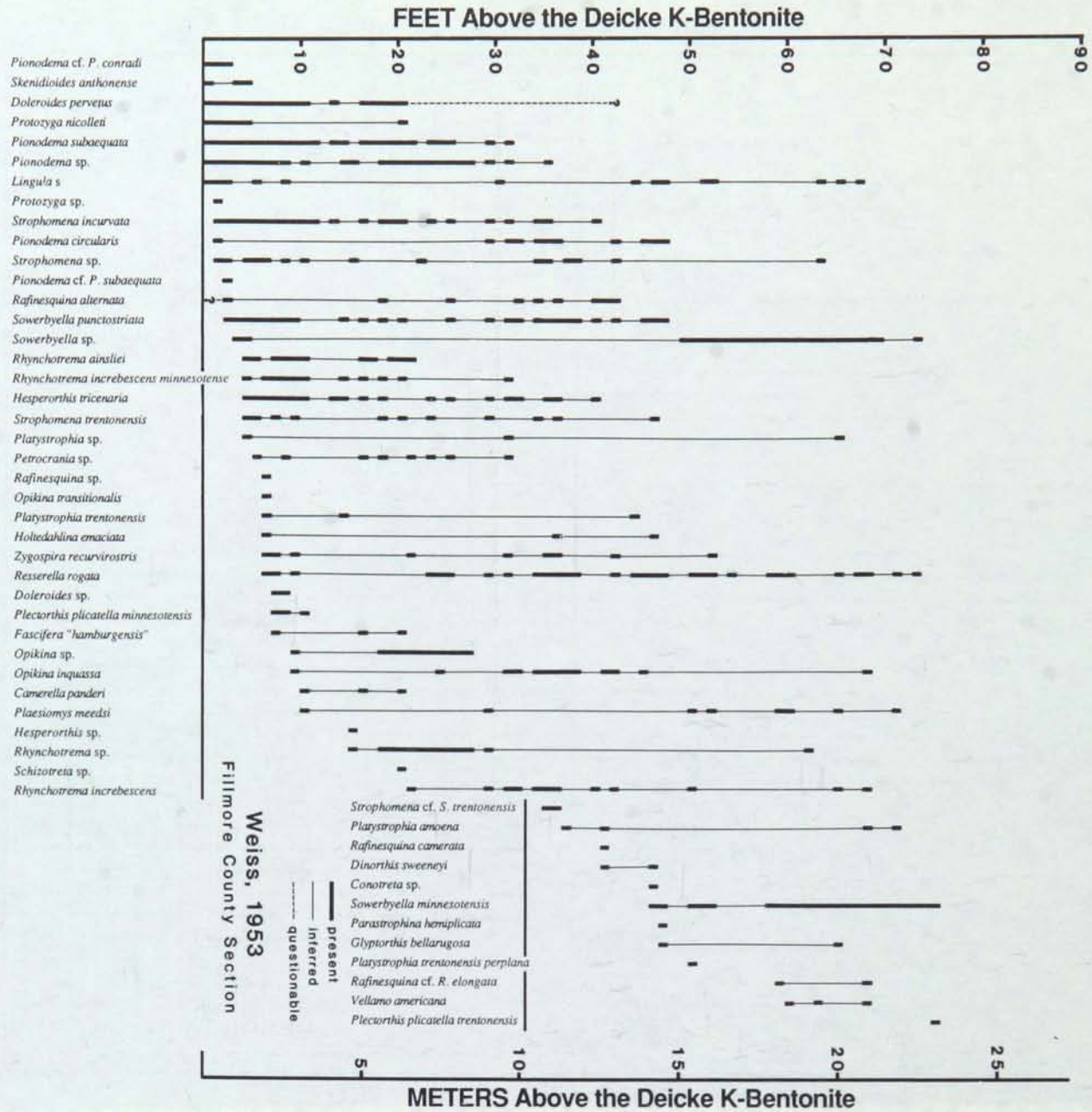


Figure 13.4. Stratigraphic distribution of brachiopods in the Decorah State in Fillmore County, Minnesota (from Weiss, 1953, Appendix A).

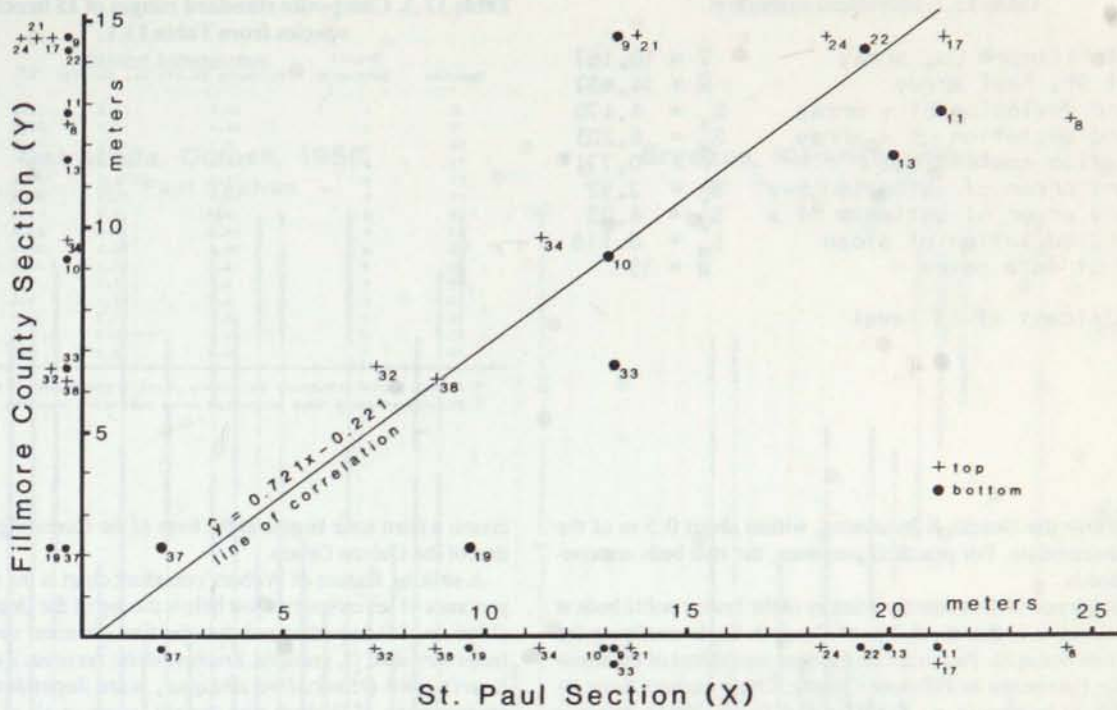


Figure 13.5. Graphic correlation of data from Table 13.1 (brachiopods). Each point on the graph represents the stratigraphic top or bottom of the local range of numbered species. The base of each section is the Carimona bentonite.

Species name	Species#	Stratigraphic position ¹		
		Top(+) bottom(o)	Fillmore Co.(Y)	St. Paul(X)
<u>Hesperorthis tricenaria</u>	8	+	12.5	24.4
<u>Glyptorthis bellarugosa</u>	9	o	14.6	13.1
<u>Dinorthis pectinella</u> ²	10	o	9.1	13.0
<u>Plaesiomys meedsi</u>	11	o	12.8	21.2
<u>Platystrophia amoena</u>	13	o	11.6	20.0
<u>Pionodema subaequata</u> ³	17	+	14.6	21.2
<u>Paucicrura rogata</u> ⁴	19	o	2.1	9.6
<u>Sowerbyella curdsvillensis</u> ⁵	21	+	14.6	13.6
<u>Sowerbyella minnesotensis</u>	22	o	14.3	19.3
<u>Strophomena filitexta</u> ⁶	24	+	14.6	18.3
<u>Rhynchotrema ainsliei</u>	32	+	6.7	7.2
<u>Rhynchotrema wisconsinense</u> ⁷	33	o	6.7	13.1
<u>Rostricellula minnesotensis</u> ⁸	34	+	9.8	11.3
<u>Zygospira recurvirostris</u> ⁹	37	o	2.1	2.0
<u>Protozyga nicoletti</u>	38	+	6.4	8.8

¹meters above arbitrary reference point - the Deicke K-bentonite

²includes Dinorthis sweeneyi of Weiss

³includes Pionodema circularis of Weiss

⁴includes Dalmanella sculpta? of this study

⁵equals Sowerbyella punctostriata of Weiss

⁶equals (Strophomena incurvata + S. trentonensis) of Weiss

⁷equals Rhynchotrema increbescens increbescens of Weiss

⁸equals Rhynchotrema increbescens minnesotense of Weiss

⁹includes Zygospira lebanonensis of this study

Table 13.1. Tops and bottoms of the local ranges of 15 brachiopod species.

Table 13.2. Statistical summary.

Mean of Fillmore Co. array	\bar{y} = 10.167
Mean of St. Paul array	\bar{x} = 14.407
Standard deviation of y array	S_Y = 4.470
Standard deviation of x array	S_X = 6.203
Correlation coefficient	r_{XY} = 0.771*
Standard error of estimate of y	S_{YX} = 2.92
Standard error of estimate of x	S_{XY} = 4.05
Standard deviation of slope	S_{SE} = 0.118
Number of data pairs	n = 15

* significant at 1% level

14.1 m above the Deicke K-bentonite, within about 0.5 m of the field measurements. For practical purposes, the two beds are contemporaneous.

A consequence of the contemporaneity of the brassy oolite beds at the two localities is that the 8.2 m of Decorah Shale overlying the brassy oolite bed at St. Paul must be the time equivalent of the Cummingsville Formation in Fillmore County. Other authors have assumed this to be true (e.g., Stauffer and Thiel, 1941), but it is important to note here that this analysis demonstrates that these beds are contemporaneous.

Comparisons to Faunal Studies by Other Authors: Figures 13.6 and 13.7 present a biostratigraphic synopsis of several faunal studies of Decorah and Galena strata in Minnesota. Those of Karklins (1969) on some of the bryozoans and Cornell (1956) on the ostracods show the stratigraphic distribution and biozonation of taxa at the brickyard section. Webers (1966) shows the stratigraphic distribution and biozonation of conodonts from a section in southern Olmsted County, about 6 km north of Fillmore County. Both Karklins and Cornell divided the Decorah brickyard section into three biozones. Cornell's zonal boundaries were poorly defined (p. 8-9; e.g., the top of the *Eurychilina subradiata* zone was defined as the base of the *Paraschmidella planilateralis* zone while the base of the *P. planilateralis* zone was defined as the top of the *E. subradiata* zone; the *Bollia simplex* zone appears to be an acme zone but was not so designated), but nevertheless, his zonal boundaries correspond very closely with those of Karklins. Cornell and Swain and others (1961) believed that Cornell's three faunal zones were roughly equivalent to the three members of the Decorah Formation in Iowa (Spechts Ferry, Guttenberg, and Ion) as defined by Kay (1928). The tops of the middle zones of both Karklins and Cornell are placed very near the bed of brassy ooids (19.0 m), which, as was shown earlier, is probably equivalent to the top of the Decorah Shale in Fillmore County. It is therefore likely that only the lower two zones of both Karklins and Cornell are equivalent to the three members of the Decorah recognized in northeastern Iowa. Consequently, the upper zones, *Bollia simplex* (Ostracoda) and *Stictopora minima* (Bryozoa) probably represent strata which are time equivalents of the lower part of the Cummingsville Formation of southeastern Minnesota. In this context it is perhaps significant that Webers' conodont data from the section just north of Fillmore County divide the Decorah into two

Table 13.3. Composite standard ranges of 15 brachiopod species from Table 13.1.

Species	Top(+) bottom(o)	Stratigraphic Position*		\hat{x} †	Composite Standard
		Fillmore Co.(Y)	St. Paul(X)		
8	+	12.5	24.4	17.6	24.4
9	o	14.6	13.1	20.6	13.1
10	o	9.1	13.0	12.9	12.9
11	o	12.8	21.2	18.1	18.1
13	o	11.6	20.0	16.4	16.4
17	+	14.6	21.2	20.6	21.2
19	o	2.1	9.6	3.2	3.2
21	+	14.6	13.6	20.6	20.6
22	o	14.3	19.3	20.1	19.3
24	+	14.6	18.3	20.6	20.6
32	+	6.7	7.2	9.6	9.6
33	o	6.7	13.1	9.6	9.6
34	+	9.8	11.3	13.9	13.9
37	o	2.1	2.0	3.2	2.0
38	+	6.4	9.8	9.2	9.2

* meters above arbitrary reference point - the Deicke K-bentonite.

† Fillmore County data projected onto reference section.

zones; a third zone begins at the base of the Cummingsville Formation of the Galena Group.

A striking feature of Webers' conodont chart is the sudden disappearance of seven species just below the top of the Decorah. Webers (1966, p. 14) hypothesized that the five common species, *Cordylodus serratus*, *C. grandis*, *Trichonodella recurva*, *Zygnathus illustris*, and *Ozarkodina obliqua*, were dependent on a shaly environment. If Webers was correct, some or all of these species ought to be present in the uppermost 8 m of shale at the brickyard section. If they are not present there, then there may be some reason to believe that the terminations actually represent regional extinctions.

Karklins collected bryozoan stratigraphic data from Fillmore County, as well as from St. Paul. His data can be graphed in exactly the same manner as has been done earlier in this chapter with brachiopods (Fig. 13.8, Table 13.4). There is an obvious "terrace," in Shaw's sense of the word (Shaw, 1964, p. 145) of data points in the area to the right of 60 ft (18.3 m) on the abscissa. The terrace results from the fact that Karklins' Fillmore County section terminated at or near the top of the Decorah Shale, because bryozoans are difficult to collect in limestone. Thus, the lower Cummingsville was not collected and the stratigraphic tops of the later ranging species at Fillmore County are artificially low.

This analysis used a composite standard reference section composed of only two sections. Shaw suggests that at least six sections are needed to produce a stable composite standard, and so the conclusions drawn from this abbreviated analysis should be approached with caution. Nevertheless, it should be apparent that the results of this type of biostratigraphic analysis can be applied to a wide range of geologic and biologic problems. Eventually, all of the biostratigraphic data from the Upper Mississippi valley could be compounded into a master composite section, but in order to do this it is obvious that specimens ought to be collected from closely spaced intervals of accurately measured sections. Furthermore, collection methods and species identification criteria ought to be as uniform as possible. Strangely enough, more than 20 years after the publication of Shaw's work, very few published studies make use of Shaw's technique, probably due to the amount of collecting and analysis required. However, the results are worth the extra effort.

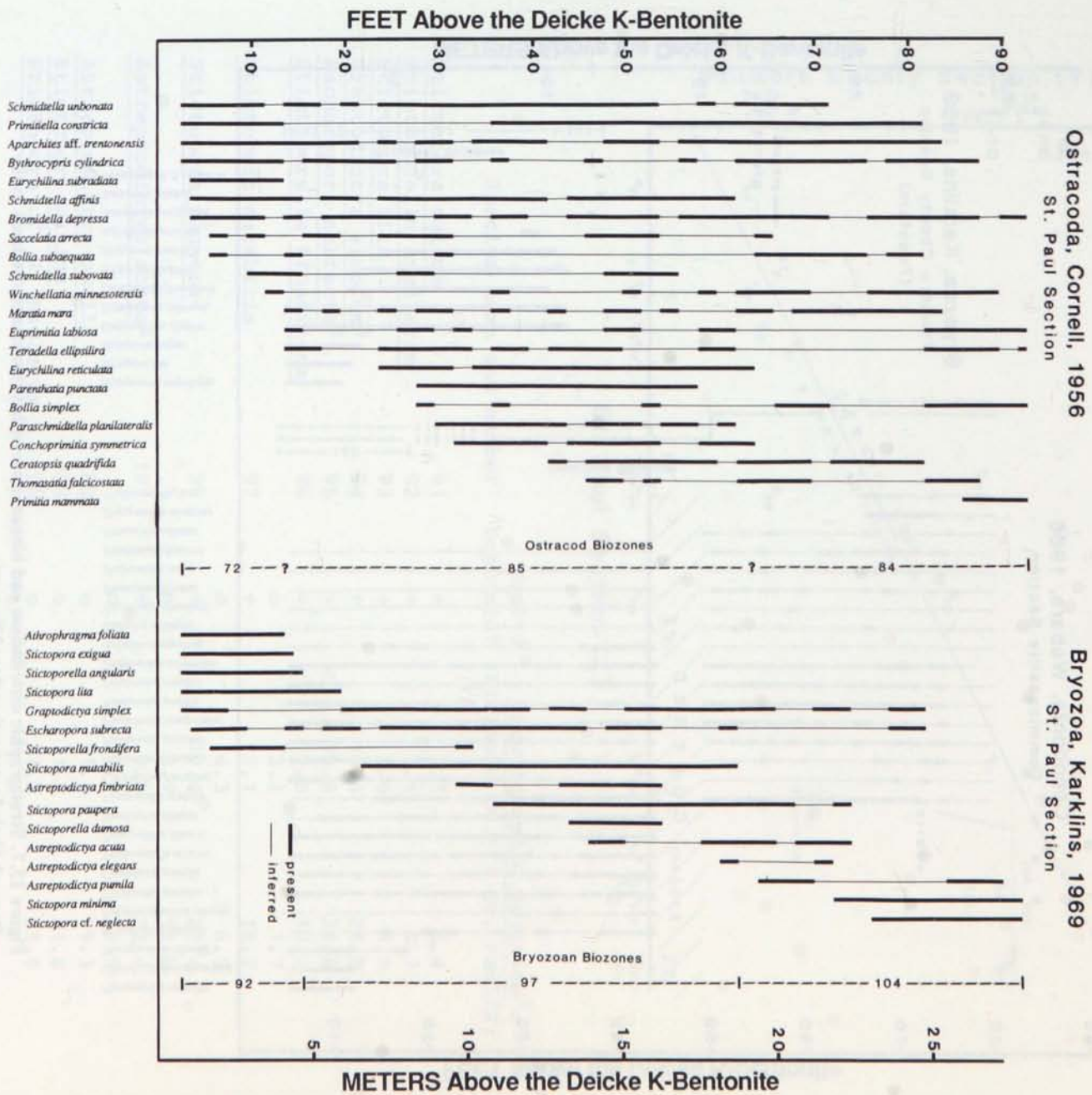


Figure 13.6. Stratigraphic distribution and biozonations of ostracods and bryozoans in the Decorah Shale at St. Paul, Minnesota. Only the more common ostracod species are included.

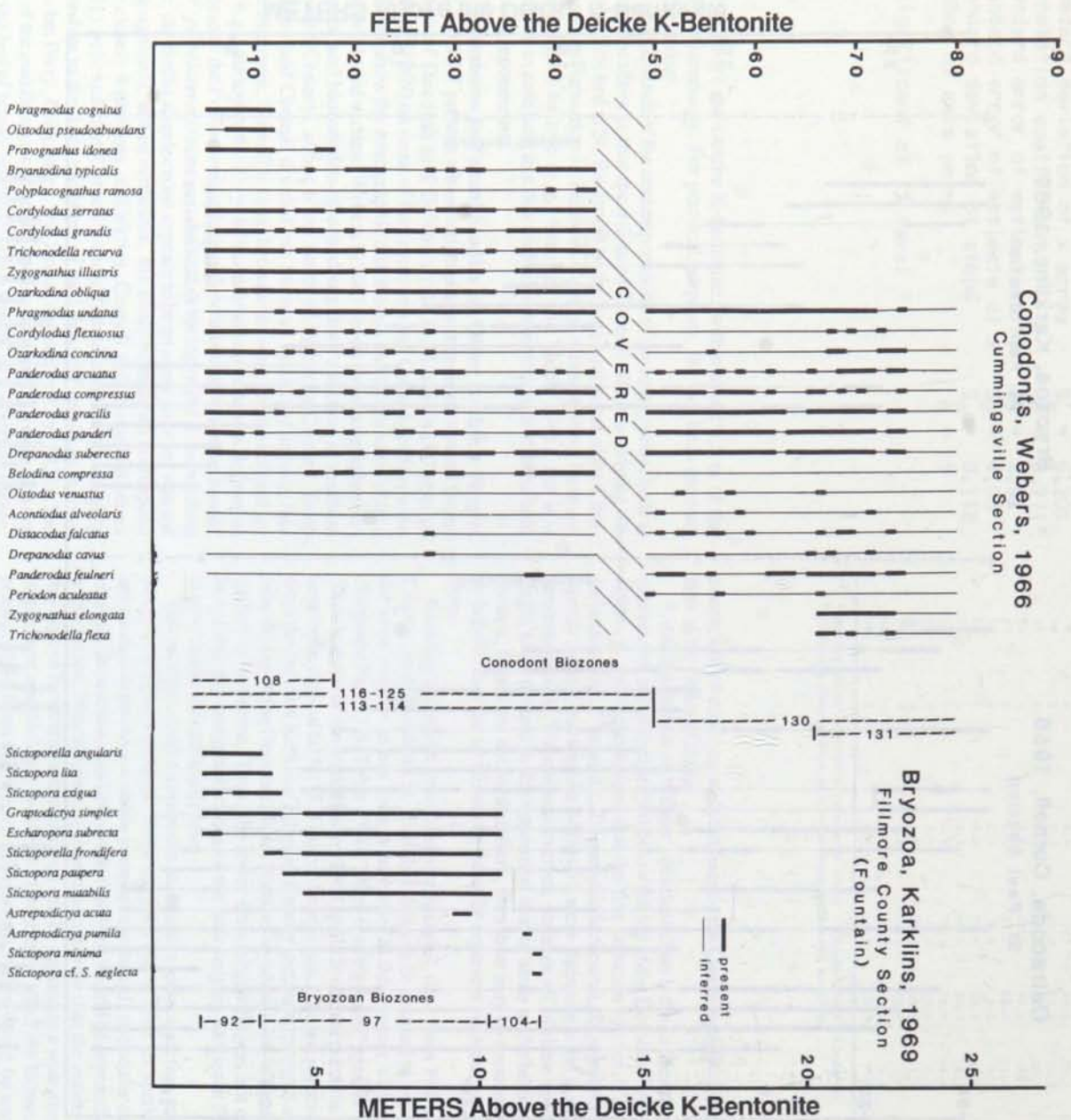
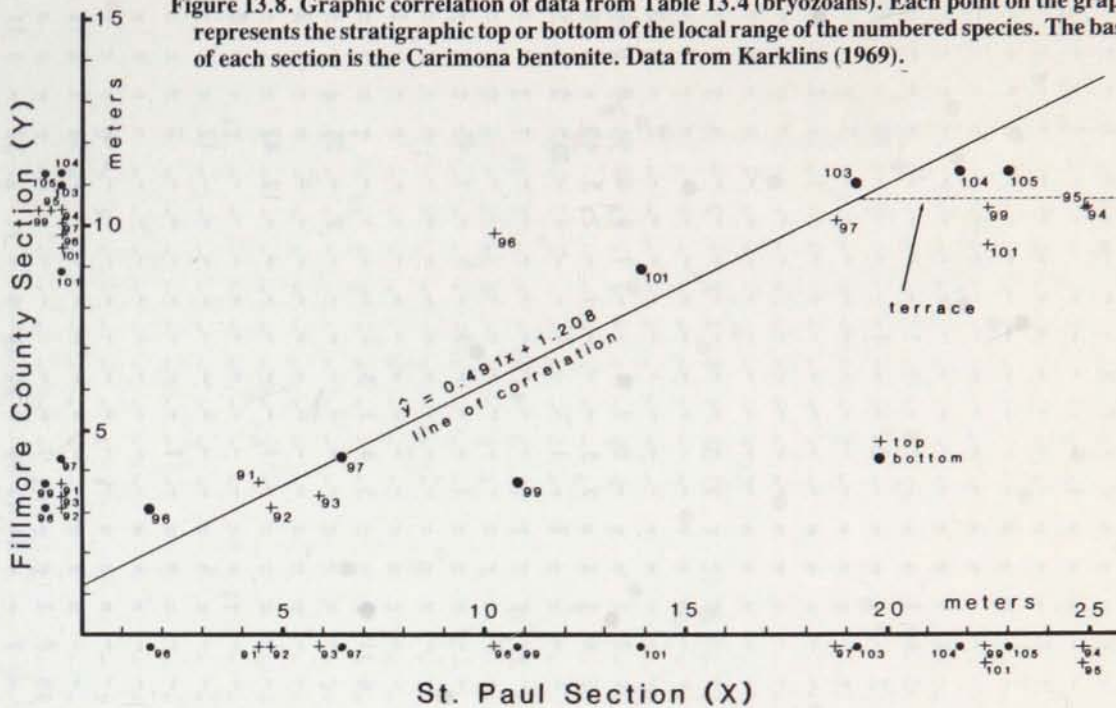


Figure 13.7. Stratigraphic distribution and biozonations of bryozoans and conodonts in the Decorah Shale from southeastern Minnesota.

Figure 13.8. Graphic correlation of data from Table 13.4 (bryozoans). Each point on the graph represents the stratigraphic top or bottom of the local range of the numbered species. The base of each section is the Carimona bentonite. Data from Karklins (1969).



Species name and number	Top(+) bottom(o)		Stratigraphic position ²	
	Fillmore Co.(Y)	St. Paul(X)	Fillmore Co.(Y)	St. Paul(X)
<u>Stictopora exigua</u>	91	+	3.7	4.4
<u>Stictoporella angularis</u>	92	+	3.1	4.7
<u>Stictopora lita</u>	93	+	3.4	5.9
<u>Graptodictya simplex</u> ³	94	+	10.4	24.8
<u>Escharopora subrecta</u> ³	95	+	10.4	24.8
<u>Stictoporella frondifera</u>	96	+	9.8	10.2
		o	3.1	1.7
<u>Stictopora mutabilis</u>	97	+	10.1	18.7
		o	4.3	6.5
<u>Stictopora paupera</u> ³	99	+	10.4	22.4
		o	3.7	10.8
<u>Astreptodictya acuta</u> ³	101	+	9.5	22.4
		o	8.9	13.9
<u>Astreptodictya pumila</u>	103	o	11.0	19.3
<u>Stictopora minima</u>	104	o	11.3	21.8
<u>Stictopora cf. S. neglecta</u>	105	o	11.3	23.0

¹The extremities of the local ranges which probably extend into the adjacent formations at both localities are omitted.

²In meters above arbitrary reference point - the Deicke K-bentonite. The thickness of the Platteville Formation above the bentonite is 0.75 m at St. Paul and about 1.25 m in Fillmore County (Weiss, 1953, Appendix A).

³Tops of 94, 95, 99 and 101 not included in the computation of the line of correlation.

Table 13.4. Tops and bottoms of the local ranges of 12 bryozoan species.

Table 13.5. Brachiopod species abundance per sample.

[Chiefly loose specimens from the shale; >1000 identified specimens in limestone slabs remain uncounted.
 Samples 30, 44, and 46 contained about twice the average amount of bulk material. X, present; -, absent.]

Species name and number	RBY sample number																																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	
1 <i>lingulaceans</i>	X	-	-	-	-	-	-	X	X	-	X	-	X	X	-	-	X	-	-	-	X	X	X	X	-	-	-	-	X	X	-	-	-	-	X	
2 <i>Pseudolingula eva</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	
3 <i>Craniops minor</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	
4 <i>Trematis</i> sp.	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	
5 <i>Schizocrania</i> sp.	-	-	-	-	-	-	-	-	-	?	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	
6 <i>Acanthocrania setigera</i>	-	-	-	-	-	-	-	-	-	-	-	-	2	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
7 <i>Petrocrania halli</i>	-	-	-	3	-	-	-	-	-	-	-	6	3	2	3	1	-	-	-	?	-	?	1	-	-	-	-	-	-	-	-	-	-	-	-	
8 <i>Hesperorthis tricenaria</i>	-	-	-	-	-	-	-	-	-	1	-	-	1	2	-	-	-	-	2	-	-	4	-	-	-	-	-	-	16	-	1	1?	2	5		
9 <i>Glyptorthis bellarugosa</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	
10 <i>Dinorthis pectinella</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	21	?	?	-	12	2		
11 <i>Plaesiomys meedsi</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
12 <i>Doleroides pervetus</i>	8	-	196	-	47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
13 <i>Platystrophia amoena</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
14 <i>Platystrophia extensa?</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
15 <i>Skenidloides anthonense</i>	?	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	5	26	30		
16 <i>Diorthisma? weissii</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	4	?	?	-	-	8	?	4	-	-	?	9	8	91	9	6	24	78	202	-	-	-	
17 <i>Pionodema subaequata</i>	8	1	267	-	25	-	-	-	?	1	-	7	6	6	7	2	6	7	1	-	2	3	-	-	1	-	2	3	49	-	1	4	3	15		
18 <i>Dalmanella sculpta?</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	?	1	-	-	?	-	-	-	235	9	3	3	2	36	-	-	
19 <i>Paucicrura rogata</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	21	
20 <i>Vellamo americana?</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
21 <i>Sowerbyella curdsvillensis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	5	-	3	-	1	43	-	-	-	-	-	-	-	
22 <i>Sowerbyella minnesotensis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
23 <i>Strophomena billingsi</i>	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1?	1	1	
24 <i>Strophomena fillitexta</i>	-	-	7	-	4	-	-	-	-	-	-	13	15	6	6	11	9	-	-	5	4	1	3	-	-	-	-	-	-	-	-	-	2?	15	-	
25 <i>Strophomena septata</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	53	-	-	-	1	-	-	
26 <i>Furcitella scofieldi</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	1	14	-	-	
27 <i>Rafinesquina</i> sp.	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	12	42	-	1	-	19	-	-	
28 <i>Rafinesquina trentonensis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	20	-	
29 <i>Oepikina inquassa</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	-	-	-	1?	-	-	
30 <i>Oepikina minnesotensis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	?	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	
31 <i>Bellimurina charlottae</i>	-	-	-	-	1	-	-	-	-	-	3	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32 <i>Rhynchotrema ainsliei</i>	?	-	4	-	-	-	-	-	-	-	14	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
33 <i>Rhynchotrema wisconsinense</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	52	?	2	11	27	61	-	
34 <i>Rostricellula minnesotensis</i>	-	-	-	-	59	-	-	-	-	2	2	-	10	11	4	18	8	1	-	-	4	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
35 <i>Zygospira lebanonensis</i>	-	-	-	-	2	-	-	4	-	-	36	-	-	-	-	-	?	-	-	11	17	79	?	22	13	6	-	21	2	32	-	5	13	99	138	
36 <i>Zygospira plinthii</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	10	-	
37 <i>Zygospira recurvirostris</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	
38 <i>Protozyga nicolleti</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39 <i>Strophomena</i> sp. unidentifiable	2	-	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	1	-	1	-	-	-	-	-

CONCLUSIONS

Previous brachiopod collections in the UMPC from St. Paul and nearby localities used surface collecting techniques almost exclusively. As a result, those collections were strongly biased in favor of large, well-preserved species and against small species and/or poorly preserved specimens. The collecting technique employed in this study insured that small specimens would be collected in a proportion more truly representative of their proportion in the rock (Table 13.5). In fact, small species, e.g., *Zygospira* spp., *Diorthis* *weissi*, *Craniops minor* and *Skenidioides anthonense* are far more abundant in the Decorah than would be indicated by the older collections. An unfortunate by-product of this sampling technique is the scarcity of large, well-preserved, photogenic specimens, of which the previous collections, particularly Sardeson's, contain an abundance. Working with small and broken specimens also presents identification problems.

The systematic paleontology section presents 40 taxonomic entities, including two new species, *Diorthis* *weissi* and *Zygospira plinthii*. Several common names in faunal lists of Upper Mississippi valley brachiopods, including *Hesperorthis colei*, *Dinorthis sweeneysi*, *Doleroides winchelli*, *D. gibbosa*, *Pionodema uniplicata*, *P. minnesotensis*, *Sowerbyella punctostriata*, and *Strophomena incurvata*, are recommended for abandonment. Two species, *Dalmanella sculpta*? and *Zygospira lebanonensis*, are identified from the Decorah for the first time.

The stratigraphic data gathered from the sampling are presented in a way which is new to the study of brachiopod biostratigraphy in the Upper Mississippi valley. The graphic method of biostratigraphic correlation developed by Shaw (1964) is simple to use, yet ultimately may be more informative and amenable to wider application than is traditional biozone biostratigraphy. By combining the Decorah sections from St. Paul and Fillmore County using Shaw's technique, I was able to draw the following conclusions:

- (1) The prominent brassy oolite beds in Fillmore County and St. Paul are contemporaneous. The upper 8 m of Decorah Shale at St. Paul is the time equivalent of the lower part of the Cummingsville Formation of the Galena Group in Fillmore County. Only the lower 19 m of Decorah Shale at St. Paul is the time equivalent of the Decorah Shale in Fillmore County.
- (2) The rate of rock accumulation at St. Paul was approximately 140 percent of that in Fillmore County.
- (3) Previous attempts by Cornell (1956) and Karklins (1969) to infer a one-to-one correspondence of their three faunal zones in St. Paul with the three members of the Decorah as recognized in Iowa are probably incorrect. Rather, the two lower faunal zones of each author are equivalent to those three members.

SYSTEMATIC PALEONTOLOGY

List of Abbreviations

AMNH	American Museum of Natural History	OD	original designation
b-g	distance along midline from beak to geniculation	pl	pedicle valve length
bl	brachial valve length	pv	pedicle valve
b-s	distance along midline from beak to origin of secondary costellae	RBV	Rice brickyard
bv	brachial valve	RSF	Rice Shadow Falls
cos	number of costae (number on fold in parentheses)	SD	subsequent designation
fh	fold height	S.D.	standard deviation
hw	width along hinge	th	thickness
l	length	UMPC	University of Minnesota Paleontology Collection
lam	lamellose	USNM-I	United States National Museum - Invertebrate Paleontology
mw	width at mid-length	w	maximum width

Phylum Brachiopoda Duméril, 1806
 Class Inarticulata Huxley, 1869
 Order Lingulida Waagen, 1885
 Superfamily Lingulacea Menke, 1828
 Family Obolidae King, 1846
 Subfamily Lingulellinae Schuchert, 1893
 Genus *Pseudolingula* Mickwitz, 1909
 type species: *Crania quadrata* EICHWALD, 1929,
 p. 273; OD.

Pseudolingula eva (Billings)
 Plate 1, Figure 1

Discussion

This collection contains only small, phosphatic chips with wavy growth lines crossed by irregular transverse lines, a pattern characteristic of *Pseudolingula eva*.

P. eva is found in samples RBV-21 and RBV-30, approximately 10.0 m and 12.5 m above the Platteville/Decorah contact at the brickyard locality.

Number of specimens: 2

Family Craniopsidae Williams, 1963
 Genus *Craniops* Hall, 1859
 type species: *Orbicula? squamiformes* HALL, 1843,
 p. 108; OD.

Craniops minor (Winchell and Schuchert)
 Plate 1, Figure 2

Pholidops trentonensis Hall var. *minor*, WINCHELL and SCHUCHERT, 1895, p. 376, pl. 29, fig. 40.

Craniops minor (Winchell and Schuchert); COOPER, 1956, p. 240.

Discussion

Craniops minor can easily be distinguished from other inarticulates in this collection by its small size, oval outline, lamellose growth lines and very delicate, calcareous shell. As pointed out by Winchell and Schuchert (1895, p. 377) the valves are very thin and neither muscle nor pallial markings are discernible.

Craniops minor occurs in the upper two-thirds of the section at the brickyard locality. It is especially abundant at RBV-46, about 20.5 m above the Platteville/Decorah contact.

Number of specimens: 90

Measurements (in mm)

catalogue	sample	l	w	h	l/w	
UMPC 14,105c	RBV-46	whole	2.3	1.8	0.6	1.28

Lingulacea gen. and sp. indet.

Discussion

Phosphatic chips of obvious lingulacean origin are encountered frequently in the Decorah Shale. Whole, identifiable specimens are quite scarce. Some lingulaceans previously identified from the Decorah Shale include *Pachyglossella elderi* (Whitfield), *Westonia clathrata* (Winchell and Schuchert) and *Pachyglossella? riciniformis* (Hall).

Lingulacean phosphatic chips are found sporadically throughout the entire section at the brickyard locality.

Order Acrotretida Kuhn, 1949
Suborder Acrotretidina Kuhn, 1949
Superfamily Discinacea Gray, 1840
Family Trematidae Schuchert, 1893
Genus *Trematis* Sharpe, 1848
type species: *Orbicula terminalis* EMMONS, 1842, p. 395;
SD. DAVIDSON, 1853, p. 130.

Trematis sp.
Plate 1, Figure 3

Discussion

Trematis can be distinguished from other inarticulates in this collection by the very distinctive shallow pits on the surface of both valves. The pits may be arranged either radially or quincuncially. The specimens in this collection comprise about half a dozen chips, most of which are quite badly abraded. These chips probably represent more than one species, because the arrangement and shape of the pits is not the same on all specimens. Cooper (1956, pp. 111, 112) stated that two, possibly three species have been reported from the Decorah Shale in Minnesota: *T. minneapolis* (Sardeson) (listed as *T. minnesotensis* Sardeson, an obvious misprint), *T. punctostriata* Hall, and *T. huronensis?* Billings. The chips in this collection are too poorly preserved to permit specific identification.

Chips of *Trematis* sp. were found in samples RSF-8, RSF-11, RBY-30 and RBY-48, from 2.1 m to 21.0 m above the Platteville/Decorah contact at the brickyard locality.

Number of specimens: 5

Genus *Schizocrania* Hall and Whitfield, 1875
type species: *Orbicula? filosa* HALL, 1847, p. 99; OD.

Schizocrania sp.
Plate 1, Figure 4

Discussion

Schizocrania filosa (Hall) is the commonly reported species of this genus in rocks equivalent in age to the Decorah Shale (Cooper, 1956, p. 275). *Schizocrania* is characterized by its nearly circular outline and, on the exterior surface of the brachial valve, very fine costellae originating at some distance from the protogugal node. *S. filosa* is usually found cemented to another brachiopod.

The single specimen in this collection is extremely poorly preserved and only marginally identifiable.

Schizocrania sp. was found in RBY-35, about 17.0 m above the Platteville/Decorah contact at the brickyard locality.

Measurements (in mm)

catalogue#	sample#	
UMPC 14,022	RBY-35	3.0

Suborder Craniidina Waagen, 1885
Superfamily Craniacea Menke, 1828
Family Craniidae Menke, 1828
Genus *Acanthocrania* Williams, 1943
type species: *Crania spiculata* ROWLEY, 1908, p. 74; OD.

Acanthocrania setigera (Hall)
Plate 1, Figure 5

Crania setigera HALL, 1866, p. 12.

Acanthocrania setigera (Hall); COOPER, 1956, p. 285, pl. 25A, figs. 1-5.

Discussion

Acanthocrania setigera can be distinguished from other inarticulates in this collection (except *Petrocrania halli*) by its conical shape and its punc-

tate, calcareous shell structure. Its pedicle valve is not known and probably did not exist (Williams and Wright, 1970, p. 39). From *P. halli*, *A. setigera* may be distinguished by its spinose or papillose surface ornamentation, and by its somewhat lesser convexity.

Both *A. setigera* and *P. halli* are often encrusted with bryozoans and are thus difficult to separate on the basis of surface ornamentation. Internally, the brachial valve of *Acanthocrania* exhibits larger anterior adductors than posterior. This condition is opposite of that found in *Petrocrania*, but as the figures in Cooper (1956, pl. 21A and 25D) illustrate, this difference is not necessarily very great.

For the purposes of the stratigraphic chart (Figure 13.4), *A. setigera* has been lumped with *P. halli* whenever the distinguishing character of the former (i.e., papillose surface ornamentation) was not evident.

Acanthocrania setigera occurs sporadically throughout the brickyard section from RBY-14 to RBY-37, 6.5 m to 18.5 m above the Platteville-Decorah contact. Most specimens are broken and abraded.

Number of specimens: 7

Measurements (in mm)

catalogue #	sample#		diameter
UMPC 13,884a	RBY-17	bv	8.0

Genus *Petrocrania* Raymond, 1911

type species: *Craniella meduanensis* OEHLERT, 1888, p. 102; OD.

Petrocrania halli (Sardeson)

Plate 1, Figure 6

Crania halli SARDESON, 1892c, p. 328, pl. 4, figs. 8-10.

Craniella ulrichi Hall and Clarke; COOPER, 1956, p. 288.

Petrocrania halli (Sardeson); COOPER, 1956, p. 288, pl. 25D, figs. 11, 12.

Discussion

See *Acanthocrania setigera* discussion.

Single valves, almost always brachial, occur sporadically from RBY-5 to RBY-53, 1.5 to 22.3 m above the Platteville/Decorah contact at the brickyard locality.

Number of specimens: 29

Measurements (in mm)

catalogue#	sample#		diameter
UMPC 13,889	RBY-18	bv	10.0

Class Articulata Huxley, 1869

Order Orthida Schuchert and Cooper, 1932

Suborder Orthidina Schuchert and Cooper, 1932

Superfamily Orthacea Woodward, 1852

Family Dolerorthidae Öpik, 1934

Subfamily Hesperorthinae Schuchert and Cooper, 1931

Genus *Hesperorthis* Schuchert and Cooper, 1931

type species: *Orthis tricenaria* CONRAD, 1843, p. 333; OD.

Hesperorthis tricenaria (Conrad)

Plate 1, Figure 7

Orthis tricenaria CONRAD, 1843, p. 333.

Orthis disparilis Conrad; WINCHELL and SCHUCHERT, 1895, p. 418.

Hesperorthis tricenaria (Conrad); SCHUCHERT and COOPER, 1932, p. 244.

Hesperorthis colei COOPER, 1956, p. 347, pl. 54D, figs. 16-21.

Discussion

Hesperorthis tricenaria is characterized by its semicircular outline, planoconvex profile, very prominent triangular pedicle interarea, and "costate" (see below) ornamentation with a single fine parvicostella occupying each interspace.

Hesperorthis is generally regarded as possessing costate ornamentation (Williams and Wright, 1965, p. 317). However, most specimens of *H. tricenaria* from the Twin Cities area which I have examined, actually are costellate, with the secondary costellae originating by branching usually less than 1 mm from the beak of both valves. This feature is quite subtle since it occurs only very near the beak and is noticeable only on well preserved specimens. Knowledge of this fact is important in correctly identifying very young specimens, on which the costellate portion of the valve is proportionately much greater.

Cooper (1956, p. 347) erected a new species, *H. colei*, based on specimens from the upper part of the Decorah Shale near Cannon Falls, Minne-

sota. (Cooper calls this part of the Decorah the "Ion Member", a name not recognized in Minnesota.) *H. colei* is distinguished from *H. tricenaria* "in the excessive development of the pseudodeltidium, smaller size, more concave brachial valve, and more strongly apsacline interarea on the pedicle valve" (Cooper, 1956, p. 345). The range of variation in each of these four characteristics as found in specimens of *H. tricenaria* from the present collection and the Sardeson collection is sufficiently large to include those specimens assigned by Cooper to *H. colei*.

Hesperorthis tricenaria is present throughout the Decorah Shale at the brickyard locality but is common only in the middle third of the section. It is rare in the lower and upper thirds of the section. Most specimens are disarticulated, broken and abraded.

Number of specimens: 38

Measurements (in mm)

catalogue#	sample#	bl	w	hw	bl/w
UMPC 13,962a	RBY-30	bv	9.5	12.5	— 0.76

Subfamily Glyptorthinae Schuchert and Cooper, 1931
Genus *Glyptorthis* Foerste, 1914
type species: *Orthis insculpta* HALL, 1847, p. 125, OD.

Glyptorthis bellarugosa (Conrad)
Plate 1, Figure 8

Orthis bellarugosa CONRAD, 1843, p. 333.

Orthis (Hebertella) bellarugosa Conrad; HALL and CLARKE, 1892, p. 222.

Orthis (Hebertella?) bellarugosa Conrad; WINCHELL and SCHUCHERT, 1895, p. 434, pl. 33, figs. 1-4.

Glyptorthis bellarugosa (Conrad); FOERSTE, 1914, p. 258.

Discussion

Glyptorthis bellarugosa is distinguished from other orthides by its biconvex profile, moderately coarse costellation, and imbricate, to the point of frilly, ornamentation.

G. bellarugosa is decidedly uncommon at the brickyard locality. All of the specimens come from the upper half of the Decorah Shale and all of them are broken and abraded.

Number of specimens: 6

Measurements (in mm)

catalogue#	sample#	bl	w	hw	bl/w
UMPC 13,948	RBY-30	bv	9.5	11.5	8.0 0.83

Family Plaesiomyidae Schuchert, 1913
Subfamily Plaesiomyinae Schuchert, 1913
Genus *Dinorthis* Hall and Clarke, 1892
Subgenus *Dinorthis* Hall and Clarke, 1892

type species: *Orthis pectinella* EMMONS, 1842, p. 394; OD.

Dinorthis (Dinorthis) pectinella (Emmons)
Plate 1, Figure 9

Orthis pectinella EMMONS, 1842, p. 394, text fig. 2 (not described).

Orthis pectinella Emmons; HALL, 1847, p. 123, pl. 32, figs. 10a-e.

Orthis charlottae N.H. Winchell; WINCHELL and SCHUCHERT, 1895, p. 424.

Orthis (Dinorthis) pectinella Emmons; HALL and CLARKE, 1892, p. 195, pl. 5, figs. 29-36, 27, 28?

Dinorthis pectinella (Emmons); SCHUCHERT, 1897, p. 215.

Plaesiomyis (Dinorthis) pectinella (Emmons); SCHUCHERT, 1913, p. 382.

Dinorthis pectinella (Emmons); SCHUCHERT and LEVENE, 1929, p. 53.

Dinorthis (Dinorthis) pectinella (Emmons); SCHUCHERT and COOPER, 1932, p. 94, pl. 9, figs. 2, 5.

Plaesiomyis (Dinorthis) pectinella (Emmons); WILLIAMS and WRIGHT, 1965, p. H319, fig. 201, no. 3a,b.

Orthis sweeneyi N.H. WINCHELL, 1881, p. 117.

Discussion

Dinorthis (Dinorthis) pectinella differs from other orthides in this collection in its costate ornamentation and its convexo-concave profile. (Very young specimens, however, are biconvex in profile and could be confused with species of *Plaesiomyis* or *Plectorthis*. The latter, however, are actually

costellate, with secondary costellae arising near the beak.) Internally *Dinorthis* differs from *Plectorthis* by not possessing fulcral plates. Cooper (1956, p. 397) pointed out that the small convex apical plate in the delthyrium, which is found in more than half of the well preserved pedicle valves of this collection, is uncommon to nonexistent in other species of *Dinorthis*.

Dinorthis sweeneyi is distinguished from *D. pectinella* only in its smaller size and somewhat thinner shell (Winchell and Schuchert, 1895, p. 426). Such a distinction has led to probable young specimens of *D. pectinella* being classified as *D. sweeneyi*. Unless it can be shown that the stratigraphic range of the large form (*D. pectinella*) is not coincident with the range of the small form (*D. sweeneyi*) it would be best to synonymize *D. sweeneyi* with *D. pectinella*. In the present collection both large and small specimens occur together throughout the upper half of the Decorah Shale.

Costation counts, rather than size, may be of some taxonomic and biostratigraphic value. Although the number of measurable specimens in this collection is small, counts on a few brachial valves suggest that costation count increases in progressively younger strata. At RBY-30, 12.5 m from the base of the Decorah Formation, the number of costae per 5 mm at a distance of 10 mm from the beak is 4 to 5 (2 specimens). At RBY-65, 25.5 m from the base, the costation count is 6 to 7 (one specimen). Obviously a much larger sample is needed before the statistical validity of this difference can be tested.

Dinorthis (Dinorthis) pectinella is found throughout the upper half of the Decorah Shale at the brickyard locality. Most specimens are disarticulated and broken but not abraded significantly. The exception is sample RBY-30, in which most specimens show significant abrasion.

Number of specimens: 48

Nomenclatural Note

Williams and Wright (1965, p. H319) relegated *Dinorthis* to the status of a subgenus of *Plaesiomyis*, whereas in this paper I consider *Plaesiomyis* a subgenus of *Dinorthis*. Although many authors (see synonymy) have dealt with these taxa in one way or another, I have chosen the latter course because Hall and Clarke (1892) gave page priority to *Dinorthis* (p. 195) over *Plaesiomyis* (p. 196), and because Schuchert (1897, p. 215), who seems to have been the earliest reviewer, made *Plaesiomyis* a junior synonym of *Dinorthis*.

Measurements (in mm)

catalogue#	sample#	pl	w	hw	pl/w
UMPC 13,964a	RBY-30	pv	19.5	—	14.0 —

Subgenus *Plaesiomyis* Hall, 1892

type species: *Orthis subquadrata* HALL, 1847, p. 126; OD.

Dinorthis (Plaesiomyis) meedsi (Winchell and Schuchert)
Plate 1, Figure 10

Orthis meedsi WINCHELL and SCHUCHERT, 1892 (April 1), p. 289; 1895, p. 427, pl. 32, figs. 39-42.

Orthis minnesotensis SARDESON, 1892c (April 6), p. 332, pl. 5, figs. 14-17.

Dinorthis (Plaesiomyis) meedsi (Winchell and Schuchert); SCHUCHERT and COOPER, 1932, p. 94.

Discussion

Dinorthis (Plaesiomyis) meedsi is similar to *D. (D.) pectinella* but *D. meedsi* has secondary costellae arising 3-7 mm from the beak on both valves. As noted by Winchell and Schuchert (1892, p. 289) the secondaries originate by bifurcation on the pedicle valve and by intercalation on the brachial valve. The median costae of some pedicle valves may trifurcate. The distance from the beak of the origination of the secondaries appears to decrease in progressively younger strata and may therefore be biostratigraphically significant. The pedicle valve of *D. meedsi* is slightly convex, a feature which may help to separate this species from *D. pectinella*, but small specimens (length <4 mm) of the two species cannot be separated with certainty.

Dinorthis (Plaesiomyis) meedsi is found in the upper third of the Decorah Shale at the brickyard section. Preservation is similar to that of *D. pectinella*.

Number of specimens: 10

Measurements (in mm)

catalogue#	sample#	pl	b-s
UMPC 14,117a	RBY-46	pv	12.0 7.0

Family Plectorthidae Schuchert and LeVene, 1929
 Subfamily Plectorthinae Schuchert and LeVene, 1929
 Genus *Doleroides* Cooper, 1930
 type species: *Orthis gibbosa* BILLINGS, 1857, p. 296;
 OD. [= *O. perveta* CONRAD, 1843, p. 333]

Doleroides pervetus (Conrad)
 Plate 1, Figure 11

Orthis perveta CONRAD, 1843, p. 333.
Orthis (Dalmanella) perveta Conrad; HALL and CLARKE, 1892, p. 224.
Orthis (Dalmanella) subaequata var. *perveta* Conrad; WINCHELL and SCHUCHERT, 1895, p. 450, pl. 33, figs. 40-42.
Hebertella (Doleroides) pervetus (Conrad); COOPER, 1930a, p. 381, pl. 35, fig. 8; pl. 36, figs. 4,7; pl. 37, figs. 1,3.
Doleroides pervetus (Conrad); SCHUCHERT and COOPER, 1932, p. 63, pl. 11, figs. 10, 12, 13.
Orthis gibbosa BILLINGS, 1857, p. 296.
Doleroides pervetus gibbosus (Billings); WEISS, 1955, p. 768, pl. 71, fig. 3a-f.
Doleroides winchelli COOPER, 1956, p. 466, pl. 93, figs. 1-7.

Discussion

Doleroides pervetus can easily be separated from other orthides in this collection (except *Pionodema*) by its biconvex profile, radial ornamentation of fine hollow costellae, usually uniplicate commissure, and fairly large adult size (same size as *P. subaequata*).

Doleroides is very easily confused with *Pionodema*. The two genera can be distinguished with certainty only with careful examination. *Pionodema* is endopunctate; *Doleroides* is impunctate. The brachiophore bases of *Pionodema* are divergent; those of *Doleroides* are convergent and unite anterior to the cardinal process. *Pionodema* possesses a small apical plate (pedicle callist) in the delthyrium; the delthyrium of *Doleroides* is open. The pedicle muscle field of *Pionodema* is subflabellate; that of *Doleroides* is suboval to subquadrate (see plates 1 and 2). One other character which is sometimes useful is the fineness of the costellation. The costellation of *Doleroides* is usually, but not always, somewhat coarser. The posterior costellae of *Doleroides* parallel the posterior of the shell, while those of *Pionodema* intersect the posterior edge.

Billings (1857, p. 296) erected *Orthis gibbosa* to include shells which were "exceedingly convex". Cooper (1956, p. 459) stated in his discussion of *D. gibbosus*,

As here identified the species is very variable as to outline and profile, development of fold, and sulcus and ornamentation. As would be expected, variations in profile are common and may have nothing to do with the biological characters of the shells. . . . specimens in all types of matrix showed a variation in the relation of length to width. [see table of measurements] Some specimens are distinctly more rounded than others. . . . Some specimens are distinctly shouldered and have cardinal extremities approaching a right angle. Most specimens referred to this species have a fairly narrow fold and sulcus, but in a few of them, the sulcus may occupy as much as half the shell width.

Winchell and Schuchert (1895, p. 452) stated,

These [var. *gibbosa*] and var. *perveta* at times merge into each other to such a degree that it is impossible to separate them.

Weiss (1955, pp. 768-769) stated that,

The thickness or gibbosity of the shells [of *D. pervetus*] shows no constant relation to other characters or to stratigraphic horizon. . . . The individuals of the genus *Doleroides* in the Ordovician rocks of Minnesota make up a single population containing a number of variations of differing intensities. Soon after their appearance in the rocks conditions were favorable for abundant and luxuriant growth. It was then that the large fat uniplicate shells dominated the population. The subspecies *D. p. gibbosus* is recognized here in order to direct attention to that fact, and because the genus is founded on some specimens of this type from the Decorah formation of Minnesota.

Billings himself later (1859b, p. 434) became somewhat uncertain of the distinctiveness of his own creation,

It [*Orthis gibbosa*] varies greatly in the amount of the gibbosity and in the length of the hinge-line, which is sometimes only half the whole width of the shell. I am not yet satisfied that it should constitute a distinct species. . . . I shall for the present keep them separate provisionally.

My observations regarding the variability of *D. pervetus* bear out those of the earlier authors. Retention of the name *D. gibbosus* for especially fat specimens can serve no biological or stratigraphic purpose; indeed, it can only serve to confuse.

D. winchelli is a name given by Cooper (1956, p. 466) to *Orthis media* N.H. Winchell because the latter was preoccupied. Winchell and Schuchert synonymized *O. media* with *O. subaequata* var. *perveta*, with which I agree.

Doleroides pervetus is very common in the lowermost part of the section (RBY-1 to RBY-5) but disappears abruptly at the base of the Millbrig K-bentonite (RBY-7), 2.1 m above the Platteville/Decorah contact. Most of the material in RBY-3 occurs as isolated shell fragments rather than in coquinas as is common in most of the rest of the section. Almost all shells are disarticulated and broken but not significantly abraded.

Number of specimens: 251

Measurements (in mm)

catalogue#	sample#	pl	w	hw	fh	pl/w
UMPC 13,812b	RBY-3	pv	19.3	21.7	15.2	4.0 0.89

Subfamily Platystrophiinae Schuchert and LeVene, 1929
 Genus *Platystrophia* King, 1850
 type species: *Terebratulites biforatus* VON SCHLOTHEIM, 1820, p. 265; OD.

Platystrophia amoena McEwan
 Plate 2, Figure 1

Platystrophia biforata (Schlotheim); WINCHELL and SCHUCHERT, 1895 (in part), p. 455.

Platystrophia amoena McEWAN, 1919, p. 412, pl. 43, figs. 1-8.

Platystrophia amoena robusta McEWAN, 1919, p. 412, pl. 43, figs. 14-17.

Discussion

Platystrophia differs from other orthides in its spiriferidine external form and from *Rhynchotrema* and *Rostricellula* in its strophic hinge. *P. amoena* differs from *P. extensa* in its somewhat smaller hinge width to length ratio, smaller size, and smaller number of costae on each side of the fold and sulcus. McEwan (1919, p. 412) proposed the name *P. amoena robusta* for shells of greater height than usual (which would include the specimen in this collection), but *P. a. robusta* is probably nothing more than a gerontic form of *P. amoena s.s.*

Platystrophia amoena is found in RBY-42, 19.5 m above the Platteville/Decorah contact at the brickyard locality.

Number of specimens: 1

Measurements (in mm)

catalogue#	sample#	bl	hw	fh	bl/hw
UMPC 14,069	RBY-42	bv	11.0	13.6	1.0 0.81

Platystrophia extensa? McEwan
 Plate 2, Figure 2

Platystrophia biforata (Schlotheim); WINCHELL and SCHUCHERT 1895 (in part), p. 455, pl. 33, fig. 53?

Platystrophia extensa McEWAN, 1919, p. 410, pl. 42, figs. 39-41.

Discussion

The umbo of the three specimens in this collection (2 brachial valves and 1 pedicle valve) are obscured by calcareous matrix and a costation count of the fold or sulcus cannot be made without risking destruction of the specimen. The size, outline, and costation count lateral to the fold on the RBY-42 brachial valve all suggest *Platystrophia extensa*. This identification is, however, not certain.

Platystrophia extensa? is found in samples RBY-42 and RBY-68, 19.5 m and 26.7 m from the base of the section, respectively.

Number of specimens: 4

Measurements (in mm)

catalogue#	sample#	bl	w	hw	fh	bl/hw
UMPC 14,070	RBY-42	bv	11.5	23.0	23.0	1.5 0.50

Family Skenidiidae Kozłowski, 1929
 Genus *Skenidioides* Schuchert and Cooper, 1931
 type species: *S. billingsi* SCHUCHERT and COOPER, 1931, p. 243; OD.

Skenidioides anthonense (Sardeson)
Plate 2, Figure 3

- Skenidium anthonensis* SARDESON, 1892c, p. 334, pl. 4, fig. 7.
Scenidium anthonensis Sardeson; WINCHELL and SCHUCHERT, 1895, p. 381, pl. 30, figs. 20-23.
Skenidium anthonense Sardeson; SCHUCHERT, 1897, p. 371.
Skenidioides anthonensis (Sardeson); SCHUCHERT and COOPER, 1932, p. 71.

Discussion

Skenidioides anthonense is easily distinguished from other brachiopods in this collection by its small size, plano-convex profile, high hemipyramidal pedicle valve with catacline interarea, and costate ornamentation. Internally it can be distinguished by the spondylium in the pedicle valve and the prominent median septum and septalium in the brachial valve.

Skenidioides anthonense is found in the upper half of the section at the brickyard locality. Other workers (e.g., Sardeson, 1892c and Weiss, 1957) have also reported this species from the Platteville Limestone in both the Twin Cities area and Fillmore County, Minnesota. It is fairly common in RBY-34 and RBY-35, about 17 m from the base of the section. Most specimens are disarticulated but are not badly broken or abraded.

Number of specimens: 89

Measurements (in mm)

Catalogue#	sample#	pl	bl	w (= hw)	th	p1/w	bl/w
UMPC 10,007a	RBY-34	pv	2.2	4.3	1.1	0.51	
UMPC 10,025a	RBY-35	whole	2.0	4.6	1.8	0.43	
UMPC 10,025b	RBY-35	bv	2.2	4.0	0.4	0.55	

Superfamily Enteletacea Waagen, 1884
Family Enteletidae Waagen, 1884
Subfamily Draboviinae Havlicek, 1950
Genus *Diorthis* Cooper, 1956
type species: *D. parvum* COOPER, 1956, p. 998; OD.

Diorthis *weissi* Rice, new species
Plate 2, Figure 4

Orthis (Dalmanella) hamburgensis? WINCHELL and SCHUCHERT (not Walcott), 1895 (in part), p. 440.

Dalmanella winchelli COOPER, 1956, figures only, pl. 158D, figs. 15, 16.

Description

Shell large for the genus; length about 80% of width but varies considerably, lateral and anterior margins usually form a smooth semicircular arc but occasionally flattened anteriorly, hinge width about 80% of width, cardinal extremities fairly sharp, typically forming an angle of about 120°; lateral profile nearly planoconvex to gently ventribiconvex, height about 50% of length; anterior commissure sulcate; surface ornamentation costellate to vaguely fascicostellate, about 5 costellae per mm at anterior margin, lateral-most costellae parallel to posterior margin; shell substance endopunctate.

Pedicle valve relatively deep and subcarinate; lateral profile gently curving but with convexity increasing somewhat in the posterior half, beak incurved; interarea curved, apsacline, with an inclination of about 135° to vertical, delthyrium open; teeth fairly prominent, crural fosses shallow; dental plates short, receding, divergent and laterally enclosing a short cordate(?) muscle field, muscle impressions quite faint; vascular impressions not visible.

Brachial valve usually very gently convex, but with broad, shallow sulcus originating within 0.5 mm of beak; brachiophores triangular in lateral view, with bases very gently convergent; interarea anacline; fulcral plates variably developed but almost always present; notothyrial platform low, cardinal process with slender shaft and slightly swollen, crenulated myophore; as in pedicle valve muscle impressions are quite faint but posterior adductor pair appears to be located postero-lateral to the anterior pair; vascular impressions not visible.

Types: holotype: UMPC 14,086a from RBY-43
paratypes: UMPC 10,011a from RBY-34, UMPC 10,030a from RBY-35, 14,086b, c from RBY-43
locality: Twin City Brick Company, St. Paul, Minnesota

Etymology

Named for Malcolm P. Weiss in honor of his contributions to our understanding of the Middle Ordovician of the Upper Mississippi valley.

Discussion

Diorthis *weissi* differs from *D. parvum* Cooper in its greater size, slightly greater length to width ratio, slightly coarser costellation, and the somewhat more prominent teeth in the pedicle valve. Cooper's definition of *Diorthis* stated "Delthyrium partially closed by lateral plates" (1956, p. 997). *Diorthis* *weissi* does not exhibit these plates, but neither are they at all obvious on the figured specimen in Cooper's monograph (1956, pl. 146B, fig. 18). The absence of the plates warrants caution in assigning this species to the genus *Diorthis*.

Diorthis *weissi* differs from other orthides in this collection in its small size, costellate ornamentation (especially in the lateral-most costellae paralleling the posterior border of the shell), and by its slightly convergent brachiophore bases.

Winchell and Schuchert (1895, p. 440) doubtfully referred some small orthides from St. Paul, Cannon Falls, Lanesboro and Fountain, Minnesota to *Orthis (Dalmanella) hamburgensis* Walcott and specifically cited two specimens from Fountain (UMPC 7892), one of which was figured (pl. 33, figs. 14-16). Cooper (1956, p. 953) gave this group of specimens a new name—*Dalmanella winchelli*—because they were "totally unlike *Orthis hamburgensis* Walcott from the Lower Ordovician (Goodwin formation) of the Eureka district, Nev." (Cooper, 1956, p. 953). Cooper did not reference any types for this new species, as was his usual practice, so it must be assumed that he regarded Winchell and Schuchert's specimens from Fountain as the syntypes of *Dalmanella winchelli*. Cooper, however, did figure two specimens (1956, pl. 158D, figs. 15, 16; USNM-I 48758a,b) from the Decorah Shale (*Rhinidictya* bed) at St. Paul, which he referred to *Dalmanella winchelli*. I have examined the syntypes of *Dalmanella winchelli* (UMPC 7892) and believe that they are distinct from Cooper's figured specimens; they are both larger and much more coarsely costellate. The syntypes must retain the name *Dalmanella winchelli* while Cooper's figured specimens are, I believe, referable to *Diorthis* *weissi* of this paper.

I also suggest that the group of specimens discussed by Winchell and Schuchert as *Orthis (Dalmanella) hamburgensis?* likely contained both *Dalmanella winchelli* as represented by UMPC 7892 and *Diorthis* *weissi*. The "series of minute black spots, probably infillings of the punctae" (1895, p. 441) is characteristic of well preserved specimens of *Diorthis* *weissi* from the present collection and does not occur on either of the syntypes from Fountain. The paleontological collections of the University of Minnesota do not contain any other specimens originally labelled as *Orthis (Dalmanella) hamburgensis*. The Sardeson collection contains many specimens of this species. Sardeson apparently considered them to be immature individuals of *Paucicrura rogata*.

Diorthis *weissi* occurs in the upper three-quarters of the brickyard section. It is especially abundant in RBY-34, RBY-35 and RBY-46. Most specimens are disarticulated and broken but not significantly abraded.

Number of specimens: 847

Measurements (in mm)

catalogue#	sample#	pl	bl	w	hw	th	p1/w	bl/w	
UMPC 10011a	RBY-34	whole	4.2	3.9	4.4	3.9	2.0	0.95	0.88
	(paratype)								
UMPC 10,011c	RBY-34	bv		3.8	4.9	3.9			0.78
UMPC 10,030a	RBY-35	whole	3.4	3.2	3.9	3.1	1.7	0.87	
	(paratype)								
UMPC 14,086a	RBY-43	whole	3.5	3.3	3.9	3.1	1.9	0.90	0.85
	(holotype)								
UMPC 14,086b	RBY-43	bv		2.7	3.2	2.8			0.84
	(paratype)								
UMPC 14,086c	RBY-43	pv	3.5		4.1	3.6		0.85	
	(paratype)								

Genus *Pionodema* Foerste, 1912
type species: *Orthis subaequata* CONRAD, 1843, p. 333; OD.

Pionodema subaequata (Conrad)
Plate 2, Figure 5

Orthis subaequata CONRAD, 1843, p. 333.
Orthis subaequata Conrad; HALL, 1847, p. 118, pl. 32, fig. 2.

Orthis (Dalmanella) subaequata Conrad; HALL and CLARKE, 1892, pp. 207-224, pl. 5C, figs. 6-11.

Pionodema subaequata (Conrad); COOPER, 1930a, p. 378, pl. 35, fig. 4; pl. 36, figs. 1, 3; pl. 37, fig. 6.

Pionodema uniplicata Cooper; WEISS, 1955, p. 769.

Pionodema minnesotensis Cooper; WEISS, 1955, p. 769.

Discussion

Pionodema subaequata can be distinguished from other orthides (except *Doleroides*; see *D. pervetus* discussion) by its biconvex profile, radial ornamentation of fine, hollow costellae, uniplicate commissure, and relatively large size (average maximum width about 2.0-2.5 cm).

Cooper (1930a) erected two new species, *P. uniplicata* and *P. minnesotensis*, to include shells which had, respectively, a strong fold and sulcus and a longer than normal hinge line. Weiss (1955, p. 769), in synonymizing these two species with *P. subaequata*, correctly pointed out that these characters are only the end members of "a wide variety of shapes, gibbosity, and degree of plication" and are of no biostratigraphic significance. In general the specimens in this collection are somewhat more transverse than the holotype, which may be a function of their small size (see *Dalmanella sculpta*?) but they nevertheless fall within the wide range of this species. Further evidence for the equivalence of *P. subaequata* and *P. minnesotensis* is afforded by the measurements of some hypotypes of these two species listed in Cooper (1956, pp. 990, 993). The character which separates the two species is the supposed wide hinge and distinctly formed shoulders of *P. minnesotensis*, yet the average hw/w ratio of that species is 0.78 (S.D. = 0.02, n = 3) while that of *P. subaequata* is 0.77 (S.D. = 0.04, n = 12). This is hardly a significant difference.

Many workers (e.g., Winchell and Schuchert, 1895; Cooper, 1956; Weiss, 1957) have reported the occurrence of *P. circularis* (N.H. Winchell) in the upper part of the Decorah Shale in Minnesota. Winchell and Schuchert (1895, p. 453) pointed out that *P. circularis* is distinguished by its subcircular shape, usually smaller size (*contra* Cooper, 1956, p. 987), and very fine costellation. The present collection contains specimens of *Pionodema* which exhibit one or two of these characters but never all three simultaneously. Therefore, I have not been able to positively identify *P. circularis* in this collection. If *P. circularis* does occur, it has been included in *P. subaequata*.

Pionodema subaequata is common in the lower half of the section at the brickyard locality. This species is especially abundant (with *Doleroides pervetus*) at RBV-3, approximately 1 m above the Platteville/Decorah contact. Most specimens are disarticulated and broken. Degree of abrasion varies from place to place, from nonexistent to very heavy.

Number of specimens: 428

Nomenclatural Note

The original spelling of the specific name of this species is *subequata* (Conrad, 1843, p. 333). Hall (1847, p. 118) substituted the diphthong (ae for e) for no apparent reason. Because Hall's spelling has been in continuous use (except for a correct spelling in Chamberlin, 1883, p. 155) for over 135 years, it is adopted here to avoid confusion.

Measurements (in mm)

catalogue#	sample#	pl	bl	w	hw	th	pl/w	bl/w
AMNH 910		14.5	13.2	16.0	12.0?	8.0	0.91	0.82
(holotype)*								
UMPC 13,810a	RBV-3 whole	18.1	18.0	22.1	12.7	8.5	0.82	0.81
<i>P. circularis</i>								
UMPC 3515		13.0	12.1	13.2	8.8	8.0	0.98	0.92
(holotype)								
UMPC 5149		13.5	13.0	16.5	12.0		0.82	0.79
(hypotype)								

*(Cooper, 1956, p. 993)

Family Dalmanellidae Schuchert, 1913

Genus *Dalmanella* Hall and Clarke, 1892; emended Williams and Wright, 1963

type species: *Orthis testudinaria* DALMAN, 1828, p. 115; OD.

Dalmanella sculpta? Cooper
Plate 2, Figure 6

Dalmanella sculpta COOPER, 1956, p. 950, pl. 158, figs. 34-46.

Orthis (Dalmanella) testudinaria (Hall and Clarke, not Dalman); WINCHELL and SCHUCHERT, 1895 (in part), p. 441.

Orthis rogata Sardeson; SARDESON, 1897b (in part), p. 95, pl. 4, figs. 1, 3-5, 7, 9, 10 (not figs. 2, 6, 8).

Discussion

Dalmanella sculpta? can be distinguished externally from other orthides in this collection (except *Paucicrura rogata*; q.v.) by its subcircular outline, plano-convex profile, radial ornamentation of medium sized costellae and an adult length of about 10 mm. There is a slight tendency for the l/w ratio to increase as length increases. Internally it is distinguished by its stout blade-like brachioophores, their bases often greatly thickened with secondary shell material, its bilobed cardinal process, and its endopunctate shell structure. For features separating this species from *Diorthelasma? weissi* and from *P. rogata*, see the discussions of those two species.

Specimens in this collection differ slightly from Cooper's figured specimens of *D. sculpta* from Virginia (1956, pl. 158, figs. 34-36) in that the Minnesota specimens usually have a slightly flatter brachial valve and lack the beaded ornamentation often found on the Virginia specimens. These differences do not seem to be great enough to warrant the creation of a new species.

As a result of the redefinitions of the genera of the Dalmanellidae by Williams and Wright (1963), those specimens previously identified as *Paucicrura rogata* which have a bilobed cardinal process must now be assigned to the genus *Dalmanella*. This includes most of the specimens of "*Orthis rogata*" from the fucoid bed (bed 5) of the Sardeson collection.

The cardinal process of *Dalmanella sculpta*? is quite variable. It ranges in size from a fairly small subtriangular knob, barely reaching the level of the posterior border of the brachioophores, to a knob twice that size (in cross-sectional area), extending well beyond the posterior border of the brachioophores and nearly filling the notothyrial opening. The shape of the myophore is also variable. In some specimens the individual lobes are narrow and flat to slightly convex on the posterior face (Figure 13.9a). In other specimens, usually those with fairly large cardinal process, each lobe of the myophore is slightly concave and forms a shallow dorso-ventral trough (Figure 13.9b). There is a complete gradation between these two extreme forms of the cardinal process, even within a single horizon (e.g., RBV-30).

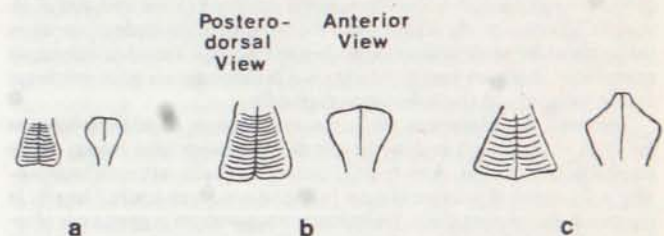


Figure 13.9 Cardinal process of *Dalmanella sculpta* (a,b) and *Paucicrura rogata* (c).

In this connection it is significant that Cooper (1956, p. 951) mentioned the presence of two specimens in his collection of *D. sculpta* which have a median crest on the myophore. The myophore shown in Figure 13.9b might well be considered the precursor to the differentially trilobed cardinal process with variably developed crest. This feature is characteristic of *Paucicrura* (Fig. 13.9c). Williams and Wright (1963, p. 12) suggested that the *Paucicrura* type myophore could have evolved from the undifferentiated trilobed myophore of *Bancroftina*. Results of this study suggest that the differentiated trilobed myophore of *Paucicrura* may instead have evolved from the myophore of *Dalmanella*. It is quite conceivable that from the variable population of *D. sculpta* represented by specimens from RBV-30, *Paucicrura rogata* split off and coexisted with *D. sculpta*? until RBV-56, at which horizon *D. sculpta*? disappears.

Dalmanella sculpta? is found from about 9 m to about 23 m above the Platteville/Decorah contact at the brickyard locality. All specimens are disarticulated and most are broken and abraded to some degree.

Number of specimens: 295

Measurements (in mm)

catalogue#	sample#	bl	w	hw	bl/w
UMPC 13,968a	RBV-30	10.5	11.0	6.6	0.95

Genus *Paucicrura* Cooper, 1956; emended Williams and Wright, 1963
type species: *Orthis rogata* SARDESON, 1892, p. 331; OD.

Paucicrura rogata (Sardeson)
Plate 2, Figure 7

Orthis rogata SARDESON, 1892c, p. 331, pl. 5, figs. 1-4.

Orthis (*Dalmanella*) *testudinaria* (Hall and Clarke, not Dalman);
WINCHELL and SCHUCHERT, 1895 (in part), p. 441, pl. 33, figs. 17-22.

Orthis rogata Sardeson; SARDESON, 1897b (in part), p. 95, pl. 4, figs. 2, 6, 8 (not figs. 1, 3-5, 7, 9, 10).

Dalmanella rogata (Sardeson); SCHUCHERT and COOPER, 1932, p. 120, pl. 17, figs. 2-5, 7, 13, 31.

Resserella rogata (Sardeson); COOPER, 1944, p. 353, pl. 138, figs. 6, 7.
Paucicrura rogata (Sardeson); COOPER, 1956, p. 957, pl. 157, figs. 18-24.

Discussion

Paucicrura rogata is distinguished from other orthides (except *Dalmanella sculpta*?) by its subcircular outline, planoconvex to gently ventribi-convex profile, radial ornamentation of medium sized costellae, and adult length of about 10 mm.

Williams and Wright (1963, p. 27, 29) redefined *Paucicrura* and *Dalmanella* and distinguished the two as follows: The brachiophore bases of *Paucicrura* are divergent relative to the tops, those of *Dalmanella* are convergent onto the median ridge; the cardinal process of *Paucicrura* is differentially trilobed with the median lobe forming a variably developed crest, that of *Dalmanella* is undifferentially bilobed. Other differences between *P. rogata* and *D. sculpta*? based on my observations on specimens from this collection include: the slightly greater (10%) maximum size and rounder shape of *D. sculpta*?, the very slightly wider dorsal interarea of *P. rogata*, and the more robust notothyrial platform and cardinal process of *P. rogata*.

It is usually possible to determine the disposition of the brachiophore bases relative to the tops only on very young valves since the bases are usually covered with a thick layer of secondary shell material deposited during subsequent development. Furthermore, the variation in disposition of the bases is probably large enough to overlap to some unknown extent with that of *D. sculpta*?. Therefore, the separation of the two genera was made primarily on the nature of the cardinal process (bilobed or trilobed). The other differences enumerated above are very slight and since both species are quite variable in those characters, no single feature is diagnostic.

There is a significant but not unexpected positive correlation between brachial valve length and the height of the median lobe (crest) of the myophore in *P. rogata*. A more striking and potentially very useful relationship is the apparent increase in crest height (at any given brachial length) in progressively younger strata. Preliminary measurements suggest a rate of increase of crest height of about 0.024 mm/100 cm of section between RBY-35 and RBY-63. Unfortunately such a rate cannot be unequivocally demonstrated with this collection because *P. rogata* is absent from a large portion of the section between RBY-35 and RBY-63 at the brickyard locality. It is quite possible that rather than representing the end member of a continuously evolving single population, RBY-63 represents a reintroduction of *P. rogata* following a local extinction at RBY-39. Nevertheless, such findings could provide the basis for an expanded study to determine (a) the evolutionary rate of change of a well-defined character, or (b) the sequence of extinction and reintroduction events and the source of such reintroductions. Such a study would be possible only with much larger collections, especially from the gap in the *P. rogata* occurrence (RBY-39 to RBY-52), and from a wider geographical area.

The Sardeson collection contains more than a thousand specimens labelled *Orthis rogata* or (*Orthis*) *Dalmanella rogata* by Sardeson. These specimens come from Sardeson's bed 5 (Fucoid bed) and bed 6 (*Orthisina* bed), at various localities. In his original description of *Orthis rogata*, Sardeson (1892c, p. 331) did not designate a holotype, nor is there such a labelled specimen in the Sardeson collection. However, he did state that the figured specimen (pl. 5, figs. 1-4) is "the largest out of several thousand, and is from the *Orthisina* bed at Berne, Dodge County, Minn." Schuchert and Cooper (1932) figured a specimen (pl. 17, figs. 7, 13; cat. # S935) from the Fucoid bed at Ellsworth, Wisconsin which they claimed to be Sardeson's holotype.

Schuchert and Cooper's figured specimen, #S935, cannot possibly be the type specimen because Sardeson explicitly stated that the type lot came from the *Orthisina* bed. This distinction is important because most specimens of *Orthis rogata* in the Sardeson collection from the Fucoid bed do not exhibit a

trilobed cardinal process and are properly referable to *Dalmanella sculpta*?. Unfortunately, the label attached to #S935 at the Yale Peabody Museum of Natural History can shed no further light on the matter (White, R.D., 1984, personal communication).

P. rogata occurs in the upper third of the section at the brickyard locality. Its preservation ranges from excellent to extremely poor. The latter condition is especially prevalent in samples RBY-65 and RBY-66. Specimens in these samples, comprising mainly notothyrial platforms and brachiophores, appear to have been thoroughly reworked.

Number of specimens: 148

Measurements (in mm)

catalogue#	sample#	bl	w	hw	bl/w	
UMPC 14,201a	RBY-61	bv	6.3	7.5	5.4	0.84

Suborder Clitambonitidina Öpik, 1934

Superfamily Clitambonitacea Winchell and Schuchert, 1893

Family Clitambonitidae Winchell and Schuchert, 1893

Subfamily Clitambonitinae Winchell and Schuchert, 1893

Genus *Vellamo* Öpik, 1930

type species: *Orthis verneuili* EICHWALD, 1841, p. 51; OD.

Vellamo americana? (Whitfield)

Plate 4, Figure 8

Hemipronites americanus WHITFIELD, 1878, p. 72.

Orthisina (*Hemipronites*) *americana* (Whitfield); SARDESON, 1892b, p. 323.

Clitambonites americanus (Whitfield); HALL and CLARKE, 1892, p. 239, pl. 40A, figs. 1-8.

Clitambonites diversa (Shaler); WINCHELL and SCHUCHERT, 1895, p. 378, pl. 30, figs. 11-17.

Vellamo americana (Whitfield); SCHUCHERT and COOPER, 1932, p. 114.

Discussion

Vellamo americana can be distinguished from other orthides in this collection by its plano-convex, pyramidal profile and by the prominent convex pseudodeltidium with apical foramen. Internally, the pedicle valve is distinguished by a well-developed spondylium. A childidium is present in the brachial valve.

A single, small pedicle valve of *Vellamo americana*, of questionable identity, occurs in sample RBY-38, approximately 18 m above the Platteville/Decorah contact. Winchell and Schuchert (1895, p. 380) reported that this species is common in the lower part of the Galena Formation in southeastern Minnesota.

Measurements (in mm)

catalogue#	sample#	pv	l	w
UMPC 14,055	RBY-38		5.4	8.0

Order Strophomenida Öpik, 1934

Suborder Strophomenidina Öpik, 1934

Superfamily Plectambonitacea Jones, 1928

Family Sowerbyellidae Öpik, 1930

Subfamily Sowerbyelliinae Öpik, 1930

Genus *Sowerbyella* Jones, 1928

type species: *Leptaena sericea* SOWERBY, 1839, p. 636; OD.

Sowerbyella curdsvillensis (Foerste)

Plate 3, Figure 1

Plectambonites sericea (Sowerby); WINCHELL and SCHUCHERT, 1895 (in part), p. 414.

Plectambonites curdsvillensis FOERSTE, 1912, p. 122, pl. 10, figs. 15a, b.

Plectambonites punctostriatus MATHER, 1917, p. 38, pl. 1, figs. 15-17.

Sowerbyella curdsvillensis (Foerste); COOPER, 1956, p. 780, pl. 201A, figs. 1-13.

Discussion

See discussion of *Sowerbyella minnesotensis* for the difference between this species and other brachiopods in this collection.

This species has been widely identified in Minnesota rocks as *S. punctostriata* (Mather) (e.g., Cooper, 1956; Weiss, 1957), while the name *S. curdsvillensis* has usually been restricted to specimens from the southern Ap-

palachians. Cooper (1956, p. 792) listed six characters in which *S. punctostriata* differs from *S. curdsvillensis*. He also stated that the two species are variable and may be "ecads of a single species" (1956, p. 780). Howe (1979, p. C2) stated that large collections of *S. curdsvillensis* from Kentucky revealed wide variations in five of the six characters upon which Cooper separated the two species. In Howe's opinion, the only character which could serve as a basis for separating the two is the somewhat greater tendency for oblique wrinkling on the posterior margin of the valves of *S. punctostriata*. Yet, Howe's figures of *S. curdsvillensis* (pl. 1, figs. 6-16) exhibit a fairly wide variation in the degree of wrinkling, and the wrinkling on the specimens in the present collection, although fairly subdued, certainly falls within the range shown in these figures. In my opinion (apparently shared by Foerste, 1912, p. 124) the small differences in degree of wrinkling on the posterior margin of these shells does not warrant a specific distinction. Thus, *S. curdsvillensis* and *S. punctostriata* are synonyms and the former name has priority.

Several specimens of both this species and *S. minnesotensis* are perforated by single, round "bore" holes (diameter, 0.25 mm), usually located on a brachial valve, within 2 to 3 mm of the beak.

Sowerbyella curdsvillensis is found in the lower half of the brickyard section but it is common only in sample RBY-30, 12.5 m above the Platteville/Decorah contact. The specimens are disarticulated, broken, and mildly abraded. *S. minnesotensis* is usually much more common within its range than is *S. curdsvillensis* within its range.

Number of specimens: 53

Nomenclatural Note

The specific name "sericea" seems to have been arbitrarily restricted to European specimens of *Sowerbyella* since 1928, when Jones erected the genus. Jones (1928) did not specifically state that "sericea" ought to be so restricted nor did the authors of *S. curdsvillensis* (Foerste) and *S. punctostriata* (Mather). If it could be shown that *S. sericea* and *S. curdsvillensis* are conspecific, *S. curdsvillensis* would have to be suppressed in favor of *S. sericea*.

Measurements (in mm)

catalogue#	sample#	bl	mw	hw	bl/hw	
UMPC 13,969a	RBY-30	bv	8.5	12.5	13.0	0.65

Sowerbyella minnesotensis (Sardeson)
Plate 3, Figure 2

Leptaena minnesotensis SARDESON, 1892c, p. 329, pl. 4, figs. 24, 25.

Plectambonites sericea (Sowerby): WINCHELL and SCHUCHERT, 1895 (in part), p. 414.

Sowerbyella minnesotensis (Sardeson): WEISS, 1957, p. 1046.

Discussion

Sowerbyella differs from other strophomenides in this collection in its small size, delicate shell, semi-circular outline, prominent pair of submedian septa in the brachial valve, and "trilobed" cardinal process. *S. minnesotensis* differs from *S. curdsvillensis* in its smaller size, greater convexity, lack of beaded ornamentation, and somewhat less prominent visceral markings. One other character which may be of some use in differentiating the two species is the number of parvicostellae between any two accentuated costellae. The small number of specimens of *S. curdsvillensis* in this collection exhibit anywhere from 3 to 7, whereas *S. minnesotensis* exhibits 2 to 4 parvicostellae in the space between accentuated costellae. A larger sample is necessary to determine whether this is a statistically valid difference.

Sowerbyella minnesotensis occurs in the upper third of the Decorah Shale at the brickyard locality, and is particularly abundant at RBY-53, 22.5 m above the base of the section. Most, but not all, specimens are disarticulated, many are broken, but many are in pristine condition.

Number of specimens: 269

Measurements (in mm)

catalogue#	sample#	pl	bl	mw	hw	th	pl/hw	bl/hw	
UMPC 14,161a	RBY-53	whole	6.0	5.7	8.9	9.4	1.6	0.64	0.61

Superfamily Strophomenacea King, 1846
Family Strophomenidae King, 1846
Subfamily Strophomeninae King, 1846
Genus *Strophomena* Rafinesque (in de Blainville), 1825
type species: *S. rugosa* RAFINESQUE (in de Blainville), 1825;
SD. KING, 1846, p. 28.

Discussion

The genus *Strophomena* has long been fraught with taxonomic difficulties. Even the validity of the generic name and the type species have been called into question (Hall and Clarke, 1892, p. 246; Pope, 1976, p. 154).

Most Minnesota authors since Winchell and Schuchert have used the name *Strophomena incurvata* (Shepard) when referring to the large, Middle Ordovician *Strophomena* which is common throughout the Upper Mississippi valley (e.g., Winchell and Schuchert, 1895; Stauffer and Thiel, 1941; Weiss, 1957). C.L. Fenton (1928, p. 146) believed that the specific name *incurvata* was invalid because Shepard's description was poor, his figures unrecognizable, the type specimens missing [if ever designated] and because no Ordovician rocks crop out in the type locality, near Green Bay, Wisconsin. G.M. Kay (1929a, p. 211) pointed out that there were indeed Ordovician rocks cropping out near Green Bay, but that they were of Late Ordovician age (Cincinnatian). He also stated that the common strophomenid of those strata was *Rafinesquina* and therefore Shepard's species probably belonged to that genus. G.A. Cooper (1956, p. 939) suggested that Shepard's figures are clear enough to establish that they represent *Strophomena*. However, he conceded a Cincinnatian age for the strata, thus dismissing all Middle Ordovician references to *Strophomena incurvata*.

Modern bedrock geologic maps of Wisconsin (e.g., Mudrey and others, 1982) show the city of Green Bay to be near the dividing line between Middle and Upper Ordovician rocks, bounded on the west by rocks of the Sinipee Group (Middle Ordovician) and on the east by the Maquoketa Formation (Upper Ordovician). I personally collected Middle Ordovician brachiopods (*Paucicrura rogata*, *Plaesiomys meedsi*, and *Sowerbyella minnesotensis*, among others) from a quarry near Duck Creek, Wisconsin, 4.3 miles NE of the Green Bay city hall. The designation of the type locality of *Strophomena incurvata*, "near Navarino" [now Green Bay, Wis.] (Shepard, 1838, p. 144), is sufficiently vague so that the locality could be either Upper or Middle Ordovician. Thus, no neotype could be chosen from an undisputed type locality. Compounding the confusion are Shepard's figures. Even if Cooper is correct in his belief that they represent *Strophomena*, they are certainly too poor to be used for identifying specimens. Therefore, in order to avoid further confusion, I recommend that the specific name *incurvata* be abandoned.

Thus, numerous records of *Strophomena* are left without a name, and, indeed, many new names have been proposed for large Middle Ordovician *Strophomena*. Cooper (1956) lists 40 species, 13 of which he named. Even at that, several names have been omitted from his list, such as *S. trentonensis* Winchell and Schuchert. Such a large number of nominal species, some of which are not very distinct, creates great difficulties for any worker wanting to identify several specimens from a single, continuously variable population. Such a population would likely comprise three or four species if one strictly adhered to Cooper's figured specimens for identification. The result would be neither biologically meaningful nor biostratigraphically useful.

In order to obviate any such difficulties, I will use *Strophomena filitexta* Hall, the oldest valid name, for Middle Ordovician large *Strophomena*. Obviously, a comprehensive review of the genus is needed.

Strophomena billingsi? Winchell and Schuchert
Plate 3, Figure 3

Strophomena recta BILLINGS (not Conrad), 1865, p. 130, fig. 108.

Strophomena billingsi WINCHELL and SCHUCHERT, 1895, p. 397, text fig. 32.

Discussion

Strophomena billingsi? can be distinguished from other members of this genus by its small size, low convexity, delicate shell, prominent, coarse, radially disposed pseudopunctae (though not nearly so coarse as in *Rafinesquina*, in which the pseudopunctae are not radially contiguous) and a pedicle muscle field not enclosed laterally or anteriorly by muscle-bounding ridges. Visceral marks of any kind are much more faint in this species than in any other species of *Strophomena* in this collection.

Caution in assigning this name to the specimens is warranted because the type specimen is lost (UMPC 8192) and is not figured by Winchell and Schuchert, who only reproduce the rather inconclusive figures of Billings (1865, fig. 108). In addition, the specimens in this collection are more alate than the figured specimen.

S. billingsi, as described and figured by Billings, closely resembles *S. anomala* Cooper (1956, p. 927, pl. 264A, figs. 1-15) in size, shape, and ornamentation.

Strophomena billingsi? occurs in samples RBY-34 and RBY-35, 17.0 m above the Platteville/Decorah contact at the brickyard section. The shell material is thin and easily broken, so this species is probably more common and widespread than its occurrence in this collection would indicate.

Number of specimens: 5

Measurements (in mm)

catalogue#	sample#	pl	bl	mw	hw	pl/hw	bl/hw
UMPC 10,029b	RBY-35	pV	14.0	17.0	19.5	0.72	
UMPC 10,029a	RBY-35	bV	13.5	17.0	19.0		0.71

Strophomena filitexta (Hall)

Plate 3, Figure 4

Leptaena filitexta HALL, 1847, p. 111, pl. 31B, fig. 3.

Strophomena filitexta (Hall); HALL and CLARKE, 1892, p. 251, pl. 9, figs. 1-7.

Strophomena incurvata (Shepard), many authors.

Discussion

Strophomena filitexta can be distinguished from other strophomenids in this collection by its large size, strongly resupinate profile, well developed muscle-bounding ridges on the pedicle valve, and absence of a median septum in the pedicle valve.

As stated in the introduction to this genus, all large specimens of *Strophomena* in this collection not otherwise assigned will be included in *S. filitexta*. This is done primarily because most of the specimens are too fragmentary to compare to those species figured in Cooper (1956), and to a lesser extent because the range of variability of *S. filitexta* is probably large enough to encompass these specimens. Obviously, a much larger collection of well preserved specimens would be needed to support the second belief.

Cooper (1956) reported the following species of *Strophomena* from the Decorah Shale in Minnesota: *S. auburnensis* Fenton, *S. delicatula* Fenton, *S. muscosa* Fenton, *S. septata* Winchell and Schuchert. *S. trentonensis* was listed on p. 112 but not reported in Cooper's systematic paleontology section.

Strophomena filitexta occurs primarily in the lower half of the Decorah Shale at the brickyard locality. All specimens are disarticulated and most are broken and abraded.

Number of specimens: 104

Measurements (in mm)*

catalogue#	sample#	pl	bl	mw	hw	th	pl/hw	bl/hw
UMPC 7537a	bed 4	pV	30.0	36.5	40.0		0.75	

* Measured specimen is from the Sardeson collection.

Strophomena septata Winchell and Schuchert

Plate 3, Figure 5

Strophomena septata WINCHELL and SCHUCHERT, 1892, p. 285; 1895, p. 390, pl. 30, figs. 1-3.

Discussion

Strophomena septata can be distinguished from other members of the genus by the strong median septum in the pedicle valve which usually originates just posterior to the anterior margin of the diductor field and extends to near the anterior margin. This species is also usually somewhat smaller than *S. filitexta* Hall.

Unfortunately, isolated brachial valves cannot be assigned to *S. septata* with certainty. Even so, some brachial valves have been included in the sample simply because they were found in close association with the easily identifiable pedicle valves. One of these brachial valves exhibits a large (2.5 mm diameter) circular "bore" hole. Its center is located about 5 mm from the beak and is nestled between the socket ridge and median septum. The hole is conspicuously beveled on the exterior surface of the valve (see Plate 3).

In this collection, *S. septata* is found primarily in sample RBY-30, 12.5 m above the base of the section. All specimens are disarticulated and most are broken.

Number of specimens: 56

Measurements (in mm)

catalogue#	sample#	pl	mw	hw	h	pl/hw	
UMPC 13,970a	RBY-30	pV	21.5	29.5	29.5	4.5	0.73

Subfamily Furcitetellinae Williams, 1965

Genus *Furcitetella* Cooper, 1956

type species: *F. plicata* COOPER, 1956, p. 877; OD.

Furcitetella scofieldi (Winchell and Schuchert)

Plate 3, Figure 6

Strophomena scofieldi WINCHELL and SCHUCHERT, 1892 (April 1), p. 286; 1895, p. 398, pl. 31, figs. 18-21.

Streptorhynchus subsulcatum SARDESON, 1892c (April 6), p. 335, pl. 4, fig. 39.

Furcitetella scofieldi (Winchell and Schuchert); COOPER, 1956, p. 878, pl. 229A, figs. 1-5, pl. 265C, figs. 5, 6.

Discussion

Furcitetella scofieldi can be distinguished from other strophomenids in this collection by its small size (usually less than 15 mm hinge width), slightly biconvex profile, generally rectimarginate anterior commissure, fine pseudopunctation (as opposed to the rather coarse pseudopunctation of *Strophomena billingsi*, with which *F. scofieldi* can be confused) and subequal costellation (as opposed to the more nearly equal costellation of *S. billingsi*). This species is also characterized by a low median septum in the pedicle muscle field. The bifurcation of the median septum of the brachial valve, which Cooper (1956, p. 876) stated was one of the diagnostic features of the genus (as well as the feature for which the genus was named), is exceedingly faint in these specimens. Most of the specimens in this collection are brachial cardinalia and only provisionally identified as *F. scofieldi*.

Furcitetella scofieldi occurs in the upper third of the brickyard section. Specimens are usually disarticulated and broken, but only slightly abraded.

Number of specimens: 37

Measurements (in mm)

catalogue#	sample#	pl	bl	mw	hw	th	pl/hw	bl/hw
UMPC 10,032a	RBY-35 whole	9.2	8.6	11.8	11.2	1.0	0.82	0.77
UMPC 8194	paratype(?)	9.1	8.9	12.5	11.0	2.0	0.83	0.81

Subfamily Rafinesquininae Schuchert, 1893

Genus *Rafinesquina* Hall and Clarke, 1892

type species: *Leptaena alternata* CONRAD, 1838, p. 115; OD.

Rafinesquina trentonensis (Conrad)

Plate 4, Figure 9

Leptaena alternata CONRAD, 1838, p. 115.

Rafinesquina alternata (Conrad); HALL and CLARKE, 1892 (in part), p. 282 (not pl. 8, figs. 6-11, pl. 20, figs. 27, 28).

Rafinesquina alternata (Conrad); WINCHELL and SCHUCHERT, 1895, p. 404, pl. 31, figs. 32-34.

Rafinesquina trentonensis (Conrad); SALMON, 1942, p. 574, pl. 85, figs. 1-10.

Discussion

Rafinesquina trentonensis can be distinguished from other strophomenids in this collection by its fairly large size, concavo-convex profile, very thin shell, delicate bilobed cardinal process, and coarse, radially disposed pseudopunctation.

See Salmon (1942, p. 564) for a discussion of the rather strange history of the nomenclature of this species.

Since the shell material of *R. trentonensis* is so thin (usually less than 0.25 mm near the edge of an adult specimen), whole shells or valves are quite scarce at the brickyard locality. More than 90% of the specimens in this collection are brachial cardinalia, the most robust part of the *Rafinesquina* shell. Since these cardinalia lack the parts necessary for their accurate specific identification (such as profile, outline, degree of alation, etc.), only those samples which contain whole, identifiable valves were identified as *R. trentonensis*. Those samples containing only the cardinalia were identified as *Rafinesquina* sp.

Rafinesquina trentonensis occurs from RBY-3 through RBY-65, approximately 1.0 m to 25.5 m from the Platteville/Decorah contact at the brickyard locality. As mentioned above, most specimens are disarticulated and broken. However, when a whole valve does occur, it is usually articulated with its mate. It should be pointed out that the screening technique employed to col-

lect specimens for this study has demonstrated that *Rafinesquina* is a much more significant component of the fauna of the brickyard section than previous, surface picked collections have indicated. Of the approximately 130 specimens in the present collection only a dozen or so would have been discovered by surface picking. In contrast, of the approximately 160 specimens of the more robust *Strophomena* more than 80 are large enough to have been picked from the surface.

The occurrences in RBY-3 and RBY-22 are single specimens. The RBY-3 specimen is somewhat anomalous not only because it appears approximately 9 m before the next occurrence of *Rafinesquina* at RBY-22, but because the chilidium and meso-cardinal ridge of the cardinal process are both more prominently developed than in the specimens higher in the section. The RBY-3 specimen is probably a different species of *Rafinesquina*, but since it is only a brachial cardinal area, it is impossible to be certain.

Measurements (in mm)

catalogue#	sample#	pl	bl	mw	hw	th	pl/hw	
UMPC 14,081a	RBY-43	whole	23.0	22.5	30.0	31.0	5.0	0.74

Subfamily Oepikinae Sokolskaya, 1960

Genus *Oepikina* Salmon, 1942

type species: *Öpikina septata* SALMON, 1942, p. 589; OD.

Oepikina iniquassa (Sardeson)

Plate 3, Figure 7

Strophomena iniquassa SARDESON, 1892c, p. 334, pl. 5, figs. 22-24.

Rafinesquina minnesotensis (N.H. Winchell), var. *iniquassa* Sardeson; WINCHELL and SCHUCHERT, 1895, p. 403, pl. 31, figs. 27, 28.

Öpikina iniquassa (Sardeson), SALMON, 1942, p. 593, pl. 87, figs. 12-14.

Discussion

See the discussion of *Oepikina minnesotensis* for distinguishing characters of this species.

At least two other species of *Oepikina* have been reported from the Decorah Shale in Minnesota. *O. lirata* Cooper (1956, p. 912) for the upper part of the Decorah Shale ("Ion member"), differs from *O. iniquassa* in its larger size and less pronounced geniculation (Cooper, 1956, p. 912). *O. transitionalis* (Okulitch), reported by Weiss (1957, p. 1046) from the lower third of the Decorah Shale, differs from *O. iniquassa* in its sinuous lateral margin, sharply projecting ears, and different convexity (Salmon, 1942, p. 596). In view of the study by Alexander (1975) on the phenotypic lability of *Rafinesquina*, a genus closely related to *Oepikina*, specimens in this collection which might otherwise be identified as *O. lirata* or *O. transitionalis* were identified as *O. iniquassa*. It should also be noted that specimens of *O. iniquassa* in the Sardeson collection from the type locality ("Stictopora bed," St. Paul) exhibit a fairly wide range of variability in outline, convexity and degree of alation.

In this collection *O. iniquassa* is found only in sample RBY-30, approximately 12.5 m above the Platteville/Decorah contact.

Number of specimens: 13

Measurements (in mm)

catalogue#	sample#	pl	bl	mw	hw	b-g	pl/hw	bl/hw
UMPC 13,972b	RBY-30	pv	23.0	27.0	22.0	1.05		
UMPC 13,972a	RBY-30	bv	22.0	27.0	26.0	20.0		0.85

Oepikina minnesotensis (N.H. Winchell)

Plate 3, Figure 8

Strophomena minnesotensis N.H. WINCHELL, 1881, p. 120.

Rafinesquina minnesotensis (N.H. Winchell); WINCHELL and SCHUCHERT, 1895, p. 401, pl. 31, figs. 25, 26, 29.

Öpikina minnesotensis (N.H. Winchell); SALMON, 1942, p. 592, pl. 87, figs. 5-11.

Discussion

Oepikina can be distinguished from other strophomenids in this collection by its concavo-convex profile, robust bilobed cardinal process, prominent trans-muscle septa and shell structure with fine, dense pseudopunctae. *O. minnesotensis* differs from *O. iniquassa* in its smaller size, greater convexity, shorter distance to geniculation, and more delicate cardinalia.

O. minnesotensis occurs in samples RBY-22 and RBY-30, 10.5 m and

12.5 m above the Platteville/Decorah contact at the brickyard locality. The specific identification of the single pedicle valve from RBY-22 is questionable. This species is quite rare in the present collection.

Number of specimens: 2

Measurements (in mm)

catalogue#	sample#	bl	mw	hw	b-g	bl/hw	
UMPC 13,973a	RBY-30	bv	13.0	16.0	14.0	11.5	0.93

Family Leptaenidae Hall and Clarke, 1894

Genus *Bellimurina* Cooper, 1956

type species: *Leptaena charlottae* WINCHELL and SCHUCHERT, 1892, p. 288; OD.

Bellimurina charlottae (Winchell and Schuchert)

Plate 3, Figure 9

Leptaena charlottae WINCHELL and SCHUCHERT, 1892 (April 1), p. 288; 1895, p. 410, pl. 32, figs. 1-5.

Strophomena halli SARDESON, 1892c (April 6), p. 334, pl. 4, figs. 36-38.

Bellimurina charlottae (Winchell and Schuchert); COOPER, 1956, p. 854, pl. 222G, figs. 11-14, pl. 223H, figs. 19-24.

Discussion

Bellimurina charlottae can be distinguished from other strophomenids in this collection by its rugose exterior and pustulose interior surfaces and by its rather sharp, dorsally directed geniculation.

Bellimurina charlottae occurs in samples RBY-5, RBY-13 and RBY-14, approximately 7.0 m above the Platteville/Decorah contact at the brickyard locality. The few specimens are all disarticulated and broken.

Number of specimens: 10

Measurements (in mm)

catalogue#	sample#	bl	mw	hw	b-g	bl/hw	
UMPC 13,864a	RBY-14	bv*	11.5	16.0	19.0	10.0	0.61

* only the left half measured

Order Rhynchonellida Kuhn, 1949

Superfamily Rhynchonellacea Gray, 1848

Family Rhynchotrematidae Schuchert, 1913

Subfamily Rhynchotrematinae Schuchert, 1913

Genus *Rhynchotrema* Hall, 1860

type species: *Atrypa increbescens* HALL, 1847, p. 146; OD.

Discussion

Rhynchotrema and *Rostricellula* may be readily distinguished from other brachiopods in this collection, except *Zygospira*, by their rostrate, non-strophic shells and costate ornamentation. From *Zygospira* they can be distinguished by their large size and uniplicate anterior commissure (as opposed to the sulcate anterior commissure of *Zygospira*). Very young specimens (length <2-3 mm), which have not yet developed a fold and sulcus, can usually be distinguished from comparably sized specimens of *Zygospira* by their much slimmer profile, somewhat narrower, more triangular outline and usually coarser costation.

The outline of both *Rhynchotrema* and *Rostricellula* becomes increasingly transverse throughout the growth of the shell. Thus, comparisons of length to width ratios of various species must be based on specimens of roughly comparable length in order to be meaningful.

The nomenclatural history of *Rhynchotrema* is somewhat tangled. Weiss (1955, p. 770-773) presented an excellent discussion of the *Rhynchotrema/Rostricellula* problem as it relates to Minnesota specimens. The type lot of *Rhynchotrema increbescens* (Hall) comprises seven specimens (Howe, 1979, p. C7). The lectotype selected by Wang (1949, p. 11) and figured by Cooper (1956, pl. 138A, figs. 1-5) is not in particularly good condition (Cooper, 1956, p. 629), but its outline, profile and number of costae are most similar to *Rostricellula minnesotensis* of this report, differing only in the presence of lamellose ornamentation and a cardinal process. Specimens of *Rhynchotrema* from the upper half of the Decorah Shale, which have heretofore been referred to *R. increbescens* (e.g., Weiss, 1955, p. 772) are herein assigned to *R. wisconsinense* Fenton and Fenton. The type lot of *R. increbescens* is obviously too small and too poorly preserved to make any inferences about the variability of that species.

Rhynchotrema ainsliei (N.H. Winchell)
Plate 4, Figure 1

Rhynchonella ainsliei N.H. WINCHELL, 1886, p. 315, pl. 2, figs. 5, 6.
Rhynchotrema ainsliei (N.H. Winchell); WINCHELL and SCHUCHERT, 1895, p. 459, pl. 34, figs. 1-8.
Rostricellula ainsliei (N.H. Winchell); COOPER, 1956, p. 631, pl. 135A, figs. 1-7, pl. 138E, fig. 39.

Discussion

Rhynchotrema ainsliei can be distinguished from other rhynchotrematids in this collection by its large size, transverse outline, number of costae (26-34), and the number of costae on the fold (5-7). As Weiss (1955, p. 773) pointed out, the surface ornamentation on unworn specimens is finely pustulose. The triangular, wing-like hinge plates of the brachial valve flair laterally much more than the somewhat subrectangular hinge plates of *Rostricellula minnesotensis* and *Rhynchotrema wisconsinense*.

Sample RBY-3 contains three brachial cardinal areas of this species. The largest of these exhibits the narrow, fairly deep septalium with no cardinal process which is characteristic of *Rostricellula*. The remaining two specimens, both from small, immature valves (lengths of septalia are 0.45 and 0.62 mm), exhibit a very low, but distinct, bladelike cardinal process on the floor of the septalium. By reason of the presence of a cardinal process, this species has therefore been assigned to *Rhynchotrema*.

The cardinal process in young individuals was presumably covered with secondary shell material during subsequent growth. The presence of a cardinal process in juveniles but not in adults of *R. ainsliei* suggests that the cardinal process present in adults of later species of *Rhynchotrema* may have developed paedomorphically.

Rhynchotrema ainsliei occurs in the lowest fourth of the Decorah Shale at the brickyard locality. Most specimens are broken and/or crushed and are somewhat abraded.

Number of specimens: 29

Measurements (in mm)*	pl	w	th	fh	#cos	pl/w
UMPC 7205b	8.6	11.0	6.8	3.4	29(7)	0.78
UMPC 7205a	13.9	17.3	11.2	7.4	26(6)	0.80

* Specimens from the Sardeson collection, beds 3 and 4.

Rhynchotrema wisconsinense Fenton and Fenton
Plate 4, Figure 2

Rhynchotrema inaequivalvis (Castelnau); WINCHELL and SCHUCHERT, 1895 (in part), p. 459, pl. 34, figs. 12-14, 18-23, 24?, 25?
Rhynchotrema wisconsinense FENTON and FENTON, 1923, p. 71, pl. 1, figs. 6-8.
Rhynchotrema increbescens increbescens (Hall); WEISS, 1955, p. 722, pl. 70, figs. 3-7.

Discussion

Rhynchotrema wisconsinense is distinguished from other rhynchotrematids in this collection by its fairly transverse outline (length to width ratio usually between 0.75 and 0.95), presence of a cardinal process in the brachial valve, lamellose ornamentation, 18-24 costae, with almost always 4 on the fold, and a triangular profile. Also the fold is somewhat narrower and more abruptly developed than that of *Rostricellula minnesotensis*. See *Rostricellula minnesotensis* for further discussion.

Rhynchotrema wisconsinense occurs in the upper half of the Decorah Shale at the brickyard locality. In this collection, most of the specimens are isolated brachial cardinal areas but there are some beautifully preserved whole shells. Fragments of *R. wisconsinense* first occur in RBY-30, about 12.5 m above the Platteville/Decorah contact.

Number of specimens: 210

Measurements (in mm)	pl	w	th	fh	#cos	pl/w
UMPC 14,113a RBY-46 whole	11.6	13.3	7.8	4.5	22(4)	0.87

Family Trigonirhynchiidae McLaren, 1965
Genus *Rostricellula* Ulrich and Cooper, 1942

type species: *R. rostrata* ULRICH and COOPER, 1942, p. 625; OD.

Discussion

Rostricellula is differentiated from *Rhynchotrema* by its lack of lamellose ornamentation and absence of a cardinal process in the brachial valve (Ulrich and Cooper, 1942, p. 626). Unfortunately, these two differentiating characters are not concatenate; some species possess a cardinal process but no lamellose ornamentation, while others exhibit lamellose ornamentation but no cardinal process. An example of the latter is *Rostricellula acutiplicata* Cooper (Cooper, 1956, pl. 133F, figs. 36-41). In order to make the distinction between these two genera more useful and more logically rigorous, the differentiating character ought to be restricted to the presence or absence of a cardinal process. Surface ornamentation is a character more suitable to species discrimination.

Rostricellula minnesotensis (Sardeson)
Plate 4, Figure 3

Rhynchonella minnesotensis SARDESON, 1892c, p. 333, pl. 4, figs. 21-23.
Rhynchotrema inaequivalvis (Castelnau); WINCHELL and SCHUCHERT, 1895 (in part), p. 459, pl. 34, figs. 9-11, 15-17.
Rhynchotrema minnesotense (Sardeson); FENTON and FENTON, 1923, p. 72, pl. 1, figs. 12-14.
Rhynchotrema missouriense FENTON and FENTON, 1923, p. 73, pl. 1, figs. 22-26.
Rhynchotrema increbescens minnesotensis (Sardeson); WEISS, 1955, p. 773, pl. 70, figs. 8-15.
Rostricellula minnesotensis (Sardeson); COOPER, 1956, p. 639, pl. 131A, figs. 1-7, pl. 139A, figs. 1-11.
Rostricellula pulchra COOPER, 1956, p. 646, pl. 135E, figs. 26-35.

Discussion

Rostricellula minnesotensis can be distinguished from other rhynchotrematids in this collection by its fairly large length to width ratio (length to width ratio usually between 0.80 and 1.00), lack of cardinal process in the brachial valve, lack of conspicuous lamellose ornamentation and 16-22 costae, with 4 or 5 on the fold. Some well-preserved specimens do exhibit faint concentric growth lines. The number of costae for this species given by Weiss (1955, p. 773) is 12-14. That number of costae is much smaller than found on any specimen in this collection. Weiss however included specimens from the Platteville Formation which, he said, contained fewer costae than did Decorah specimens. In addition, the profile of this species is more globose than that of *Rhynchotrema wisconsinense*, which has a somewhat triangular profile.

Rostricellula minnesotensis occurs in the lower half of the Decorah Shale at the brickyard locality. Most specimens are broken and/or crushed and abraded, but several samples contain whole, well preserved specimens.

Number of specimens: 126

Measurements (in mm)	pl	w	th	fh	#cos	pl/w
UMPC 13,880a RBY-16 whole	9.6	10.3	7.3	4.5	18(4)	0.93

Order Spiriferida Waagen, 1883
Suborder Atrypidina Moore, 1952
Superfamily Atrypacea Gill, 1871
Family Atrypidae Gill, 1871
Subfamily Zygospirinae Waagen, 1883
Genus *Zygospira* Hall, 1862
type species: *Atrypa modesta* SAY in HALL, 1847, p. 141; OD.

Zygospira lebanonensis Cooper
Plate 4, Figure 4

Zygospira recurvirostra (Hall); WINCHELL and SCHUCHERT, 1895 (in part), p. 466.
Zygospira lebanonensis COOPER, 1956, p. 671, pl. 142C, figs. 11-15.

Discussion

See the discussion of *Rhynchotrema* for distinctions between *Zygospira* and other brachiopods in this collection. *Zygospira lebanonensis* can be distinguished from *Z. recurvirostris* by its slightly greater length to width ratio,

its slimmer profile and its slightly less numerous costae (18-23 versus 20-28 in *Z. recurvirostris*). Young specimens of *Z. lebanonensis* can be distinguished from those of *Z. recurvirostris* only when the number of costae is small enough (20) to fall outside the range of *Z. recurvirostris*.

Zygospira lebanonensis occurs in the upper lower third and middle third of the Decorah Shale at the brickyard section. Most specimens are whole but many are crushed or otherwise distorted and most are coated with a reddish iron oxide, a condition which renders costation counts difficult.

There is a significant overlap of the ranges of *Z. lebanonensis* and *Z. recurvirostris*. In the five meter interval between RBY-30 and RBY-35 it is often difficult to distinguish between the two species. Statistical treatment of large samples in this interval might reveal significant differences and/or an evolutionary relationship between the two.

Number of specimens: 506

Measurements (in mm)

catalogue#	sample#	l	w	th	#cos	l/w	
UMPC 13.916a	RBY-22	whole	3.5	3.0	1.6	20	1.09

Zygospira plinthii Rice, new species
Plate 4, Figure 5

Description

Shell small for the genus; outline subpentagonal with pronounced shoulders, length-to-width ratio typically between 0.90 and 1.00, apical angle about 110°, anterior margin somewhat flattened; lateral profile strongly ventribiconvex, with a thickness typically 55% to 65% of width; sulcus broad and about 30% to 40% of thickness; ornamentation strongly costate, intercostal spaces deep and markedly triangular in cross-section giving the anterior commissure a distinctly zig-zag appearance, costae number 14 to 18, with usually 3 in the sulcus; some specimens exhibit lamellose ornamentation, especially near the shell margin.

Surface of brachial valve on either side of sulcus gently swelling and sloping to the lateral margins, creating an undulating anterior profile; lateral profile of brachial valve smoothly and gently curving; sulcus originating at or very near beak; median costa of sulcus occasionally slightly stronger than surrounding costae.

Pedicle valve smoothly and strongly curved in lateral profile, curvature slightly greater in posterior half; anterior profile subcarinate, with nearly straight flanks extending to the margins; median intercostal space may be slightly enlarged.

Interior unknown.

Types: holotype: UMPC 10.017a from RBY-34
paratypes: UMPC 10.017b from RBY-34, UMPC 14.036a from RBY-35
locality: Twin City Brick Company, St. Paul, Minnesota

Etymology

From the Greek πλινθείον — brickyard.

Discussion

Zygospira plinthii is distinguished by its relatively wide outline, coarse costation, with costae numbering between 14 and 18, and deep, triangular costal cross-sections. Lamellose ornamentation is also present on some specimens, but this character is not unique to this species; both *Z. lebanonensis* and *Z. recurvirostris* occasionally exhibit very faint growth lamellae.

Z. plinthii occurs in samples RBY-34 and RBY-35 at the brickyard locality, which are dominated by *Z. recurvirostris*.

Number of specimens: 18.

Measurements (in mm)

catalogue#	sample#	pl	bl	w	th	#cos	lam	pl/w
UMPC 10.017a	RBY-34	whole	2.96	2.68	2.84	14(3)	X	1.04
(holotype)								
UMPC 10.017b	RBY-34	whole	2.96	2.66	2.93	15(3)		1.01
(paratype)								
UMPC 14.036a	RBY-35	whole	3.82	3.48	3.90	15(3)	X	0.98
(paratype)								

Zygospira recurvirostris (Hall)
Plate 4, Figure 6

Atrypa recurvirostra HALL, 1847, p. 140, pl. 33, figs. 5a-d.

Zygospira recurvirostra (Hall); CHAMBERLIN, 1883, p. 155, fig. 30, p-r.

Zygospira recurvirostra (Hall); WINCHELL and SCHUCHERT, 1895 (in part), p. 466, pl. 34, figs. 38-40, 41?

Zygospira recurvirostris (Hall); COOPER, 1944, p. 317, pl. 120, fig. 56.

Discussion

See the discussion of *Z. lebanonensis* for the differentiating characters of this species.

The mean of the number of costae per specimen per sample of *Zygospira recurvirostris* ranges from about 22 to 26. There is sufficient overlap of costae-count ranges to assign all of the specimens to the single species, *Z. recurvirostris*. This assignment is consistent with the variability observed in the size, shape, and disposition of the spirulum of these same specimens.

Serial sections of half a dozen specimens from RBY-53 and RBY-56 reveal that the jugam of *Z. recurvirostris* is broadly U-shaped and situated just posterior to the mid length of the brachial valve. However, contrary to the figure in Winchell and Schuchert (1895, pl. 34, fig. 41), the number of volutions in each spire is 1 to 2 rather than 4.

Zygospira recurvirostris occurs in the upper half of the Decorah Shale at the brickyard locality. It is the most common species in this collection and is extremely abundant in several samples, notably: RBY-35, RBY-44, RBY-53, and RBY-56. Most specimens are whole, but of these many are crushed and/or abraded. An occasional specimen is so abraded that the entire shell has been worn away.

Number of specimens: 1708

Measurements (in mm)

catalogue#	sample#	l	w	th	#cos	l/w	
UMPC 14.166a	RBY-53	whole	5.0	4.6	2.7	23	1.09

Genus *Protozyga* Hall and Clarke, 1893
type species: *Atrypa exigua* HALL, 1847, pl. 41; OD.

Protozyga nicolleti Winchell and Schuchert
Plate 4, Figure 7

Hallina nicolleti WINCHELL and SCHUCHERT, 1892 (April 1), p. 293; 1895, p. 474, pl. 34, figs. 59-62.

Zygospira aquila SARDESON, 1892c (April 6), p. 335, pl. 4, figs. 15-18.

Protozyga nicolleti (Winchell and Schuchert); COOPER, 1944, p. 317, pl. 120, figs. 52, 53.

Discussion

Protozyga nicolleti can be distinguished from other articulates in this collection by its small size, sulcate to intraplicate anterior commissure, non-strophic hinge and smooth to very faintly costate ornamentation. Most of the specimens in this collection are quite small (young) so that they do not exhibit the intraplicate anterior commissure. Examination of dozens of individuals on a single slab (UMPC T6715a, plate 70, figure 14 in Weiss, 1955) reveals that this species is quite variable with regard to outline, profile, degree of plication and costation, and degree of incurving of the pedicle beak.

P. nicolleti occurs in samples RBY-16 and RBY-17, between 7.5 m and 8 m above the Platteville-Decorah contact at the brickyard locality. To my knowledge, this is the highest reported occurrence of this species in Minnesota rocks. All specimens are articulated and only slightly abraded.

Number of specimens: 11

Measurements (in mm)

catalogue#	sample#	pl	bl	w	th	pl/w	bl/w	
UMPC 13.881a	RBY-16	whole	3.0	2.7	2.9	1.1	1.03	0.93

PLATE 1

- Figure 1.** *Pseudolingula eva* fragment, X4, UMPC 13,900, RBY-21.
- Figure 2.** Craniops minor: (2a) brachial(?) exterior, X4, UMPC 14,141a, RBY-49; (2b) several valves on surface of coquina slab, X2, UMPC 14,105, a, b, RBY-46.
- Figure 3.** *Trematis* sp.; exfoliated, broken brachial valve exterior, X4, UMPC 13,946a, RBY-30.
- Figure 4.** *Schizocrania* sp.; (4a) broken brachial valve exterior, X2, UMPC 14,022, RBY-35; (4b) *S. filosa* cluster attached to *Strophomena*. X1, UMPC 7529b; (4c) *S. filosa* brachial interior, X1, UMPC 7529a; 4b and 4c from Sardeson collection bed 4, St. Paul.
- Figure 5.** *Acanthocrania setigera*; brachial exterior, X2, UMPC 13,884a, RBY-17.
- Figure 6.** *Petrocrania halli*; (6a-c) dorsal and lateral exterior and interior of brachial valve, X2, UMPC 13,889, RBY-18.
- Figure 7.** *Hesperorthis tricrenaria*; (7a-c) dorsal, posterior and lateral exterior, X1, UMPC 14,250, Stauffer collection, brickyard; (7d) brachial interior, X1, UMPC 13,962a, RBY-30; (7e) pedicle interior, X1, UMPC 7802a, Winchell and Schuchert collection, Trenton Shales, Decorah, Iowa.
- Figure 8.** *Glyptorthis bellarugosa*; (8a-c) dorsal, anterior and lateral exterior, X1, UMPC 7086a, Sardeson collection bed 6, St. Paul; (8d-e) brachial and pedicle interior, X1, UMPC 7079a,b, Sardeson collection bed 5, St. Paul; (8f) pedicle valve exterior, X2, UMPC 13,948, RBY-30.
- Figure 9.** *Dinorthis pectinella*; (9a-d) dorsal, anterior and lateral exterior, UMPC 7107a, brachial interior, UMPC 7107b, X1, Sardeson collection bed 5, St. Paul; (9e) pedicle interior, X1, UMPC 13,964a, RBY-30.
- Figure 10.** *Plaesiomys meedsi*; (10a) brachial exterior, X2, UMPC 14,117a, RBY-46; (10b) pedicle exterior, X2, UMPC 14,199a, RBY-61.
- Figure 11.** *Doleroides pervetus*; (11a-c) dorsal, anterior and lateral exterior, X1, UMPC 5148a, Winchell and Schuchert collection, Trenton Shales; (11d) brachial cardinal area interior, X2, UMPC 13,812a, RBY-3; (11e) pedicle interior, X1, UMPC 13,812b, RBY-3.

PLATE 2

- Figure 1.** *Platystrophia amoena*; (1a-c) dorsal, anterior and lateral exterior, X1, UMPC 7035a, Sardeson collection bed 6, St. Paul; (1d) pedicle exterior, X1, UMPC 14,069, RBY-42.
- Figure 2.** *Platystrophia extensa*?: pedicle interior, X1, UMPC 14,070, RBY-42.
- Figure 3.** *Skenidioides anthonense*; (3a-c) dorsal, posterior and lateral exterior, X4, UMPC 10,025a, RBY-35; (3d) brachial interior, X4, UMPC 10,025b, RBY-35; (3e) pedicle interior, X4, UMPC 10,007a, RBY-34.
- Figure 4.** *Diorthelasma ? weissi*; (4a-c) dorsal, ventral and lateral exterior, X4, UMPC 10,030a (paratype), RBY-35; (4d-f) dorsal, anterior and lateral exterior, X4, UMPC 14,086a (holotype), RBY-43; (4g) brachial interior, X4, UMPC 14,086b (paratype), RBY-43; (4h) brachial interior, X4, UMPC 10,011c, RBY-34; (4i) pedicle interior, X4, UMPC 14,086c (paratype), RBY-43.
- Figure 5.** *Pionodema subaequata*; (5a-c) dorsal, anterior and lateral exterior, slightly crushed dorsoventrally, X1, UMPC 13,810a, RBY-3; (5d) brachial interior, X2, UMPC 13,810b, RBY-3; (5e) pedicle interior, X1, Sardeson collection bed 5, UMPC 7546a, St. Paul.
- Figure 6.** *Dalmanella sculpta*?: (6a-c) dorsal, anterior and lateral exterior, X2, Sardeson collection bed 5, Cannon Falls, Minnesota; (6d-e) brachial and pedicle interiors, X2, UMPC 13,968a, b, RBY-30.
- Figure 7.** *Paucicrura rogata*; (7a-c) dorsal, anterior and lateral exterior, X2, Sardeson collection bed 6, UMPC 7565a, St. Paul; (7d) brachial interior, X2, UMPC 14,201a, RBY-61; (7e) pedicle interior, X2, Sardeson collection bed 6, UMPC 7565b, St. Paul.

PLATE 3

- Figure 1.** *Sowerbyella curdsvillensis*; (1a-c) dorsal, anterior and lateral exterior, X2, Sardeson collection bed 5, UMPC 7551a, St. Paul; (1d) brachial interior, X2, UMPC 13,969a, RBY-30; (1e) pedicle interior, X2, Sardeson collection bed 5, UMPC 7,551b, St. Paul.
- Figure 2.** *Sowerbyella minnesotensis*; (2a-d) dorsal, anterior and lateral exterior and brachial interior, X2, UMPC 14,161a, c, RBY-53; (2e) brachial interior with bore hole, X2, UMPC 14,180a, RBY-56; (2f) pedicle interior, X2, UMPC 14,161b, RBY-53.
- Figure 3.** *Strophomena billingsi*; (3a-d) brachial and pedicle exterior, brachial and pedicle interior, X1, UMPC 10,029a, b, RBY-35.
- Figure 4.** *Strophomena filitexta*; pedicle interior, X1, Sardeson collection bed 4, UMPC 7537a, St. Paul.
- Figure 5.** *Strophomena filitexta*; (5a-c) dorsal, posterior and lateral exterior, X1, UMPC 13,809a, RBY-3.
- Figure 5.** *Strophomena septata*; (5d) brachial interior with bore hole, X1, UMPC 13,970i, RBY-30; (5e) pedicle interior, X1, UMPC 13,970a, RBY-30.
- Figure 6.** *Furcitella scofieldi*; (6a-c) dorsal, anterior and lateral exterior, X2, UMPC 10,032a, RBY-35; (6d) brachial interior, X2, Sardeson collection bed 6, UMPC 7570a, St. Paul; (6e) pedicle interior, X2, UMPC 10,013, RBY-34.
- Figure 7.** *Oepikina inquassa*; (7a) dorsal exterior, X1, Sardeson collection bed 4, UMPC 7427a, St. Paul; (7b-c) brachial and pedicle interior, X1, UMPC 13,972 a,b, RBY-30.
- Figure 8.** *Oepikina minnesotensis*; (8a-b) dorsal and lateral exterior, X1, Sardeson collection bed 4, UMPC 7535a, St. Paul; (8c) brachial interior, X1, UMPC 13,973a, RBY-30.
- Figure 9.** *Bellimurina charlottae*; (9a-e) dorsal, anterior, and lateral exterior and brachial and pedicle interior, X1, Sardeson collection bed 4, UMPC 7534a, b, c, St. Paul.

PLATE 4

- Figure 1.** *Rhynchotrema ainsliei*; (1a-c) dorsal, anterior and lateral exterior, X1, UMPC 7205a, Sardeson collection bed 4, St. Paul; (1d) brachial cardinal area interior, adult, X4, UMPC 13,873a, RBY-3; (1e) brachial interior, immature, showing low bladeliike cardinal process, X4, UMPC 13,873b, RBY-3.
- Figure 2.** *Rhynchotrema wisconsinense*; (2a-c) dorsal, anterior and lateral exterior, UMPC 14,113a, X1, RBY-46; (2d) brachial interior, X1, Sardeson collection bed 6(?), UMPC 7155a, St. Paul.
- Figure 3.** *Rostricellula minnesotensis*; (3a,b,f) dorsal, anterior and lateral exterior, X1, UMPC 13,880a, RBY-16; (3d-e) brachial and pedicle interior, X1, UMPC 7182b, f, Sardeson collection bed 4, Browntown, Wisconsin; (3c) oblique lateral view of interior showing unbroken crura, X2, UMPC 7182a, Sardeson collection bed 4, Browntown, Wisconsin.
- Figure 4.** *Zygospira lebanonensis*; (4a-c) dorsal, anterior and lateral exterior, X4, UMPC 13,916a, RBY-22.
- Figure 5.** *Zygospira plinthii*; (5a-c) dorsal, anterior and lateral exterior, X4, UMPC 10,017a (holotype), RBY-34; (5d-e) dorsal and anterior exterior, X4, UMPC 10,017b (paratype), RBY-34.
- Figure 6.** *Zygospira recurvirostris*; (6a-c) dorsal, anterior and lateral exterior, X4, UMPC 14,166a, RBY-53.
- Figure 7.** *Protozyga nicolleti*; (7a) dorsal exterior, X4, UMPC 13,881a, RBY-16; (7b) ventral exterior, X4, UMPC 13,888, RBY-17.
- Figure 8.** *Vellamo americana*; (8a-c) dorsal, posterior and lateral exterior, X1, UMPC 7076a, b; (8d) brachial interior, X1, UMPC 5853a; (8e) pedicle interior, X1, UMPC 7076c; 8a-8e from Sardeson collection bed 6, Kenyon, Minnesota; (8f) *V. americana*? pedicle exterior, X4, UMPC 14,055, RBY-38.
- Figure 9.** *Rafinesquina trentonensis*; (9a-b) dorsal and ventral exterior, X1, UMPC 14,081a, RBY-43; brachial cardinal area interior, X4, UMPC 10,033a, RBY-35.

Plate No. 1

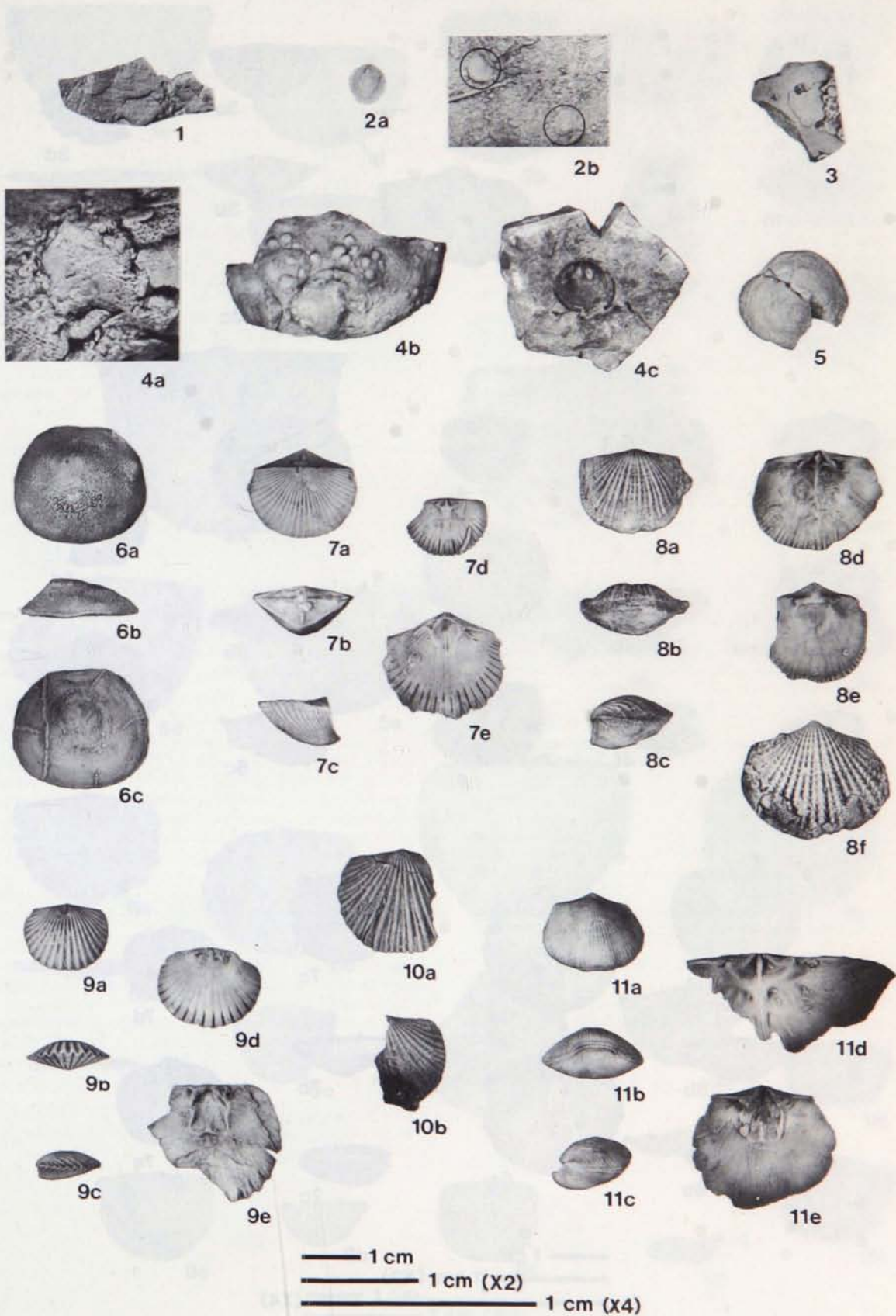
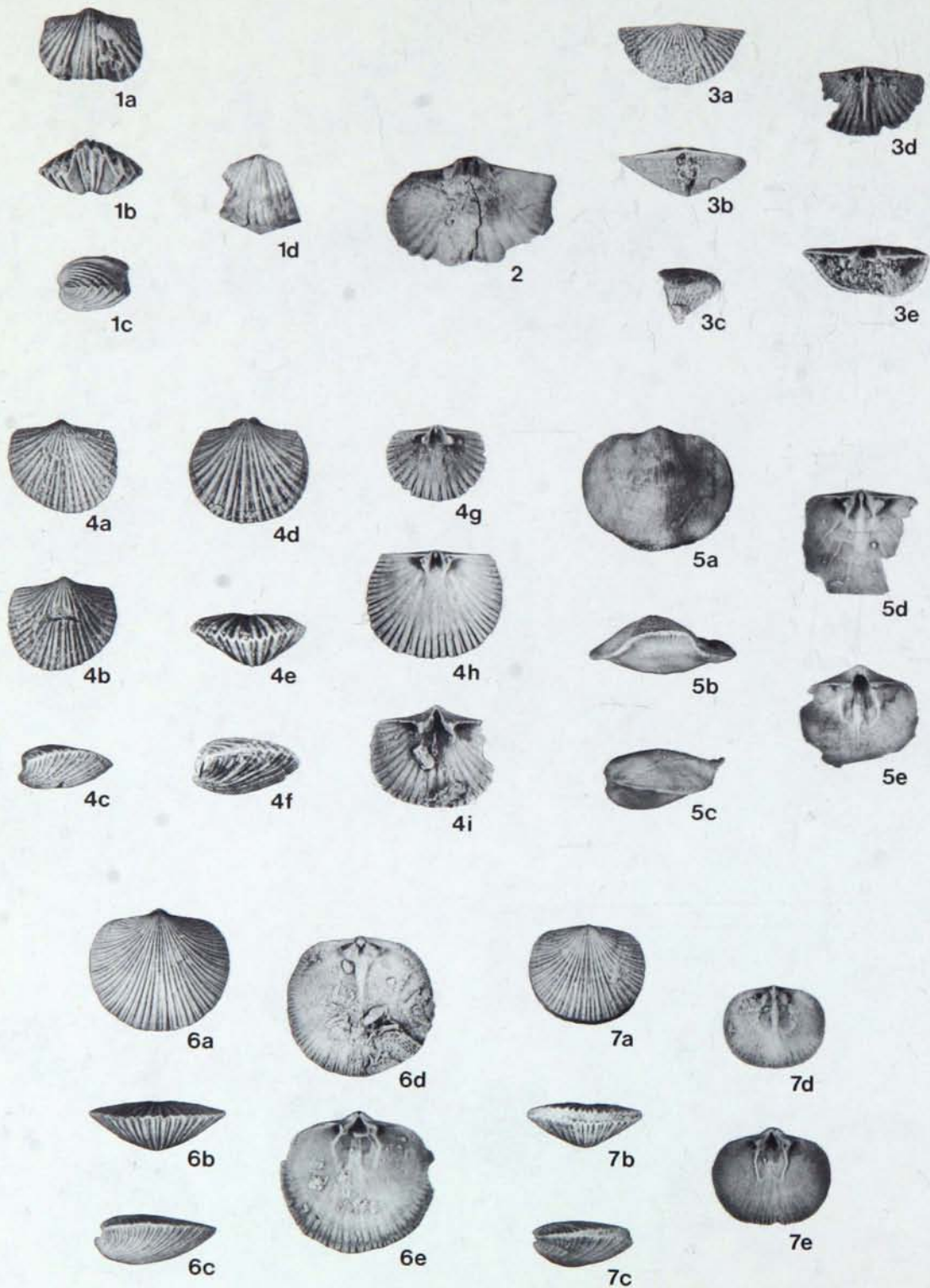


Plate No. 2



_____ 1 cm
 _____ 1 cm (X2)
 _____ 1 cm (X4)

Plate No. 3

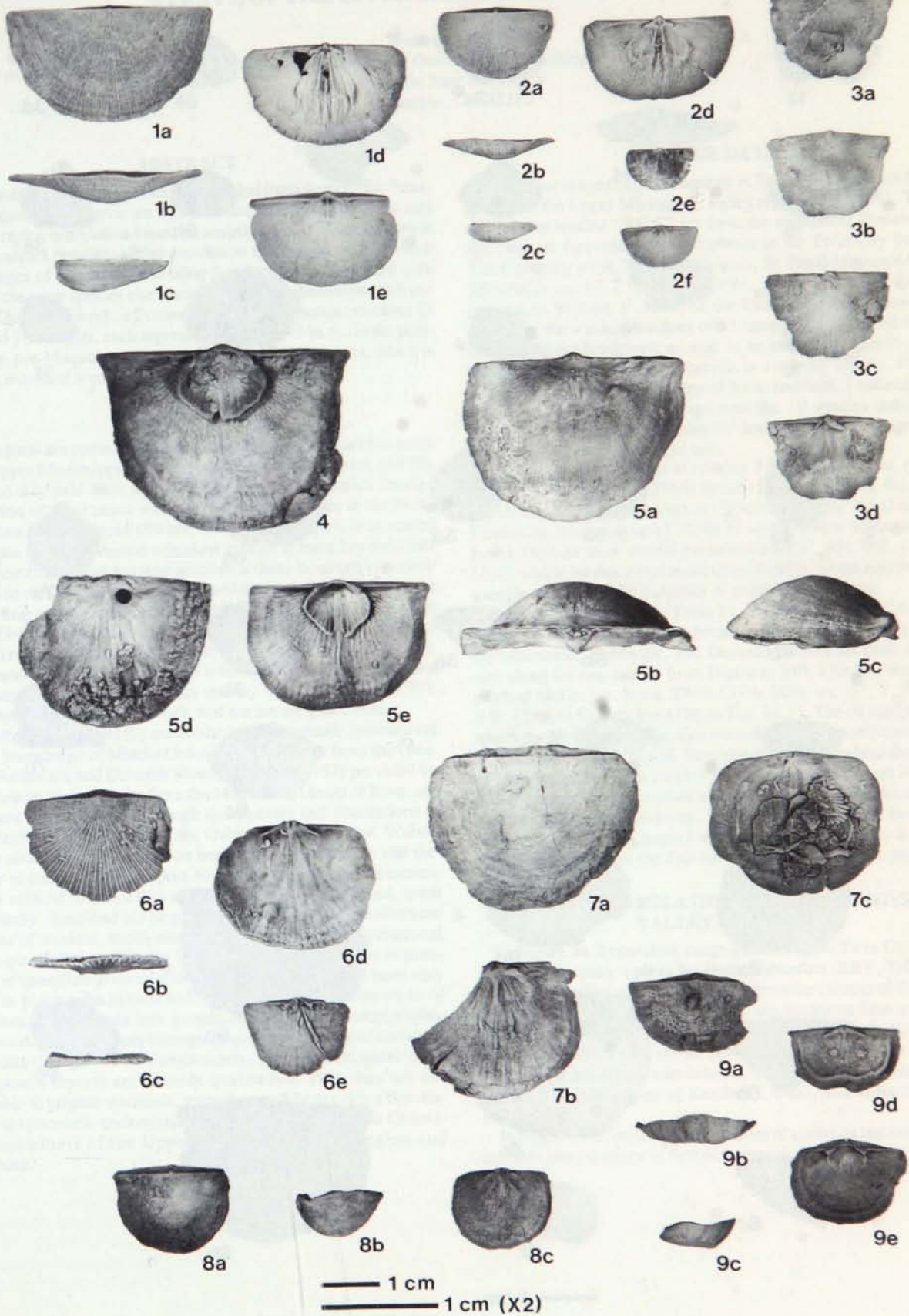
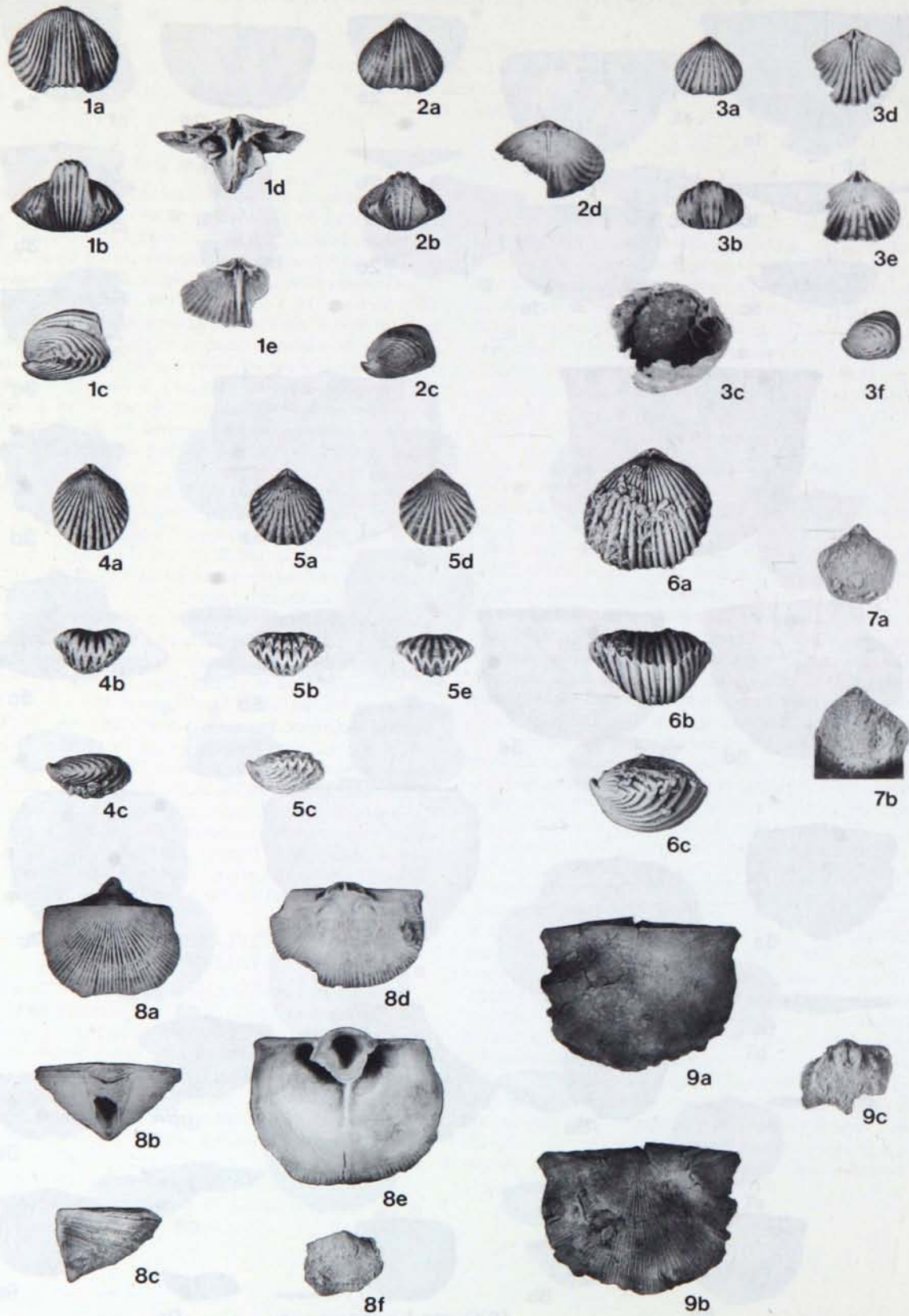


Plate No. 4



— 1 cm —
— 1 cm (X4) —

DISTRIBUTION AND SIGNIFICANCE OF CONODONTS IN MIDDLE AND UPPER ORDOVICIAN STRATA OF THE UPPER MISSISSIPPI VALLEY REGION

Walter C. Sweet

Department of Geology and Mineralogy
The Ohio State University
Columbus, OH 43210

ABSTRACT

Thirty-five conodont species are recorded from the post-St. Peter, pre-Maquoketa Ordovician strata in sections in Minnesota and Iowa. Graphic correlation based on scaled ranges of these species at three localities provides a high-resolution framework within which local ranges of conodonts and other fossils may be compared with those of the same species elsewhere in the North American Midcontinent. That framework, a Composite Standard Section, resolves 25 Standard Time Units, each representing about 0.5 m. y., in the post-St. Peter, pre-Maquoketa sequence of Iowa and Minnesota, which is thus the record of some 12.5 m. y. of Ordovician time.

INTRODUCTION

Conodonts are common fossils in post-St. Peter Ordovician strata in the Upper Mississippi valley region of Minnesota, Iowa, and Illinois, and they have been used with good effect to establish detailed correlation of those strata with coeval ones elsewhere in the North American Midcontinent (Sweet, 1984). This report uses scaled range data for better known conodont species at three key localities in Minnesota and Iowa to relate sections at these localities to a continent-wide chronostratigraphic scale and thus to provide the basis for assembling a range chart of Upper Mississippi valley Middle and Upper Ordovician conodont species that may be useful as the basis for addressing various stratigraphic and paleobiologic questions. The conodonts on which this report is based have been described and illustrated in numerous previous studies (e. g., Glenister, 1957; Ethington, 1959; Webers, 1966), and are not refigured here.

Stauffer (1935a, 1935b) established the systematic groundwork for our knowledge of Middle Ordovician conodonts from the Glenwood Formation and Decorah Shale; Glenister (1957) provided information on typical forms from the Maquoketa Group of Iowa; and Ethington (1959) added thorough descriptions and illustrations of characteristic conodonts from the Galena Group of Iowa. Webers (1966) added important data on bed-by-bed distribution and frequency of conodonts in the post-St. Peter, pre-Maquoketa succession at critical localities in southeastern Minnesota and, most importantly, described his large, carefully documented collections in terms of modern, multi-element taxonomy. The distributional and frequency information in Webers' report thus fits the requirements of quantitative correlation methodologies and has been very useful in placing the Middle and lower Upper Ordovician rocks of southeastern Minnesota into a continent-wide chronostratigraphic framework built up largely through graphic compilation of conodont range data (Sweet, 1984). Unfortunately, the data in Glenister's and Ethington's reports are entirely qualitative. Thus they are not amenable to graphic synthesis, even though they provide a firm basis for a systematic understanding of late Middle and Late Ordovician conodonts of the Upper Mississippi valley region and elsewhere.

RANGE DATA

Conodont range data summarized in Table 14.1 are from three localities in the Upper Mississippi valley region (Fig. 14.1). Those in the column headed "RBY" are from the uppermost Platteville and the Decorah formations in an exposure in the Twin City Brick and Tile Company pit at Cherokee Heights, St. Paul, Minnesota (SW¹/₄ SE¹/₄ SE¹/₄ sec. 12, T. 28 N., R. 23 W., Ramsey County). I am very grateful to William F. Rice, of the University of Minnesota, for providing the washed residues of 65 samples he collected from the Decorah at the brickyard; as well as an unprocessed slab of limestone from the top of the Platteville in a nearby section. From the heavy or nonmagnetic fractions of these residues, I collected 3965 conodont elements, which represent the 19 species indicated in Table 14.1 and provide the basis for determining their ranges in the Decorah Shale of the St. Paul area.

Range data summarized in column 3 headed SE Minn. of Table 14.1 are from Webers' (1966) detailed report, and are the data on which my previous correlation (Sweet, 1984) of the Glenwood, Platteville, Decorah and Galena of southeastern Minnesota was based. Data are from several partial sections (C, RH, WR, L on Fig. 14.1), which are described in detail by Webers but are here treated as a single section for the purposes of graphic correlation.

Figures in the column of Table 14.1 headed McGregor, Iowa, are the ranges of the 17 conodont species represented in collections from the Glenwood, Platteville, and Decorah formations from an exposure along the east side of Iowa Highway 340, a bit less than 1 mile south of McGregor, Iowa, SW¹/₄ SW¹/₄ SE¹/₄ sec. 27, T. 95 N., R. 3 W. Clayton County Iowa (M on Fig. 14.1). The 40 samples from which the McGregor range data were derived were collected on two different occasions. Stig M. Bergström and I assembled the first set of 26 samples from this locality in July 1961, and Robert B. Votaw added 14 more in the summer of 1970, while he was a doctoral student at Ohio State University. Information from these two sets of samples from the McGregor locality was used by Votaw in his doctoral dissertation, but the data have not previously been published.

GRAPHIC CORRELATION OF UPPER MISSISSIPPI VALLEY SECTIONS

In Figure 14.2 conodont range data from the Twin Cities Brick and Tile Company's pit in St. Paul, Minnesota (RBY, Table 14.1) are plotted against appropriate values from the column of Table 14.1 headed CS. Numbers in this column are minimum first- and maximum last-occurrence values for the conodont species indicated, in a composite section that summarizes range data for more than 100 species in some 80 sections in terms of a standard reference section in the Cincinnati region of Kentucky, Ohio, and Indiana (Sweet, 1984).

In Figure 14.2, crosses plot positions of common last occurrences and dots plot positions of first occurrences. The positions of the De-

icke and Millbrig K-bentonites are indicated by asterisks marked D and M, respectively. Numbers adjacent to dots and crosses are index numbers, which may be identified by reference to the left edge of Table 14.1.

Note that first-occurrence dots plot to the left of, and above, the line joining *D, *M, +61 and +47, and last-occurrence crosses plot to the right of, and below, the same line, which thus forms the interface between first- and last-occurrence "countries." It is an operational character of the graphic correlation method that points like those through which the line is passed in Figure 14.2 represent the best-located of the chronologically significant events recorded in the two sections being compared. The equation for the line fitted to this array of points may thus be used as the most concise statement of relationship between the two data sets compared. The equation in Figure 14.2 permits us to state that the rate of rock accumulation was very nearly the same in northern Kentucky and the present site of St. Paul, Minnesota, and that the lowest bed in the St. Paul section (86RBY) is equivalent to one 979.3 m above the base of the standard reference section in the Cincinnati region.

In Figure 14.3, data from the column of Table 14.1 headed SE Minn. are plotted against appropriate values from the column of Table 14.1 headed CS. Note that there is again an almost perfect separation of first-occurrence dots and last-occurrence crosses, and that the line defining the interface between first- and last-occurrence "countries" passes through *47, *75, *61, *D, *54, +38, and very nearly intersects +63, +61, and *33, as well. The equation for the line fitted to this array of points, $CS = 1.55 SEM + 967$, indicates that the lowest point in Webers' Southeastern Minnesota section is equivalent to one 967 m above the base of the standard reference section in northern Kentucky and that only 0.64 m of rock accumulated in southeastern Minnesota during the time represented by 1.0 m in northern Kentucky. Also, because rock-accumulation rates were essentially the same in the St. Paul area of Minnesota and northern Kentucky, it is clear that, at least during the interval of time compared, more rock accumulated per unit of time in the St. Paul area than in the sections of southeastern Minnesota studied by Webers.

Finally, in Figure 14.4 conodont range data from the McGregor, Iowa, section (Table 14.1) are plotted against comparable information from the column of Table 14.1 headed CS. Note in this graph that the array .61, +70, +47 is clearly rectilinear, and has little dispersion. A line fit to it would also represent the interface between first- and last-occurrence "countries." However, such a line would completely bypass the plotted positions of the Deicke and Millbrig K-bentonites, which are unique points in the two data sets and are customarily accorded great chronostratigraphic significance. Thus, in Figure 14.4 I suggest that in the McGregor section there is a discontinuity of some sort in the half-meter interval between the two K-bentonites. That discontinuity need not be the unconformity suggested by the symbol used in Figure 14.4. It might represent an interval of exceptionally slow rock accumulation in the McGregor area. Whatever the explanation, it seems best to compile range data from the lower and upper parts of the McGregor section separately. Thus I suggest that Glenwood and Platteville strata below the discontinuity may have accumulated rather rapidly relative to those that represent the same interval of time in the standard reference section in Kentucky, but that Decorah rocks above the discontinuity accumulated much more slowly than did those in the St. Paul area of Minnesota or those in a comparable part of the standard reference section. Careful collecting from Galena Group strata above the Decorah at McGregor might help determine the appropriateness of this solution, which must be regarded as provisional for the present.

There are, of course, other possible explanations for the fact that K-bentonites identified as Deicke and Millbrig in the McGregor, Iowa, section plot outside the array defined by well-controlled first- and last-occurrence events for conodont species. For example, the bentonites identified as Deicke and Millbrig at McGregor might be

much younger than those identified with the same names in either the southeastern Minnesota or St. Paul sections. This explanation seems unlikely, however, in view of recent work by Kolata and others (1986; this volume), which has established that the Deicke and Millbrig K-bentonites have distinctive chemical "fingerprints" that aid in their correct identification in numerous sections.

A second possible explanation for the "dogleg" in the array of time-significant points in the McGregor section (Fig. 14.4) is provided by noting that a line fit to the array *D, *M, +47 would very nearly intersect all three points, but would intersect the X axis well to the left of the portion of the graph shown and would also pass above the plotted positions of *75 and *61. Such a fit for the "line of correlation" would suggest that *Polyplacognathus ramosus* (species 75) and *Phragmodus cognitus* (species 61) made their continent-wide debuts in the McGregor, Iowa, area long before they appeared anywhere else. This would explain the fact that those events plot well to the right of the "line of correlation" in Figure 14.4. While this explanation is possible, I do not favor it because the two first-occurrence events (*75, *61) are each controlled, at the levels plotted in Figure 14.4, by occurrences that cluster around the 970-m level in at least three of the other sections that have contributed distributional information to the composite standard section.

COMPOSITE RANGES OF UPPER MISSISSIPPI VALLEY CONODONTS

In Figure 14.5 I sketch the stratigraphic relationships between Upper Mississippi valley sections and the standard reference section indicated in Figures 14.2, 14.3, and 14.4. The vertical scale of Figure 14.5 is that of the standard reference section, and the thickness of component Upper Mississippi valley sections is given in terms of the standard section. I have also added on the right margin a ladder scale that shows the extent of successive 6-m divisions of the standard reference section; an indication of the extent of the *Compressa*, *Undatus*, *Tenuis*, and *Confluens* conodont chronozones; and the position of the boundary between the Mohawkian and Cincinnati Series. Divisions of the ladder scale were termed Standard Time Units by Shaw (1964) and may be regarded as the record in the composite section of successive intervals of time that were probably no more than 0.5 m.y. long.

Finally, in Figure 14.6, I provide a chart that exhibits ranges of the 35 conodont species thus far recorded in post-St. Peter, pre-Maquoketa Ordovician strata of the Upper Mississippi valley region. Note that the full range of about half the conodont species known from sections in Iowa and Minnesota is documented in Upper Mississippi valley collections. The remaining species mostly occur first at localities outside those considered in this report and range into Ordovician rocks younger than those documented here. A majority of the species shown in Figure 14.6 to range into younger strata are represented by specimens in the Maquoketa, which cannot yet be added to the graphically assembled Composite Standard Section because scaled range data are not yet available.

Conodont elements in collections available to me are all thermally unaltered (CAI 1.0) and collectively represent species that are typical of the biogeographic region Sweet and Bergström (1984) termed the Ohio Valley Province. In the *Velicuspis* Chron, a somewhat later part of the Ordovician than has been considered here, the Ohio Valley Province included a part of North America between about 18 and 23 degrees south latitude that was evidently submerged beneath relatively shallow, subtropical seas. The known occurrence in Maquoketa strata of conodonts that represent species characteristic of the Red River Province, which during the *Velicuspis* Chron lay between the Ohio Valley Province and the Ordovician equator, may indicate that the Upper Mississippi valley region was geographically transitional between the two provinces.



Figure 14.1 Location of sections yielding the conodonts considered in this report.

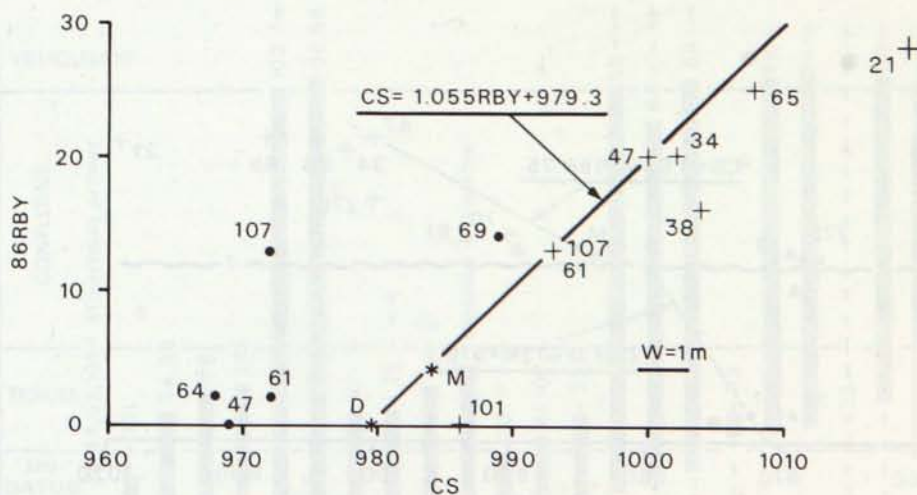


Figure 14.2 Graphic correlation of the uppermost Platteville and the Decorah formations of the St. Paul, Minnesota, area (86RBY) with the Composite Standard Section (Sweet, 1984) (CS). Numbers near dots or crosses refer to the conodont species listed in Table 14.1. Dots mark first occurrences; crosses mark last occurrences; asterisks mark unique occurrences of the Deicke (D) and Millbrig (M) K-bentonites. W, width of the array, empirical limit of error.

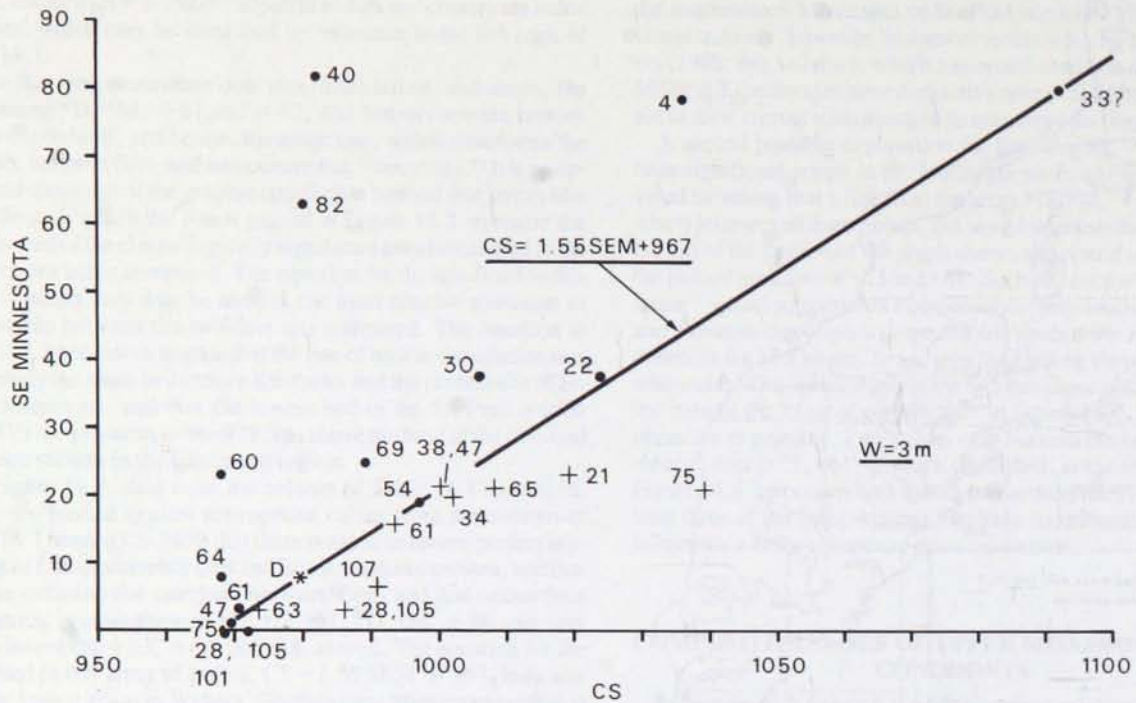


Figure 14.3 Graphic correlation of Glenwood, Platteville, Decorah, Stewartville, and Dubuque formations of southeast-Minnesota sections studied by Webers (1966) (Fig. 14.1, localities C, RH, WR, L) with the Composite Standard Section (Sweet, 1984). Numbers near dots or crosses refer to the conodont species listed in Table 1. Dots mark first occurrences; crosses mark last occurrences; the asterisk marked "D" marks the unique occurrence of the Deicke K-bentonite.

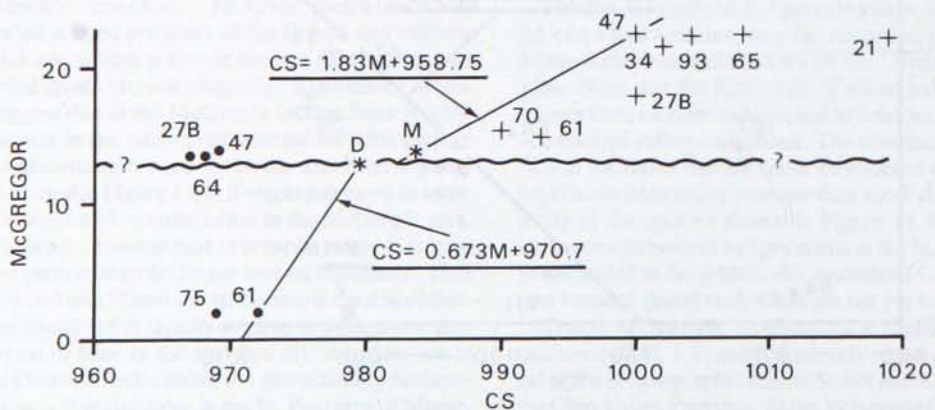


Figure 14.4 Graphic correlation of Glenwood, Platteville, and Decorah formations in section at McGregor, Iowa, with the Composite Standard Section (Sweet, 1984). Numbers near dots or crosses refer to the conodont species listed in Table 14.1. Dots mark first occurrences; crosses mark last occurrences; asterisks mark unique occurrences of the Deicke (D) and Millbrig (M) K-bentonites.

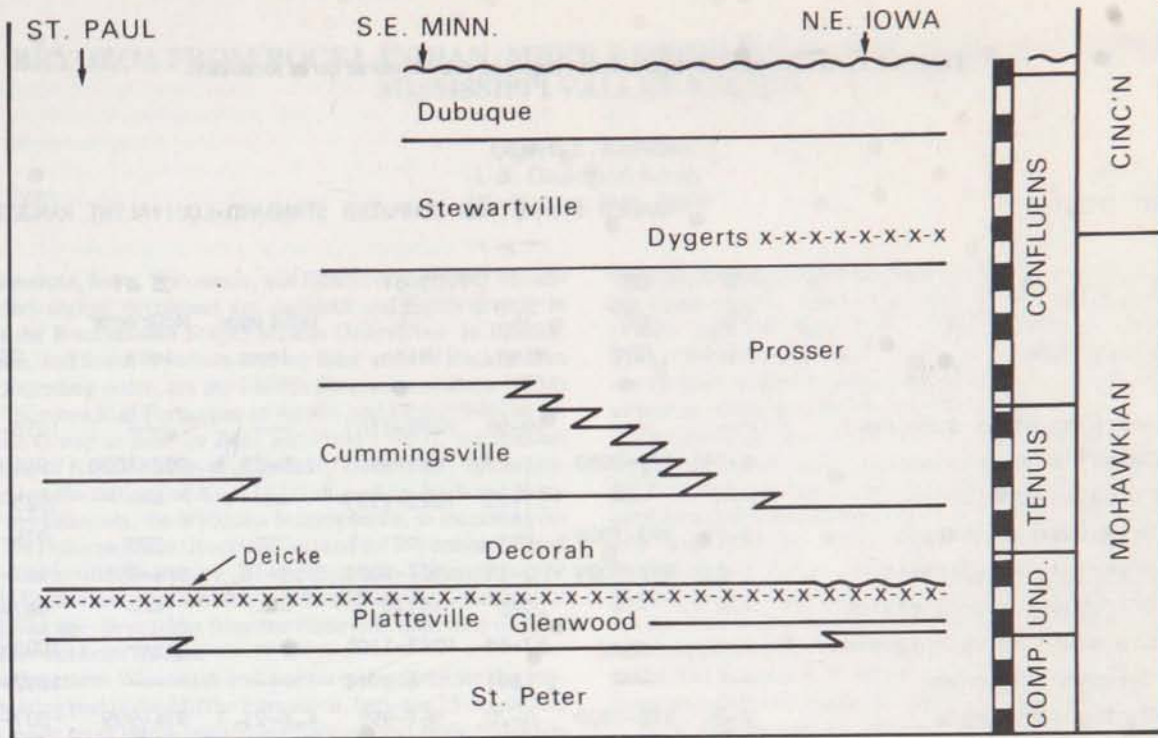


Figure 14.5 Chronostratigraphic relations between sections of Middle and early Late Ordovician rock considered in this report. Divisions in the ladder scale at the right are standard time units; the abbreviations "COMP." and "UND." refer to the COMPRESSA and UNDATUS chronozones, respectively; and the rows of "x's" indicate the approximate positions of the Deicke and Dygerts K-bentonites. The position of the Dygerts K-bentonite is not established within the graphically controlled network, but it should have about the position indicated. An unnamed K-bentonite occurs within the same Standard Time Unit as the Dygerts in the Cincinnati Region of Ohio.

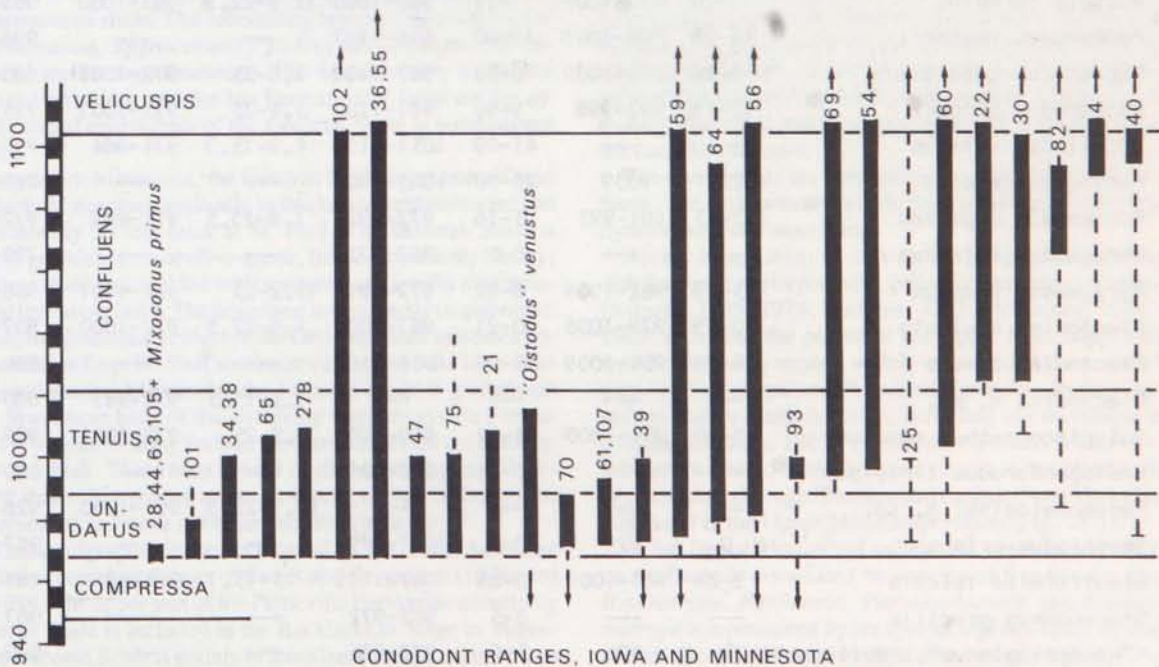


Figure 14.6 Ranges of conodont species represented in Middle and early Late Ordovician of the Upper Mississippi Valley Region. Ladder scale at left is composed of (STU's) Standard Time Units approximately 0.5 m. y. long; oldest conodonts known in Upper Mississippi Valley occur at level 967 m above base of Composite Standard Section; youngest occur at level 1107 m above base of CSS. Numbers above bars refer to conodont species named in Table 14.1; arrows below and above bars indicate that species is also known from older or younger rocks elsewhere.

Table 14.1. Actual and CS-equivalent ranges of conodonts at three localities.

CONODONT SPECIES		RANGES (in m) AND COMPUTED STANDARD-EQUIVALENT RANGES						
Index#	Name	RBV St. Paul	CS of RBY	SE Minn.	CS of SE Minn.	McGregor Iowa	CS of McGregor Iowa	CS
4	<i>Amorphognathus superbus</i>	---	---	79-90	1090-1107	---	---	1036-1151
21	<i>Belodina compressa</i>	0-28	979-1009	1-23	969-1003	1.5-22.5	972-1000	944-1019
22	<i>Belodina confluens</i>	---	---	37-90	1025-1107	---	---	1025-1169
25	<i>Bryantodina? abrupta</i>	19-20	999-1000	---	---	---	---	973-1133
27B	<i>Bryantodina typicalis</i>	3-28	982-1009	0-21	967-1000	13.9-18.5	984-993	967-1009
28	<i>Chirognathus duodactylus</i>	---	---	0-3	967-972	---	---	967-986
30	<i>Coelocerodontus trigonius</i>	---	---	37-88	1025-1103	---	---	1005-1126
33	<i>Culumbodina penna</i>	---	---	(80)	(1091)	---	---	1092-1167
34	<i>Curtognathus spp.</i>	0-20	979-1000	0-20	967-998	4.6-21.7	974-999	807-1002
36	<i>Drepanoistodus suberectus</i>	0-28	979-1009	0-90	967-1107	2-23	972-1001	680-1288
38	<i>Erismodus quadridactylus</i>	0-14	979-994	0-21	967-1000	---	---	873-1000
39	<i>Erismodus radicans</i>	---	---	---	---	3-22.1	973-999	807-1002
40	<i>Icriodella superba</i>	---	---	82-89	1094-1105	---	---	972-1205
	<i>Mixoconus primus</i>	---	---	0-3	967-972	---	---	967-972
	" <i>Oistodus</i> " <i>venustus</i>	---	---	1-31	969-1015	3-20	973-994	?
44	" <i>Oneotodus</i> " <i>ovatus</i>	---	---	0-3	967-972	---	---	967-972
47	<i>Oulodus serratus</i>	0-20	979-1000	1-21	969-1000	13.2-22.5	983-1000	969-1000
54	<i>Panderodus feulneri</i>	16-28	996-1009	19-90	996-1107	---	---	996-1288
55	<i>Panderodus gracilis</i>	0-28	979-1009	0-90	967-1107	1.5-23	972-1001	680-1286
56	<i>Panderodus panderi</i>	12-18	992-998	9-90	981-1107	3.4-23	973-1001	793-1286
59	<i>Dapsilodus mutatus</i>	---	---	41-89	1031-1105	4.9-13.7	974-984	795-1278
60	<i>Periodon grandis</i>	28	1009	23-90	1003-1107	---	---	968-1149
61	<i>Phragmodus cognitus</i>	2-13	981-993	3-16	972-992	1.8-15.3	972-985	972-993
63	<i>Phragmodus inflexus</i>	---	---	0-3	967-972	---	---	789-973
64	<i>Phragmodus undatus</i>	3-28	982-1009	8-82	979-1094	13.2-23	983-1001	968-1282
65	<i>Plectodina aculeata</i>	0-25	979-1006	0-21	967-1000	1.8-22.5	972-1000	807-1008
69	<i>Plectodina tenuis</i>	14-28	994-1009	25-90	1006-1107	---	---	989-1272
70	<i>Plectodina n. sp.</i>	---	---	---	---	1.5-15.3	972-987	680-990
75	<i>Polyplacognathus ramosus</i>	0-20	979-1000	1-21	969-1000	1.8-23	972-1001	969-1039
82	<i>Protopanderodus liripipus</i>	---	---	63-81	1065-1093	---	---	980-1198
93	<i>Pseudobelodina? n. sp.</i>	---	---	---	---	18.5-22.5	993-1000	926-1004
101	<i>Scyphiodus primus</i>	0	979	0-8	967-979	---	---	967-986
102	<i>Staufferella falcata</i>	2-28	981-1009	0-89	967-1105	3-13.1	973-983	881-1167
105	<i>Stereoconus gracilis</i>	---	---	0-3	967-972	---	---	967-986
107	" <i>Tetraprioniodus</i> " <i>breviconus</i>	13	993	3-6	972-976	---	---	972-993
	Millbrig K-bentonite	4	983.5	10.8	983.7	13.5	983.5	---
	Deicke K-bentonite	0	979.3	8	979.4	13.0	979.4	---

BRYOZOA FROM ROCKLANDIAN (MIDDLE ORDOVICIAN) ROCKS OF THE UPPER MISSISSIPPI VALLEY REGION

Olgerts L. Karklins
U.S. Geological Survey
Washington, D.C. 20560

In Minnesota, Iowa, Wisconsin, and Illinois of the Upper Mississippi valley region, bryozoans are abundant and highly diverse in rocks of the Rocklandian Stage, Middle Ordovician. In Illinois, Wisconsin, and Iowa, bryozoan-bearing lithic units of Rocklandian age, in ascending order, are the Mifflin Formation of Bays (1938) and the Quimbys Mill Formation of Agnew and Heyl (1946) of the Platteville Group as used by Bork and Perry (1967), the Spechts Ferry Shale of Kay (1928) as used by Perry (1962), and the Guttenberg and Ion Formations of Kay (1928) as used by Bork and Perry (1967). In Minnesota, the bryozoan-bearing rocks, in ascending order, are the Decorah Shale (Rocklandian) and the lowermost beds of the Cummingsville Formation (Kirkfieldian). In Minnesota, the Decorah Shale rests conformably on the Platteville limestone of Rocklandian age. Bryozoans from the Platteville limestone of Minnesota have not been studied.

In southwestern Wisconsin and northwestern Illinois, the bryozoan-bearing part of the Mifflin Formation, between 15 and 46 feet thick, is made up of thinly bedded argillaceous and shaly fossiliferous limestone. The succeeding Quimbys Mill Formation, from 12 to 14 feet thick, consists mainly of medium to thin beds of limestone and dolomite separated by thin shale laminae. In northwestern Illinois, southwestern Wisconsin, and northeastern Iowa, the bryozoan-bearing part of the Spechts Ferry Shale succeeds the Quimbys Mill Formation. The Spechts Ferry Shale is no more than 10 feet thick. It is made up of dark-green to green-gray, thin-bedded, soft, locally pyritic shale interbedded with fine- to medium-grained argillaceous limestone. The overlying Guttenberg Formation, 10 to 20 feet thick, is made up of gray lithographic limestone interbedded with carbonaceous shale. The succeeding bryozoan-bearing part of the Ion Formation, approximately 16 feet thick, consists of calcareous and argillaceous limestone. The Spechts Ferry Shale, the Guttenberg Formation, and the Ion Formation of Iowa are the approximate lateral equivalents of the Decorah Shale in southeastern Minnesota.

In southeastern Minnesota, the Decorah Shale is between 40 and 50 feet thick. It increases gradually in thickness northwestward and is approximately 90 feet thick at St. Paul. The Decorah Shale is made up of greenish-gray or olive-green, fissile, commonly blocky, fossiliferous shale interbedded with scattered and locally discontinuous, thin limestone beds. The limestone is commonly coquinoideal. In general, the limestone content of the Decorah Shale increases upward in a section from St. Paul southeastward toward the Iowa state line. In southeastern Minnesota, the Decorah Shale is gradational with the lowermost beds of the overlying Cummingsville Formation. The bryozoan-bearing beds of the Cummingsville are between 5 and 10 feet thick. These beds consist of alternating layers of limestone and shale. Bryozoans in the Cummingsville Formation are poorly preserved and have not been described in detail.

In the biostratigraphic framework based on the North American Midcontinent conodont faunas of Sweet and Bergstrom (1976) and Sweet (1984), the upper part of the Platteville Formation underlying the Decorah Shale is included in the Rocklandian Stage in Minnesota. The Decorah Shale is mainly of Rocklandian age, except for its uppermost part which together with the succeeding Cummingsville Formation, is included in Middle Ordovician Kirkfieldian Stage in Minnesota (Sweet and Bergstrom, 1976; Sweet, 1984).

The composite section of the bryozoan-bearing strata for the Upper Mississippi valley region is shown in Figure 15.1. The bryozoan

taxa listed in Figure 15.1 are compiled from various sources including Ulrich (1886a, 1893), Coryell (1921), Loeblich (1942), Perry (1962), Bork and Perry (1967, 1968a,b), Karklins (1969, 1984), Ross (1984) and Marintsch (1986). Bryozoan taxa included in Figure 15.1 are only those with adequate illustrations and descriptions, as well as adequate stratigraphic information.

The bryozoan fauna (Fig. 15.1) from the composite section for the Upper Mississippi valley region consists of three bryozoan orders: the Trepostomata, the Cystoporata, and the Cryptostomata. The trepostomes dominate the fauna and are referred to 41 taxa of 17 genera: *Amplexopora*, *Batostoma*, *Balticopora*, *Cyphotrypa*, *Diplotrypa*, *Eridotrypa*, *Hemiphragma*, *Heterotrypa*, *Homotrypa*, *Monotrypa*, *Monticulipora*, *Nicholsonella*, *Orbignyella*, *Parvohalloporella*, *Prasopora*, *Stigmatella*, and *Tarphophragma*. In the Upper Mississippi valley region, the trepostomes appear for the first time in the Mifflin Formation of the Platteville Group (Fig. 15.1). They become abundant and highly diverse in the succeeding strata.

The Cryptostomata are represented mainly by the suborder Ptilodictyina. The ptilodictyines (so-called bifoliate bryozoans) have been described only from the Decorah Shale and the Cummingsville Formation of the Galena Group (Ulrich, 1893; Karklins, 1969) in southeastern Minnesota and the Spechts Ferry Shale in Iowa, Wisconsin, and Illinois (Perry, 1962). The ptilodictyine bryozoans are known to occur elsewhere in the Middle Ordovician rocks in the Upper Mississippi valley region, but they have not been described. The ptilodictyine bryozoans are referred to 18 species of 7 genera: *Athrophragma*, *Escharopora*, *Graptodictya*, *Pseudostictoporella*, *Stictopora*, *Stictoporellina*, and *Trigonodictya*. The ptilodictyines form a major part of the bryozoan fauna of the Decorah Shale and occur abundantly throughout the formation (Karklins, 1969). In addition to the ptilodictyines, the fauna includes some poorly known arthrotylid and phylloporinid cryptostomes. These taxa are inadequately illustrated and described and need to be revised. They are not considered herein.

The Cystoporata are rare and form a small part of the bryozoan fauna. The cystoporates include two species assigned to two genera: *Bythotrypa* and *Constellaria*.

Recent compilation of data on the geographic and stratigraphic distribution of the trepostome, ptilodictyine, and cystoporate genera (Astrova, 1965, 1978; Karklins, 1983; McKinney, 1974; Utgaard, 1983) show that the genera of the Upper Mississippi valley occur worldwide and in regions widely separated at the present time, except for *Bythotrypa* and *Pseudostictoporella*. *Bythotrypa* is found only in eastern North America, according to a revision of its generic concept (Utgaard, 1983). *Pseudostictoporella* is known only from the eastern United States where it occurs in the Middle Ordovician (Rocklandian through Shermanian) rocks in New York (Ross, 1970, 1984) and in the Upper Mississippi region (Fig. 15.1).

In the Upper Mississippi valley, the trepostome part of the bryozoan fauna is dominated by species of five genera: *Homotrypa*, *Heterotrypa*, *Batostoma*, *Parvohalloporella*, and *Eridotrypa*. *Homotrypa* is represented by six species and one taxon in open nomenclature (Bork and Perry, 1968b). *Heterotrypa* includes five species, and *Batostoma*, *Eridotrypa*, and *Parvohalloporella* are with three species each. Eight trepostome genera: *Amplexopora*, *Cyphotrypa*, *Diplotrypa*, *Hemiphragma*, *Nicholsonella*, *Prasopora*, *Stigmatella*, and *Tarphophragma* include two species each. The remaining four genera: *Balticopora*, *Monotrypa*, *Monticulipora* and

Orbignyella have one species each. The ptilodictyine part of the bryozoan fauna in the Decorah Shale of southeastern Minnesota is dominated by three genera: *Stictopora*, *Trigonodictya*, and *Pseudostictoporella*. *Stictopora* is represented by 6 species, *Trigonodictya* by 5 species, and *Pseudostictoporella* by 3 species. The remaining three genera: *Athrophragma*, *Escharopora*, and *Graptodictya* are with one species each.

The known geographic and stratigraphic distribution of 61 taxa listed in Figure 15.1 indicates that on the species level the bryozoan fauna in the Rocklandian rocks of the Upper Mississippi valley is the result of intermingling of species endemic to the Upper Mississippi valley region with immigrant species from elsewhere. The immigrant species are those that are common to the Upper Mississippi valley but that first occur elsewhere in rocks older than Rocklandian in the biostratigraphic framework based on the conodont faunas of Sweet and Bergström (1976).

The immigrant part of the bryozoan fauna includes 17 species, of which 9 species are from Blackriveran (Middle Ordovician) rocks of the southwestern United States, and 6 species are from the New York-Ontario region (1-14, 16 in Fig. 15.1). Two species are from early Rocklandian rocks of New York (15, 17 in Fig. 15.1).

In Oklahoma, *Amplexopora winchelli*, *Hemiphragma irrasum*, and *Heterotrypa praeunntia echinata* appear for the first time in the upper part of the Bromide Formation (Blackriveran), Simpson Group (Loeblich, 1942). In the Upper Mississippi valley, *Amplexopora winchelli* and *Heterotrypa praeunntia echinata* first occur in the Quimbys Mill Formation (Bork and Perry, 1967, 1968a) and *Hemiphragma irrasum* in the lower part of the Decorah Shale. The three species range through the Decorah Shale and its lateral equivalents in the Upper Mississippi valley region. *Hemiphragma irrasum* continues into the Cummingsville Formation where it disappears. *Amplexopora winchelli*, however, ranges into Shermanian rocks of New York (Ross, 1984, and references therein) and *Heterotrypa praeunntia echinata* dispersed into the Hermitage Formation (late Middle Ordovician) of Marintsch (1986) in eastern Tennessee.

In northeastern Alabama, *Batostoma increbescens*, *B. varium*, *Eridotrypa minor*, and *Homotrypa subramosa* appear for the first time in the lower Chickamauga Group of McKinney (1971) of Blackriveran age. In the Upper Mississippi valley, *Homotrypa subramosa* occurs first in the Quimbys Mill Formation. It continues through the Decorah Shale and its lateral equivalents into the Ion Formation of Bork and Perry (1967) and dispersed into the Hermitage Formation of Marintsch (1986), late Middle Ordovician, in eastern Tennessee. In the Upper Mississippi valley, *Batostoma varium* occurs first in the middle part of the Decorah Shale and *B. increbescens* in the Guttenberg Formation of Bork and Perry (1967). Both species range into the Ion Formation where they disappear. *Eridotrypa minor* is found only in the upper part of the Decorah Shale and in the overlying Cummingsville Formation. It is not known to occur in rocks of younger ages.

In central Tennessee, *Diplotrypa catenulata* and *Orbignyella sublamellosa* appear first in the Murfreesboro Limestone, Blackriveran, of the Stones River Group. In the Upper Mississippi valley, both are known only from the Mifflin Formation (Bork and Perry, 1968a,b).

In Ontario, *Homotrypa similis*, *Prasopora simulatrix*, and *Tarphophragma multitabulata* appear for the first time in the Pamela beds of Fritz (1957), Blackriveran, and *Hemiphragma ottawaensis* in the undifferentiated Leray-Rockland beds of Fritz (1957), Blackriveran-Rocklandian, of the Ottawa Formation. In the Upper Mississippi valley, *Homotrypa similis* and *Prasopora simulatrix* first occur in the Quimbys Mill Formation. Both species range through the Decorah Shale and its lateral equivalents. *Prasopora simulatrix* ranges into the Ion Formation and probably continues into the overlying Cummingsville Member of the Galena Dolomite. *Homotrypa similis* ranges into the Cummingsville Member where it

disappears. *Tarphophragma mutabalata* occurs first in the middle part of the Decorah Shale and continues into the Cummingsville Formation of the Galena Group. *Hemiphragma ottawaensis* is known only from the Cummingsville Formation in Minnesota. In addition to the Upper Mississippi valley region, these four species are widely distributed in the late Middle Ordovician rocks of the eastern United States.

In New York, *Prasopora simulatrix* appears at the base of the Selby Limestone of Kay (1937; Ross 1967, 1984), Rocklandian, and continues through strata of Kirkfieldian and Shermanian Stages. In north-central Kentucky, *Prasopora simulatrix* and *Tarphophragma multitabulata* occur first in the Kirkfieldian rocks of the Lexington Limestone near the base of the formation and continue into the early Shermanian rocks of the Lexington Limestone (Brown, 1965; Karklins, 1984). *Homotrypa similis* occurs in the Shermanian rocks of the Lexington Limestone in Kentucky (Karklins, 1984).

In eastern Tennessee, *Hemiphragma ottawaensis*, *Homotrypa similis*, *Prasopora simulatrix*, and *Tarphophragma multitabulata* occur in the Hermitage Formation of late Middle Ordovician age (Marintsch, 1986). In New York, *Amplexopora minnesotensis* and *Trigonodictya acuta* (*Pachydictya* of Ross, 1964) occur for the first time in the Lowville Limestone, Blackriveran (Ross, 1984) and range through rocks of Rocklandian, Kirkfieldian and Shermanian Stages. *Trigonodictya acuta* is not known above strata of Shermanian age and *Amplexopora minnesotensis* continues in early Edenian (Late Ordovician) strata in New York (Ross, 1984). In southeastern Minnesota, *Trigonodictya acuta* first occurs in the lower part of the Decorah Shale and ranges throughout the formation. *Amplexopora minnesotensis*, however, is known only from the middle part of the Decorah Shale in Minnesota.

In New York, *Balticopora tenuimurale* and *Eridotrypa mutabilis* appear for the first time near the base of the Selby Limestone, Rocklandian, and range through strata of Kirkfieldian and Shermanian Stages (late Middle Ordovician) into strata of early Edenian (Late Ordovician) age (Ross, 1984). Both species dispersed into north-central Kentucky and southeastern Minnesota, where both occur in the Cummingsville Formation but appear to be restricted to this unit. In north-central Kentucky, they first occur in the Kirkfieldian rocks of the Lexington Limestone and range into the Shermanian rocks of the Lexington Limestone and its lateral equivalents of the Clays Ferry Formation. *Balticopora tenuimurale* is not known from strata younger than Shermanian (Middle Ordovician); *Eridotrypa mutabilis* ranges into strata of early Edenian Stage, in Kentucky. In eastern Tennessee, *Eridotrypa mutabilis* occurs in the Hermitage Formation of late Middle Ordovician age (Marintsch, 1986).

In the Upper Mississippi valley region, four species: *Cyphotrypa acervulosa*, *Heterotrypa praeunntia simplex*, *H. trentonensis*, and *Tarphophragma ampla* appear for the first time in rocks of Rocklandian age and subsequently occur in rocks of younger age elsewhere. In southeastern Minnesota, *Cyphotrypa acervulosa* and *Heterotrypa trentonensis* occur in the upper part of the Decorah Shale. In north-central Kentucky, *Heterotrypa trentonensis* is found in Kirkfieldian strata, and *Cyphotrypa acervulosa* in Kirkfieldian and Shermanian strata of the Lexington Limestone. In the Upper Mississippi valley, *Heterotrypa praeunntia simplex* occurs in the Quimbys Mill and the Guttenberg Formations and *Tarphophragma ampla* in the middle part of the Decorah Shale. In eastern Tennessee, both species and *Cyphotrypa acervulosa* are found in the Hermitage Formation, late Middle Ordovician, of Marintsch (1986).

The remaining 40 species of the bryozoan fauna appear to be endemic to the Rocklandian or Kirkfieldian (Middle Ordovician) rocks in the Upper Mississippi valley region on the basis of the known stratigraphic and geographic distribution of bryozoans.

In southeastern Minnesota, the Decorah Shale is divided into three local biostratigraphic units on the basis of the stratigraphic dis-

tribution of the cryptostome ptilodictyine bryozoans (Karklins, 1969). These biostratigraphic units, in ascending order, are: the *Stictoporella* (now *Pseudostictoporella*) *angularis* zone, the *Stictopora mutabilis* zone, and the *Stictopora minima* zone. In general, the thickness of each of the zones diminishes gradually to the south-east, the zones occurring over thicker intervals of strata at St. Paul than at Spring Grove, Minnesota, just a few miles north of the Iowa border. It is not known whether the ptilodictyine zones can be recognized in Iowa and elsewhere in the Upper Mississippi valley region, because the ptilodictyine bryozoans have not yet been studied. Biostratigraphic zonation based on the trepostome bryozoans has not been attempted in the area.

In southeastern Minnesota, the *Stictoporella angularis* zone is the approximate equivalent of the upper two-thirds of Sardeson's *Stictoporella* bed (Sardeson, 1897a) and roughly approximates the "lower third of the Trenton shales" of Ulrich (1893). Furthermore, the *Stictoporella angularis* zone corresponds roughly to the Spechts Ferry Shale in Iowa. The base of the *Stictoporella angularis* zone is placed at the first occurrence of *Pseudostictoporella angularis* at the base of the Decorah Shale. The top of the zone is placed at the first appearance of *Stictopora mutabilis* in the section. At St. Paul, the *Stictoporella angularis* zone is approximately 18 feet thick. This zone is characterized by abundant ptilodictyine bryozoans. *Pseudostictoporella angularis*, *Athropragma foliata*, and *Suctopora exigua* are restricted to this zone. *Pseudostictoporella frondifera* is common in this zone; it ranges into the overlying *Stictopora mutabilis* zone and occurs abundantly in the Spechts Ferry Shale in the Upper Mississippi valley. Most trepostomes found in the Spechts Ferry Shale and in the *Stictoporella angularis* zone of the Decorah appear for the first time in the Quimbys Mill.

The base of the succeeding *Stictopora mutabilis* zone is placed at the first occurrence of *S. mutabilis* in the section. The top of the zone is placed at the highest occurrence of *S. mutabilis* in the Decorah Shale. The *Stictopora mutabilis* zone appears to include the *Ctenodonta*, *Phylloporina*, and a part of the furoid bed of Winchell and Ulrich (1897) and the *Stictopora* bed and parts of the furoid bed of Sardeson (1897a). The zone roughly approximates the middle third of the Trenton shales of Ulrich (1893) and is the approximate

lateral equivalent of the Guttenberg Formation of Bork and Perry (1967). At St. Paul the base of the *Stictopora mutabilis* zone is placed in the Decorah Shale about 18 feet above the base of the formation. There the zone is about 42 feet thick. In Minnesota and in the Guttenberg Formation in Iowa and adjacent region, it contains the main part of the bryozoan fauna of the Upper Mississippi valley (Fig. 15.1). In Minnesota, the zone records a diverse ptilodictyine fauna including *Stictoporellina* and the different species of *Trigonodictya*, *Stictopora*, and *Pseudostictoporella*, in addition to the trepostome species.

The base of the overlying *Stictopora minima* zone is placed at the highest occurrence of *Stictopora mutabilis* in the Decorah Shale in Minnesota, and the top is placed at the highest known occurrence of *Stictopora minima*. The *Stictopora minima* zone may include locally the lowest beds of the overlying Cummingsville Formation in Minnesota. The zone roughly approximates the "upper third of the Trenton shales" of Ulrich (1893), parts of the furoid bed and the *Orthisina* (*Vellamo*) bed of Sardeson (1897a), and the furoid and *Clitamboonites* beds of Winchell and Ulrich (1897). In addition, the *Stictopora minima* zone appears to be the approximate lateral equivalent of the Ion Formation. At St. Paul, where it is about 30 feet thick, its base is placed in the Decorah Shale about 60 feet above the base of the formation, and its top coincides roughly with the top of the Decorah Shale. Most of the ptilodictyine bryozoans occurring in the underlying *Stictopora mutabilis* zone continue into the *Stictopora minima* zone. The *Stictopora minima* zone records the first appearance of *Trigonodictya conciliatrix*, *T. pumila*, and *T. elegans* (*Astreptodictya* of Karklins, 1969). Most of the trepostomes occurring in the *Stictopora mutabilis* zone of the Decorah and in the Guttenberg Formation range into the *Stictopora minima* zone of the Decorah and in the Ion Formation elsewhere. The bryozoan fauna is not known from rocks of Ordovician age succeeding the Ion Formation of Bork and Perry (1967) in Iowa, Wisconsin, and Illinois. In Minnesota, the bryozoan fauna is little known from the Cummingsville Formation overlying the Decorah Shale. Available material of the trepostomes indicates that the fauna decreases considerably in abundance and diversity in the Cummingsville Formation.

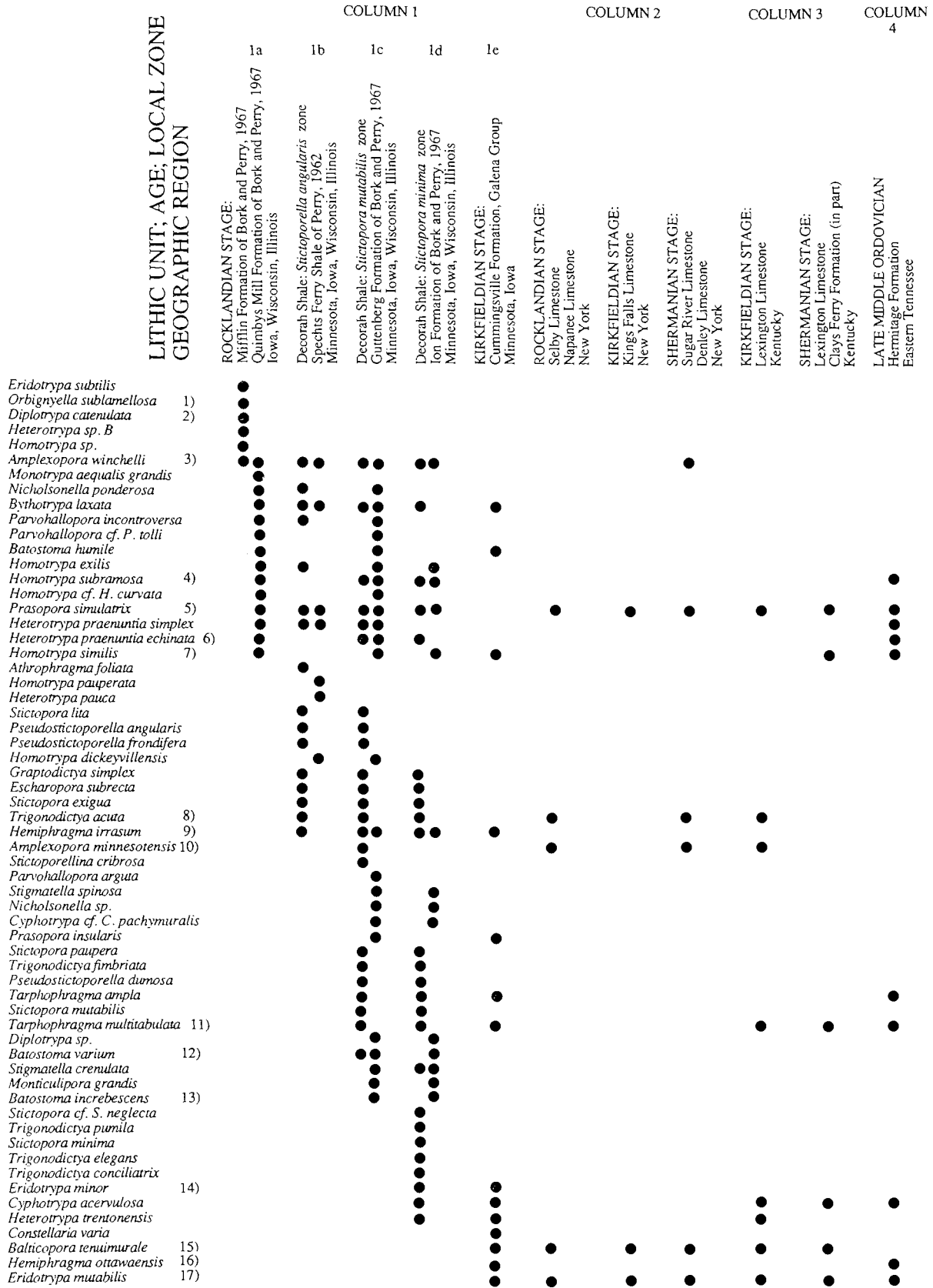


Figure 15.1. Stratigraphic distribution of the trepostome, cryptostome ptilodictyine, and cystoporate bryozoans in the Middle Ordovician rocks of Minnesota, Iowa, Wisconsin, and Illinois and their occurrence in the eastern United States. Biostratigraphy based on the North Midcontinent conodont faunas of Sweet and Bergstrom (1976).

1-14, 16 Taxa appearing for the first time in rocks of Black Riveran (Middle Ordovician) age elsewhere.

15, 17 Taxa appearing for the first time in rocks of early Rocklandian (Middle Ordovician) age elsewhere.

THE MIDDLE ORDOVICIAN CRINOID FAUNA OF THE TWIN CITIES AREA

James C. Brower

Heroy Geology Laboratory, Syracuse University
Syracuse, N. Y. 13244

INTRODUCTION

Over the past 100 years, approximately 150 crinoid crowns and dorsal cups and several thousand isolated plates, stems, and attachment devices have been collected from the Platteville and Decorah of the Twin Cities area. Most early studies were published by Sardeson (1899, 1908, 1925, 1928, and 1939a) whose work was highly innovative in several respects. He speculated on evolution, paleobiology, and paleoecology at a time when most other works were preoccupied with descriptive taxonomy, and proposed a novel classification for crinoid holdfasts. Unfortunately Sardeson's caustic personality prevented his work from having the influence that it deserved. Ulrich (1886a) described *Cremacrinus punctatus*. Fenton (1929a, b) illustrated a cincinnaticrinid and some lichenocrinid holdfasts, and Kesling and Paul (1968) proposed *Porocrinus elegans*. The crinoids from the Twin Cities were recently monographed by Brower and Veinus (1978). The purpose of this paper is to discuss the biostratigraphy, biogeography, and paleoecology of the crinoids. Table 16.1 lists the stratigraphic distribution of the taxa in terms of Sardeson's beds. These are related to the standard Ordovician nomenclature as follows: Bed 1, Mifflin and Pecatonica Members of the Platteville Formation. Bed 2, Hidden Falls and Magnolia Members of the Platteville Formation. Bed 3, Carimona Member of the Platteville and Spechts Ferry of the Decorah. Beds 4, 5, and 6, Decorah Shale. Brief study of Table 16.1 shows the presence of several strikingly different faunas which are discussed here from oldest to youngest.

HIDDEN FALLS MEMBER

Almost all crinoids from Sardeson's bed 2 were found on a single bedding plane in the Johnson Street Quarry. Four crinoid species are present in this fauna which is dominated by *Cremacrinus arctus* and lichenocrinid holdfasts (Table 16.1). *C. arctus* and *Cupulocrinus gracilis* are common in the Platteville of Wisconsin, Illinois, and Iowa. The cupulocrinid was originally reported from the Trenton of New York. Although this assemblage exhibits the strongest affinities with the Platteville of adjacent states, there are also links with crinoids from the northern Appalachians.

The crinoids occur together with the starfish *Protopalaeaster narrawayi*, edrioasteroids, cystoids, articulate brachiopods, graptolites, bryozoans and some molluscs. The matrix consists of fine-grained dolomitic limestone. Specimens, such as brachiopods, are commonly preserved in living orientation. The starfish lived with the food grooves down, disk exposed, and the arm tips under the sediment. *Cremacrinus arctus* had a non-functional hinge, and the cup was partially buried in the substrate with the arms spread horizontally to form a collecting bowl (Fig. 16.1). The fine-grained sediment and specimens in living position indicate that the water was mostly quiet. This is consistent with the immovable hinge and the feeding orientation of the cremacrinid designed for catching a vertical rain of food particles. Slow sedimentation rates probably prevailed when the animals were alive. The occurrence of many complete echinoderms and specimens in living position suggests catastrophic burial, and the fauna is believed to be a consensus assemblage.

CARIMONA MEMBER

A small slab of calcarenite contains several specimens of *Cupulocrinus jewetti*. This animal is a wide-range protean form, which

has been observed in the Dunleith of Illinois, the Decorah of Minnesota and Iowa, the Trenton of New York and Ontario, the Curdsville Limestone of Kentucky, and the Upper Ordovician Brainard Shale of Iowa. The nature of the sediment suggests an agitated habitat.

DECORAH SHALE

In Sardeson's beds 4, 5, and 6, of the group *Cupulocrinus jewetti*, *Grenprisia billingsi*, *Palaeocrinus angulatus*, and *Isotomocrinus tenuis*, all are shared with the Ottawa Limestone of Ontario and Quebec, two with the Curdsville Limestone of Kentucky, and two with the Dunleith or Decorah of Illinois, Iowa, and Wisconsin. *Porocrinus pentagonius* is also found in the Platteville and Galena of Iowa and Illinois. *Cremacrinus punctatus* is widely distributed in the Midcontinent, being known from the Decorah of Iowa, Minnesota, and Wisconsin, the Trenton of Michigan, and the Lebanon Limestone of Tennessee. *Carabocrinus dicyclicus* and *C. magnificus* are confined to the Decorah of the Twin Cities and nearby parts of Wisconsin. *Glyptocrinus tridactylus*, *Pycnocrinus sardesoni*, *P. multibrachialis*, *Periglyptocrinus spinuliferus*, and *Cupulocrinus canaliculatus* are endemic to the Twin Cities. However, similar crinoids are known from the Ottawa Limestone of Canada (five taxa), the Curdsville Limestone of Kentucky (one species), the Galena Group of Illinois (one form), and the Platteville Limestone of Illinois and Iowa (one species). Thus, the Decorah fauna of the Twin Cities has its strongest affinities with the Canadian assemblages and is less similar to the crinoids of neighboring regions in the United States.

The crinoids, cystoids and other echinoderms are found in bioclastic limestone or calcareous shale. The main fossil constituents are brachiopod shells and fragmented echinoderms and bryozoans. The typical bryozoans are branching massive twig-like and sheet-like colonies that were erect and probably rigid during life. A few encrusting and hemispherical skeletons are present. The sediment ranges from coarse-grained calcite, largely organic in origin, to clay. Many of the ramose bryozoans are aligned. The sediment textures, the disarticulated echinoderms, and the aligned bryozoans and their colony types indicate that the habitat was strongly agitated at times. During the agitated intervals, the seafloor was unconsolidated and fossil fragments and sediment particles were actively transported. The finer sediment was presumably deposited during intervals of relatively quiet water.

The most common type of crinoid preservation is the form of isolated plates and short stem segments, whereas dorsal cups and crowns are rarely found. Relatively complete specimens are attributed to rapid burial under piles of debris. Although suitable burial conditions were uncommon, the Decorah crinoids are moderately diverse and 16 species and 6 types of rooting devices can be counted, in contrast to the 4 taxa of the older Hidden Falls assemblage. The Decorah fauna is dominated by filter-feeders. The highly agitated environment obviously provided the animals with a continuous supply of food and dissolved oxygen.

Broken bryozoans provided favorable attachment sites on an unstable and shifting substrate for many crinoids with lobate, digitate, and other kinds of holdfasts. Carabocrinids cemented their disk-shaped roots to hardgrounds, bryozoan colonies, and tops of fossil debris on the seafloor. Several other holdfasts were cemented to or rooted in the sediment. All in all, the agitated habitat of the Decorah represented a more favorable area for crinoids than did the quiet-water environs of the underlying Hidden Falls.

Table 16.1. Range chart of Twin Cities crinoids.

	Bed 1	Bed 2	Bed 3	Bed 4	Bed 5	Bed 6
Archaeocrinus sp.				■		
Glyptocrinus tridactylus					■	
Pycnocrinus sardesoni					■	
P. multibrachialis						■
Periglyptocrinus spinuliferus				■		
Unknown camerate crinoid		■				
Cupulocrinus gracilis						
C. jewetti					■	
C. canaliculatus				■		
Grenprisia billingsi						
Carabocrinus dicyclius						■
C. magnificus						■
Palaeocrinus angulatus					■	
Porocrinus pentagonius					■	
P. elegans					■	
Isotomocrinus tenuis					■	
Unknown cincinnaticrinid		■				
Cremacrinus arctus						
C. punctatus						
Lichenocrinid holdfasts		■				
Tree-stump cirrus root						
Stem with grasping cirri on bryozoan						
Massive conical attachment disk						■
Lobate and digitate holdfasts cemented to bryozoans				■		

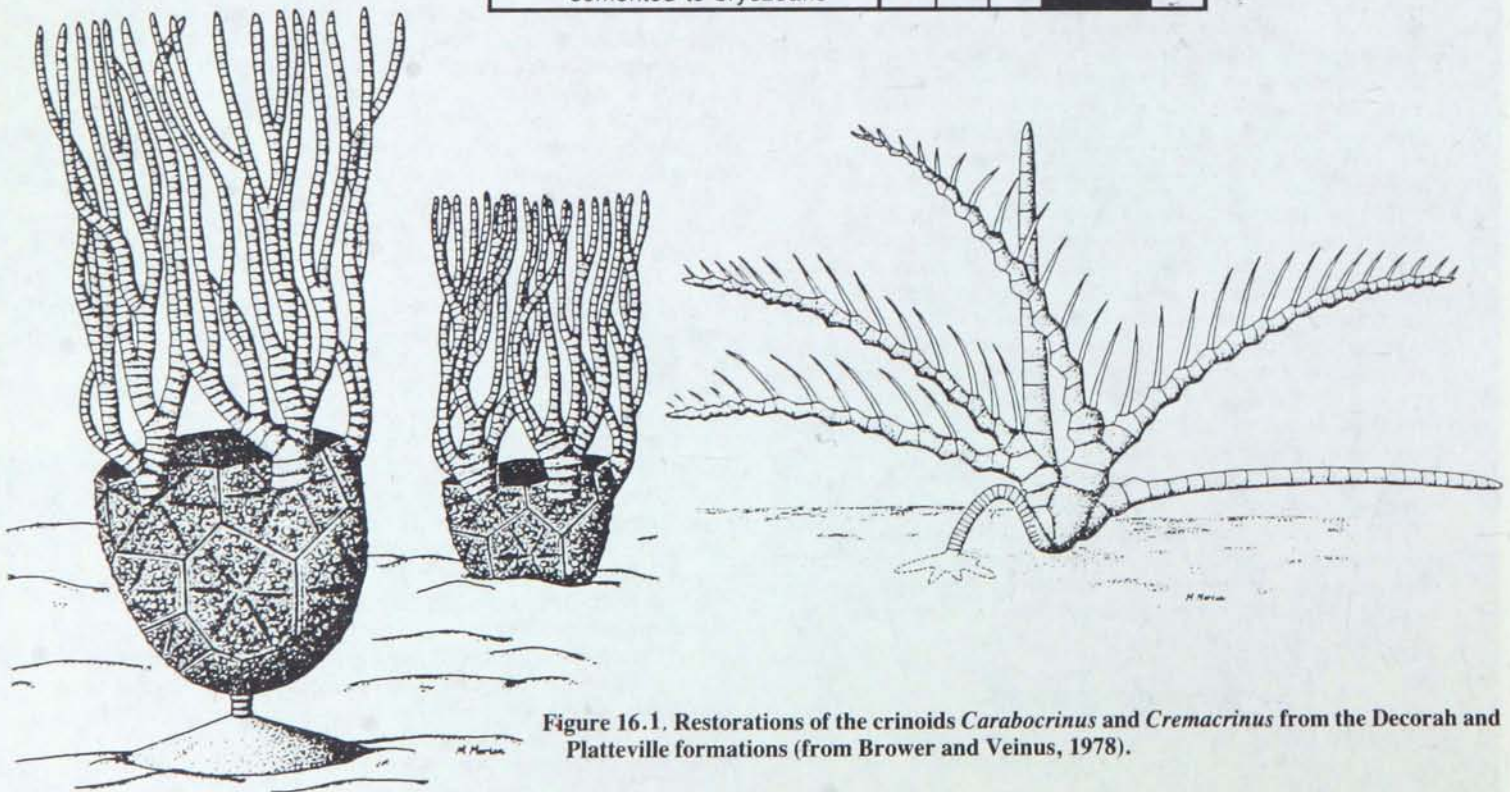


Figure 16.1. Restorations of the crinoids *Carabocrinus* and *Cremacrinus* from the Decorah and Platteville formations (from Brower and Veinus, 1978).

UPPER MISSISSIPPI VALLEY CHAMPLAINIAN AND CINCINNATIAN ECHINODERMS

Dennis R. Kolata¹, James C. Brower², and Terrence J. Frest³¹Illinois State Geological Survey
Champaign, IL 61820²Heroy Geology Laboratory, Syracuse University
Syracuse, NY 13244³Burke Museum, University of Washington
Seattle, WA 98195

Echinoderms belonging to at least 10 classes are a numerically and volumetrically significant part of Middle and Upper Ordovician (Champlainian-Richmondian) invertebrate faunas of the Upper Mississippi valley region. Sizable faunas are now known from the Platteville of Illinois, Iowa, Minnesota, and Wisconsin; Decorah of Illinois, Minnesota, and Wisconsin; Galena (Buckhorn, Eagle Point, and Sherwood Members) of Illinois, Iowa, Minnesota, and Wisconsin; and Maquoketa (Fort Atkinson and Brainard Members) of Iowa. Crinozoans are dominant but locally blastozoans and homalozoans are equally important. Greatest diversity is in dicyclic and monocyclic inadunate crinoids. Strong endemism is characteristic at the species level in each fauna, but a few major exceptions permit correlation with the echinoderm faunas of other areas in North America.

Platteville, Decorah, and lower Galena Group (Blackriveran-

Trentonian) echinoderm faunas show greatest overall resemblance to those of the Ottawa Formation (Trentonian) of Ontario, but also share strong affinities with that of the Trentonian Curdsville Member of the Lexington Limestone of central Kentucky. Even Platteville (Blackriveran) faunas are more closely similar to Trentonian faunas of Canada than to more nearly contemporaneous Blackriveran faunas of the Bromide Formation (Oklahoma) and Benbolt Formation (Virginia, Tennessee). Maquoketa (Richmondian) faunas are a mixture of subequal endemic, Cincinnati area, and Girardeau Limestone (Missouri-Illinois) components. Despite their similarity to each other in age and facies, the Iowa Fort Atkinson and Missouri Kimmswick faunas share almost no species.

Except for a few crinoid and rhombiferan taxa, species ranges are short and assemblages from each member with a large fauna are easily distinguishable. Little endemism of each unit is noted within the Upper Mississippi valley.

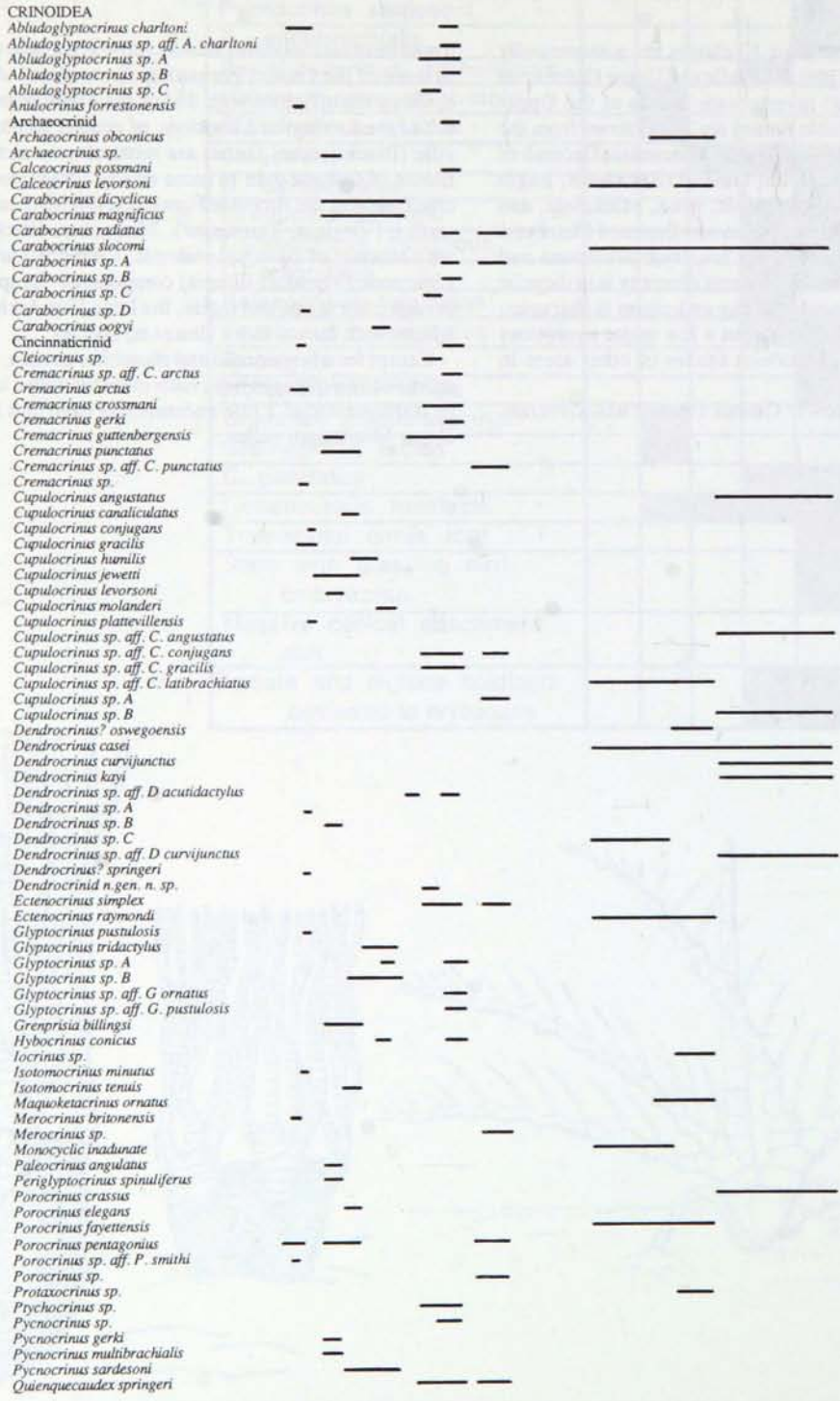
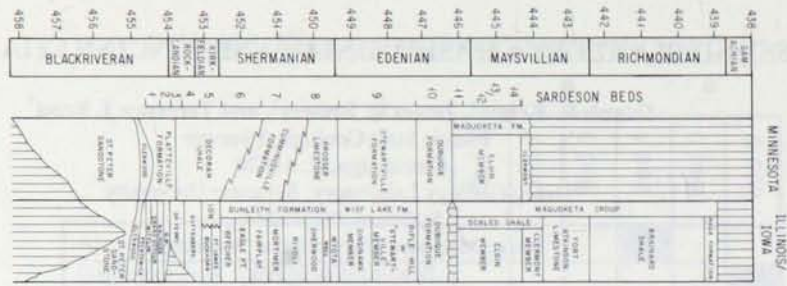


Figure 16.2. Stratigraphic occurrences of echinoderms in the Middle and Late Ordovician rocks of the Upper Mississippi valley region.

ORDOVICIAN PELECYPODS FROM THE UPPER MISSISSIPPI VALLEY

John Pojeta, Jr.

U.S. Geological Survey
Washington, D.C. 20560

Few monographic taxonomic studies of Ordovician pelecypods from the Upper Mississippi valley have been made in the 20th Century (Ladd, 1929). The major monographs about the Ordovician pelecypods from this area were by Ulrich (1890a,b,c; 1892a,b; 1894a) and Sardeson (1892a,c; 1896b). Ulrich (1894a) included references to all the highly scattered literature produced by previous workers. Subsequent works by Sardeson (1902, 1924, 1939b,c), Bayer (1967), and Snyder and Bretsky (1971), are devoted largely to paleoecological studies.

Bassler (1915) listed 137 species names for Ordovician pelecypods from Minnesota, Wisconsin, Iowa, and Illinois. To this list, one new species name was added by Ladd (1929). By 1915, all of the larger scale lithostratigraphic units in the area had been named and defined, and Bassler gave occurrences in terms of the St. Peter, Platteville, Decorah, Prosser, Galena, and Maquoketa formations as those units were understood at that time. He is the most recent worker to try to place the Ordovician pelecypods in the stratigraphic framework of the area.

It is most unlikely that 138 species names are required for Ordovician pelecypods of the Upper Mississippi valley. I have assembled most of the previously described specimens from this area, both types and figured specimens, and thus have been able to compare the nomenclatural standards for the various species. Where possible, stratigraphic information is taken from museum labels; where this is not possible, it is taken from Bassler (1915). Figures of species of all genera listed below can be seen in Pojeta (1962, 1966, 1971, 1978) and Pojeta and Runnegar (1985).

As an example of overzealous splitting, the species *Cyrtodonta huronensis* Billings (1858) has four probable synonyms from the Upper Mississippi valley, and seven other probable synonyms from other eastern North American cratonic outcrop areas: (1) *C. affinis* Ulrich (1894), Decorah Shale, 6 miles south of Cannon Falls, Minnesota; (2) *C. affinis fillmorensis* Ulrich (1894), Prosser Limestone, near Wykoff, Fillmore County, Minnesota; (3) *C. billingsi* Ulrich (1894), Platteville Formation, Cannon Falls, Minnesota, and Dunleith, Illinois; and (4) *C. janesvillensis* Ulrich (1894), Platteville Formation, Janesville and Beloit, Wisconsin. The seven probable synonyms of *C. huronensis* outside the Upper Mississippi valley are for specimens from New York, Ontario, and Kentucky. Numerous other examples of unduly enthusiastic species naming can be provided.

The type and figured specimens kindly lent to me by various United States, Canadian, and British institutions will allow modern concepts of population variation to be applied to the taxonomy and nomenclature of Ordovician pelecypods. This in turn will allow more meaningful biostratigraphic and paleobiologic studies to be carried out using these fossils.

Because the study of Upper Mississippi valley Ordovician pelecypods has not kept pace with the study of the Ordovician stratigraphy of the area, it is exceedingly difficult to relate stratigraphic occurrences noted in the old literature, or information on museum labels, to the complex modern stratigraphic nomenclature (Weiss and Bell, 1956; Karklins, 1969; Austin, 1972; Witzke, 1980; and Sloan, herein). Many formation names used by Bassler (1915) are now lithostratigraphic groups; other formations are now divided into several members. What is needed is to return to classical productive localities and to collect the pelecypods using modern stratigraphic and environmental frameworks.

OCCURRENCES OF GENERA

The oldest pelecypods in the Upper Mississippi valley occur in the St. Peter Sandstone of Whiterockian-Blackriveran age (Ross and others, 1982). Sardeson (1896b) was the only person to study St. Peter pelecypods in detail, and all his localities are from a small area of

St. Paul, Minnesota. None of the known specimens is well preserved, only one is articulated, and all occur in clean, friable to iron-cemented sandstone. All known taxa are readily interpreted as infaunal to semi-infaunal. The three subclasses represented by six genera are (1) Palaeotaxodonta—*Deceptrix* and *Psilococoncha*; (2) Pteriomorpha—*Cyrtodonta*; and (3) Isofilibranchia—*Modiolopsis*, *Orthodesma*, and *Goniophora*?

Most of the pelecypods listed from the Platteville Formation were collected at Minneapolis or Cannon Falls, Minnesota, and Beloit, Janesville, and Mineral Point, Wisconsin. A few specimens were collected from isolated localities in Illinois. The most diverse group of pelecypods in the Platteville is the semi-infaunal to epifaunal pteriomorphs placed in the genera *Ambonychiopsis*, *Cleionychia*, *Cyrtodonta*, *Cyrtodontula*, *Sphenolium*, and *Vanuxemia*. The infaunal paleotaxodonts are poorly known and show little diversity in the Platteville. Semi-infaunal isofilibranchs are known only from the species *Eurymya plana* (Hall). The genera *Endodesma* and *Whiteavesia* are of uncertain higher taxonomic placement.

All pelecypods listed from the Decorah Shale are from various localities in Minnesota, including Chatfield, Minneapolis, Cannon Falls, St. Paul, Preston, and Fountain. The fauna is not dominated in diversity by any one subclass of pelecypods. The infaunal paleotaxodonts are represented by the genera *Ctenodonta*, *Similodonta*, *Deceptrix*, *Tancrediopsis*, and *Palaeoneilo*. Pteriomorphs are represented only by semi-infaunal genera—*Cyrtodonta*, *Cyrtodontula*, *Plethocardia*, and *Vanuxemia*. The semi-faunal isofilibranchs are *Colpomya*, *Modiolodon*, *Modiolopsis*, and *Orthodesma*. The subclass Heteroconchia appears in the local section for the first time in the Decorah, and is represented by the single infaunal genus *Lyrodesma*. The genus *Aristerella* also occurs in the Decorah, but its higher systematic position is uncertain.

The pelecypod fauna of the Prosser Limestone is the most diverse of any Ordovician formation of the Upper Mississippi valley. All five subclasses of pelecypods are first known from the Prosser in this area. Almost all pelecypods known from this formation were collected from various localities in Minnesota, particularly Cannon Falls, Spring Valley, Wykoff, and Fountain. A few specimens were collected in Illinois and Iowa. Semi-infaunal and epifaunal pteriomorphs are the most diverse group in the Prosser; the known genera are *Ambonychiopsis*, *Cleionychia*, *Cyrtodonta*, *Cyrtodontula*, *Plethocardia*, *Prolobella*, *Sphenolium*, and *Vanuxemia*. Infaunal paleotaxodonts are represented by the genera *Nuculites*, *Similodonta*, *Deceptrix*, and *Ctenodonta*. Isofilibranchs in the Prosser are *Modiolodon*, *Modiolopsis*, and *Orthodesma*. Heteroconchs are known only from the genus *Lyrodesma*. The subclass Anomalodesmata appears in the local section for the first time, and is known from the infaunal genera *Cuneamyia* and *Rhytimya*. *Endodesma*, *Matheria*, *Saffordia*, and *Allodesma*, also present in the Prosser, are of uncertain higher taxonomic position.

Six species, placed in six genera, have been described from what Bassler (1915) called the Galena Dolomite of Dodgeville, Wisconsin; Mount Carrol, Dixon, and Scales Mound, Illinois; and Dubuque, Iowa. These are the paleotaxodont *Similodonta*, pteriomorphs *Cyrtodonta* and *Vanuxemia*, isofilibranch *Orthodesma*, anomalodesmatan *Cuneamyia*, and the genus *Endodesma* of uncertain higher taxonomic position.

Maquoketa Formation pelecypods are known from scattered localities in Illinois, Minnesota, Wisconsin, and Iowa. Anomalodesmatans and heteroconchs are not known from the Maquoketa. Pteriomorphs are represented by species of the epifaunal and semi-infaunal genera *Ambonychia*, *Cyrtodonta*, *Cyrtodontula*, and "*Pterinea*." Paleotaxodonts are also diverse, and are known from the genera *Nuculites*, *Palaeoneilo*, and *Similodonta*. Isofilibranch genera are *Modiolopsis* and *Orthodesma*. *Saffordia*, a genus of uncertain higher taxonomic position, also occurs in the Maquoketa.

STRATIGRAPHIC RANGES OF MIDDLE AND LATE ORDOVICIAN GASTROPODA AND MONOPLACOPHORA OF MINNESOTA

Robert E. Sloan¹ and Gerald F. Webers²

¹Department of Geology and Geophysics, University of Minnesota
Minneapolis, MN 55455

²Department of Geology, Macalester College
St. Paul, MN 55105

Although the taxonomy of the Middle and Late Ordovician gastropods of Minnesota is reasonably up to date, that of the monoplacophorans is not. Ulrich and Scofield's 1895 monograph is still the current standard on snails at both the generic and specific level—the more recent *Treatise on Invertebrate Paleontology, Volume I*, by Knight and others (1960) did not really modify the 1895 work. Monoplacophoran taxonomy, however, is another story. The *Treatise* classification is woefully coarse, and many new genera need to be described. Webers is in the process of reviewing the monoplacs, based on the foundation of his work on Cambrian forms. He finds that the monoplacs have been overdescribed at the species level and lumped at the generic level, and he will redescribe the 109 specimens elsewhere.

The present chart (Fig. 17.1) is based on a review of the Sardeson Collection at the University of Minnesota, Weiss (1953), Ulrich and Scofield (1895), the unpublished work of Leverson and Gerk, and the list in Stauffer and Thiel (1941). We have translated the stratigraphic nomenclature of description to conform with current terminology as closely as possible. The result is a chart which identifies more precisely than before the ranges of these taxa. For convenience

we have also included the generic ranges given above by Pojeta. Cephalopods are charted separately in the note by Catalani below. Chitons, rostroconchs and scaphopods are insufficiently known, and so they are not plotted at all. Sloan does not know of any occurrence in the region in the rocks in question.

Many species terminate within the Sinsinawa Member of the Stewartville Formation at horizons not currently known, and probably not at the same horizon for all Taxa. These have been plotted as if they became extinct in the middle of the Sinsinawa. Of all gastropod taxa in the Platteville Formation below the Deicke K-bentonite, 80 percent had geographic ranges included entirely within the fall of that ash and became extinct. The largest number of snail species within these rocks occurs in the Prosser Limestone (current usage), but the Cummingsville is not far behind. Most of these species became extinct as a result of the shoaling during deposition of Sinsinawa strata recorded by the abundant corrosion zones or hardgrounds. Upper Stewartville strata are dominated by a few species of snails that lived under very harsh conditions. Gastropod faunas of the Maquoketa Formation above the Elgin Member are poorly known in Iowa and are omitted.

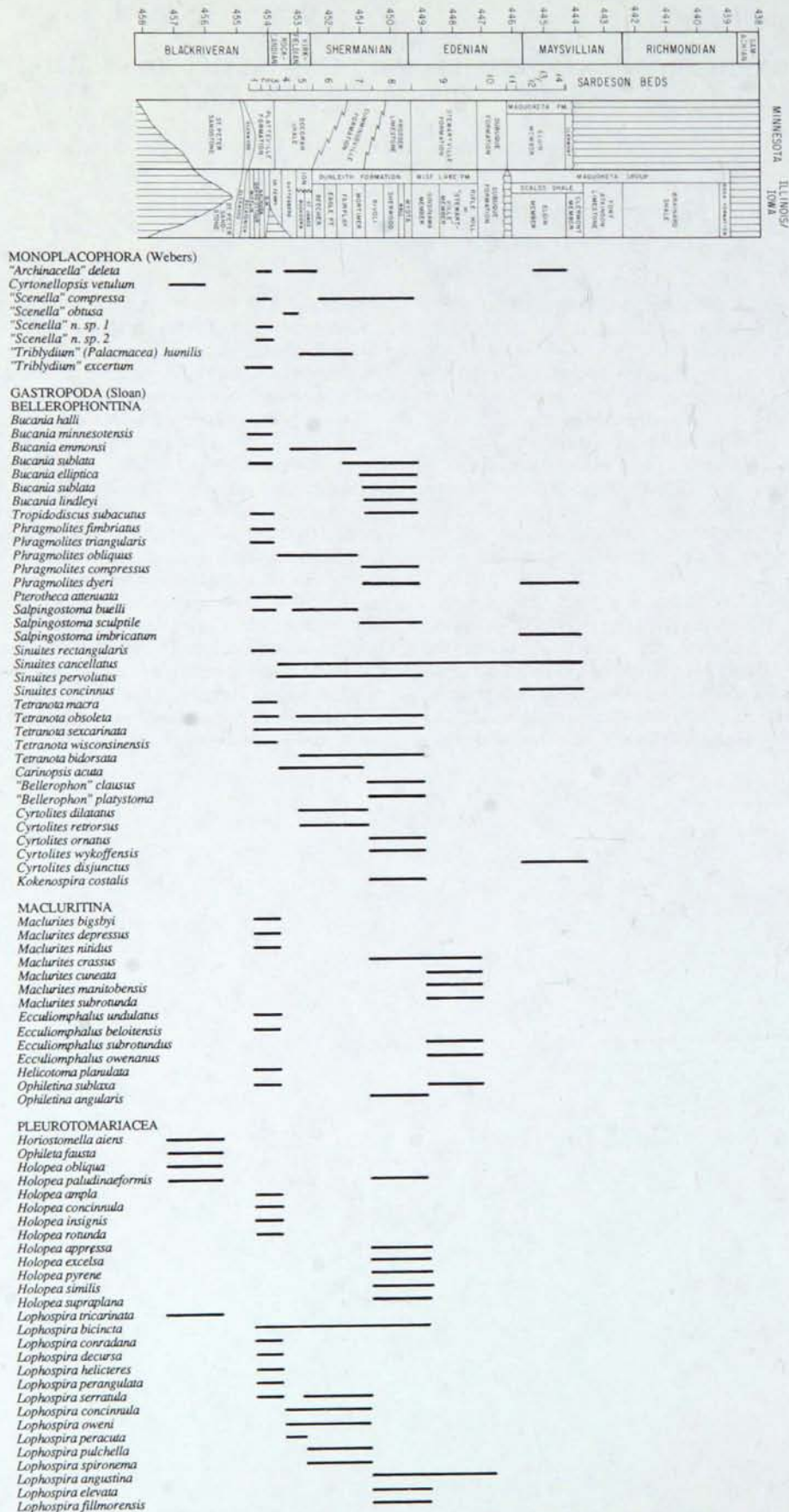


Figure 17.1. Stratigraphic occurrences of Monoplacophora, Gastropoda and Bivalvia in the Upper Mississippi valley region.

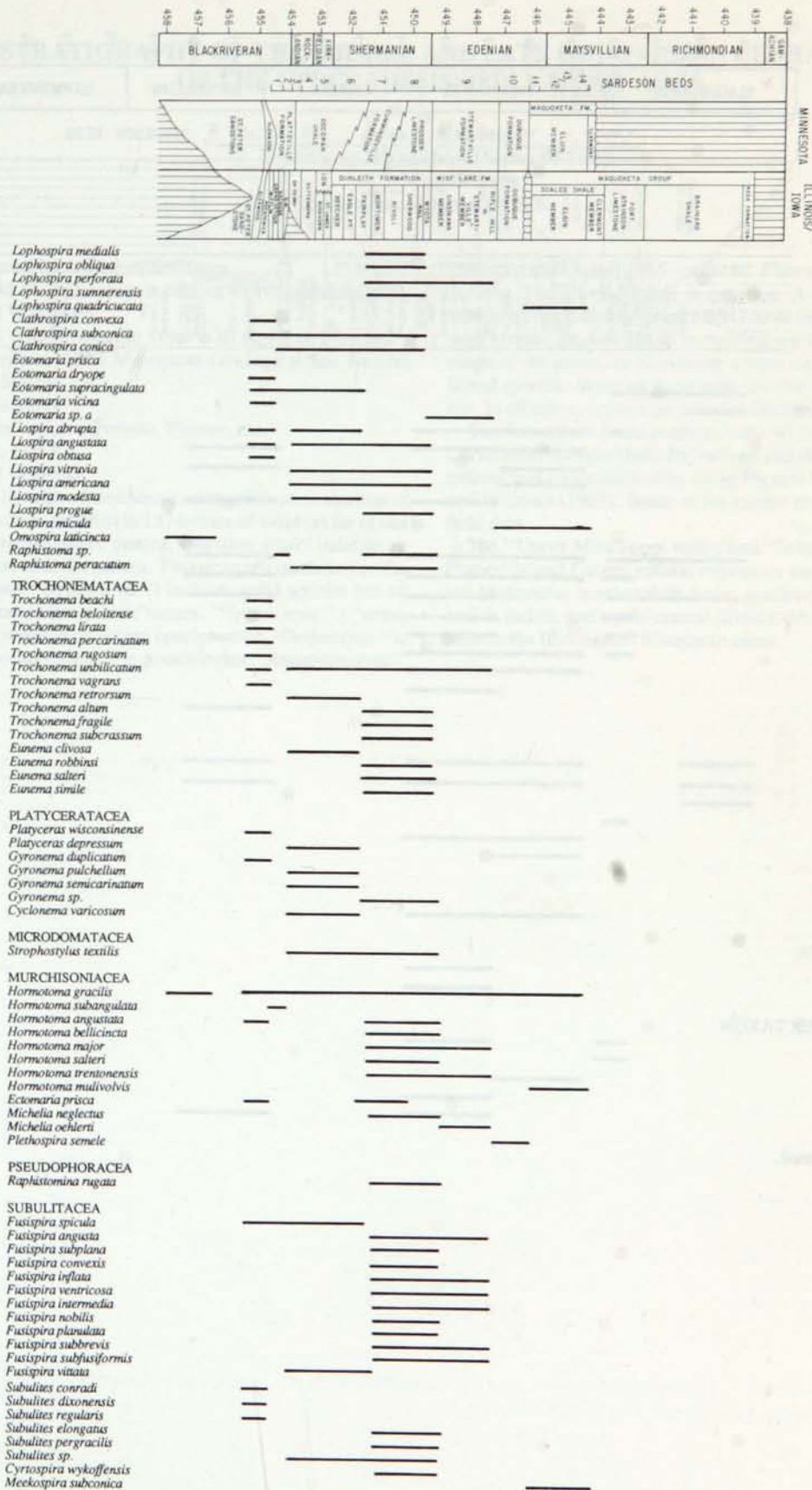
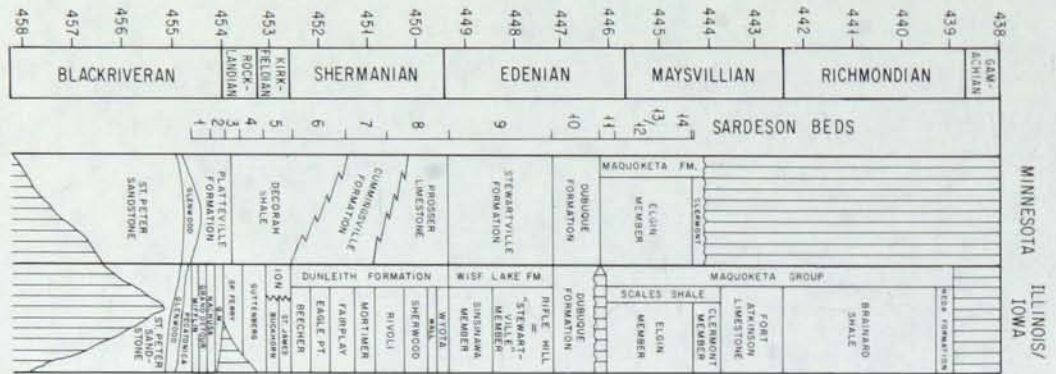


Figure 17.1 continued.



PALEOTAXODONTA

- Deceptrix*
- Psiloconcha*
- Ctenodonta*
- Similodonta*
- Palaeoneilo*
- Tancrediopsis*
- Nuculites*

PTERIOMORPHA

- Cyrtodonta*
- Cyrtodontula*
- Ambonychiopsis*
- Cleionychia*
- Sphenolium*
- Vanuxemia*
- Plethocardia*
- Prolobella*
- "Pterinea"*

ISOFILIBRANCHIA

- Modiolopsis*
- Orthodesma*
- Goniophora*
- Eurymya plana*
- Modiolodon*
- Colpodon*

HETEROCONCHIA

- Lyrodesma*

ANOMALODESMATA

- Cuneamya*
- Rhytimya*

UNCERTAIN HIGHER TAXON

- Endodesma*
- Whiteavesia*
- Aristerella*
- Matheria*
- Saffordia*

Figure 17.1 continued.

BIOSTRATIGRAPHY OF THE MIDDLE AND LATE ORDOVICIAN CEPHALOPODS OF THE UPPER MISSISSIPPI VALLEY AREA

John A. Catalani

Community High School District 99 South
1436 Norfolk Street
Downers Grove, IL 60516

The list in Figure 17.2 was compiled from:

- (1) Whitfield's (1882) report in volume 4 of Chamberlin's Geology of Wisconsin
- (2) Clarke's (1897) report in volume III part 2 of Winchell's Final Reports of the Minnesota Geological and Natural History Survey
- (3) Bassler's Index
- (4) Individual articles (Foerste, Flower, etc.)
- (5) Treatise, Part K
- (6) Personal field data

A search of the literature listed above, along with an evaluation of my personal collection, resulted in 137 entries of valid (as far as can be determined) species and/or genera. Question marks indicate an author's uncertainty as to the genera. Two genera in quotation marks ("Spyroceras" and "Orthoceras") indicate valid species but no subsequent revision of the generic names. "Spyroceras" ("sensu stricto") is now limited to Devonian species while "Orthoceras" is restricted to European forms. It is possible that "Anaspyroceras"

(Shimizu and Obata, 1935, emmend. Flower, 1943) replaces "Spyroceras" for those species in question. A generic name followed simply by sp. indicates genera that I have found and cannot identify with known species. I have included them to indicate the complete range of the genus, or to indicate a form not comparable with published species. Some of these may involve more than one species. but, in all cases, represents actual collections that I have made.

The formations listed conform with Willman and Kolata (1978). Correlation between these formations and older stratigraphic designations was accomplished by using Figures 16 and 19 of Templeton and Willman (1963). Some of the entries are based on my personal field data.

The "Upper Mississippi valley area" is meant to include relevant Platteville and Galena natural exposures and quarries in southeastern Minnesota, northeastern Iowa, southwestern Wisconsin as far east as Beloit, and north-central Illinois. Most of my collecting has been in the Illinois and Wisconsin areas.

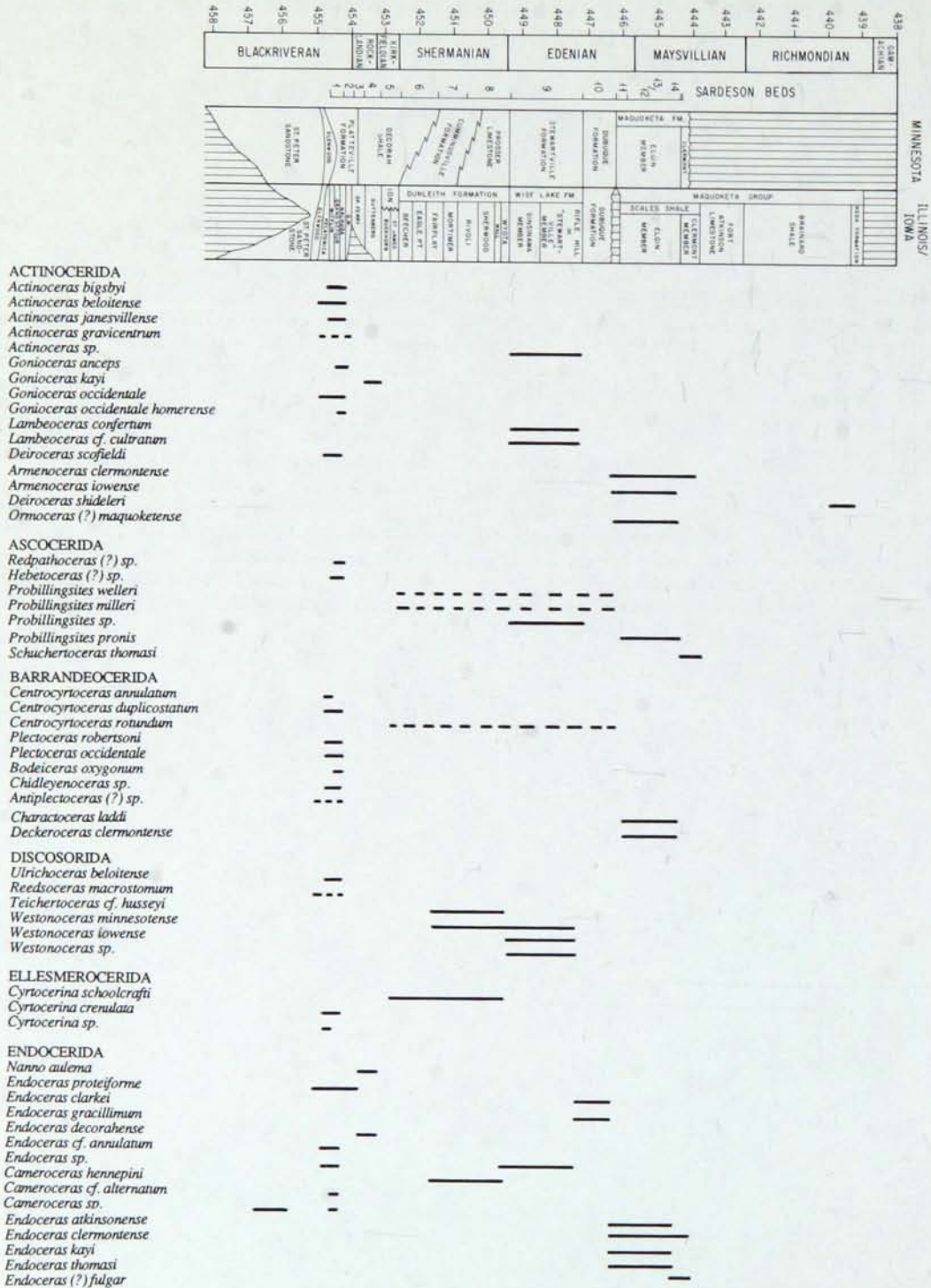
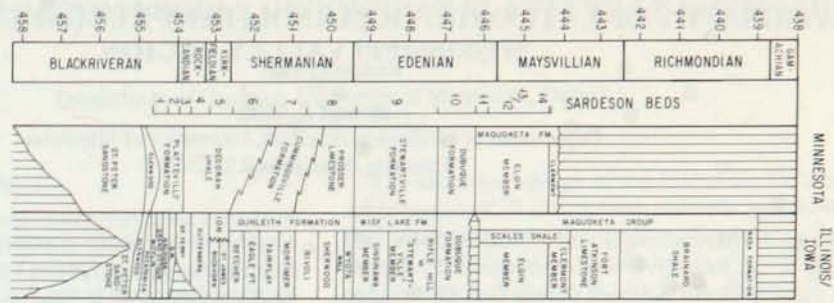


Figure 17.2. Stratigraphic occurrences of Cephalopoda in the Middle and Late Ordovician rocks of the Upper Mississippi valley region.



ONCOCERIDA

- Oncoceras abruptum*
- Oncoceras tetraevillense*
- Oncoceras douglassi*
- Beloitoceras pandion*
- Beloitoceras plebeium*
- Beloitoceras lycum*
- Beloitoceras janessvillense*
- Beloitoceras carveri*
- Beloitoceras norwoodi*
- Beloitoceras houghtoni*
- Beloitoceras cf. huronense*
- Richardsonoceras simplex*
- Richardsonoceras beloitense*
- Richardsonoceras romingeri*
- Richardsonoceras (?) clarkii*
- Richardsonoceras (?) scofieldi*
- Diesticeras alceum*
- Diesticeras clarkii*
- Diesticeras sp.*
- Zitteloceras beloitense*
- Zitteloceras clarkeanum*
- Zitteloceras scofieldi*
- Zitteloceras percurvatum*
- Zitteloceras (?) brevicurvatum*
- Zitteloceras (?) tenuistriatum*
- Manitoulinoceras neleum*
- Manitoulinoceras (?) warsawense*
- Manitoulinoceras (?) wykoffense*
- Kentlandoceras husseyi*
- Kentlandoceras cf. schrocki*
- Cyrtorizoceras minneapolis*
- Staufferceras featherstonhaughi*
- Scofieldoceras shumardi*
- Scofieldoceras (?) depressum*
- Fayetteoceras (?) beloitense*
- Tripteroceras planoconvexum*
- Tripteroceras oweni*
- Tripteroceras scofieldi*
- Allumetoceras planodorsatum*
- Allumetoceras cf. planodorsatum carletonense*
- Loganoceras sp.*
- Valcouroceras sp.*
- Beloitoceras grafense*
- Beloitoceras whitneyi*
- Beloitoceras (?) discrepans*

ORTHO CERIDA

- Whiffieldoceras mumiaforme*
- Whiffieldoceras clarkii*
- Whiffieldoceras minimum*
- Whiffieldoceras cf. exiguum*
- Anaspyroceras anellus*
- Metaspyroceras minneapolis*
- Metaspyroceras perlineatum*
- Metaspyroceras clarkii*
- Metaspyroceras (?) wisconsinense*
- Metaspyroceras (?) nicolleti*
- "Spyroceras" lesueuri*
- "Spyroceras" cylindratum*
- "Spyroceras" scofieldi*
- Polygrammoceras prestonense*
- Geisonoceras scofieldi*
- Michelinoceras multicameratum*
- Michelinoceras sp.*
- Kionoceras decorahense*
- Kionoceras sp.*
- "Orthoceras" beltrami*
- "Orthoceras" junceum*
- Gorbyoceras sp.*
- Ephippiorthoceras sp.*
- Whiteavestites sp.*
- Anaspyroceras calvini*
- Anaspyroceras clermontense*
- Anaspyroceras perroti*
- Ephippiorthoceras laddi*
- Ephippiorthoceras tenuistriatum*
- Geisonoceras (?) clermontense*
- Isorthoceras sociale*
- Kionoceras postvillense*
- Kionoceras tenuitectum*
- Kionoceras thomasi*
- Polygrammoceras sp.*

Figure 17.2 continued.

BIOSTRATIGRAPHY OF LATE ORDOVICIAN SOLITARY RUGOSE CORALS IN THE UPPER MISSISSIPPI VALLEY REGION

Robert J. Elias

Department of Geological Sciences, University of Manitoba
Winnipeg, Manitoba R3T 2N2

Solitary Rugosa of the Maquoketa Group in Illinois, Iowa, and Minnesota belong to the Red River-Stony Mountain Province, which occupied most of North America during Late Ordovician time. Within this province, a *Grewingkia*-dominated assemblage is succeeded by a *Salvadorea*-dominated assemblage. This change occurred in the early-mid Maysvillian in New Mexico-Texas and early-mid Richmondian in the Williston and Hudson Bay basins. The *Salvadorea*-dominated assemblage ranges into late Richmondian strata in those areas. An evolutionary change in *Bighornia* occurred at approximately the same time. The ancestral species ranges into the early Maysvillian in New Mexico-Texas and is known from mid Maysvillian strata in the Williston basin. The descendant, *B. patella*, occurs in mid-late Richmondian strata in those areas and in the Hudson Bay basin.

Within the Maquoketa Group, *Grewingkia* n. sp. is common in the upper Elgin Member of the Maquoketa Formation in southeastern Minnesota. It is likely Maysvillian to perhaps early Richmondian in age. A specimen that is probably from the Clermont

Member of the Scales Formation in northeastern Iowa represents *Salvadorea randi*, a species known from mid Maysvillian and mid Richmondian strata in the Williston basin. *B. patella* occurs in the Fort Atkinson Formation of northeastern Iowa, suggesting a Richmondian age. *S. randi* is present in the Brainard Formation in northeastern Iowa and northwestern Illinois, and the Orchard Creek Member of the Scales Formation in southern Illinois. Those units are considered to be Richmondian.

Red River-Stony Mountain solitary Rugosa of the Maquoketa Group are succeeded by a *Streptelasma*-dominated assemblage representing the Edgewood Province, which occupied the east-central United States from Gamachian to earliest Silurian time. In the Mississippi valley, these corals occur in the Leemon Formation (Gamachian) of southern Illinois and southeastern Missouri; the Noix Limestone (Gamachian), Bryant Knob Formation (early Llandovery), and Cyrene Formation (Gamachian to early Llandovery) of northeastern Missouri; and the lower Mosalem Formation (?Gamachian, early Llandovery) of northwestern Illinois and Iowa.

TRACE FOSSILS FROM MIDDLE ORDOVICIAN PLATTEVILLE FORMATION

Kayo Dokken

Department of Geology, University of Minnesota, Duluth
Duluth, MN 55812

ABSTRACT

Trace fossils within the Middle Ordovician Platteville Formation are numerous, diverse, and moderately well preserved. The Platteville trace fossil assemblage generally conforms with the *Cruziana* ichnofacies. A total of 20 ichnogenera have been identified: *Arenicolites*, *Bifungites*, *Chondrites*, *Conostichus*, *Cylindrichnus*, *Diplichnites*, *Fustiglyphus*, *Gyrolithes*, *Lingulichnus*, *Muensteria*, *Nereites*, *Palaeophycus*, *Planolites*, *Rhizocorallium*, *Rusophycus*, *Subphyllochora*, *Teichichnus*, *Thalassinoides*, (?)*Torrowangea*, and *Trypanites*, as well as three unidentified Problematic forms. Two other ichnogenera, *Skolithus* and *Diplocraterion*, are found in the subjacent St. Peter and Glenwood formations.

The dominant trace fossil association within the Platteville Formation consists of the ichnogenera *Chondrites* and *Planolites*. The isochronous Deicke K-bentonite horizon is typified by seven traces: *Arenicolites*, *Bifungites*, *Chondrites*, *Lingulichnites*, *Thalassinoides*, *Planolites*, and Problematica type I. This association is consistent with shallow marine (about 10 to 20 m) conditions which appear to have been uniform throughout the Hollandale embayment.

The Deicke K-bentonite is calculated to have been compressed from an original 27 cm to the present average 7-cm thickness based on the deformation of *Chondrites* and *Planolites* burrows within the ash bed.

Orientation of *Endoceras* within the Platteville shows a strong northwest-southeast trend. It is suggested that these animals were oriented after death with the long axis of the shell parallel to a current flow to the southeast.

INTRODUCTION

Investigation of the Platteville ichnoassemblage located, identified, and catalogued trace fossils from the Platteville Formation at 28 localities in southeastern Minnesota (Table 19.1). Special emphasis was placed on the Carimona Member and the bedding units containing the Deicke K-bentonite. The isochronous Deicke K-bentonite was used to examine the distribution of ichnofossils and facies along the closest approximation possible to time-equivalent beds. Burrow deformation within the bentonite was used to calculate the original 27-cm thickness of the ash fall.

Both trace fossils and body fossils in the Platteville reflect a relatively high population density and diversity. These fossils are chiefly infaunal suspension feeders, together with some infaunal and fewer epifaunal deposit feeders. The record of epifaunal organisms was less apt to be preserved because of erosion, subsequent bioturbation, and the special requirement of a covering blanket of contrasting rock type. Generally preservation is best where traces were not wholly contained within a single lithology, but rather penetrated and followed along subjacent bedding planes of contrasting lithic type. Where contained within a single lithology, trace fossils are better preserved in thicker, evenly bedded units than in thin, irregular, wavy- or nodular-bedded units.

THE PLATTEVILLE ICHNOASSEMBLAGE

The Platteville ichnoassemblage is generally equivalent to the *Cruziana* ichnofacies of Seilacher (1964a,b, 1967). Characteristic trace fossils in the *Cruziana* ichnofacies include crawling traces, inclined U-shaped burrows, irregular three-dimensional burrow networks having both horizontal and inclined components, and less common vertical cylindrical burrows (Frey and Seilacher, 1980).

The ichnoassemblage of the Platteville Formation includes 23 ichnospecies of 20 ichnogenera and three problematica. The identified ichnogenera are: *Arenicolites*, *Bifungites*, *Chondrites*, *Conostichus*, *Cylindrichnus*, *Diplichnites*, *Fustiglyphus*, *Gyrolithes*, *Lingulichnus*, *Muensteria*, *Nereites*, *Palaeophycus*, *Planolites*, *Rhizocorallium*, *Rusophycus*, *Subphyllochora*, *Teichichnus*, *Thalassinoides*, (?)*Torrowangea*, and *Trypanites*. Two additional ichnogenera, *Diplocraterion* and *Skolithus*, are found in the subjacent St. Peter and Glenwood formations.

DOMINANT ICHNOGENERA

The dominant ichnogenera in the Platteville Formation are *Chondrites* and *Planolites*. *Chondrites* is represented by two equally common ichnospecies differentiated on the basis of burrow diameter. *Planolites* is also represented by two ichnospecies, although only one is common. The three common traces are unrestricted geographically throughout southeastern Minnesota, although *Chondrites* occurs to the exclusion of all other traces including *Planolites* at some horizons. Both ichnogenera have a wide facies range and are believed to have been formed by infaunal deposit feeders that required a substrate soft enough to penetrate, yet cohesive enough so that burrow walls could be unlined.

The two *Chondrites* ichnospecies, which differ from each other in size, typically occur together, although both do occur separately. Simpson (1957), Sellwood (1970), Stasko (1974), and Shourd and Levin (1976) all have noted a similar bimodal size distribution, which was attributed by Simpson and by Shourd and Levin to two species of organisms.

In the Carimona Member of the Platteville a regular association occurs consisting of the ichnogenera *Arenicolites*, *Bifungites*, *Chondrites*, *Lingulichnus*, *Planolites*, *Thalassinoides*, and Problematica type I. This association is also typical of the Deicke K-bentonite horizon.

Bifungites has been reported from (1) intertidal or nearly intertidal Devonian strata in Western Montana (Rodriguez and Gutschick, 1970; Gutschick and Lamborn, 1975); (2) Upper Devonian interbedded shale and siltstone in Ohio and Pennsylvania (Szmuc and others, 1976); (3) Middle Ordovician limestone in Quebec, Canada (Pickerill and Forbes, 1977); (4) a transitional environment between the shoreface zone and the nearshore shelf of Carboniferous strata in Libya (Turner and Benton, 1983); and (5) the *Cruziana* ichnofacies in the Lower Cambrian of Pakistan (Seilacher in Turner and Benton, 1983). *Bifungites* has not been reported from sediments deeper than the shallow subtidal shelf.

Lingulichnus is the burrow of inarticulate linguloid brachiopods (Hakes 1976), a group which has been an important element in the nearshore community since the Ordovician (Bretsky, 1969). Modern *Lingula* (hence *Lingulichnus*) exists in environments from shallow nearshore to deep basin, but *Lingula* finds optimum conditions in the shallow marine environment. After its first appearance in the Platteville stratigraphic record in the lowest bed of the Carimona Member, it rapidly became widely distributed throughout the Hollandale embayment.

Thalassinoides has been described frequently from rocks ranging in age from Mesozoic to the present, mostly from sediments of shallow to intermediate depth. More recently it has been reported from rocks of Early Paleozoic age including Ordovician, e.g., from the Great Basin (Miller, 1977; Sheehan and Schiefelbein, 1984), Saskatchewan and Manitoba (Kendall, 1977), the Canadian Arctic (Morrow, 1978), and Wisconsin (Delgado, 1983a).

Thalassinoides in the Carimona Member consists of a complex three-dimensional burrow system that is predominantly horizontal. Its main shaft ranges in diameter from 0.75 to 2.5 cm with Y and T branches which are considerably smaller, and observed burrow depth ranges from 10 to 25 cm. Sheehan and Schiefelbein (1984) have described Ordovician *Thalassinoides* burrows from fine-grained carbonates of the Great Basin which extended at least 10 cm and possibly 1 to 3 m below the sediment-water interface. It is possible that burrow depths in the Carimona Member could have been as great as the depths observed in the Great Basin.

COMPACTION OF THE DEICKE K-BENTONITE HORIZON AND DEFORMATION OF BURROWS

An estimate of the original thickness of the Deicke K-bentonite prior to compaction was made on the basis of burrow deformation. Burrows parallel to bedding, which characteristically have a circular cross section (such as *Chondrites* or *Planolites*), become elliptical when compressed (Fig. 19.1). If the infill is essentially the same as the surrounding sediment, then the dimension of the two axes of the ellipse can indicate the amount of compaction since the burrow was formed (Crimes, 1975).

Measurements of the two radii of the ellipse are used to calculate decompaction using the formula

$N_d = r_0/r_1$ where N_d = the decompaction number, r_0 = the original radius, and r_1 = the radius of the compacted burrow perpendicular to the bedding (Wetzel and Aigner, 1986).

Twelve burrows (*Chondrites* and *Planolites*) from four locations were observed in the Deicke K-bentonite (Table 19.2). Each burrow displayed deformation, but two were much less elliptical. It was assumed that these two intruded into the bentonite late in the compaction process, and they were not included in the calculation. Using these data, N_d was calculated to be equal to 3.4. An average thickness for the compacted bentonite was calculated based on measurements taken by Majewske (1953), Ford (1958), and Hoefl (1959) at 24 locations; this average was 7.0 cm. Using the formula, the calculated thickness of the wet, uncompacted bentonite was 27.0 cm. This thickness should probably be regarded as a minimum, because some compaction must have occurred prior to the biologic repopulation of the area and the subsequent burrowing.

CEPHALOPOD ORIENTATION

A total of 28 *Endoceras* shells were observed, of which two were from the Pecatonica and two were from the McGregor members. Of the 24 from the Carimona Member, 17 were from the Deicke K-bentonite or from the limestone beds bounding it. The distribution and orientation of these shells are shown in Table 19.3. When plotted on a rose diagram (Fig. 19.2), the orientation of the cephalopods shows strongly bimodal-bipolar distribution northwest-southeast. The data support Bretsky and others (1977) that sediments were washed from west to east in southeastern Minnesota and southern Wisconsin during the period of Platteville deposition.

ACKNOWLEDGMENTS

I would like to thank Dr. David G. Darby for reading and making suggestions to improve this paper and Dr. Gerald F. Webers who accompanied me in the field. Funding was provided in part by the Department of Geology, University of Minnesota, Duluth, as well as grants from Sigma Xi and the Minnesota Geological Survey.

SUMMARY SYSTEMATIC ICHNOLOGY

(Fig. 19.3)

Ichnogenus Arenicolites Salter, 1857

Description: A simple U-shaped burrow without spreiten, essentially perpendicular to bedding. The diameter of the burrow is 0.2 to 0.4 cm, the dis-

tance between limbs is 1 to 1.5 cm, and the height is variable. A few paired circular entrances were noted on bedding plane surfaces.

Classification: Dwelling (domichnia) burrow.

Ichnogenus Bifungites Desio, 1940

Description: Dumbbell-shaped burrows preserved in convex hyporelief consisting of a 0.5-cm-diameter central tube joining two roughly spherical chambers 1.0 cm in diameter; maximum total length of the trace is 4.0 cm.

Classification: Dwelling (domichnia) burrow.

Ichnogenus Chondrites von Sternberg, 1833

Chondrites sp. type I and *C.* sp. type II

Description: A smooth-walled asymmetrical, dendritic burrow system. Interpenetration and interconnection between different burrows is rarely seen. The diameter of the burrows within individual systems remains essentially constant. *Chondrites* sp. type I burrow diameter ranges from 1.0 to 3.0 mm. *Chondrites* sp. type II burrow diameter ranges from 4.0 to 6.0 mm.

Classification: Feeding (fodichnia) and (?)dwelling (domichnia) burrow system.

Ichnogenus Conostichus Lesquereux, 1876

Conostichus sp. type I and *C.* sp. type II

Description: *Conostichus* sp. type I is a conical burrow tapering from 5.0 cm at the top to 2.3 cm at the base with a height of 6.2 cm. The burrow walls are regular, distinct, and possibly lined. *Conostichus* type II is a circular burrow 2.2 cm in diameter terminating in a rounded, not pointed lower end. It is oriented perpendicular to bedding with a remaining height of 5.0 cm, and originally must have extended farther. The wall is unlined and somewhat irregular due to subsequent *Chondrites* burrowing.

Classification: Feeding (fodichnia) and dwelling (domichnia) burrow.

Ichnogenus Cylindrichnus Howard, 1966

Description: Generally tubular, straight to slightly curved burrow with a circular to oval cross section from 1.0 to 2.0 cm in diameter. Orientation varies from slightly inclined to more commonly vertical.

Classification: Dwelling (domichnia) burrow.

Ichnogenus Diplichnites Dawson, 1873

Description: A simple 1.0- to 2.0-cm-wide track consisting of two parallel grooves (epirelief) with the separate grooves radiating out from the direction of motion obliquely and/or a parallel series of two circular imprints.

Classification: Locomotion (repichnia) trail.

Ichnogenus Diplocraterion Torell, 1870

Description: U-shaped burrows with spreiten perpendicular to the bedding plane. The limbs of the tubes are parallel and have a diameter of 0.3 to 0.75 cm and a distance between vertical shafts of 2.0 to 5.0 cm.

Classification: Dwelling (domichnia) burrow.

Ichnogenus Fustiglyphus Vyalov, 1871

Description: Consists of a gently curving tube parallel to bedding 1.0 cm in diameter and 31.5 cm in length which is interrupted at intervals of 2.5 to 4.0 cm by swellings 2.0 cm in diameter, somewhat similar to a string of beads.

Classification: Crawling (repichnia), feeding (fodichnia) or (?) dwelling (domichnia) trace.

Ichnogenus Gyrolithes De Saporta, 1884

Gyrolithes polonicus

Description: Consists of one-half to three-quarters of a complete whorl, the diameter of which ranges from 4.0 to 5.0 cm, whereas the diameter of an individual burrow tube ranges from 1.0 to 1.5 cm. Preserved as convex hyporelief with greater relief distal from the point where the burrow corkscrews out of the base of the bedding unit.

Classification: (?).

Ichnogenus Lingulichnus Hakes 1976 = *Lingulichnites* Szmuc, Osgood, and Meinke 1976

Lingulichnus verticalis

Description: Tongue-shaped to spade-shaped vertical burrows with the widest dimension at the top. The aperture and upper tongue-like part appear very elliptical in transverse section. A basal stem substantially smaller in diameter having a circular cross section may be present. The depth of the burrow reaches at least 7.0 cm.

Classification: Dwelling (domichnia) structure.

Ichnogenus Muensteria von Sternberg, 1833

Description: A walled, unlined, horizontal burrow 0.5 cm in diameter, with distinct meniscate concavo-convex segments 2.0 to 4.0 mm wide. The filling is indistinguishable from the matrix.

Classification: Feeding burrow (fodichnia).

Ichnogenus *Nereites* MacLeay, 1839

Description: Slightly undulating furrow 9.0 cm long, 0.3 cm wide, flanked by nominal lobe-ridges.

Classification: Meandering grazing trail (pascichnia).

Ichnogenus *Palaeophycus* Hall, 1847*Palaeophycus tubularis*

Description: A subcylindrical to cylindrical, lined, infrequently branched, straight to slightly sinuous burrow system, horizontal or at a low angle to the bedding, with thin, smooth, unornamented walls; diameter 0.75 to 1.5 cm. Burrows are infilled with a lithology and texture the same as the host sediment.

Classification: Feeding (fodichnia) burrow.

Ichnogenus *Planolites* Nicholson, 1873*Planolites beverleyensis* and *Planolites montanus*

Description: *P. beverleyensis* is a subcylindrical to cylindrical, unlined, infrequently branched, straight to slightly sinuous, burrow system, horizontal or at a low angle to the bedding. Burrows range from 4.0 to 12.0 cm in length and from 0.5 to 1.0 cm in diameter. *P. montanus* is a small curved cylindrical burrow as much as 2.0 cm in length and less than 0.5 cm in diameter, unbranched. Both types of burrows are infilled with a lithology and texture different from the host sediment.

Classification: Feeding (fodichnia) burrow.

Ichnogenus *Rhizocorallium* Zenker, 1836

Description: A U-shaped burrow with spreiten, oriented parallel or oblique to the bedding plane. Limbs are essentially parallel and most have a burrow diameter from 1.0 to 2.0 cm. Believed to be of crustacean origin.

Classification: Feeding (fodichnia) burrow.

Ichnogenus *Rusophycus* Hall, 1852

Description: Bilobate coffee-beanlike form possessing a large median furrow and anterolateral striae ranging from fine to coarse. Shape is variable, length ranges from 3.0 to 4.5 cm, and width ranges from 1.2 to 1.8 cm.

Classification: Resting (cubichnia) trace.

Ichnogenus *Skolithos* Haldeman, 1840

Description: Cylindrical, unbranched, straight tubes perpendicular to bedding. Diameters range from 0.5 to 1.3 cm, and lengths reach 35 cm.

Classification: Dwelling (domichnia) burrow.

Ichnogenus *Subphyllochorda* Gotzinger and Becker, 1932

Description: Very slightly convex (epirelief) trail, 1.0 to 1.4 cm wide, which has faint parallel striations (1.0-mm-wide) one-third of the way in from each side. A faint 1.0-mm-wide lateral ridge on one side is present for a short distance.

Classification: Crawling (repichnia) and feeding (fodichnia) trace.

Ichnogenus *Teichichnus* Seilacher, 1955

Description: Horizontal cylindrical burrow on top of U-shaped trough which forms spreiten. Burrow diameter ranges from 0.4 to 1.0 cm. Heights up to 7 cm noted; length was not determinable.

Classification: Feeding (fodichnia) burrow.

Ichnogenus *Thalassinoides* Ehrenberg, 1944

Description: A three-dimensional, but predominantly horizontal burrow network with a diameter of 0.75 to 2.5 cm, occasionally swelling to 4.5 cm at turnarounds and branching points. Branches commonly a Y at 20° to 30° angle, less commonly a T branching at 70° to 90° angles. The diameter of T branchings may be considerably less than the main shaft.

Classification: Dwelling (domichnia) and feeding (fodichnia) burrow system.

Ichnogenus *Torrowangea* Webby, 1970

Description: Consists of an irregular trail 1.0 to 3.0 cm in diameter broken into irregular constricted segments 1.0 to 5.0 mm in length (convex epirelief).

Classification: Feeding trail (fodichnia).

Ichnogenus *Trypanites* Magdefrau, 1932*Trypanites weisei*

Description: Near-vertical cylindrical borings 1.0 to 2.0 cm in diameter and as much as 2.5 cm in length.

Classification: Dwelling (domichnia) borings.

Problematica type I

Description: Near-vertical straight burrow 0.4 to 0.5 cm in diameter and 4 to 5 cm in length. The ends turn abruptly up into the overlying carbonate bed and can sometimes be found as much as 4 cm up into the sediment. X-rays indicate that the upturned tubes continue to separate slightly and have spreiten between them.

Classification: Dwelling (domichnia) or feeding (fodichnia) structure.

Problematica type II

Description: Consists of a single pair of slightly offset convex (epirelief) gently tapering structures parallel to bedding, 3.0 to 5.0 cm long, 0.3 to 1.0 cm wide. The texture is markedly different from that of the surrounding sediments, having a large concentration of shell fragments and other particles after passage through the alimentary canal of an infaunal deposit feeder.

Classification: (?) Feeding (fodichnia) burrow.

Problematica type III

Description: Consists of gently curving burrows or trails 0.5 mm in diameter and greater than 6.0 cm in length. Classification: (?).

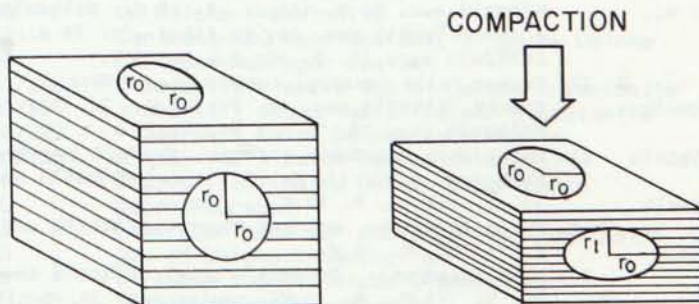


Figure 19.1. Measurement of compaction of burrows in the Deicke K-bentonite.

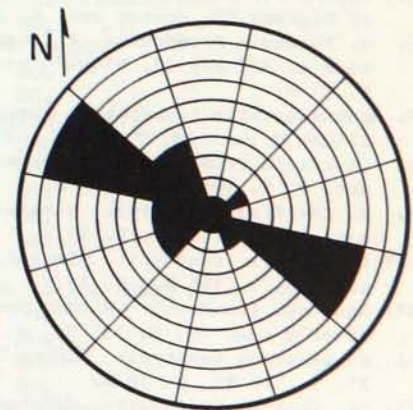


Figure 19.2. Cephalopod orientation within the Platteville Formation.

[O, Carimona Member; Δ, McGregor Member; □, Pecatonica Member; ■, all members present; +, float]

	LOCALITY																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
<i>Arenicolites</i>								○		○	○	○				○						○	○	○				
<i>Bifungites</i>		○		○											○		○											
<i>Chondrites</i>	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
<i>Conostichus</i>			○		+																	○						
<i>Cylindrichnus</i>		○				Δ			○					○			○			Δ	○	+	+					
<i>Diplichnites</i>		○																						○				
<i>Fustiglyphus</i>									○								○											
<i>Gyrolithes</i>									○										○									
<i>Lingulichnus</i>		○		○		○	○	○	○								○	○						○	○			
<i>Muensteria</i>					+																	○						
<i>Nereites</i>		○	+						○																			
<i>Palaeophycus</i>				Δ					○						○	+									⊕			
<i>Planolites</i>	○	○	■	■	Δ	■	■	Δ	■	■	■		□		○	Δ	○	■	Δ	○	Δ	■	Δ	○	○	○	Δ	Δ
<i>Rhizocorallium</i>	○								○			○		○	○							○						
<i>Rusophycus</i>					+	+									○										○			
<i>Subphyllochorda</i>																								○		○		
<i>Teichichnus</i>				Δ										○		○					+				○			
<i>Thalassinoides</i>	○	○		⊕	Δ				○	○		○						○	○			+						
(?) <i>Torrowangea</i>																									○	○		
<i>Trypanites</i>	□	□	□	□		□										Δ			+			Δ						
<i>Problematica type I</i>		○				○			○		○	○			○		○								○	○		
<i>Problematica type II</i>																										+		
<i>Problematica type III</i>																											+	

1. S. Spring Grove (quarry): Houston County, SW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 36, T. 101 N., R. 7 W.
2. E. Spring Grove (quarry): Houston County, SE $\frac{1}{4}$ SE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 5, T. 101 N., R. 6 W.
3. W. Spring Grove (quarry): Houston County, NW $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 20, T. 101 N., R. 7 W.
4. N. Mabel (quarry): Fillmore County, SW $\frac{1}{4}$ SE $\frac{1}{4}$ and SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 15, T. 101 N., R. 8 W.
5. Preston (roadcut): Fillmore County, north side of Highway 52, center sec. 4, T. 102 N., R. 10 W.
6. S. Fountain (roadcut): Fillmore County, east side of Highway 52, W $\frac{1}{2}$ SW $\frac{1}{4}$ sec. 14, T. 103 N., R. 11 W.
7. Cummingsville (roadcut): Olmsted County, SE $\frac{1}{4}$ NW $\frac{1}{2}$ sec. 28, T. 105 N., R. 12 W.
8. Chatfield (roadcut): Fillmore County, NE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 5, T. 104 N., R. 11 W.
9. E. Chatfield (quarry): Olmsted County, SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 33, T. 104 N., R. 11 W.
10. Lucky Hill (roadcut): Olmsted County, SE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 35, T. 105 N., R. 10 W.
11. Saratoga (roadcut): Winona County, north edge of SE $\frac{1}{4}$ sec. 18, T. 105 N., R. 10 W.
12. N. Saratoga (quarry): Winona County, SE $\frac{1}{4}$ sec. 31, T. 106 N., R. 10 W.
13. St. Charles (roadcut): Olmsted County, SE $\frac{1}{4}$ sec. 22, T. 106 N., R. 11 W.
14. N. Viola (quarry): Olmsted County (north side of Highway 9, 1.5 mile east of intersection with County 7), south edge SE $\frac{1}{4}$ sec. 3, T. 107 N., R. 12 W.
15. Golden Hill (roadcut): Olmsted County, west side of Highway 52, NW $\frac{1}{4}$ sec. 14, T. 106 N., R. 14 W.

16. Daneville (quarry): Olmsted County, S $\frac{1}{2}$ NE $\frac{1}{4}$ sec. 18, T. 107 N., R. 15 W.
17. N. Douglas (quarry): Olmsted County, S $\frac{1}{2}$ NW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 26, T. 108 N., R. 15 W.
18. N. Pine Island (quarry): Goodhue County, SW $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 18, T. 109 N., R. 15 W.
19. Wanamingo (quarry): Goodhue County, SW $\frac{1}{4}$ NW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 29, T. 110 N., R. 16 W.
20. Faribault (quarry): Rice County, SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 33, T. 110 N., R. 20 W.
21. Nerstrand (quarry, roadcut): Rice County, N $\frac{1}{2}$ SE $\frac{1}{4}$ sec. 9, T. 110 N., R. 19 W.; SE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 3 and NE $\frac{1}{4}$ NW $\frac{1}{2}$ sec. 10, T. 110 N., R. 19 W.; SW $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 35, T. 111 N., R. 19 W.
22. Cannon Falls (quarry, roadcut): Goodhue County, S $\frac{1}{2}$ SE $\frac{1}{4}$ sec. 18, T. 112 N., R. 17 W.; SE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 20, T. 112 N., R. 17 W.
23. White Rock (roadcut, quarry): Goodhue County, NW $\frac{1}{4}$ sec. 4, T. 112 N., R. 16 W.; SE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 31, T. 112 N., R. 16 W.
24. Wangs (quarry): Goodhue County, SE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 5, T. 111 N., R. 18 W.
25. Sogn (roadcut): Goodhue County, NW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 24, T. 111 N., R. 18 W.; center sec. 36, T. 111 N., R. 18 W.; E $\frac{1}{2}$ NW $\frac{1}{4}$ and SW $\frac{1}{4}$ sec. 1, T. 111 N., R. 18 W.
26. Shadow Falls Park: Ramsey County, SW $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 5, T. 28 N., R. 23 W.
27. Hidden Falls Park: Ramsey County, SE $\frac{1}{4}$ sec. 17, T. 28 N., R. 23 W.
28. Airport (freeway roadcuts): Hennepin County, sec. 29, T. 28 N., R. 23 W.

Table 19.1. Trace fossil distribution in the Platteville Formation.

Table 19.2. Ellipse measurements of burrows in the Deicke K-bentonite.

Location	r_0	r_1
	(Both in mm)	
North Douglas		
Quarry	4.5	1.0
Do.	3.0	0.75
Do.	4.5	1.0
East Chatfield		
Quarry	2.5	0.75
Do.	4.75	1.0
Do.	5.25	1.5
Do.	3.5*	2.5*
East Spring Grove		
Quarry	4.25	1.25
Do.	3.5*	2.5*
Sogn Roadcut	1.5	0.375
Do.	3.0	1.0
Do.	3.0	0.75
*Not used	Sums: 36.25	9.375
Averages (N=10):	3.63	0.94
$N_d = r_0 / r_1 = 3.63 / 0.94 = 3.86$		
$N_d \times \text{thickness} = 3.86 \times 7.0 \text{ cm} = 27 \text{ cm}$		

Table 19.3. Cephalopod orientation with in the Platteville Formation.

Bearing	Level	Outcrop
300	6.5' below Deicke K-bentonite (Mid-McGregor)	Lower Nerstrand roadcut
305	3.5' below Deicke K-bentonite (Basal Carimona)	Do.
120	Basal Pecatonica just above Glenwood	South Fountain roadcut
120	Basal Pecatonica just above Glenwood	Do.
010	On Deicke K-bentonite	Lucky Hill roadcut
328	On Deicke K-bentonite	Do.
062	Carimona-McGregor contact, 6" below Deicke	Do.
140	Carimona-McGregor contact	North Douglas quarry
110/290	2 beds (12") above top of Deicke K-bentonite	Do.
120/300	1 bed (6") above top of Deicke K-bentonite	Do.
040/220	1 bed (6") below Deicke K-bentonite	Do.
075/255	2 beds (12") below Deicke K-bentonite	Do.
140	2 beds (12") below Deicke K-bentonite	Do.
300	Upper McGregor	Wanamingo quarry
145	Lower Carimona 12" above Deicke K-bentonite	North Pine Island quarry
140	Top of Deicke K-bentonite	Do.
100	8" above top of Deicke K-bentonite	Do.
070/250	Top of Deicke K-bentonite	Do.
130/310	Top of Deicke K-bentonite	Do.
100	Top of Deicke K-bentonite	Danesville quarry
240	6" above top of Deicke K-bentonite	Golden Hill roadcut
122	Top of Deicke K-bentonite	East Chatfield quarry
125/305	36" above top of Deicke K-bentonite	Do.
335	Top of Deicke K-bentonite	West Spring Grove quarry
300	Below Deicke K-bentonite	Do.
120	Top of Deicke K-bentonite	Do.
120	Top of Deicke K-bentonite	Wangs quarry
070	4" below Deicke K-bentonite	Saratoga roadcut

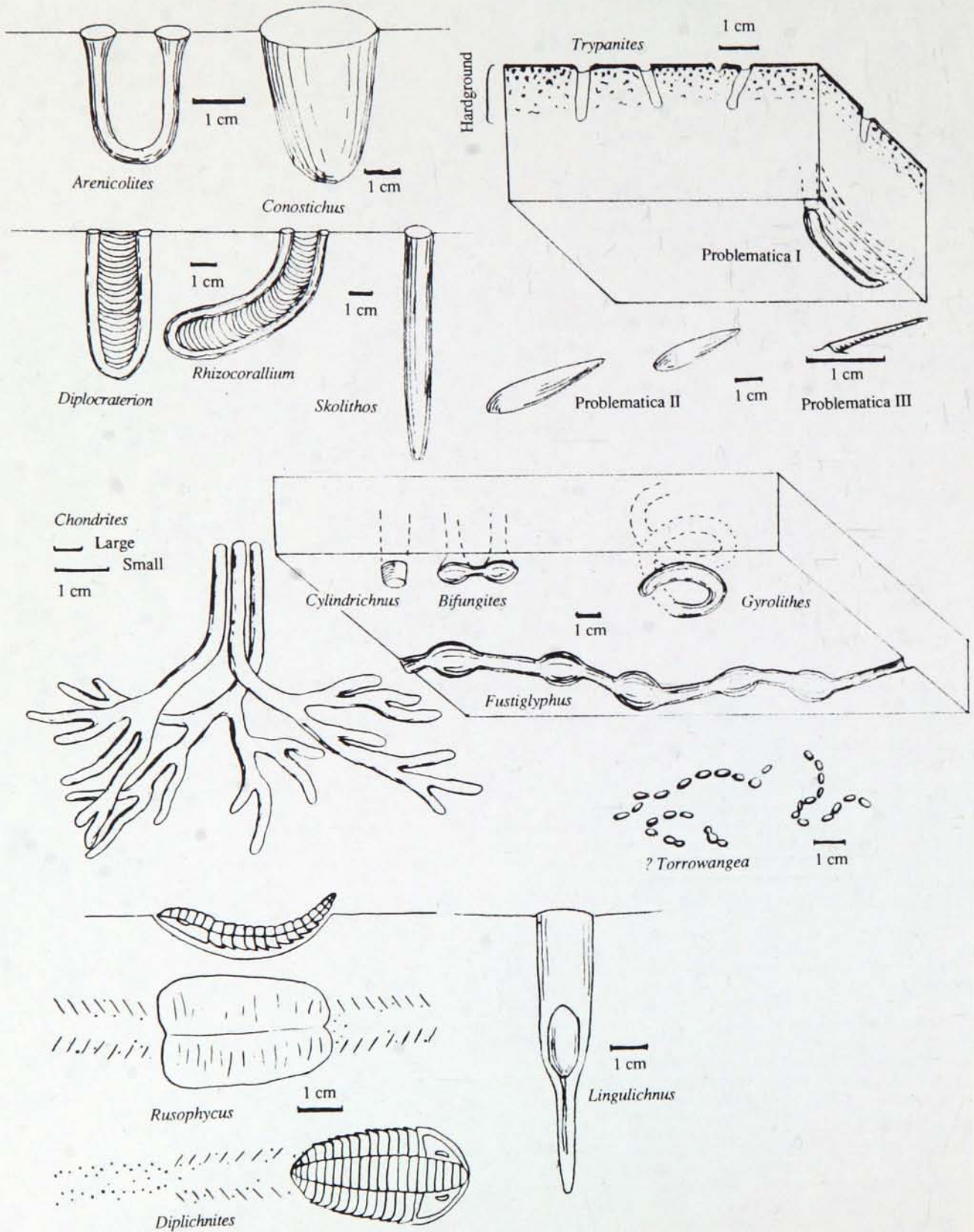


Figure 19.3. Sketches of trace fossils; the bar scale for all is 1 cm. The grouping is random.

DESCRIPTION OF MAJOR OUTCROPS IN MINNESOTA AND IOWA

Robert E. Sloan¹, Dennis R. Kolata²,
Brian J. Witzke³, and Gregory A. Ludvigson³

¹Department of Geology and Geophysics, University of Minnesota
Minneapolis, MN 55455

²Illinois State Geological Survey, 615 East Peabody Drive
Champaign, IL 61820

³Iowa Geological Survey Bureau
Iowa City, IA 52242

SHADOW FALLS

The best exposed and most accessible outcrop of the upper St. Peter, Glenwood, Platteville, and lower Decorah in the Twin Cities is at Shadow Falls, a small park at Summit Avenue and East River Road in St. Paul along the Mississippi River in the SE¹/₄NW¹/₄ sec. 5, T. 28 N., R. 23 W. Synonymous locality names in the literature are Finn's Glen (Sardeson) and Summit Avenue (Kolata).

A condensed section is as follows; see also the graphic section (Figs. 20.1, 20.2).

More than 25 feet (7.6 m) of Decorah Shale is exposed, with the 1-inch (3 cm) Millbrig K-bentonite clearly visible 7.3 feet (2.2 m) above the top of the Carimona Member of the Platteville and 9.4 feet (2.9 m) above the Deicke K-bentonite. Sardeson's bed 3, the *Stictoporella* bed, is the interval between these K-bentonites, and approximately equivalent to the lower half of the Spechts Ferry Member of the Decorah in Iowa and Illinois. The conodont density in it is as much as 300 conodonts per 100 grams of rock. The higher beds here are within Sardeson's bed 4, the *Stictopora* or *Rhindictya* beds, in which the conodont density is 30 per 100 grams. The type of the crinoid *Cremacrinus punctatus* Ulrich came from bed 4 at this locality (Fig. 16.2).

The Carimona Member of the Platteville Formation is 3.6 feet (1.1 m) thick here. It consists of richly fossiliferous, massive beds of limestone. *Isotelus* is common, suggesting that this unit represents a shallower facies than the other Platteville members. The 10-cm-thick Deicke K-bentonite is 1.2 feet (0.36 m) above the base of the Carimona Member here, always in a deep slot due to geologists digging in for a sample. The fall of the Deicke ash killed everything in eastern North America, and many species, such as the conodont *Scyphiodus primus*, terminate at this horizon. The type specimen of *Scyphiodus primus* and other rare specimens from the top of the overlying Decorah all appear to be reworked. As best as we can determine on the basis of trilobites and conodonts, the Deicke is the boundary between the Blackriveran and Rocklandian (the basal Trentonian).

The Decorah and Carimona rock types are interbedded near the contact. Here a bed of about 8 inches (20 cm) of Carimona-type rock is separated from the rest of the Carimona by about 28 inches (70 cm) of typical Decorah Shale. At Sogn, Minnesota, this bed is part of the Platteville. Minnesota practice is to draw the boundary between the Platteville and Decorah at the point where the Decorah interbeds are thinner than the Carimona interbeds. This means, of necessity, that the formation boundary is diachronous, but always within the interval between the Deicke and Millbrig K-bentonites. The base of the Carimona is similarly diachronous, and depends on local lithofacies, depths, and biofacies. The lower Carimona is laterally equivalent to the Quimbys Mill Formation of Illinois, as well as to parts of the Magnolia and McGregor Members of Minnesota. The upper Carimona is laterally equivalent to the lower Spechts Ferry Formation of Illinois.

The Magnolia Member of the Platteville Formation (Fig. 20.3) here is about 8 feet (2.44 m) thick. It has a conchoidal fracture, is subliothographic in character, and contains a rich fauna dominated by

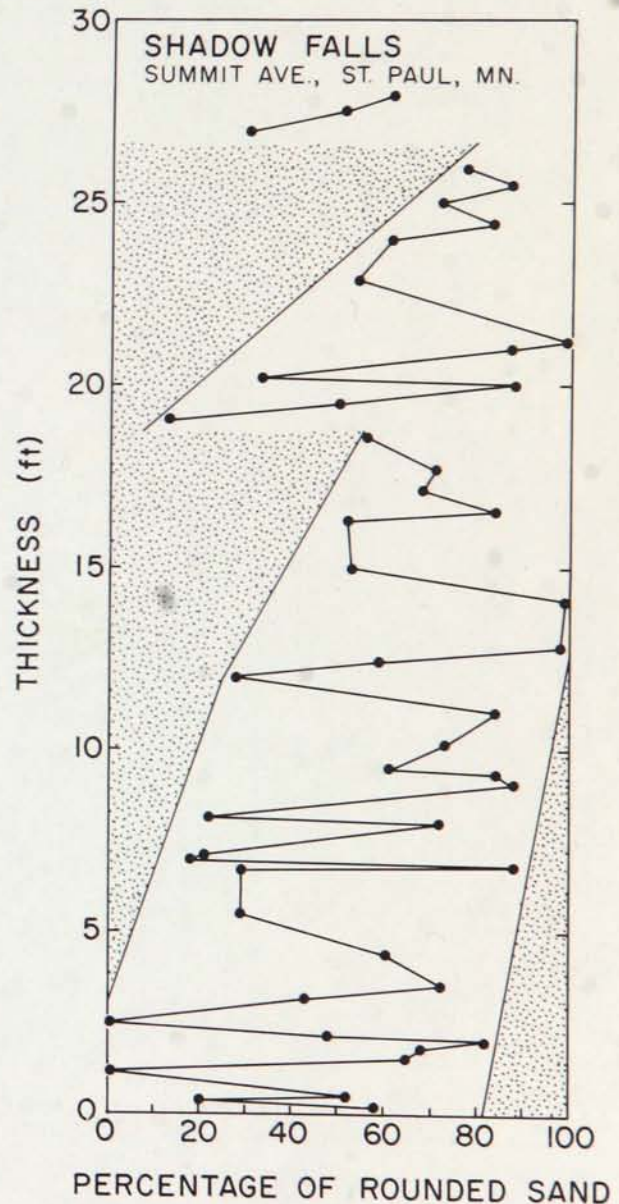


Figure 20.1 Graphic section of the St. Peter Sandstone at the Shadow Falls locality, also known as the Summit Avenue or Finn's Glen locality (modified from Mazzullo and Ehrlich, 1979).

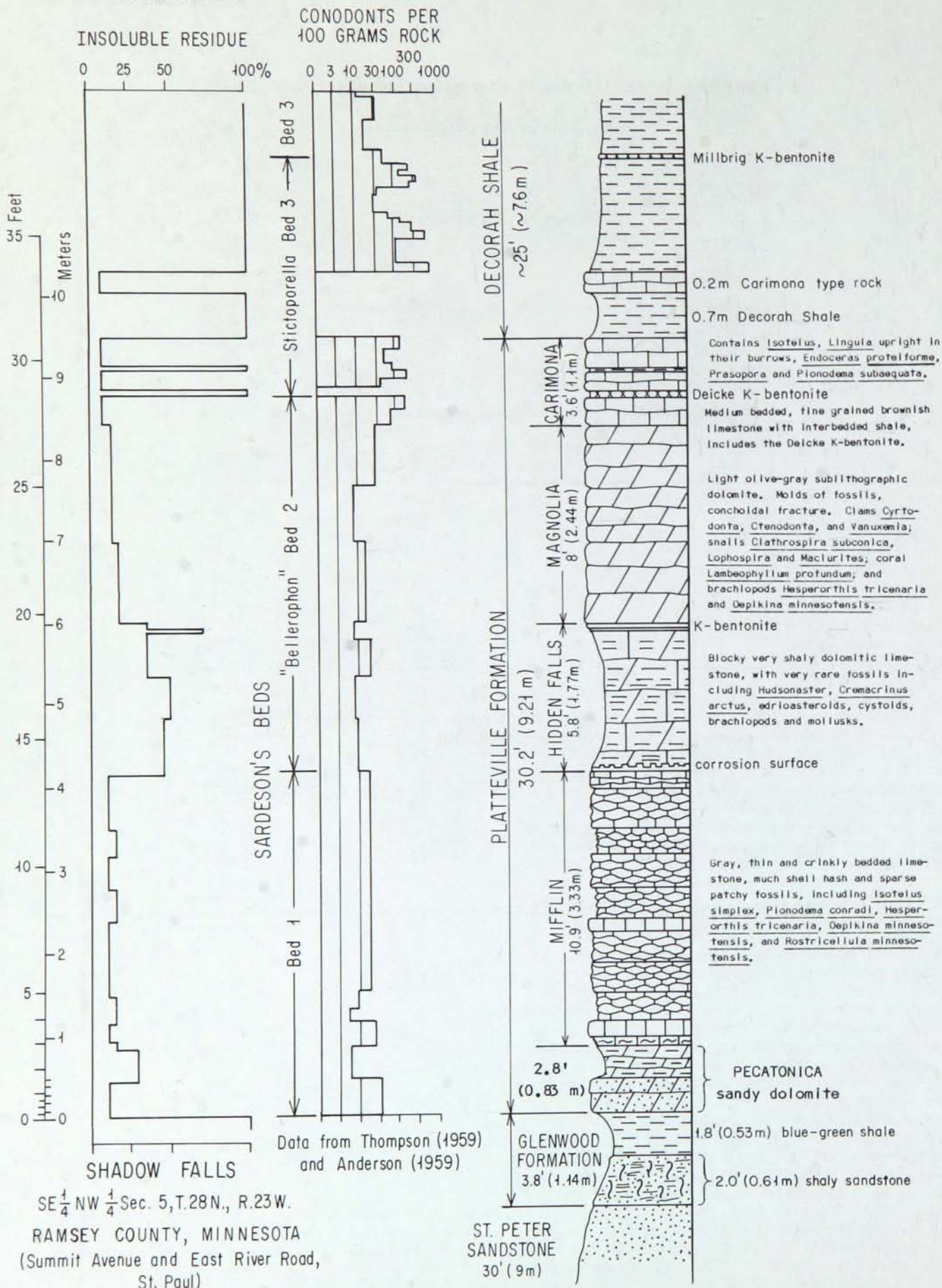


Figure 20.2. Graphic section of the Glenwood, Platteville, and Decorah Formations of Shadow Falls, with conodont and insoluble residue logs.

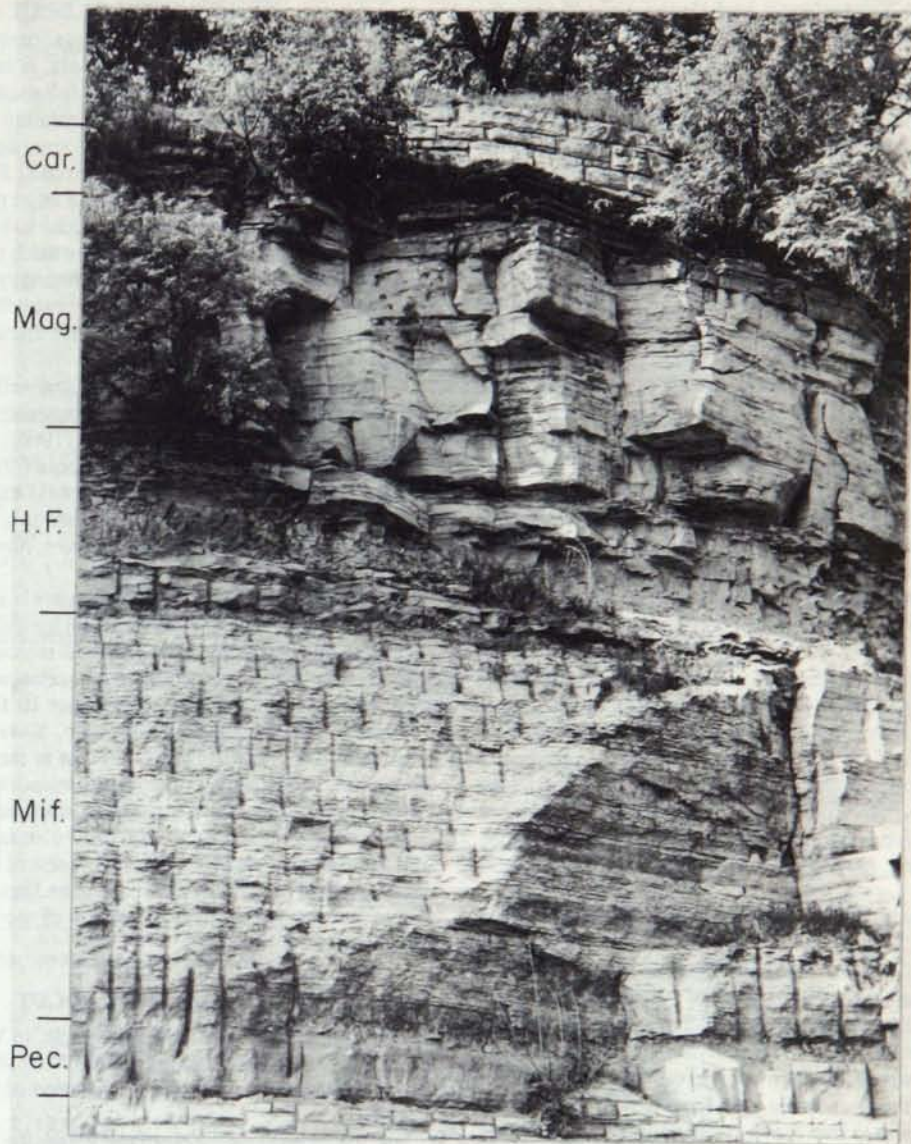


Figure 20.3. Cliff exposure of the Platteville Formation below Fairview Hospital in Minneapolis (from Ford, 1958).

the clams *Cyrtodonta*, *Ctenodonta*, and *Vanuxemia*; the snails *Clathrospira subconica*, *Maclurites*, and *Lophospira*; monoplacs; the coral *Lambeophyllum profundum*; and the brachiopods *Hesperorthis tricenaria* and *Oepikina minnesotensis*. All the fossils are preserved as dolomite rhomb-lined molds. The conodont density is about 10 per 100 grams of rock. The Magnolia Member apparently correlates with the Nachusa Formation of Illinois, although it more closely resembles the Quimbys Mill in rock type.

The 5.8-foot (1.77 m) thickness of the Hidden Falls Member of the Platteville Formation reflects an early epeirogenic uplift of the Transcontinental Arch just before the big uplift that produced the Decorah Shale. The insoluble residue of this member is as high as 45 percent. A 1-inch (2 cm) orange clay layer at the top may be a K-bentonite. Fossil occurrences are patchy, but where present, are very rich. Sardeson mined out a spot in this unit in the old Johnson Street Quarry in Minneapolis (now filled with garbage, and covered with Interstate 35) that produced about 20 specimens of the starfish *Protopalaeaster narrawayi*, several specimens of the crinoid *Cremacrinus arcus* (Fig. 16.2), edriasteroids, cystoids, brachiopods, bryozoans, molluscs, and graptolites. The conodont density is about 10 per 100 grams of rock. The Hidden Falls Member apparently correlates with the Grand Detour Formation of Illinois, which also is more shaly than adjacent rocks, although by no means as shaly as this. Sardeson's bed 2 includes the Hidden Falls and Magnolia Members.

The Mifflin Member of the Platteville Formation here is 10.9 feet (3.33 m) thick. This gray, thin- and crinkly bedded unit contains much shell hash and spotty horizons of fossils. It resembles the McGregor Member south of the Twin Cities basin, and is correlative with the Mifflin of Illinois. Many old foundations in the Twin Cities were built of typical quarry blocks of Mifflin. Good fossils are sparse, but include *Pionodema conradi*, *Hesperorthis tricenaria*, *Oepikina minnesotensis*, *Rostricellula minnesotensis*, and *Isotelus simplex*.

The Pecatonica Member of the Platteville Formation is 2.75 feet (0.83 m) thick here. Templeton and Willman (1963) named the equivalent of this local unit the Hennepin Member of the Pecatonica Formation, but they used the name for parts of the Pecatonica at only two other places, and then for rocks quite unlike this exposure. The conodont density is about 30 per 100 grams of rock. The Pecatonica here is equivalent to part of the Glenwood at the Sogn roadcut section and to the top of the Pecatonica at Cummingsville Annex and Spring Grove Underpass. Here it is a rusty dolomite, containing many small rounded phosphate nodules of collophane and some floating sand grains of the St. Peter type that were clearly blown in by the wind. The upper 1.33 feet (41 cm) is very shaly, although the basal Platteville is commonly sandy. Sardeson's bed 1 includes the Pecatonica and Mifflin Members.

The underlying 1.8 feet (53 cm) of blue-green Glenwood shale, containing the *Chirognathus* zone conodonts and a very few small macrofossils, is underlain by 2 feet (61 cm) of shaly sand, showing much bioturbation. This transition from the St. Peter Sandstone to the Glenwood shale is usually included in the Glenwood Formation.

At the base of the exposure is 30 feet (9 m) of typical upper St. Peter Sandstone (Fig. 20.1), measured from the river level. It shows three of the large rounding-upward cycles of deposition described by Mazzullo and Ehrlich (1979; this volume).

WANGS ROADCUT

The roadcut 1.2 miles north of Wangs, center sec. 16, T. 111 N., R. 18 W., Goodhue County, Minnesota, is one of the better exposures of the top of the Platteville, the full thickness of the Decorah, and the base of the Cummingsville Formation of the Galena Group.

The Decorah Shale rapidly grows over and is best exposed in roadcuts; other excellent exposures are on U.S. 52, 5 miles east, but it is not possible to collect there with a large party. The upper Platteville, Carimona Member and the Deicke K-bentonite, and the base of the Decorah are exposed here in the ditch to the west. The complete Decorah and the base of the Cummingsville can be seen in the cuts on the east side of the road for the next 0.7 mile. These outcrops are richly fossiliferous. Karklins (1969) discussed the cryptostome bryozoans from this locality.

Conodonts are extremely abundant and well preserved in the beds just above and below the Deicke K-bentonite. The most convenient reference for identification is Webers (1966).

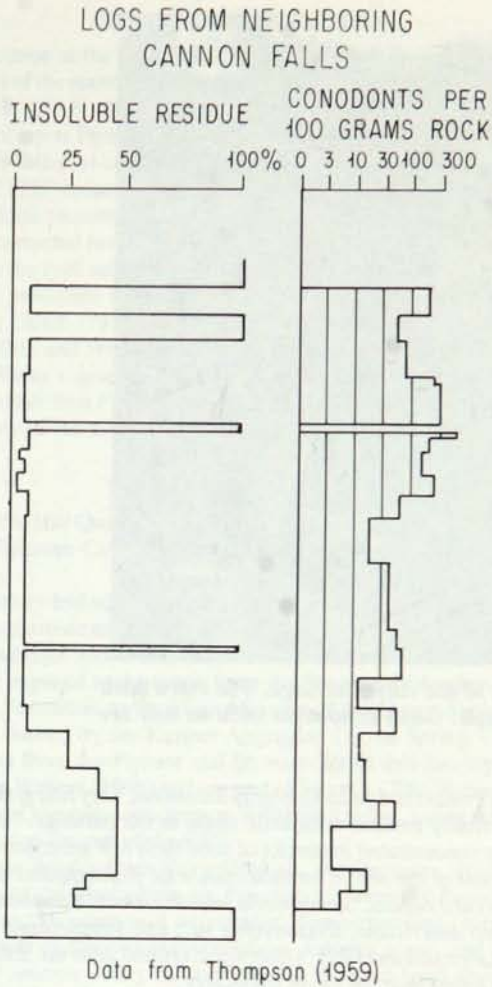
The Cummingsville Formation is about 60 feet thick in Goodhue County, but only the lower 20 feet or so is exposed here, a rubbly, white, nodular shaly limestone. Common fossils are *Vellamo*, *Platystrophia*, *Rafinesquina*, *Paucicrura*, *Sowerbyella*, *Ischadites*, and *Fisherites*.

The Decorah Shale in Goodhue County is about 61 feet (18.6 m) thick. It is a yellowish-green shale with fossiliferous, lenticular, and persistent thin interbeds of limestone. It is moderately to abundantly fossiliferous throughout. *Pionodema subaequata* is abundant 4 to 5 feet above the base and in the upper 10 feet. The *Prasopora conoidea* faunule with *Rhynchotrema*, *Sowerbyella*, *Paucicrura*, *Dinorthis*, and *Hesperorthis* is present in the upper 10 feet (3 m). The lower 14 feet (4.3 m) has the *Stictoporella angularis* zone of Karklins (1969) and the *Eurychilina subradiata* zone of Swain and others (1961). The top of the *Stictopora mutabilis* zone of Karklins and the *Byrsolopsina planilateralis* zone of Swain and others are about 45 feet (14 m) above the base. The *Stictopora minima* and the *Bollia simplex* zones range to the top of the Decorah and into the Cummingsville.

SOGN ROADCUT

In the NE $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 24, T. 111 N., R. 18 W., Goodhue County, Minnesota, the roadcut (Figs. 20.4, 20.5) shows the entire Glenwood Formation and the thinnest section of Platteville Formation known.

The lower three members of the Platteville in the Twin Cities are here represented by part of the Glenwood shale. As is typical, the beds of the Carimona Member just above and below the Deicke K-bentonite are rich in conodonts, here about 300 conodonts per 100 grams of limestone. As closely as we can tell, the Deicke is also the Black River-Trenton boundary. At the Cannon Falls quarry 7 miles to the north, a nitrogen analysis of the 1-cm-thick petroliferous shale at the base of the Deicke K-bentonite indicates a quantitative plankton kill. The Millbrig K-bentonite from the lower Decorah is absent in Goodhue County, although it is generally present throughout the Upper Mississippi valley.



SOGN ROADCUT
NW $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 24, T.111 N., R.18W.
GOODHUE COUNTY, MINNESOTA
(Southeast corner of Sogn)

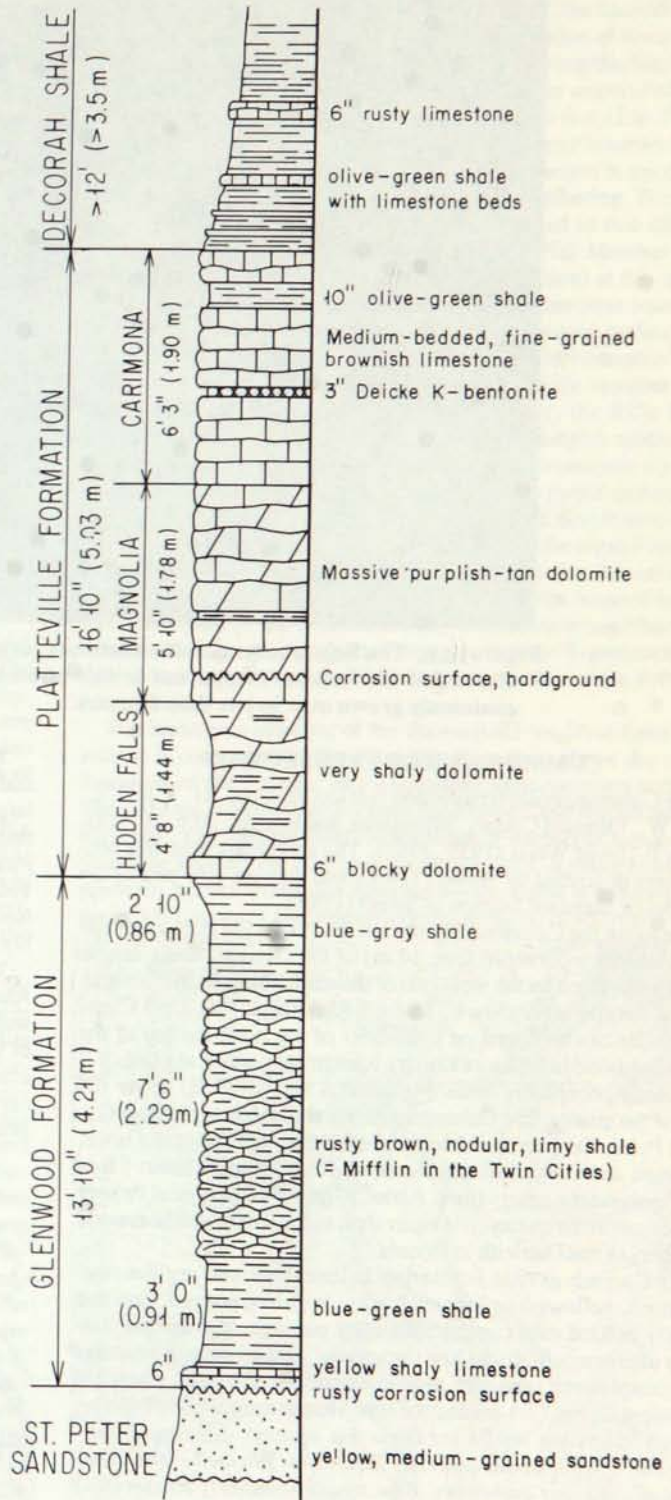


Figure 20.4. Graphic section of the Sogn roadcut, 0.1 mile south of the intersection of Goodhue County roads 9 and 14.



Figure 20.5. The Sogn roadcut on the southeast corner of the village of Sogn. The extra thick Glenwood Shale is very apparent in this photograph. Good exposures such as this are commonly grown over in less than 10 years.

CUMMINGSVILLE TYPE SECTION

The Cummingsville type section is in the SE $\frac{1}{4}$ sec. 21, T. 105 N., R. 12 W., Olmsted County, Minnesota, and is (Figs. 20.6, 20.7) location F-164 of Weiss (1955, 1957). The conodonts from this section were described by Webers (1966) and they are now part of the Composite Standard Section of Sweet (1984).

The top of the Carimona Member of the Platteville Formation and the complete section (46 feet; 14 m) of the Decorah Shale can be found in the ditch on the west side of the road, although the Decorah is now totally overgrown. The 63-foot-thick (19.2 m) Cummingsville can be found on both sides of the road; the top of the Cummingsville in Fillmore County is arbitrarily drawn at a thin (5-7 cm) sandy phosphatic limestone about 4 feet (1.20 m) above the floor of the quarry. The Cummingsville is equivalent to the Beecher, Eagle Point, Fairplay, and Mortimer Members of Illinois and Iowa. Levorson and Gerk draw the Mortimer-Rivoli contact about 1 foot (0.3 m) above the quarry floor. About 30 feet (9 m) of typical Prosser can be seen in the quarry; it is equivalent to the Rivoli and Sherwood Members of the Dunleith in Illinois.

The Cummingsville Formation is limestone and argillaceous limestone, yellowish or brownish gray, very fine grained, thin and wrinkly bedded with conspicuous shaly partings. The detrital content is alternately high and low throughout, and so the unit weathers to a conspicuous sawtooth profile except for the basal (Beecher equivalent) 7 feet (2.1 m) and the top (Mortimer equivalent) 16 feet (4.9 m). Common fossils are *Dinorthis sweenyi*, *Glyptorthis bellarugosa*, *Platystrophia amoena*, *Plectorthis plicatella trentonensis*, *Rafinesquina camerata*, *Paucicrura* (formerly *Resserella*) *rogata*, *Rhynchotrema wisconsinense* (formerly *increbescens*), *Sowerbyella minnesotensis*, *Strophomena* sp., *Vellamo americana*, *Aspidopora* sp., *Batostoma* sp., *Monotrypa* sp., *Prasopora* sp., *Rhinidictya* sp., *Iliaenus americanus*, *Bumastus billingsi*, *Hormotoma bellicincta*, *Salpingostoma* sp., *Streptelasma corniculum*, and *Fisherites reticulatus* (= "*Receptaculites oweni*" Finney and Nitecki, 1979). The lower *Receptaculites* zone extends from 18 feet (5.5 m) above the base to 5 feet (1.5 m) below the top of the Cummingsville.

The Prosser is a yellowish-gray limestone, very fine grained, thin and wrinkly bedded with little shale in the partings. Fossils are largely concentrated in streaks of shell hash that are coarser grained than most of the unit. Common fossils are *Rafinesquina camerata*, *Paucicrura rogata*, *Sowerbyella minnesotensis*, *Strophomena* sp., *Vellamo americana*, *Byssonychia* sp., and *Streptelasma corniculum*. Levorson and Gerk's Sherwood crinoid zone no. 2 can probably be found near the top of the quarry.

The Platteville can be better seen and collected at Cummingsville Annex, half a mile away along the road. Conodonts from there also were studied by Webers and are part of Sweet's CSS. The rich fauna of the *Protozyga nicolleti* beds of the Carimona Member also includes *Pionodema subaequata*, *Strophomena filitexta* (formerly *incurvata*), *Eomonorachus intermedius*, *Isotelus* sp., *Hormotoma gracilis* and conodonts as abundant as 1200 per 100-gram sample.

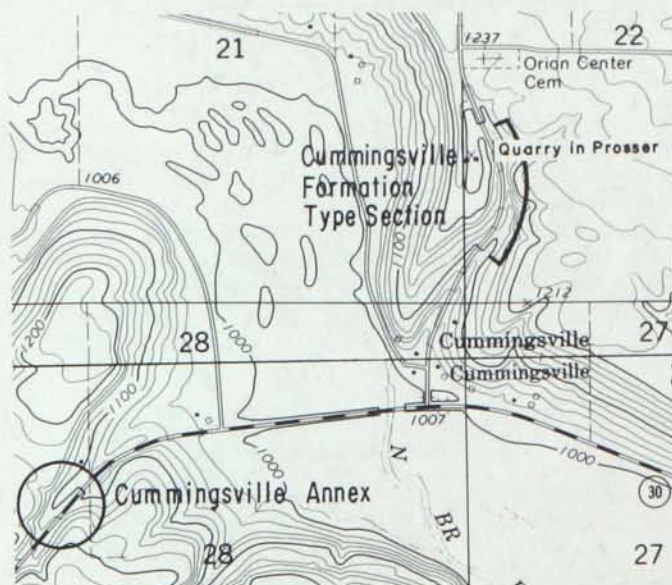


Figure 20.6. Topographic map of the area around Cummingsville.

PROSSER TYPE SECTION

The section at the Mahoods Creek (Fig. 20.8) is measured from the center of the south edge of the SE $\frac{1}{4}$ sec. 8, southward to the SE $\frac{1}{4}$ sec. 20, T. 103 N., R. 12 W., Fillmore County, Minnesota; it was earlier known as Prosser's Ravine and is Weiss's (1953) F-192. The typesetter failed to correct some errors in the published version of Weiss's (1957) measured section, the worst of which were recording Weiss's inch measurements for units 43 and 53-58 as feet. The errors are corrected here.

This is the type section for the Prosser Limestone. Its description was first published by Winchell and Ulrich in 1897; it was mentioned by Ulrich (1911), remeasured by Kay (1935b), Stauffer and Thiel (1939), and Weiss, who described it in greater detail than ever before. Weiss's description should be seen for the details of fossil content, other than *Fisherites*, and for the precise details on location of the parts of the section.

RIFLE HILL QUARRY

The Rifle Hill Quarry in the NE $\frac{1}{4}$ NW $\frac{1}{4}$ sec. 35, T. 102 N., R. 12 W., Fillmore County, Minnesota, is location F-171 of Weiss (1957).

This quarry and adjacent roadcuts (Figs. 20.9, 20.10) expose the Prosser Limestone and Stewartville Formation of the Galena Group, and the Dubuque and lower Maquoketa Formations. In Illinois-Iowa terms the exposed rocks range from the Sherwood Member of the Dunleith Formation to the Elgin Member of the Scales Shale. The quarry is owned by the Kapper Aggregate Co. of Spring Valley. Conodonts from the Prosser and Stewartville of this locality were studied by Webers (1966) and are part of Sweet's CSS. Webers also studied the Dubuque conodonts at Wubbels Ravine, 1 mile south of here; they too are part of the CSS.

Common fossils from the yellowish, argillaceous, dolomitic limestone of the Maquoketa are *Paucicrura* (formerly *Resserella*) *corpulenta*, *Megamyonia uncostata*, *Eoplectodonta* (formerly *Thaerodonta* or *Sowerbyella*) *recedens*, *Isotelus gigas*, and *Flexicalymene senaria*. They can be found at the road bend above the quarry and 50 yards (45 m) to the west.

The Dubuque is interbedded gray limestone and gray shale. Its fossils are most easily collected in the ditch above the quarry, where feldspathized shale (an altered K-bentonite) 5 inches (12 cm) thick is exposed. They include *Megamyonia uncostata*, *Paucicrura* (formerly *Resserella*) *corpulenta*, *Rafinesquina sardesoni*, *Sowerbyella minnesotensis*, *Eoplectodonta recedens*, *Tetraphalerella planodorsata*, and *Flexicalymene senaria*. Levorson and others (1979) divided the Dubuque into three beds, better considered members. They showed that a conspicuous marker bed, about 8 inches (20 cm) thick and set off from adjacent beds by shale partings, was traceable from the most northern exposures in Minnesota to northwestern Illinois. This bed is below the previous base of the formation and occurs in the interval that most prior authors referred to the Stewartville or Wise Lake formations. All prior definitions were based on the lowest occurrence of shale beds, but this type of definition resulted in much variation from locality to locality in the thickness of the Dubuque and in the level of the basal contact. The three members of the Dubuque are typified by increasing undulation of the bedding surface of the limestone beds and increasing thicknesses of shale interbeds. In order from the bottom up, they are the Frankville Member, here 16' 4" (4.97 m); the Luana Member, here 17' 2" (5.23 m); and the Littleport Member, here 14' 4" (4.36 m) thick. The change in rock type from the Stewartville to the Dubuque has always been recognized as transitional, but the transition beds are now included in the Frankville Member.

The Stewartville Formation in Minnesota consists of 69.75 feet (21.26 m) of yellowish-gray to grayish-orange dolomitic limestone with thin and wrinkled beds, welded into massive ledges, mottled

and pitted when weathered. It becomes crinoidal near the top, where it grades imperceptibly into the lower Dubuque. The Stewartville of Minnesota is equivalent to the Wise Lake Formation of Iowa and Illinois, and it includes more than the former Stewartville Member of those states. The zonal trace fossil (holothurian or worm) *Paleosynapta flaccida* Weiss (1954) occurs from 6 to 35 feet (2 to 10.5 m) below the top. The zonal dasycladacean green alga *Fisherites reticulatus* (formerly "*Receptaculites oweni*") is common in the quarry, but is difficult to collect along the road due to weathering. To resolve the problem of the term Stewartville being used in two different senses, Sloan (this volume) defined the Rifle Hill Member of the Stewartville Formation (and Wise Lake Formation) at this quarry, replacing the Illinois use of Stewartville in the narrower sense. The Rifle Hill Member extends from the highest corrosion surface at the top of the Sinsinawa Member of the Stewartville Formation to the base of the marker bed at the base of the Frankville member of the Dubuque Formation. Here at the type locality, the Rifle Hill is 37' 11" (11.56 m) thick, and is composed of orangish mottled and bioturbated dolomite, in massive beds, with prominent stylolitic bedding planes in the upper half. It includes the purest carbonate in the Galena Group. The very restricted fauna is dominated by the snails *Hormotoma* and *Maclurites*, and includes the algae *Fisherites* in the lower half, and the burrow *Palaeosynapta flaccida* in the upper half. The Rifle Hill fauna closely resembles the fauna of the Red River Dolomite of the Williston basin. This faunal resemblance and the absence of any siliciclastics suggests that the Transcontinental Arch was totally submerged during the deposition of the Rifle Hill Member.

The Sinsinawa Member of the Stewartville (or Wise Lake) Formation is composed of the dolomitic limestone above the cherty limestone of the Prosser, and it contains many corrosion surfaces. The bedding is more massive than the Prosser, but less so than the Rifle Hill. The fauna is nearly as abundant in number of species as is that of the Prosser, but is more difficult to collect. A major extinction gradually occurs within the Sinsinawa—the fauna is reduced from some 300 species of macroinvertebrates to the 30 or so typical of the

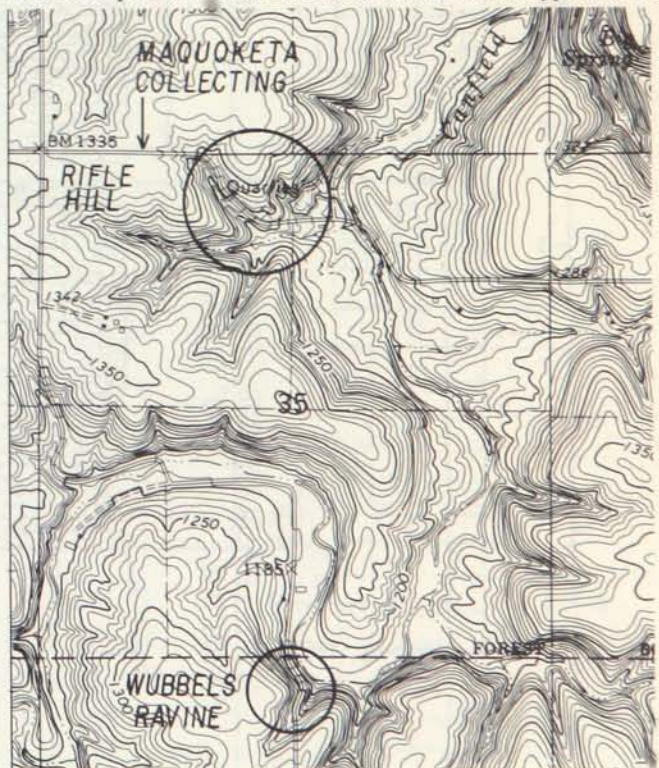


Figure 20.9. Topographic map of the area around Rifle Hill.

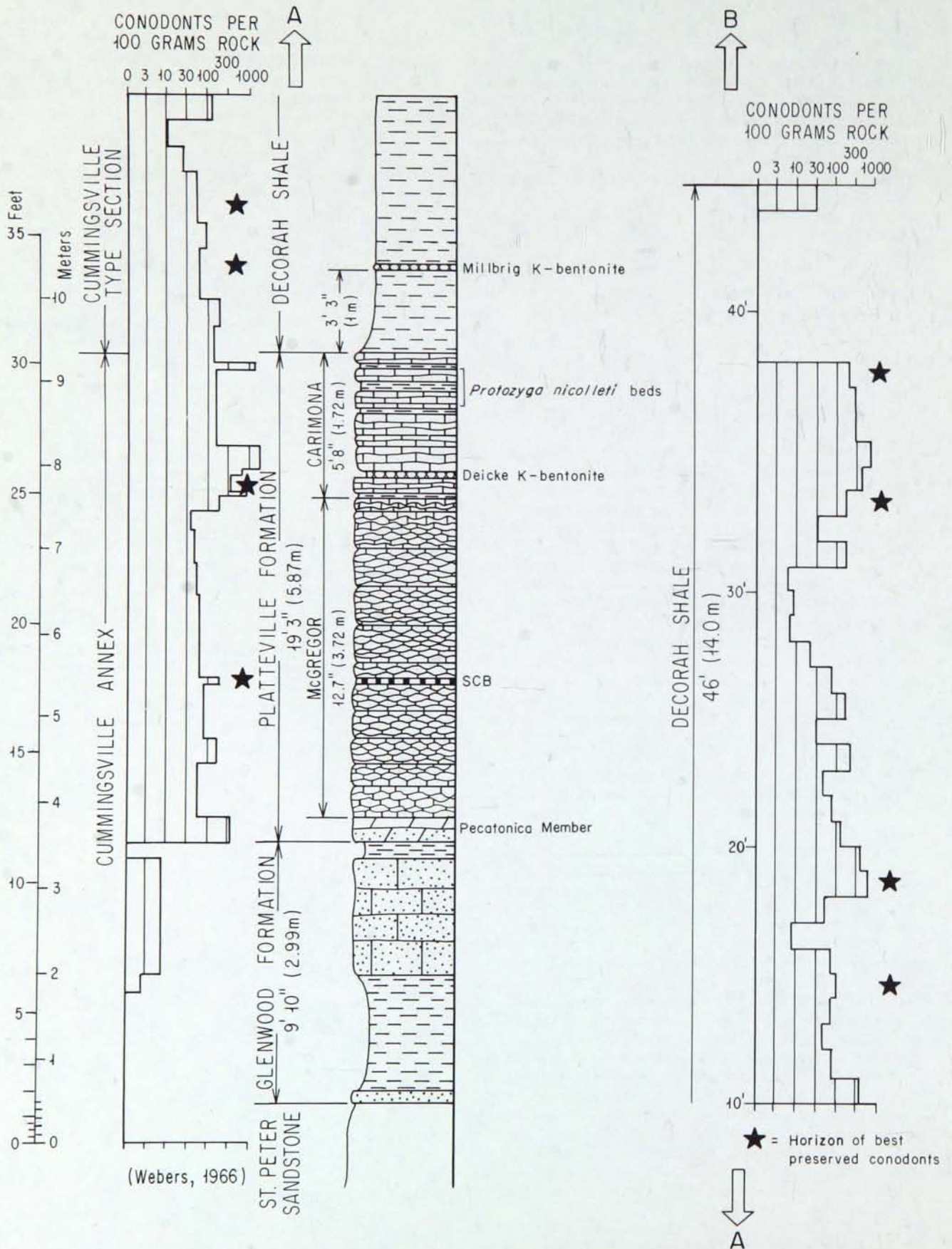
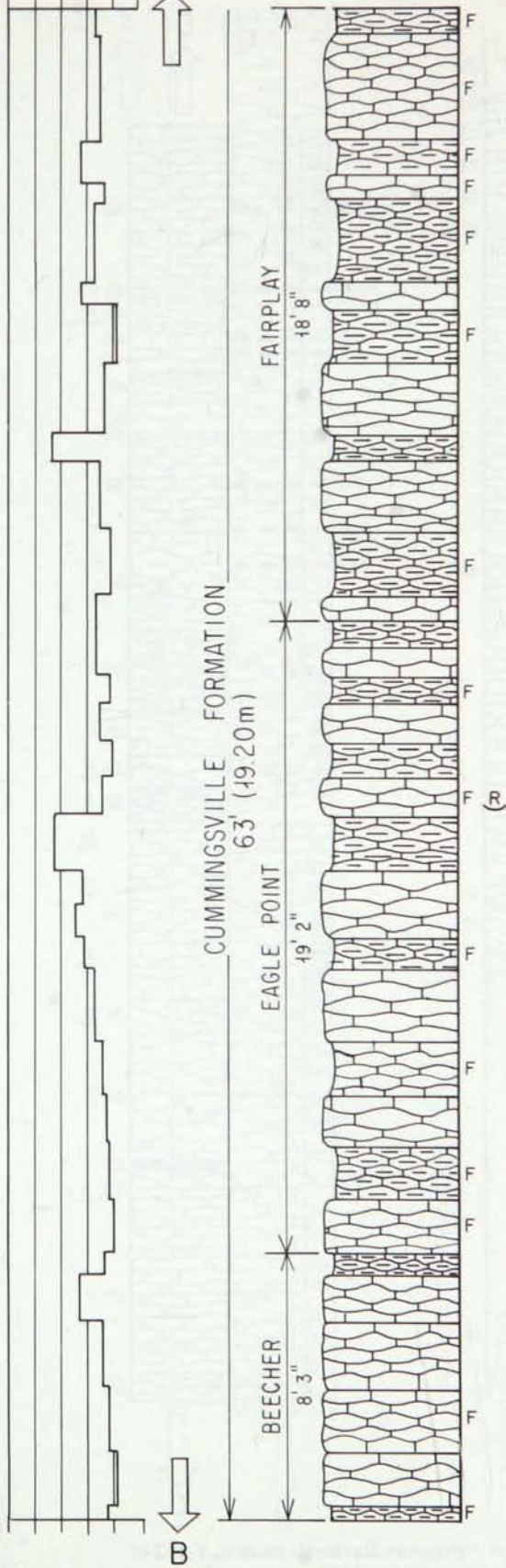


Figure 20.7. Graphic section of the Platteville Limestone at Cummingsville Annex and the Decorah through Prosser formations at the type locality for the Cummingsville Formation.

Figure 20.7. continued.

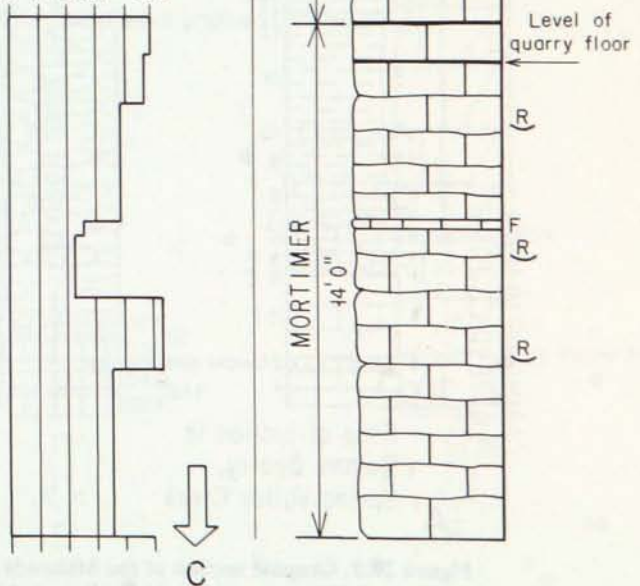
CONODONTS PER
100 GRAMS ROCK

0 3 40 30 300 C



CONODONTS PER
100 GRAMS ROCK

0 3 40 30 300



MAHOODS CREEK SECTION
"PROSSER'S RAVINE"

OF WINCHELL & ULRICH 1895
F-192 of WEISS, 1957

TYPE SECTION OF PROSSER
FORMATION

SECTION & FOSSILS AFTER
WEISS, 1957a

0 1 2 FEET

B = FISHERITES

F = FOSSIL HORIZON

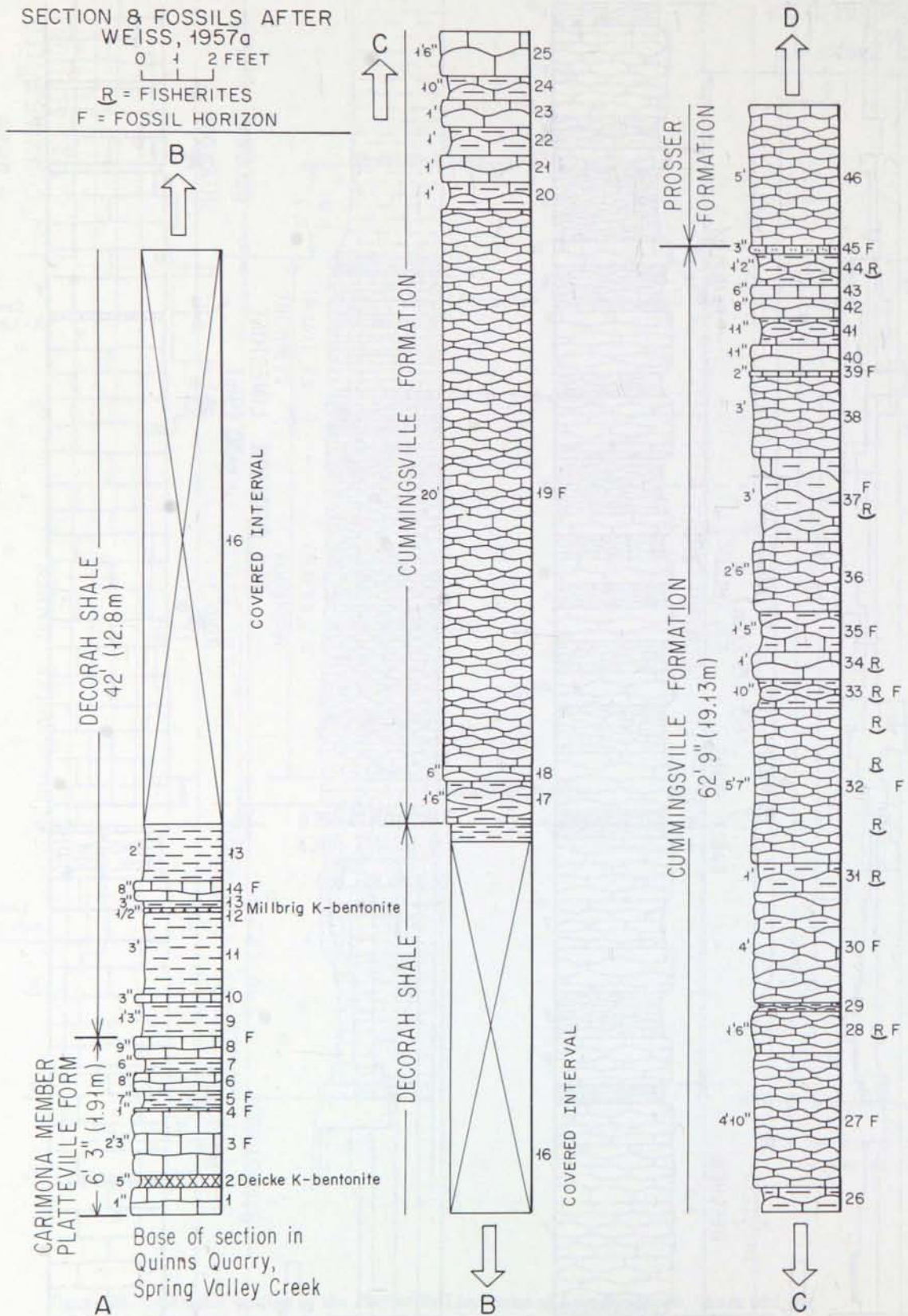
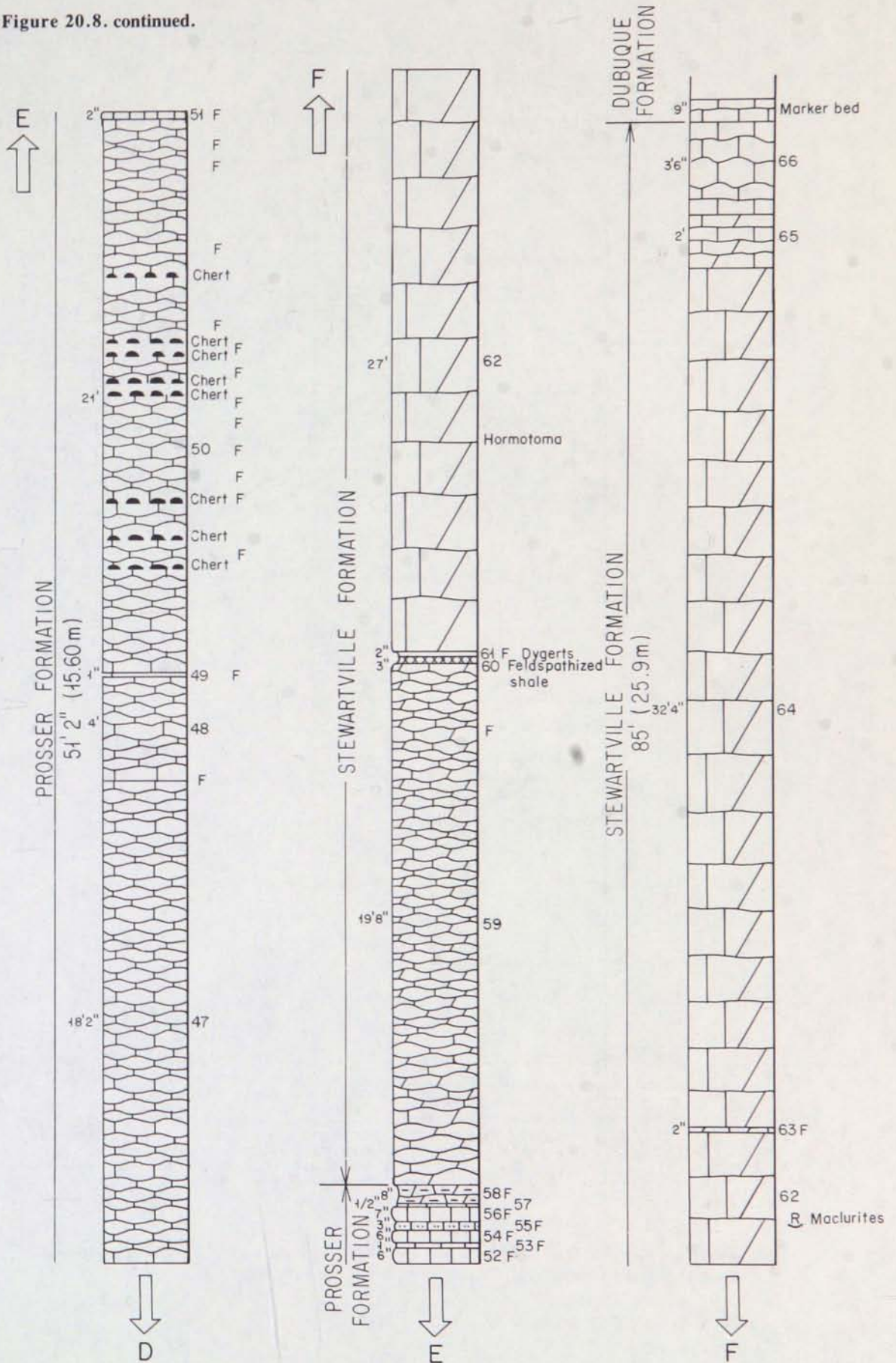


Figure 20.8. Graphic section of the Mahoods Creek (= "Prossers Ravine") section, F-192 of Weiss (1957a); type section of the Prosser Limestone. From Weiss (1957a, corrected).

Figure 20.8. continued.



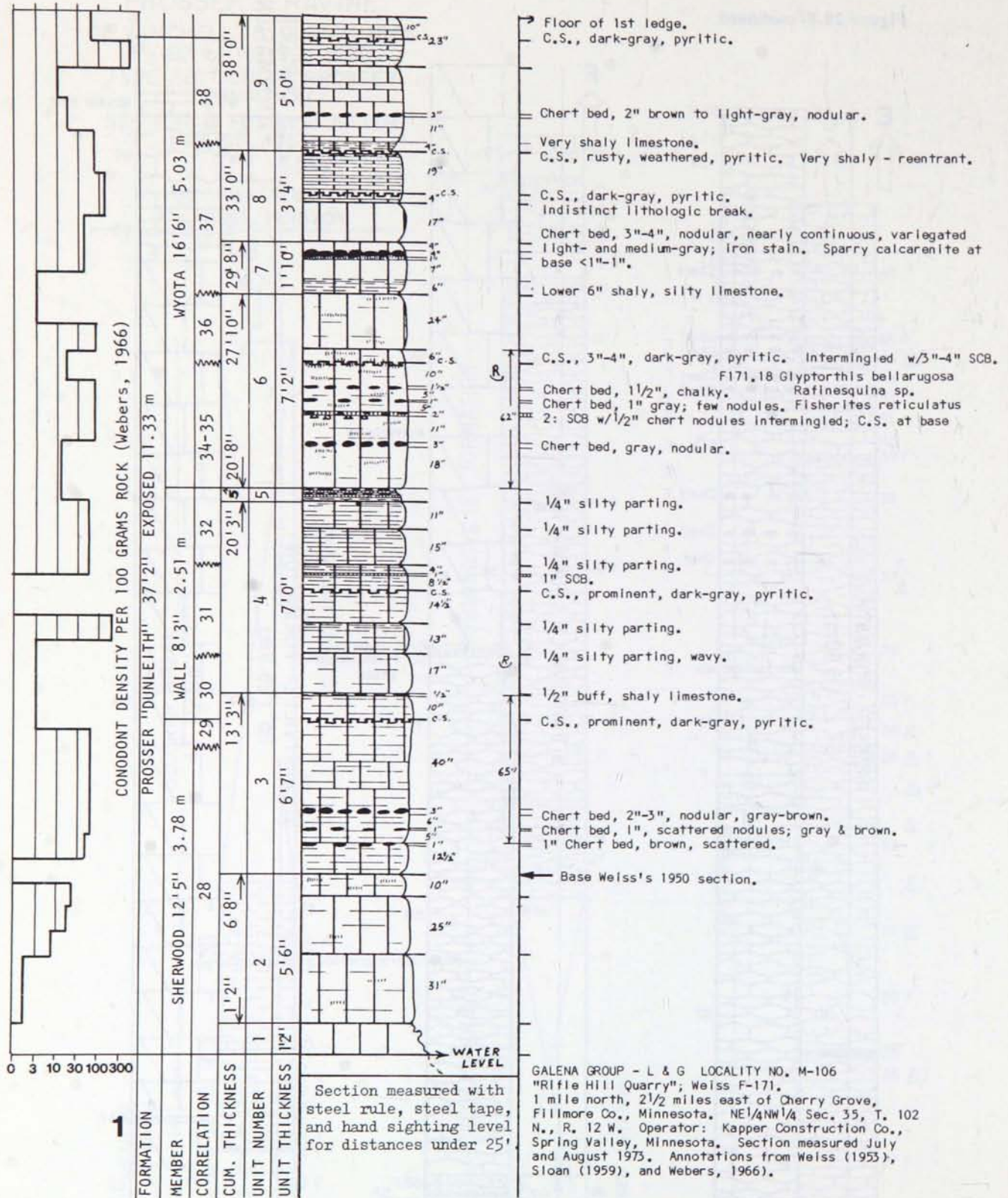


Figure 20.10. Graphic section of Rifle Hill Quarry by Levorson and Gerck, with additional annotations from Weiss (1953), Sloan (1959), and Webers (1966).

Figure 20.10 continued.

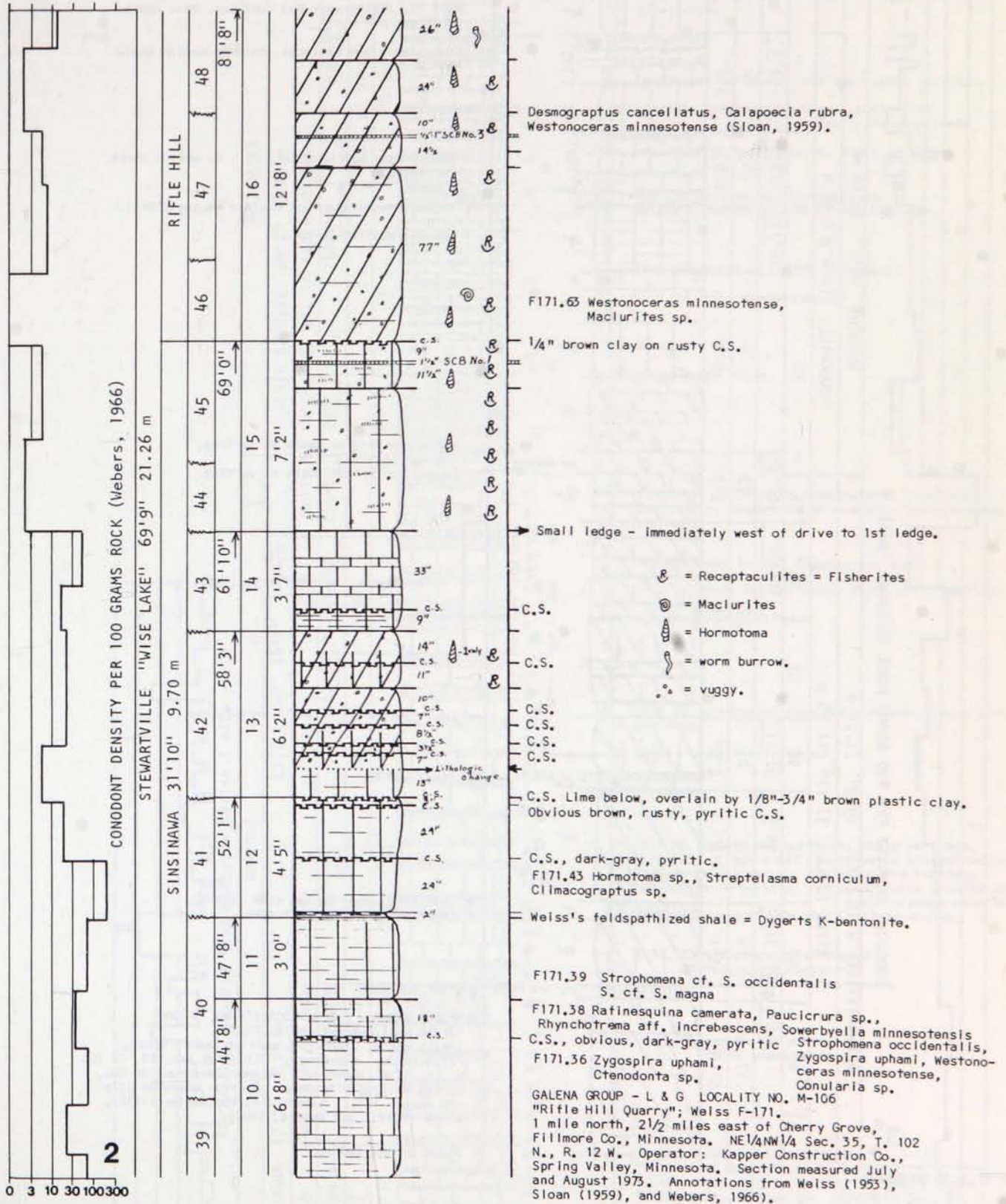


Figure 20.10 continued.

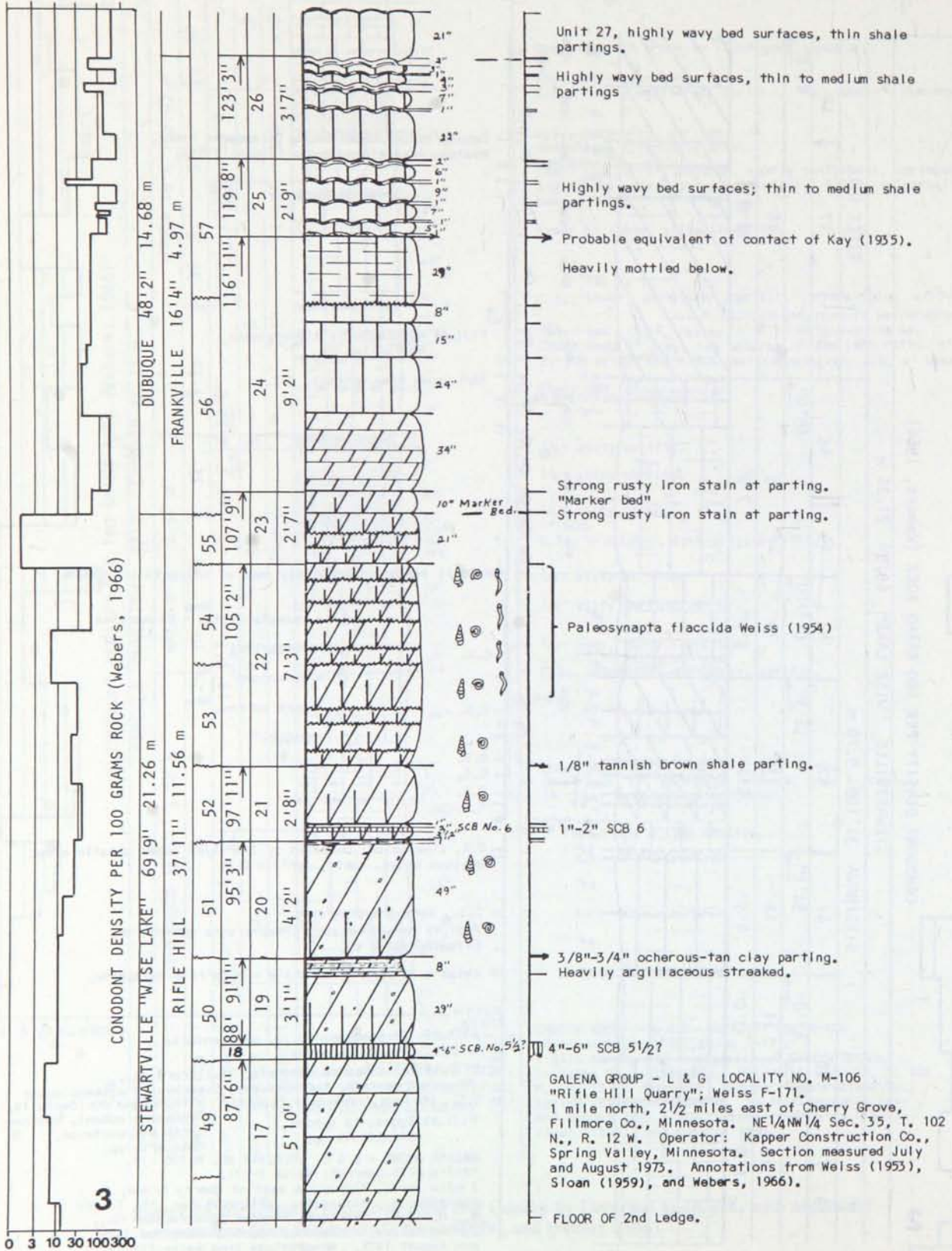
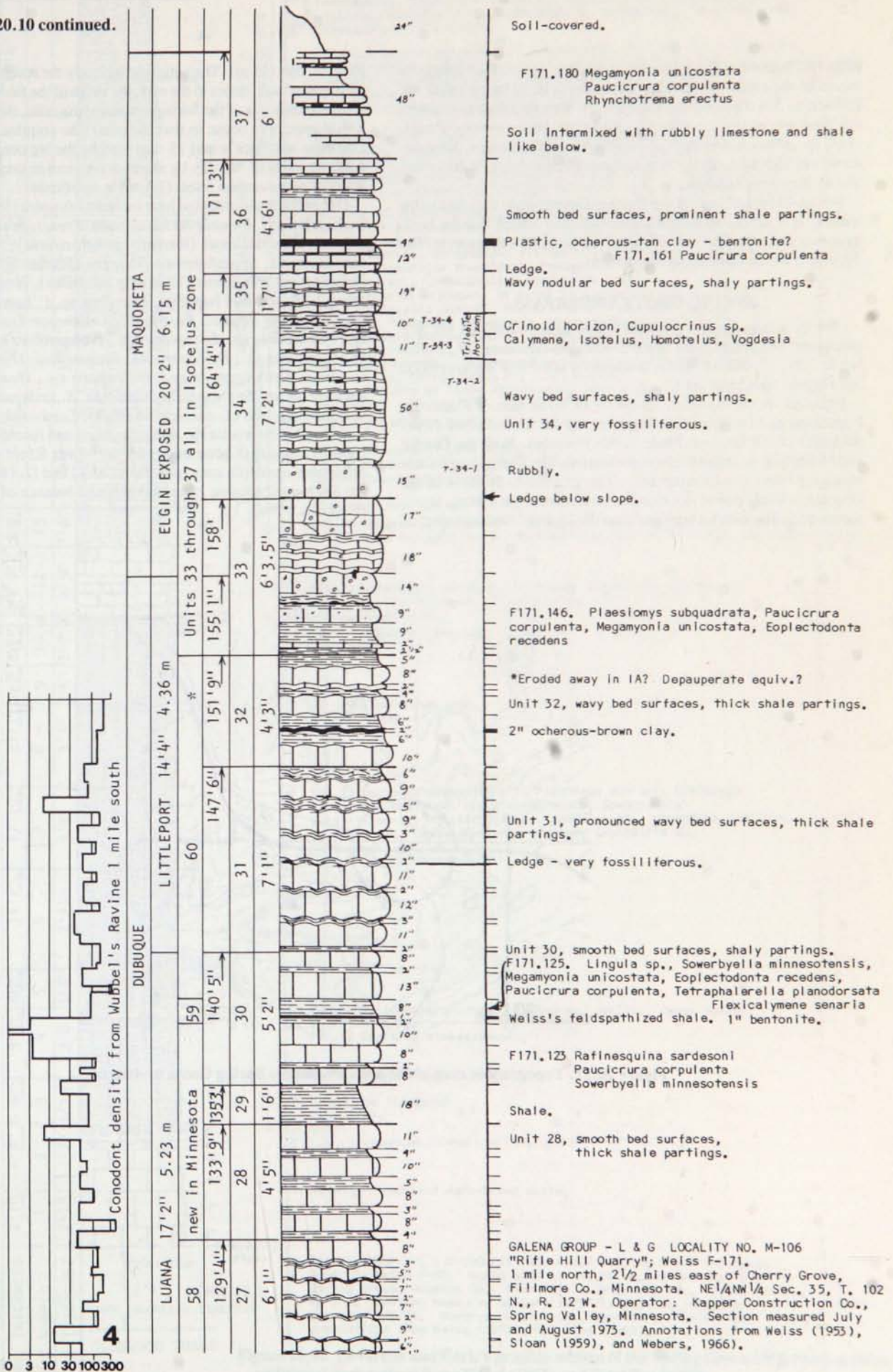


Figure 20.10 continued.



Rifle Hill Member. These species do not reappear. Sloan interprets this to be the result of shoaling from a depth of 50 m typical of the Prosser, to 5 or 10 m for the Rifle Hill. Common Sinsinawa fossils are *Westonoceras minnesotense*, *Rafinesquina camerata*, *Paucicrura* sp., *Rhynchotrema* sp., *Sowerbyella minnesotensis*, *Strophomena occidentalis*, *Zygospira uphami*, *Hormotoma gracilis* and *Streptelasma corniculum*.

About 43 feet (13 m) of the Prosser Limestone is exposed in the quarry. It is similar to that at Cummingsville except that the hardgrounds and chert layers are more obvious in this quarry. The Prosser is not notably fossiliferous here.

SPRING GROVE UNDERPASS

Formerly the site of a railroad bridge over Minnesota 44, 3.2 miles west of Spring Grove in the SW $\frac{1}{4}$ SW $\frac{1}{4}$ SE $\frac{1}{4}$ sec. 17, T. 101 N., R. 7 W., Houston County, this locality is F-85 of Weiss (1957). See Figures 20.11 and 20.12.

Exposed are the complete 29.6-foot (9 m) section of Platteville Formation and the lower 20 feet (6 m) of the total 23-foot (7 m) thickness of the Decorah Shale in this township. Both the Deicke and Millbrig K-bentonites are well exposed. The Decorah and Carimona are richly fossiliferous here. The anomalous thinness of the Decorah is likely due to Rocklandian deformation on a local, asymmetric anticline with an amplitude on the Jordan-Oneota contact of

about 50 feet (15 m). The anticline is clearly the result of motion on a basement fault, down to the east; the strike of the fault is N. 40° W. From the thinness of the *Stictopora mutabilis* zone, the deformation would appear to occur in that horizon. The coquina at the top of Levorson and Gerk's unit 15 may well be the lag concentrate from washing away of the clay by storm-wave erosion during that small uplift of no more than 5 feet (1.5 m) in amplitude.

Decorah fossils collected here include: *Idiospira* (formerly *Camarella*) *panderi*, *Pionodema subaequata*, *Protozyga nicolleti*, *Sowerbyella curdsvillensis* (formerly *punctostriata*), *Strophomena trentonensis*, *Strophomena filitexta* (formerly *incurvata*), *Rafinesquina trentonense* (formerly *alternata*), *Hesperorthis tricenaria*, *Doleroides pervetus*, *Fascifera* sp. ("hamburgensis"), *Rhynchotrema ainsliei*, *Rostricellula minnesotensis*, *Schizotreta* sp., *Petrocrania* sp., *Loxoplocus* sp., *Phragmolites* sp., *Tetranota* sp., *Ceraurus* sp., *Eomonorachus intermedius*, *Dimeropyge galenensis*, *Escharopora* sp., *Hallopora* sp., *Homotrypa* sp., *Rhinidictya* sp., *Stictoporella frondifera*, *S. cribrosa*, *Batostoma* sp., *Streptelasma* cf. *corniculum* (high), *Lambeophyllum profundum* (low), *Favositella* sp., *Raufella filosa* and fucoids. The *Stictoporella angularis* zone occupies the lower 8 feet (2.4 m), the *Stictopora mutabilis* zone runs from 8 to 12 feet (2.4 to 3.6 m), and the *Stictopora minima* zone occupies the balance of the Decorah (Karklins, 1969).

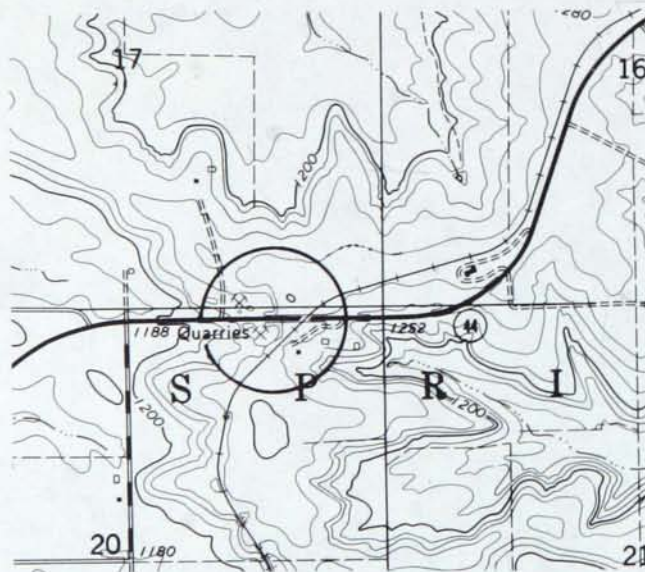


Figure 20.11. Topographic map of the area around the Spring Grove underpass.

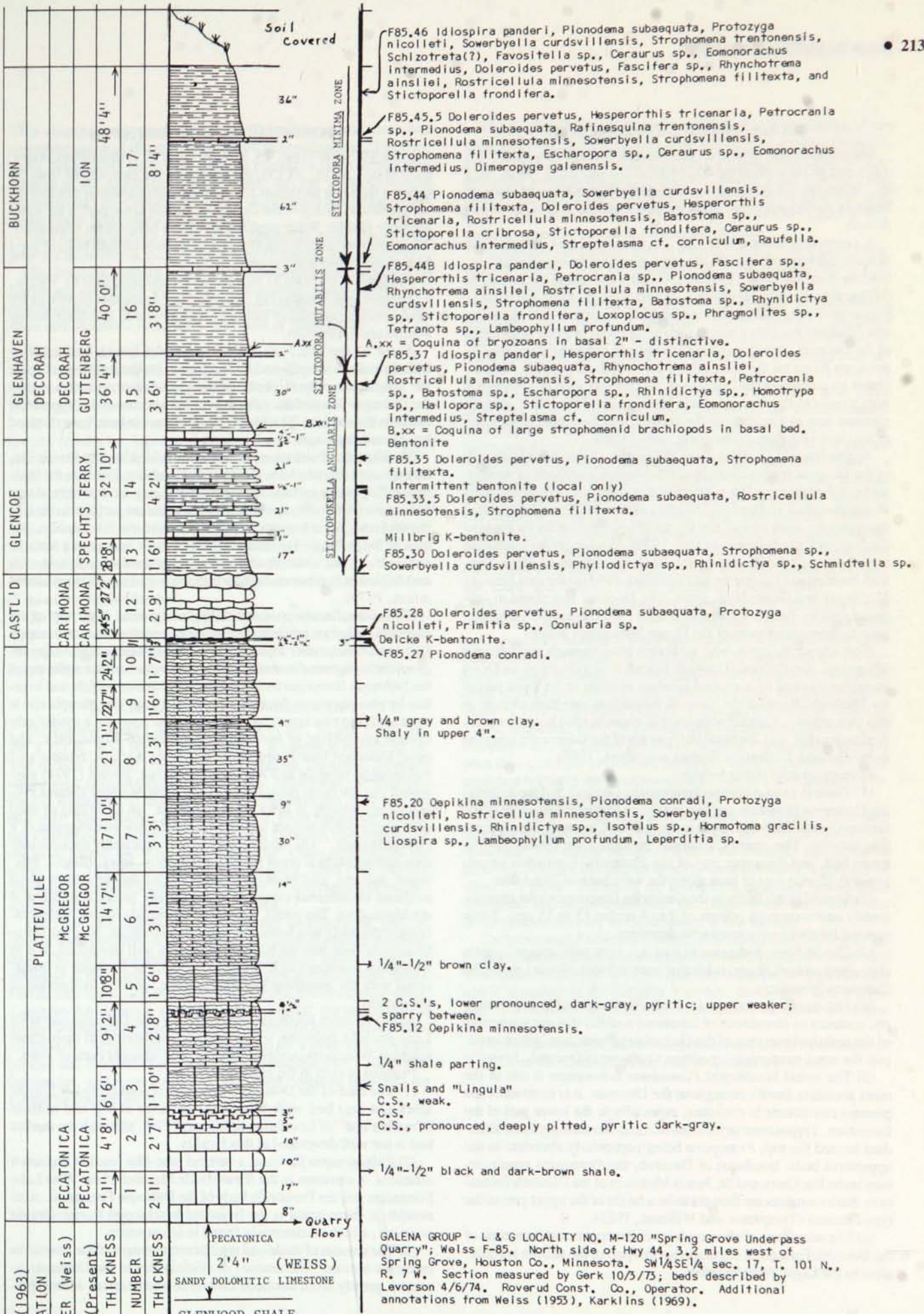


Figure 20.12. Leverson and Gerk's graphic section of the Spring Grove Underpass section, with additional annotations from Weiss (1953) and Karklins (1969).

DECORAH SHALE TYPE SECTION

The current type section of the Decorah Shale is in a quarry 1.8 miles east of Decorah in the NE¹/₄NE¹/₄SE¹/₄ sec. 22, T. 98 N., R. 8 W., Winneshiek County, Iowa. This is the best outcrop of Decorah Shale in the type region. Such outcrops routinely grow over in a decade.

A composite section (Fig. 20.13), measured and described by Witzke, Ludvigson, and Kolata, was compiled from exposures behind the barn and about 300 feet (100 m) west behind the house. At this locality the Decorah Shale is 35 feet (10.6 m) thick and consists primarily of interbedded shale and nodular limestone. The thickness and lithology are very close to Calvin's (1906) original description of the Decorah, which was based mainly on outcrops along the Upper Iowa River on the west side of town. Calvin's (1906) Figure 7 shows an outcrop of the Decorah at the Dugway west of town that is very similar to the outcrop at this locality. The Decorah is partially exposed now in a roadcut on the north side of the Upper Iowa River at Ice Cave Hill Park on the north side of town.

Approximately 15 miles south of Decorah, Iowa, the middle part of the Decorah grades abruptly to lithographic limestone of the Guttenberg Formation. The Guttenberg is locally overlain by shaly strata assigned to the Ion Member (Kay, 1928) and underlain throughout a wide area of the Upper Mississippi valley by shale of the Spechts Ferry Formation (Kay, 1928). The Ion grades southward to carbonate of the Buckhorn and St. James Members of the Dunleith Formation (Templeton and Willman, 1963) in the area between McGregor and Guttenberg, Iowa. The Decorah was raised to subgroup rank by Templeton and Willman (1963) because of its heterogeneity throughout most of the Upper Mississippi valley.

Near Decorah, Iowa, and northwestward through southeastern Minnesota, the Decorah-Dunleith boundary is a diachronous facies transition marked by a gradual increase in shale in the basal part of the Dunleith. Because the Decorah formations lose their identity in this part of Iowa, the subgroup level of classification is neither practical nor useful, and the basal shaly strata of the Galena are assigned to the Decorah Formation (Kolata and others, 1986).

Features to note at this locality:

(1) There is a sharp contact between the Decorah and the underlying Carimona limestone and the overlying Dunleith limestone of the Galena Group. Only the upper surface of the Carimona is exposed at this locality. The entire Carimona, including the Deicke K-bentonite bed, and the upper part of the Platteville Formation are exposed 0.25 mile east of here along the west bank of Trout Run.

(2) Several small faults in the Carimona limestone strike approximately east-west with offsets of 2 to 6 inches (5 to 15 cm). Some vertical fractures are coated with dripstone.

(3) The Millbrig K-bentonite bed is a very pale orange, plastic clay about an inch (2 cm) thick that occurs 3 feet (90 cm) above the Carimona limestone.

(4) The middle part of the Decorah, best exposed in the western pit, contains an abundance of limestone nodules that are suggestive of the nodular limestone of the Guttenberg Formation, which occupies the same stratigraphic position southeast of Decorah, Iowa.

(5) The orthid brachiopod *Pionodema subaequata* is one of the most abundant fossils throughout the Decorah. It is commonly the primary constituent in coquinas, especially in the lower part of the formation. Trepostome bryozoans become increasingly more abundant toward the top, *Prasopora* being particularly abundant in the uppermost beds. Southeast of Decorah, the *Prasopora* zonule occurs in the Buckhorn and St. James Members of the Dunleith Formation. Both members are thought to be a facies of the upper part of the type Decorah (Templeton and Willman, 1963).

(6) The occurrence of chert nodules in the uppermost limestone of the Dunleith Formation suggests that this part of the section is equivalent to the Eagle Point Member.

POSTVILLE NORTH SECTION

In the SW¹/₄SW¹/₄ sec. 16, T. 96 N., R. 6 W., Allamakee County, Iowa (Figs. 20.14, 20.15), the quarry on the east side of Iowa 51 exposes the same section as the roadcut, and in addition exposes the hardground at the top of the Dubuque, and the lower part of the Elgin Member (Scales Shale equivalent) of the Maquoketa Formation. The upper part of the Elgin Member is exposed on both sides of Iowa 51 for half a mile to the south.

The roadcut on Iowa 51 was measured and described by Witzke, Ludvigson, and Kolata (Fig. 20.15). The Maquoketa section in the quarry on the east side of Route 51 was measured and described by Witzke and Ludvigson.

About 35 feet (10.7 m) of Dubuque and 4 feet (1.2 m) of Wise Lake limestone are exposed in the roadcut on the west side of Iowa 51. Judging from the thickness of the Dubuque strata in the quarry, the Dubuque-Maquoketa contact probably occurs at the uppermost bench in the roadcut. The hardground appears to have been covered by soil and vegetation.

The Dubuque Formation has been subdivided into the Frankville, Luana, and Littleport beds (Levorson and others, 1979) on the basis of bedding plane surface topography, ranging from nearly planar beds in the Frankville, upward to highly undulose surfaces in the Littleport beds. These features are quite prominent at this locality. The base of the Dubuque Formation is picked at the bottom of a remarkably uniform and widespread limestone or dolomite bed 8 inches (20 cm) thick that is separated off by thin shaly partings (Levorson and others, 1979).

One of the finest exposures of the hardground at the top of the Galena Group can be seen on the upper bench within the quarry. Here, as at many other localities in the Upper Mississippi valley region, the hardground is characterized by a pitted surface at the top of the Dubuque limestone that is encrusted with iron sulfide and overlain by phosphorite as thick as 6 inches (15 cm). The phosphorite is separated into two layers by silty shale that contains a moderately diverse assemblage of invertebrates dominated by molluscs. The most abundant fossils are *Michelinoceras sociale*, *Hindia* sp., *Palaeoneilo fecunda* and *Nuculites neglectus*. Brown (1974) suggested that the basal phosphorite of the Elgin Member (Scales Formation equivalent) in Iowa originated from "an upwelling of deep cold nutrient-rich waters into the warm shallow environment of a carbonate shelf." The hardground has been repeatedly traced in outcrop and subsurface cores through Wisconsin, Iowa, Illinois, Missouri, Indiana, and Michigan. Throughout this area there is no evidence of subaerial exposure of the Galena before deposition of the Maquoketa. The pitted, planar, upper surface of the Galena carbonates probably was formed by submarine solution. Near the Iowa-Minnesota state line the hardground is less well developed, and in Minnesota (compare to Rifle Hill Quarry), the Dubuque is gradational with the overlying Maquoketa shale, and the hardground is not present.

About 10 miles southeast of this locality, the Dubuque and Wise Lake grade to dolomite which extends southeastward throughout southern Wisconsin, northern Illinois, and adjacent parts of Iowa.

Features to note in the roadcut:

(1) The base of the Dubuque Formation is marked by a 9.5-inch-thick (24 cm) bed with thin shaly partings at top and bottom ("marker bed" of Levorson and others, 1979), although the marker bed is not well developed at this locality.

(2) *Paleosynapta flaccida*, a vertical tube-like fossil of unknown affinities, is common in the Stewartville Member of the Wise Lake Formation and the Frankville beds of the Dubuque Formation. Also notable in these strata is the linguloid brachiopod *Pseudolingula iowensis*, which is commonly found in life position.

(3) The amount of shale and argillaceous content of the limestone increases upward. The amount of siliciclastics in the Dubuque increases greatly from northern Illinois to southeastern Minnesota.

This arrangement suggests that the Transcontinental Arch was emergent and shed siliciclastics during Cincinnatian time. The overlying Maquoketa shale was derived primarily from terrigenous sources in the Appalachian mobile belt, but the Transcontinental Arch also may have contributed some siliciclastics to the Maquoketa in the Upper Mississippi valley region.

(4) Two grainstones occur in the Frankville beds. These have been traced widely in the outcrop belt by Levorson and Gerk (1983).

(5) Undulose bedding, which occurs near the top of the section is commonly associated with thick shaly partings. It may be the result of soft-sediment deformation due to differential compaction of the shale and limestone or possibly the result of bioturbation.

Features to note in the quarry:

(1) Approximately 43 feet (13 m) of the Elgin Member (Scales Shale equivalent) of the Maquoketa Formation, occur above the Dubuque limestone in the quarry (see Fig. 20.15).

(2) The orthoconic cephalopod *Michelinoceras sociale* and the sponge *Hindia* sp. (spherical masses 5 to 8 mm in diameter) are abundant in the phosphorite bed on the upper bench of the quarry.

(3) The brownish-black shale overlying the phosphorite also has been observed in northwestern Illinois (Argo-Fay bed of Kolata and Graese, 1983), where it has a total organic carbon (TOC) content of about 16 percent. Analyses of samples from this locality indicate TOC of 10 percent. The linguloid brachiopod *Leptobolus* is very abundant on some bedding planes in this shale.

(4) Graptolites are common and well preserved in the basal 15 feet (5 m) of the Elgin Member.

(5) The upper beds in the Elgin Member contain abundant fragments, but rarely whole specimens, of trilobites including *Isotelus*, *Anataphrus* (*Vogdesia*), and *Flexicalymene*. These trilobite zonules occur in the same stratigraphic position in northwestern Illinois.

NORTH GUTTENBERG ROADCUT

The roadcut along County X-56, NW¹/₄ sec. 32 and SW¹/₄ sec. 29, T. 93 N., R. 2 W., Clayton County, is shown in Figure 20.16. The section exposes the top of the Canadian Shakopee dolomite (along west embankment of the Chicago, Milwaukee, St. Paul and Pacific Railroad and along roadcut on road between X-56 and the railroad). Also exposed are most of the St. Peter Sandstone, the entire Glenwood, Platteville, Decorah, and Dunleith Formations and the basal part of the Wise Lake Formation. Other notable cuts are along U.S. 52 north and south of Guttenberg, Iowa (Fig. 20.17). The total composite section in Figure 20.16 was measured and described by Witzke, Ludvigson, and Kolata.

The Platteville contains an abundant and diverse fauna, particularly in the equivalent of the Mifflin Formation of Illinois terminology. The strophomenid brachiopod *Oepikina minnesotensis* is abundant at this locality. Other brachiopods that have been identified include the orthids *Hesperorthis concava*, *Doleroides pervetus*, *Campylorthis deflecta*, and *Pionodema conradi*, the strophomenid *Strophomena plattinensis*, and rhynchonellid *Rostricellula minnesotensis*. Bryozoans are represented by a diversity of small ramose and bifoliate types, especially *Hemiphragma*, *Eridotrypa*, *Stictopora*, and *Astreptodictya*. The most common trilobites are *Ceraurus* and *Thaleops*.

The Spechts Ferry shale is the southeastward extension of the basal Decorah Shale. Compare this section with those at Decorah, Iowa, and St. Paul, Minnesota, where the shale is much thicker. Farther to the south in western Illinois the Spechts Ferry grades to carbonate. The Millbrig K-bentonite is present at this locality and most other places in the vicinity of Guttenberg, Iowa. The Deicke K-bentonite is generally absent in the immediate area.

Pionodema subaequata and, to a lesser extent, *Rafinesquina trentonensis* are the most abundant fossils in the Spechts Ferry here. Both brachiopods occur in thin lenses of coquina.

The Guttenberg Member consists of lithographic to fine-grained limestone that contains an abundant, diverse, and well-preserved fauna. The wavy, nodular beds are separated by reddish-brown carbonaceous shale partings that have as much as 40 percent total organic carbon. The primary organic constituent is *Gloeocapsamorpha prisca*, a microscopic single-cell, blue-green alga. The most conspicuous macrofossils are the strophomenids *Rafinesquina trentonensis* and *Sowerbyella punctostriata*. This locality has yielded several well-preserved specimens of the mitrate carpoid *Ateleocystites guttenbergensis* Kolata and Jollie (1982), a primitive echinoderm that is elsewhere very rare. Other echinoderms that have been reported from these strata include *Cupulocrinus levorsoni*, *C. jewetti*, and *Pycnocrinus gerki* (Kolata, 1986).

The Elkport K-bentonite is a bed 1 to 5 cm thick that occurs at the conspicuous re-entrant near the base of the Guttenberg. It has been chemically correlated here and at other localities between McGregor, Iowa, and Galena, Illinois (Kolata and others, 1986).

The Guttenberg is conformably overlain by the Dunleith Formation of the Galena Group. The characteristic reddish-brown shale partings of the Guttenberg grade upward into the greenish-gray shale and limestone of the Buckhorn Member. The Buckhorn and overlying St. James Member are equivalent to the uppermost calcareous shale at Decorah, Iowa. In the Guttenberg area, the greenish-gray shale is less prominent than it is northwestward toward the Transcontinental Arch. To the southeast in north-central Illinois, the Buckhorn and St. James consist of slightly argillaceous dolomite with thin greenish-gray shale partings. At this locality the most abundant fossils in the Buckhorn and St. James are *Prasopora*, *Pionodema*, *Hesperorthis*, and *Sowerbyella*.

Above the St. James Member, the Dunleith Formation becomes increasingly pure, except for some strata in the Mortimer and Rivoli Members. The cherty members within the Dunleith can be traced from southeastern Minnesota to north-central Illinois, a distance of about 250 miles. The top of the Dunleith is generally picked at the uppermost bed of chert nodules. The Dunleith members above the Sherwood are not easy to differentiate at this locality.

The green alga *Fisherites* (formerly *Receptaculites*) is one of the most abundant and conspicuous fossils in the Dunleith and overlying Wise Lake Formation. It occurs sparsely in the Eagle Point Member and is abundant in the Fairplay Member. *Ischadites*, also a green alga, is abundant in the Dunleith, in and above the Sherwood Member.

The Nasset K-bentonite bed occurs here and at nearby outcrops on U.S. 52 on the north and south side of Guttenberg, Iowa.

Bruening Quarry, Route 9, Decorah, Iowa

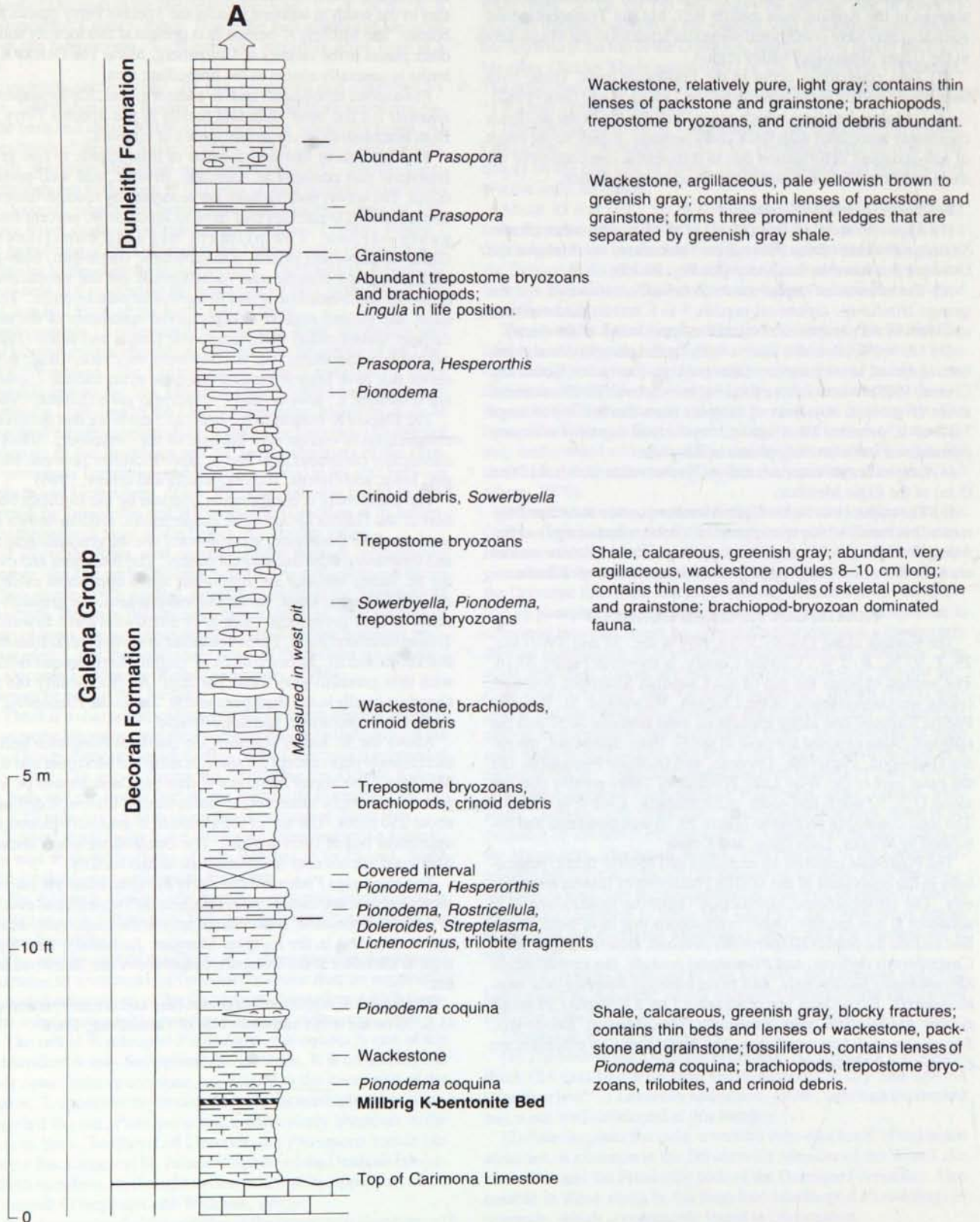


Figure 20.13. Graphic section of the type section of the Decorah Shale, Bruening Quarry, Decorah, Iowa.

Bruening Quarry, Route 9, Decorah, Iowa Figure 20.13 continued.

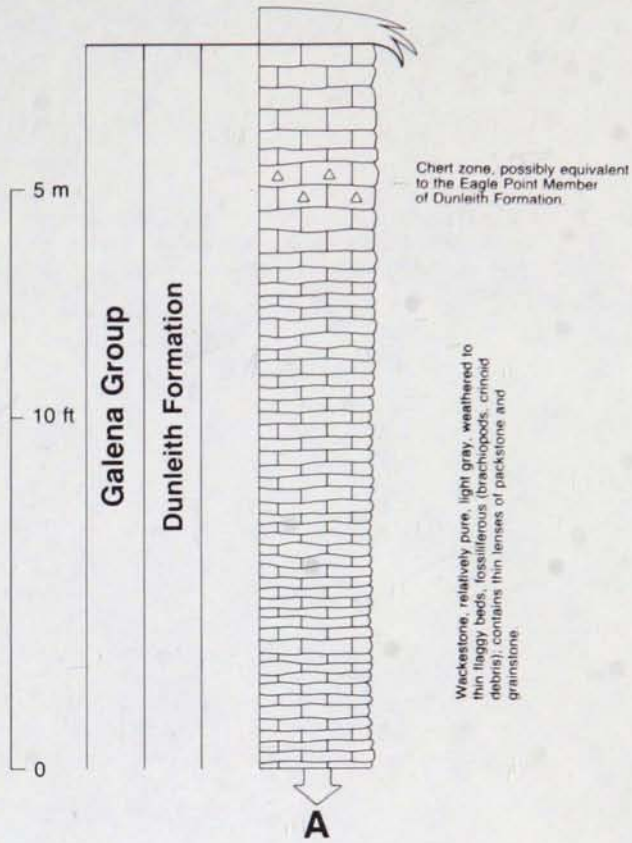


Figure 20.14. Postville North Quarry, uppermost Wise Lake Formation overlain by complete Dubuque Formation, which is much less shaly than at Rifle Hill, and in turn overlain by the depauperate zone hardground and the basal Elgin Member of the Maquoketa Formation.

Postville North Road Cut, Highway 51

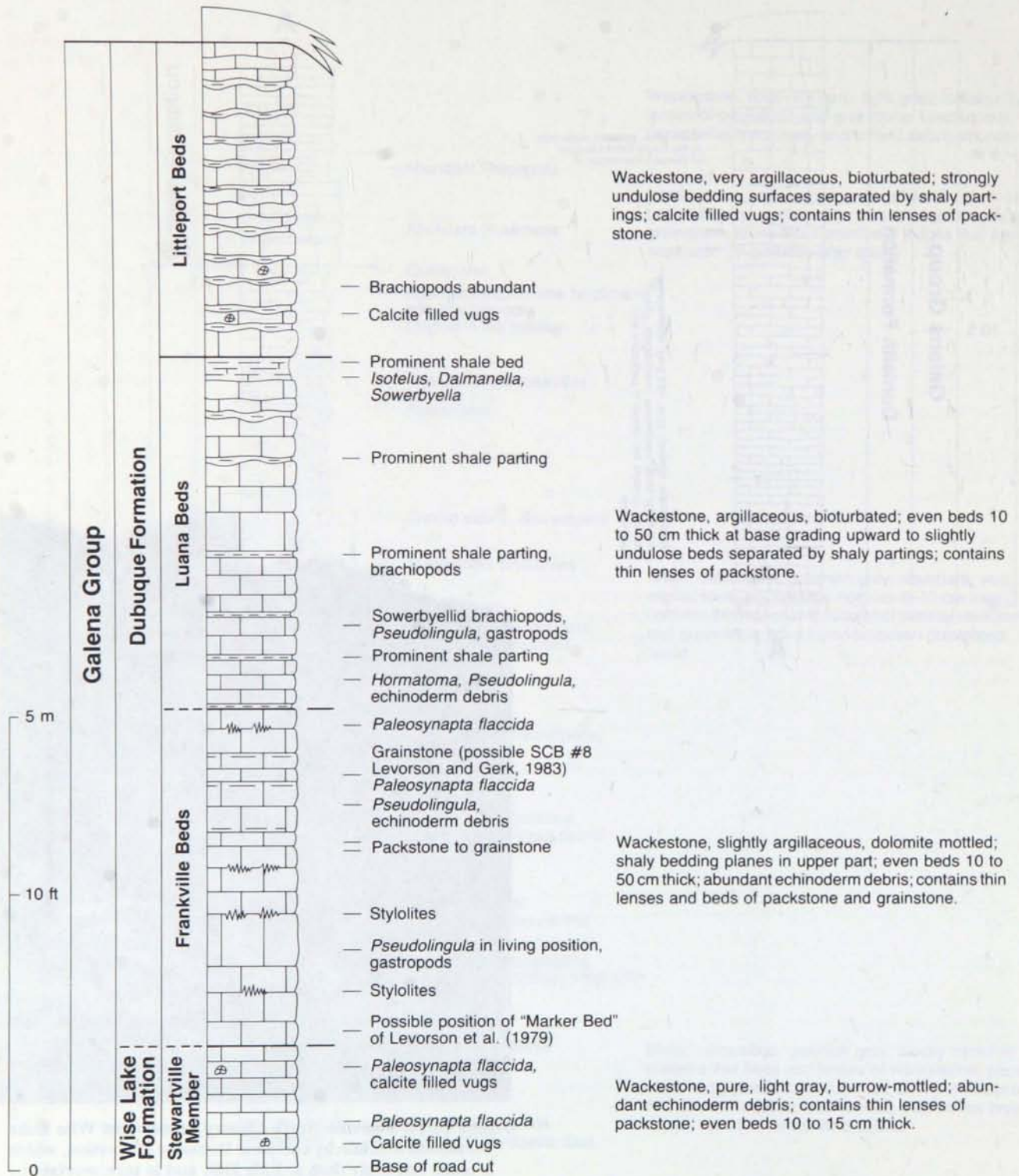
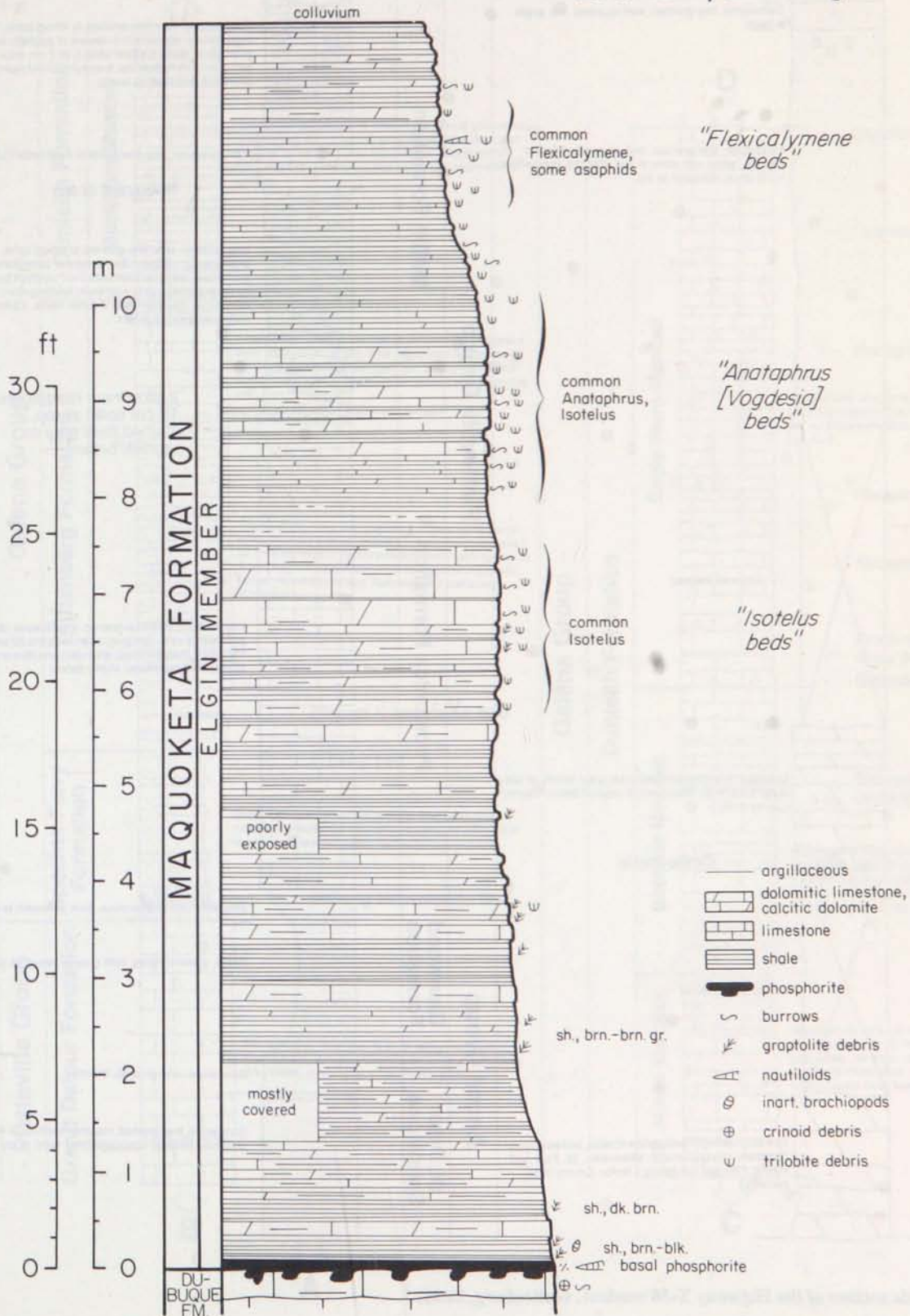


Figure 20.15. Graphic section of the Postville North roadcut and quarry.

Figure 20.15 continued.

Postville North Quarry
 SWSW sec. 16, T96N, R6W Allamakee Co., Iowa
 (Maquoketa section)

B. Witzke, G. Ludvigson



Highway X-56 Road Cut, Guttenberg, Iowa

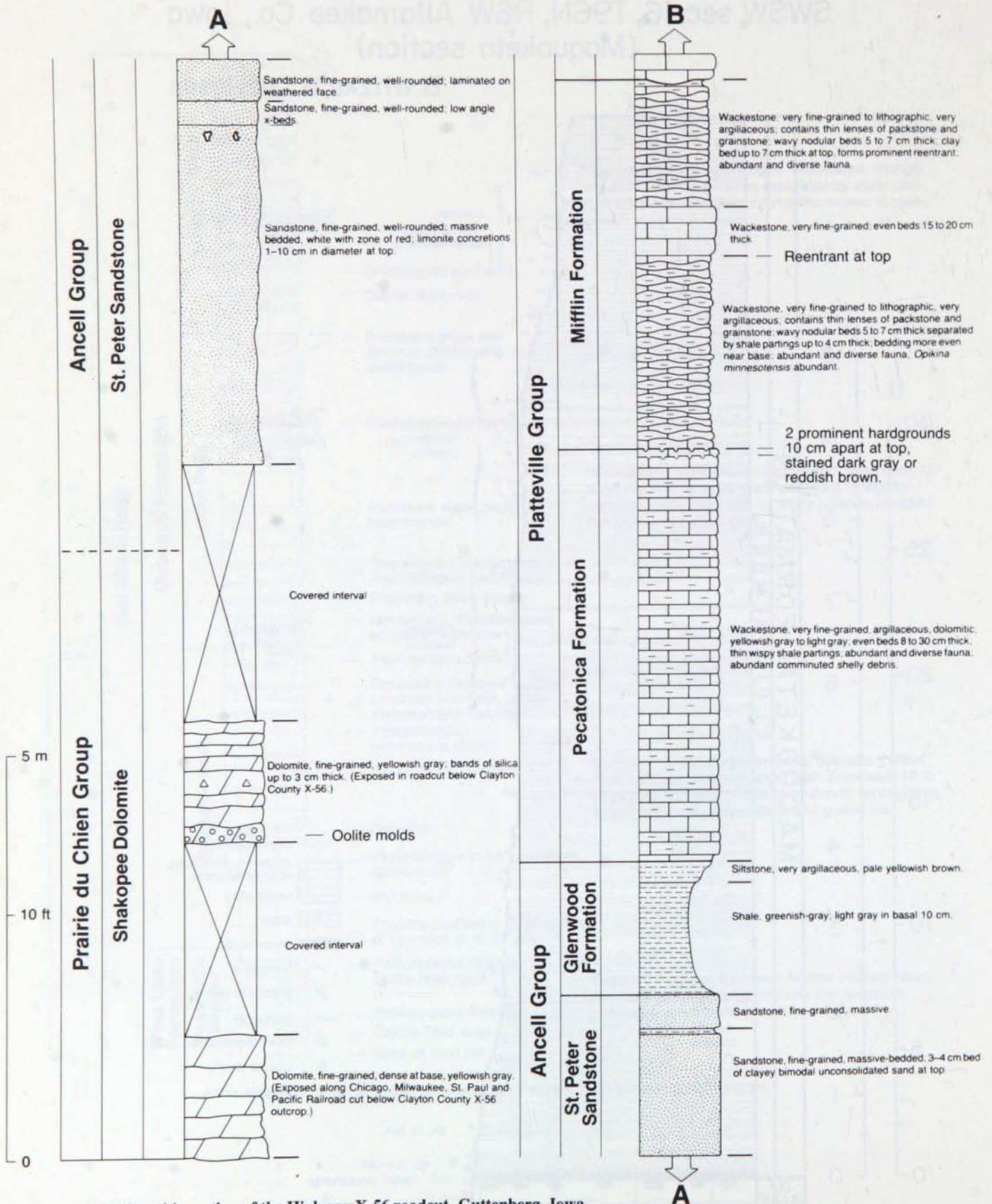


Figure 20.16. Graphic section of the Highway X-56 roadcut, Guttenberg, Iowa.

Figure 20.16 continued.

Highway X-56 Road Cut, Guttenberg, Iowa (continued)

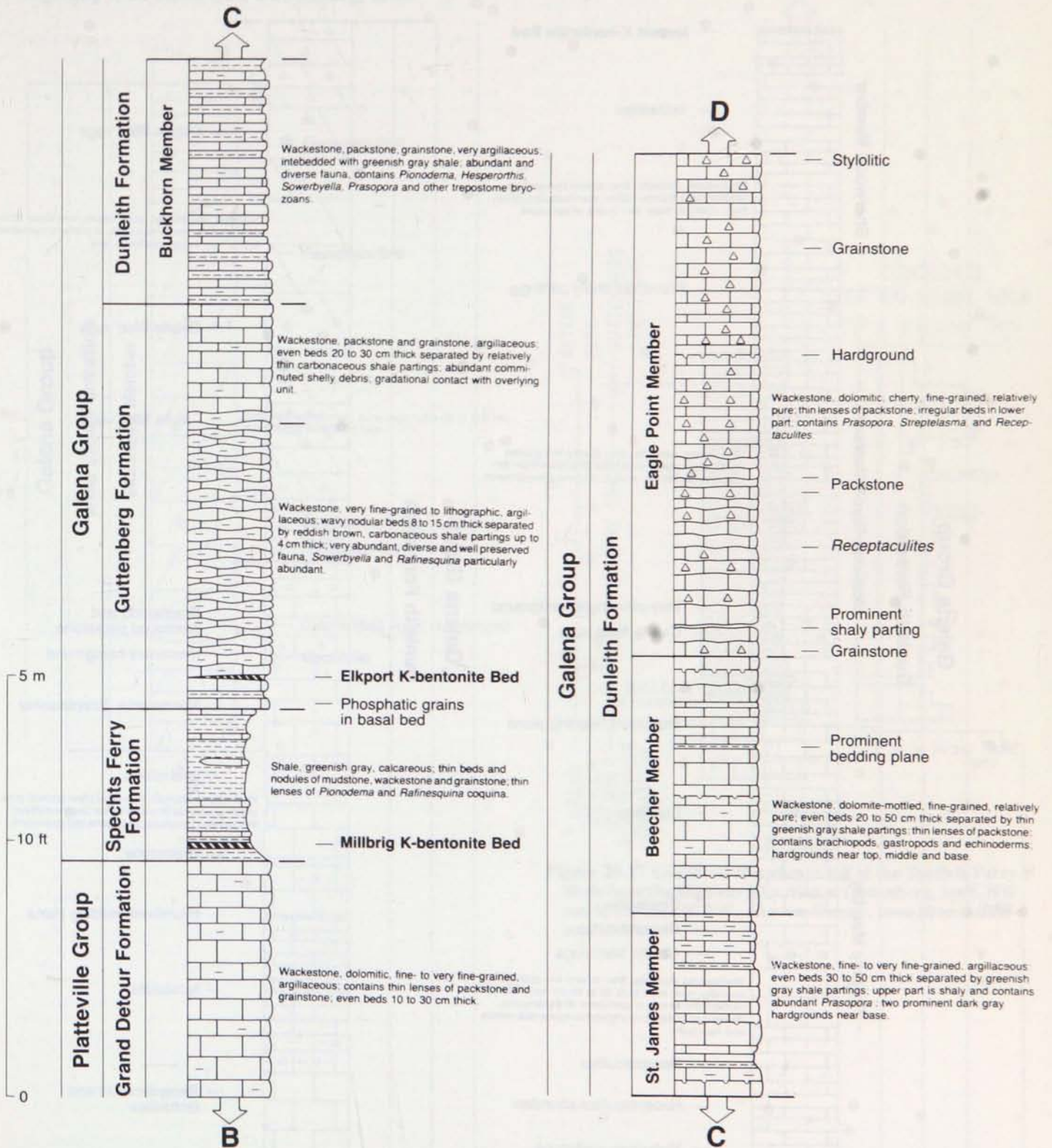


Figure 20.16 continued.

Highway X-56 Road Cut, Guttenberg, Iowa (continued)

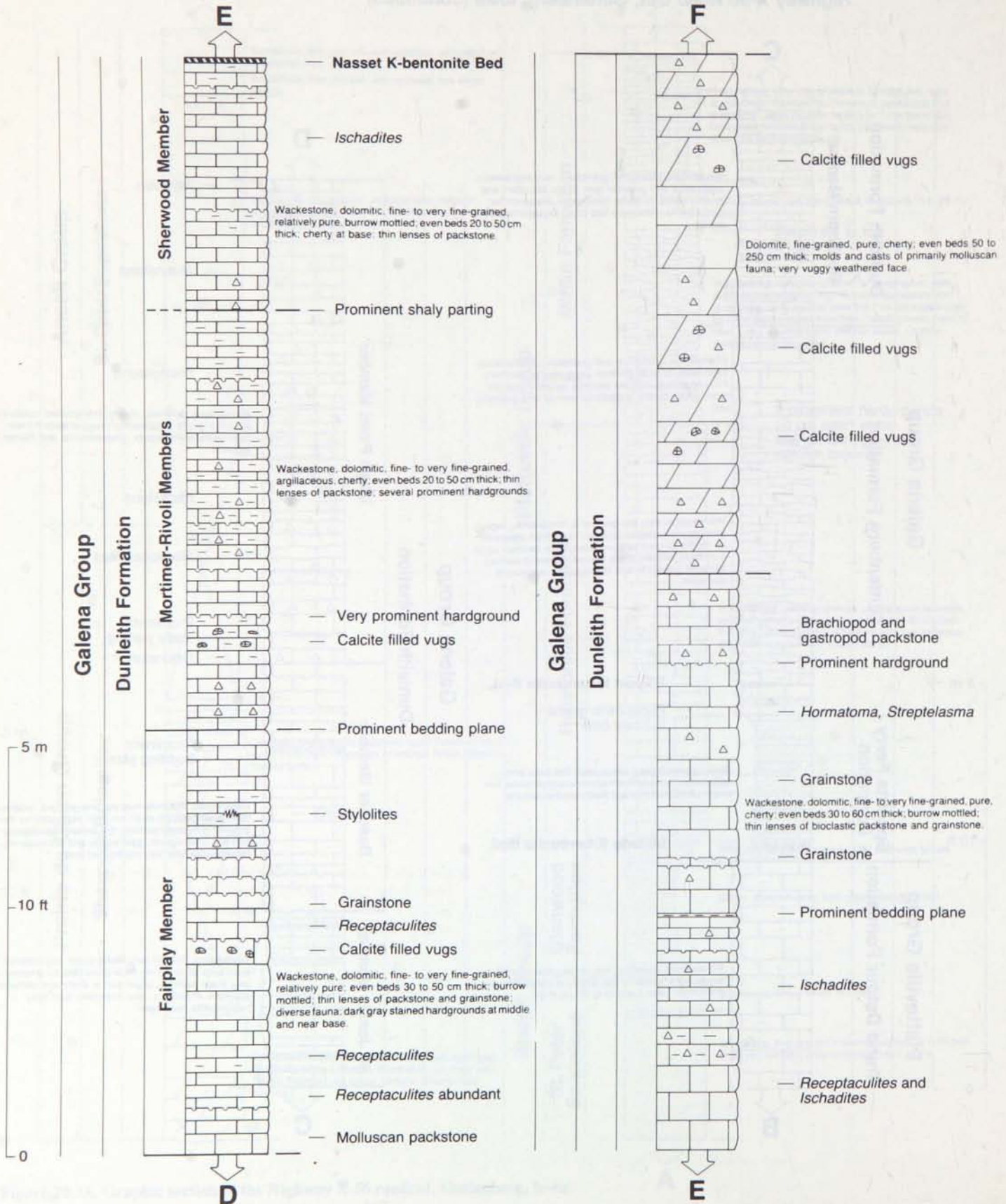


Figure 20.16 continued.

Highway X-56 Road Cut, Guttenberg, Iowa

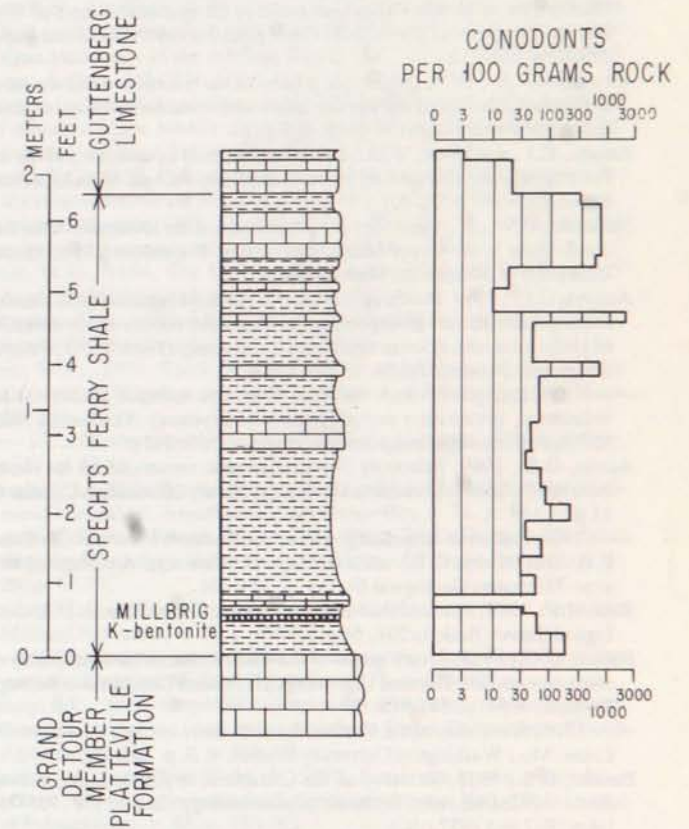
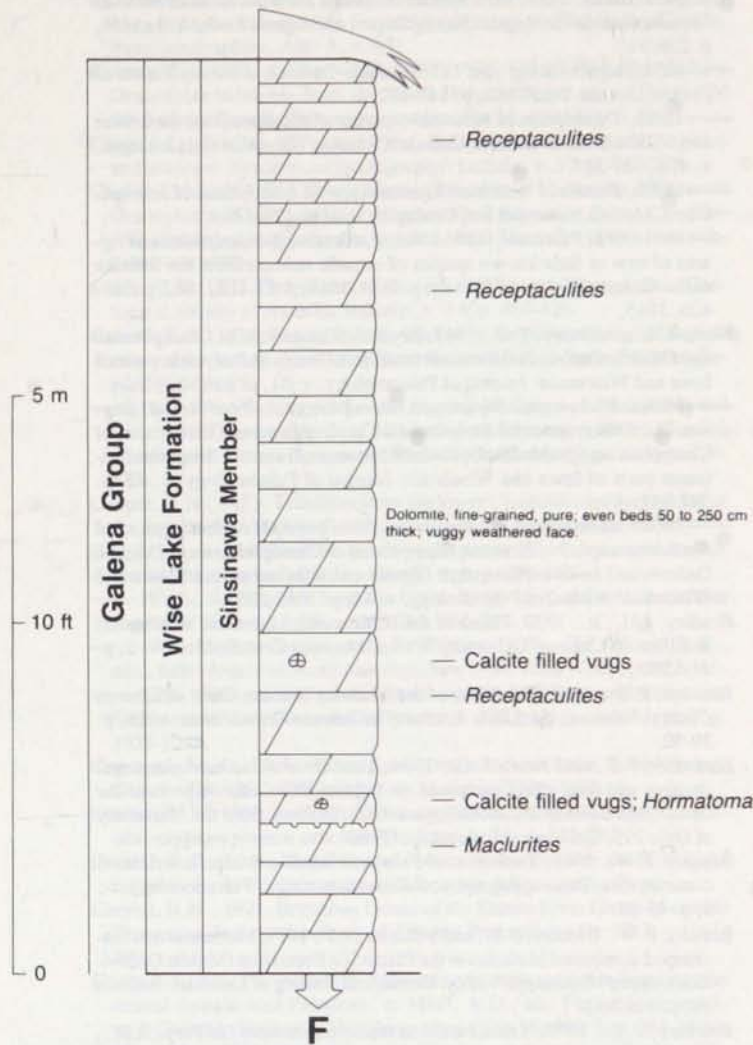


Figure 20.17 Conodont abundance log of the Spechts Ferry Shale from the Highway 52 section at Guttenberg, Iowa, NW sec. 8, T. 92 N., R. 2 W., Clayton County, Iowa (from Anderson, 1959).

REFERENCES CITED

- Ager, D.V., 1963, Principles of paleoecology: New York, McGraw-Hill, 371 p.
- Agnew, A.F., 1949, The Middle and Upper Ordovician strata of the Upper Mississippi Valley, a restudy: Stanford University Abstracts of Dissertations, 1948-49, v. 24, p. 241-243.
- 1955, Facies of Middle and Late Ordovician rocks of Iowa: American Association of Petroleum Geologists Bulletin, v. 39, p. 1703-1752.
- 1956, Facies of Platteville, Decorah and Galena rocks of the Upper Mississippi Valley, in Schwartz, G.M., and others, eds., Lower Paleozoic of the upper Mississippi Valley: Geological Society of America, Annual Meeting, Minneapolis, Minnesota, 1956, Guidebook for field trip no. 2, p. 41-54.
- Agnew, A.F., and Heyl, A.V., Jr., 1946, Quimbys Mill, new member of Platteville Formation, Upper Mississippi Valley: American Association of Petroleum Geologists Bulletin, v. 30, p. 1585-1587.
- Agnew, A.F., Heyl, A.V., Jr., Behre, C.H., Jr., and Lyons, E.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.
- Alexander, R.R., 1975, Phenotypic lability of the brachiopod *Rafinesquina alternata* (Ordovician) and its correlation with the sedimentologic regime: Journal of Paleontology, v. 49, p. 607-618.
- Amaral, E.J., and Pryor, W.A., 1976, Depositional environment of the St. Peter Sandstone deduced by textural analysis: Journal of Sedimentary Petrology, v. 47, p. 32-52.
- Anderson, H.W., Jr., 1959, The conodont fauna of the lower part of the Decorah Shale in the Upper Mississippi Valley: Unpublished M.S. thesis, University of Minnesota, Minneapolis.
- Astrova, G.G., 1965, Morfologiya, istoriya razvitiya i sistema ordovikskikh i siluriyskikh mshano [Morphology, evolutionary history and systematics of Ordovician and Silurian bryozoans]: Akademiya Nauk SSSR, Paleontologicheskyy Institut Trudy, v. 106, 432 p.
- 1978, Istoriya razvitiya, sistema i filogeniya mshanok [Historical development, systematics and phylogeny of Bryozoa]: Akademiya Nauk SSSR, Paleontologicheskyy Institut Trudy, v. 169, 240 p.
- Austin, G.S., 1969, Paleozoic lithostratigraphic nomenclature for southeastern Minnesota: Minnesota Geological Survey Information Circular 6, 11 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. 459-484.
- Bain, H.F., 1905, Zinc and lead deposits of northwestern Illinois: U.S. Geological Survey Bulletin 246, 56 p.
- Barton, D.C., 1913, A new genus of the Cheiruridae, with descriptions of some new species: Harvard University, Museum of Comparative Zoology Bulletin, v. 54, p. 547-556.
- 1915, A revision of the Cheiruridae with notes on their evolution: St. Louis, Mo., Washington University Studies, v. 3, p. 101-152.
- Bassler, R.S., 1913, Revision of the Ostracoda, in Zittel, K.A., author; Eastman, Charles, ed., Textbook of paleontology (2nd ed.): P. 735-742 [also 1927 and 1937 eds.].
- 1915, Bibliographic index of American Ordovician and Silurian fossils: U.S. National Museum Bulletin 92, 2 v., 1521 p.
- 1919, The Cambrian and Ordovician: Maryland Geological Survey, 424 p.
- Bassler, R.S., and Kellett, Betty, 1934, Bibliographic index of Paleozoic Ostracoda: Geological Society of America Special Paper 1, 500 p.
- Bayer, T.N., 1959, The subsurface bedrock stratigraphy of northwestern Minnesota: Unpublished M.S. thesis, University of Minnesota, Minneapolis.
- 1965, The Maquoketa Formation in Minnesota and an analysis of its benthonic communities: Unpublished Ph.D. dissertation, University of Minnesota, Minneapolis, 209 p.
- 1966, *Astylospongia* from the Maquoketa Formation in Minnesota: Journal of Paleontology, v. 40, p. 1387-1388.
- 1967, Repetitive benthonic community in the Maquoketa Formation (Ordovician) of Minnesota: Journal of Paleontology, v. 41, p. 417-422.
- Bays, C.A., 1938, Stratigraphy of the Platteville Formation [abs.]: Geological Society of America Proceedings for 1937, p. 269.
- Bergström, S.M., 1986, The graptolite correlation of the North American Upper Ordovician standard: Lethaia, v. 19, p. 247-266.
- Berkey, C.P., 1906, Paleogeography of St. Peter time: Geological Society of America Bulletin, v. 17, p. 229-250.
- Billings, Elkanah, 1857, New species of fossils from the Silurian rocks of Canada: Canada Geological Survey Report of Progress for the Year 1856, p. 256-345.
- 1858, Report for the year 1857: Canada Geological Survey Report of Progress for the Year 1857, p. 147-192.
- 1859a, Description of some new species of trilobites from the Lower and Middle Silurian rocks of Canada: Canadian Naturalist and Geologist, v. 4, p. 367-383.
- 1859b, Fossils of the Chazy Limestone, with descriptions of new species: Canadian Naturalist and Geologist, v. 4, p. 426-470.
- 1861-1865, Paleozoic fossils: Vol. 1, containing descriptions and figures of new or little known species of organic remains from the Silurian rocks: Canada Geological Survey, p. 1-24, 1861; p. 25-168, 1862; p. 169-426, 1865.
- Bork, K.B., and Perry, T.G., 1967, Bryozoa (Ectoprocta) of Champlainian age (Middle Ordovician) from northwestern Illinois and adjacent parts of Iowa and Wisconsin: Journal of Paleontology, v. 41, p. 1365-1392.
- 1968a, *Bythotrypa*, *Diplotrypa*, *Hemiphragma*, *Heterotrypa*, *Stigmatella*, *Eridotrypa*, and *Nicholsonella*, pt. 2 of Bryozoa (Ectoprocta) of Champlainian age (Middle Ordovician) from northwestern Illinois and adjacent parts of Iowa and Wisconsin: Journal of Paleontology, v. 42, p. 337-355.
- 1968b, *Homotrypa*, *Orbignyella*, *Prasopora*, *Monticulipora*, and *Cyphotrypa*, pt. 3 of Bryozoa (Ectoprocta) of Champlainian age (Middle Ordovician) from northwestern Illinois and adjacent parts of Iowa and Wisconsin: Journal of Paleontology, v. 42, p. 1042-1065.
- Bradley, J.H., Jr., 1930, Fauna of the Kimmswick Limestone of Missouri and Illinois: Chicago University Walker Museum Contributions, v. 2, p. 219-290.
- Branson, E.B., 1909, The fauna of the residuary Auburn Chert of Lincoln County, Missouri: St. Louis Academy of Science Transactions, v. 18, p. 39-52.
- Brenchly, P.J., and Newall, G., 1984, Late Ordovician environmental changes and their effect on faunas, in Bruton, D.L., ed., Aspects of the Ordovician System: Palaeontological Contributions from the University of Oslo 295, Universitetsforlaget, p. 65-80.
- Bretsky, P.W., 1969, Evolution of Paleozoic benthic marine invertebrate communities: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 6, p. 45-49.
- Bretsky, P.W., Bretsky, S.S., and Schaefer, P.J., 1977, Molluscan and brachiopod dominated biofacies in the Platteville Formation (Middle Ordovician), upper Mississippi Valley: Geological Society of Denmark Bulletin 26, p. 115-132.
- Bromley, R.G., 1975, Trace fossils at omission surfaces, in Frey, R.W., ed., The study of trace fossils: New York, Springer-Verlag, p. 399-428.
- Brower, J.C., and Veinus, Julia, 1978, Middle Ordovician crinoids from the Twin Cities area of Minnesota: Bulletins of American Paleontology, v. 74, no. 304, p. 372-506.
- Brown, E.C., 1974, Phosphatic zone in the lower part of the Maquoketa shale in northeastern Iowa: U.S. Geological Survey Journal of Research, v. 2, p. 219-232.
- Brown, G.D., Jr., 1965, Trepostomatous Bryozoa from the Logana and Jesamine Limestone (Middle Ordovician) of the Kentucky Bluegrass region: Journal of Paleontology, v. 39, p. 974-1006.
- Burr, J.H., Jr., 1958, Ostracoda of the Dubuque and Maquoketa formations of Minnesota and northern Iowa: Unpublished M.S. thesis, University of Minnesota, Minneapolis.
- Burr, J.H., Jr., and Swain, F.M., 1965, Ostracoda of the Dubuque and Maquoketa Formations of Minnesota and northern Iowa: Minnesota Geological Survey Special Publication Series SP-3, 40 p.
- Buschback, T.C., 1961, The morphology of the sub-St. Peter surface of northeastern Illinois: Illinois Academy of Science Transactions, v. 54, p. 83-89.
- Calvin, Samuel, 1906, Geology of Winneshiek County: Iowa Geological Survey Annual Report, v. 16, 1905, p. 37-146.

- Cameron, B., Mangion, S., 1977, Depositional environments and revised stratigraphy along the Black River-Trenton boundary in New York and Ontario: *American Journal of Science*, v. 277, p. 486-502.
- Chamberlain, T.C., 1878, *Geology of Wisconsin; survey of 1873-1877*, v. 2 (2nd rev. ed.): Wisconsin Geological Survey, 768 p.
- 1883, *Geology of Wisconsin; survey of 1873-1879*, v. 1: Wisconsin Geological Survey, 725 p.
- Chatterton, B.D.E., 1980, Ontogenetic studies of Middle Ordovician trilobites from the Esbataottine Formation, Mackenzie Mountains, Canada: *Palaeontographica*, Abt. A, v. 171.
- Chatterton, B.D.E., and Ludvigsen, Rolf, 1976, Silicified Middle and Late Ordovician trilobites from the South Nahanni River Area, District of Mackenzie, Canada: *Palaeontographica*, Abt. A, v. 154, p. 1-106.
- Cisne, J.L., Gildner, R.F., and Rabe, B.D., 1984, Epeiric sedimentation and sea level: Synthetic ecostratigraphy: *Lethaia*, v. 17, p. 267-288.
- Clarke, J.M., 1894, The Lower Silurian trilobites of Minnesota: Minnesota Geological and Natural History Survey Final Report, v. 2, pt. 2, p. 694-759. [Published under separate cover in 1894. The entire volume was published in 1897.]
- Collie, G.L., 1903, Ordovician section near Bellefonte, Pennsylvania: *Geological Society of America Bulletin*, v. 14, p. 407-420.
- Conrad, T.A., 1838, Report of T.A. Conrad on the palaeontological department of the survey: New York State Natural History Survey Annual Report, p. 107-119.
- 1843, Observations on the lead bearing limestone of Wisconsin, and descriptions of a new genus of Trilobites and fifteen new Silurian fossils: *Academy of Natural Sciences of Philadelphia Proceedings*, v. 1, p. 329-335.
- Cooper, B.N., 1953, Trilobites from the lower Champlainian formations of the Appalachian Valley: *Geological Society of America Memoir* 55.
- Cooper, G.A., 1930a, The brachiopod genus *Pionodema* and its homeomorphs: *Journal of Paleontology*, v. 4, p. 369-382.
- 1930b, New species from the Upper Ordovician of Perce: *American Journal of Science*, v. 20, p. 265-288, 365-392.
- 1944, Phylum Brachiopoda, in Shimer, H.W., and Shrock, R.R., eds., *Index fossils of North America*: New York, John Wiley, p. 277-365.
- 1956, Chazyan and related brachiopods: Smithsonian Institution, *Smithsonian Miscellaneous Collections*, v. 127, pt. 1, p. 1-1024; pt. 2, p. 1025-1245.
- Copeland, M.H., 1965, Ordovician Ostracoda from Lake Temiskaming, Ontario: *Canada Geological Survey Bulletin* 127, p. 1-52.
- Cordua, W.S., 1985, Rock Elm structure, Pierce County, Wisconsin: A possible cryptoexplosion structure: *Geology*, v. 13, p. 372-374.
- Cornell, J. R., 1956, The Ostracoda zones of the Decorah shale: Unpublished M.S. thesis, University of Minnesota, Minneapolis, 91 p.
- Coryell, H.N., 1921, Bryozoan faunas of the Stones River Group of central Tennessee: *Indiana Academy of Science Proceedings* for 1919, p. 261-340.
- Cotter, E., 1978, The evolution of fluvial style, with special reference to the central Appalachian Paleozoic, in Miall, A.D., ed., *Fluvial sedimentology*: Canadian Society of Petroleum Geologists Memoir 5, p. 361-383.
- Cowan, John, 1971, Ordovician and Silurian stratigraphy of the Interlake area, Manitoba, in Turnock, A.C., ed., *Geoscience studies in Manitoba*: Geological Association of Canada Special Paper 9, p. 235-241.
- Crimes, T.P., 1975, The stratigraphical significance of trace fossils, in Frey, R.W., ed., *The study of trace fossils*: New York, Springer-Verlag, p. 109-130.
- Cummings, E.R., 1903, The morphogenesis of *Platystrophia*: A study of the evolution of a Paleozoic brachiopod: *American Journal of Science*, Ser. 5, v. 20, p. 265-288, 365-392.
- Dake, C.L., 1921, The problem of the Saint Peter Sandstone: Unpublished Ph.D. dissertation, University of Missouri, School of Mines and Metallurgy, 356 p.
- Dapples, E.C., 1955, General lithofacies relationship of the St. Peter Sandstone and the Simpson Group: *American Association of Petroleum Geologists Bulletin*, v. 39, p. 444-467.
- Dean, W.T., 1979, Trilobites from the Long Point Group, Ordovician, Port au Port Peninsula, southwestern Newfoundland: *Canada Geological Survey Bulletin* 290, 23 p.
- Dekay, J.E., 1894, Observations of the structure of trilobites: New York Academy of Sciences, *Lyceum of Natural History of New York Annals*, v. 1, p. 174-184.
- Delgado, D.J., 1983a, The Ordovician Galena Group in south central Wisconsin, in *Sedimentology of Ordovician carbonates and sandstones in southwestern Wisconsin*: Geological Society of America, North-Central Section, 17th Annual Meeting, Madison, Wisconsin, 1983. *Field Trip Guide Book*, p. 17-24.
- editor, 1983b, Ordovician Galena Group of the Upper Mississippi valley—deposition, diagenesis and paleoecology: Society of Economic Paleontologists and Mineralogists, Great Lakes Section, 13th Annual Field Conference, Guidebook, 139 p.
- Delo, D.M., 1935, A revision of the phacopid trilobites: *Journal of Paleontology*, v. 9, p. 402-420.
- 1940, Phacopid trilobites of North America: *Geological Society of America Special Paper* 29, 135 p.
- DeMott, L.L., 1963, Middle Ordovician trilobites of the Upper Mississippi Valley: Unpublished Ph.D. dissertation, Harvard University, Cambridge, Mass., 236 p.
- DesAutels, D.A., 1978, The paleoecology of an Ordovician marine community from the Galena Limestone, Goodhue County, Minnesota: Unpublished M.S. thesis, University of Minnesota, 113 p.
- Dott, R.H., Jr., Byers, C.W., Fielder, G.W., Stenzel, S.R., and Winfree, K.E., 1986, Aeolian to marine transition in Cambro-Ordovician cratonic sheet sandstones of the northern Mississippi Valley, USA: *Sedimentology*, v. 33, p. 345-367.
- Elias, R.J., 1981, Solitary Rugose corals of the Selkirk Member, Red River Formation (Late Middle or Upper Ordovician), southern Manitoba: *Canada Geological Survey Bulletin* 344, 31 p.
- Emery, K.O., 1956, Sediments and water of the Persian Gulf: *American Association of Petroleum Geologists Bulletin*, v. 40, p. 2354-2383.
- Emmons, Ebenezer, 1842, *Geology of New York: Part 2*, comprising the survey of the second geological district: Albany, 437 p.
- Ernst, W.G., 1954, The St. Peter Sandstone-Glenwood Shale contact: *American Mineralogist*, v. 39, p. 1026-1031.
- Ethington, R.L., 1959, Conodonts of the Ordovician Galena Formation: *Journal of Paleontology*, v. 33, p. 257-736.
- Evitt, W.R., 1951, Some Middle Ordovician trilobites of the families Cheiruridae, Harpidae and Lichidae: *Journal of Paleontology*, v. 25, p. 587-616.
- 1953, Observations on the trilobite *Ceraurus*: *Journal of Paleontology*, v. 27, p. 33-48.
- Fenton, C.L., 1928, Forms of *Strophomena* from Black River and Richmond Formations: *American Midland Naturalist*, v. 11, p. 144-159.
- Fenton, C.L., and Fenton, M.A., 1923, Some Black River brachiopods from the Mississippi Valley: *Iowa Academy of Science Proceedings*, v. 29, p. 67-77.
- Fenton, M.A., 1929a, The supposed calyx of *Lichenocrinus*: *American Midland Naturalist*, v. 11, p. 491-493.
- 1929b, Notes on several forms of *Lichenocrinus* from Black River Formations: *American Midland Naturalist*, v. 11, p. 494-499.
- Finney, S.C., 1986, Graptolite biofacies and correlation of eustatic, subsidence and tectonic events in the Middle to Upper Ordovician of North America: *Palaios*, v. 1, p. 435-461.
- Finney, S.C., and Nitecki, M.H., 1979, *Fisherites* n. gen. *reticulatus* (Owen, 1844), a new name for *Receptaculites oweni* Hall, 1861: *Journal of Paleontology*, v. 53, p. 750-753.
- Foerste, A.F., 1912, *Strophomena* and other fossils from the Cincinnati and Mohawkian horizons chiefly in Ohio, Indiana and Kentucky: Granville, Ohio, Denison University, Science Laboratories Bulletin, v. 17, p. 17-173.
- 1914, Notes on the Lorraine faunas of New York and the province of Quebec: Granville, Ohio, Denison University, Science Laboratories Bulletin, v. 17, p. 247-328.
- 1919, Silurian fossils from Ohio with notes on related species from other horizons: *Ohio Journal of Science*, v. 19, p. 367-404.
- 1920, The Kimmswick and Plattin Limestones of northeastern Missouri: Granville, Ohio, Denison University, Science Laboratories Bulletin, v. 19, p. 175-224.
- Ford, G.R., 1958, A study of the Platteville formation in Dakota, Goodhue and Rice Counties, Minnesota: Unpublished M.S. thesis, University of Minnesota, Minneapolis.
- Fraser, G.S., 1976, Sedimentology of a middle Ordovician quartz arenite-carbonate transition in the upper Mississippi Valley: *Geological Society of America Bulletin*, v. 86, p. 833-845.

- Frey, R.W., and Seilacher, A., 1980, Uniformity in marine invertebrate ichnology: *Lethaia*, v. 13, p. 183-207.
- Fritz, M., 1957, Bryozoa (mainly Trepostomata) from the Ottawa Formation (Middle Ordovician) of the Ottawa-St. Lawrence Lowland: *Canada Geological Survey Bulletin* 42, 75 p.
- Ginsburg, Robert, Rezak, Richard, and Wray, J.L., 1972, Geology of calcareous algae [notes for a short course]: *Sedimenta 1*: University of Florida, Miami, Rosenstiel School of Marine and Atmospheric Science, Comparative Sedimentology Laboratory, 72 p.
- Glenister, A.T., 1957, The conodonts of the Ordovician Maquoketa Formation in Iowa: *Journal of Paleontology*, v. 31, p. 715-736.
- Goldschmidt, V.M., 1954, *Geochemistry* (Muir, Alex, ed.): London, Oxford University Press, 730 p.
- Grabau, A.W., and Shimer, H.W., 1910, North American index fossils: Invertebrates: New York, v. 1, 853 p.; v. 2, 909 p.
- Green, Jacob, 1832, A monograph of the trilobites of North America: Philadelphia, Penn., 93 p.
- Gutschick, R.C., and Lamborn, R., 1975, *Bifungites* trace fossils from Devonian-Mississippian rocks of Pennsylvania and Montana, U.S.A.: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 18, p. 193-212.
- Hakes, W.G., 1976, Trace fossils and depositional environment of four clastic units, Upper Pennsylvanian megacyclothems, northeastern Kansas: *University of Kansas Paleontological Contributions*, art. 63, 43 p.
- Hall, James, 1847, Organic remains of the Lower Division of the New York System, v. 1 of *Paleontology of New York*: 308 p.
- 1851a, Description of new and rare species of fossils from the Paleozoic Series, in Foster, J.W., and Whitney, J.D., Report on the geology of the Lake Superior land district; part 2, The iron region, together with the general geology: U.S. Congress, 32nd, Special Session, Senate Executive Document 4, p. 203-231.
- 1851b, Lower Silurian System: Upper Silurian and Devonian Series, in Foster, J.W., and Whitney, J.D., Report on the geology of the Lake Superior land district; part 2: The iron region, together with the general geology: U.S. Congress, 32nd, Special Session, Senate Executive Document 4, p. 140-166; also *American Journal of Science*, 2nd Ser., v. 17, p. 181-194 (1954).
- 1861, Report of the superintendent of the geological survey, exhibiting the progress of the work, January 1, 1861 (including descriptions of new species of fossils from the investigations of the survey): Madison, Wisconsin Geological Survey, 52 p.
- 1862, Paleontology of Wisconsin, in Hall, James, and Whitney, J.D., Report of the geological survey of the state of Wisconsin: Albany, N.Y., printed by the authority of the legislature of Wisconsin, v. 1, p. 425-442.
- 1866, Descriptions of some new species of Crinoidea and other fossils from the Lower Silurian strata of the age of the Hudson River group and Trenton limestone, *advance copy from New York State Cabinet Report for 1866*, 17 p.: New York State Museum of Natural History Annual Report 24, 1872, p. 205-224 [a reprint of the 1866 edition, with additions].
- 1871, Description of new species of fossils: Cincinnati, Ohio, p. 7, pl. 4, fig. 12.
- Hall, James, and Clarke, J.M., 1892-1894, An introduction to the study of the genera of Paleozoic Brachiopoda, in *Paleontology of New York*: V. 8, pt. 1, 367 p. (1892); pt. 2, 394 p. (1894).
- Hall, James, and Whitfield, R.P., 1875, Description of invertebrate fossils, mainly from the Silurian System: Ohio Geological Survey Report 2, pt. 2, *Palaeontology*, p. 101-105.
- Hansen, D.L., 1951, Distribution of Ostracoda in the Decorah shale formation at St. Paul, Minnesota: Unpublished M.S. thesis, University of Minnesota, Minneapolis.
- Harland, W.B., Cox, A.V., Llewellyn, P.G., Pickton, C.A.G., Smith, A.G., and Walters, R., 1982, A geologic time scale: Cambridge University Press, 131 p.
- Harris, R.W., 1931, The stratigraphy and physical characteristics of the Simpson Group: *Oklahoma Geological Survey Bulletin* 55, p. 87-95, pls. 3, 5, 10, 11, 14.
- 1936, Field conference for the study of the Simpson Formation: Oklahoma City Geological Society Guidebook, 1936, p. 7, unnumbered illus.
- 1957, Ostracoda of the Simpson Group: *Oklahoma Geological Survey Bulletin* 75, p. 1-333, pls. 1-10.
- Haskin, L.A., and Schmitt, R.A., 1967, Rare-earth distributions, in Ahrens, L.H., ed., *Origin and distribution of the elements*: Oxford, England, Pergamon Press, p. 889-912.
- Hayes, M.O., 1967, Hurricanes as geological agents: Case studies of Hurricanes Carla, 1961, and Cindy, 1963: University of Texas at Austin, Bureau of Economic Geology Report of Investigations 61, 54 p.
- Hedblom, E.P., in prep., The trilobites of the Decorah Shale: Unpublished M.S. thesis, University of Minnesota, Minneapolis.
- Henningsmoen, Gunnar, 1951, Remarks on the classification of trilobites: *Norsk Geologisk Tidsskrift*, v. 29, p. 174-217.
- 1953, Classification of Paleozoic straight-hinged ostracodes: *Norsk Geologisk Tidsskrift*, v. 31, p. 185-288.
- Hintze, L.F., 1952, Lower Ordovician trilobites from western Utah and eastern Nevada: *Utah Geological and Mineralogical Survey Bulletin* 48, 249 p.
- Hoeft, D.R., 1959, The litho-stratigraphy of the Glenwood and Platteville formations of southeastern Minnesota: Unpublished M.S. thesis, University of Minnesota, Minneapolis.
- Howe, H.J., 1979, Middle and Late Ordovician Plectambonitacean, Rhynchonellacean, Syntrophiacean, Trimerellacean, and Atrypacean brachiopods: U.S. Geological Survey Professional Paper 1066-C, p. C1-C18.
- Huff, W.D., 1983, Correlation of Middle Ordovician K-bentonites based on chemical fingerprinting: *Journal of Geology*, v. 91, p. 657-669.
- Huff, W.D., Kolata, D.R., and Frost, J.K., 1986, Distribution of the Ordovician Deicke and Millbrig K-bentonite beds in eastern North America [abs.]: *Geological Society of America Abstracts with Programs*, v. 18, p. 310.
- Hupé, Pierre, 1953-1955, Classification des trilobites: *Annales de Paléontologie*, v. 39, 61-168; v. 41, p. 91, 325.
- Imbrie, J., 1956, Biometrical methods in the study of invertebrate fossils: *American Museum of Natural History Bulletin*, v. 108, art. 2, p. 211-252.
- Jaanusson, Valdar, 1954, Zur morphologie und taxonomie der Illaeniden: *Arkiv för Mineralogi och Geologi*, v. 1, p. 545-583.
- Jones, O.T., 1928, *Plectambonites* and some allied genera: *Great Britain Geological Survey Memoirs: Paleontology*, v. 1, no. 5, p. 367-527.
- Jones, T.R., 1889, Notes on some Palaeozoic bivalved Entomostraca; no. 28: *Annals and Magazine of Natural History*, Ser. 6, v. 4, p. 267-273.
- 1890, On some Palaeozoic Ostracoda from North America, Wales, and Ireland: *Geological Society of London Quarterly Journal*, v. 46, p. 1-31.
- 1891, On some Ostracoda from the Cambro-Silurian, Silurian, and Devonian rocks, pt. 3 of *Contributions to Canadian micropaleontology*: *Canada Geological Survey*, p. 59-99.
- Jones, T.R., and Holl, H.B., 1865, Notes on the Palaeozoic bivalved Entomostraca; no. 20, On the genus *Beyrichia* and some new species: *Annals and Magazine of Natural History*, Ser. 5, v. 17, p. 337-363.
- Karklins, O.L., 1966, Cryptostome Bryozoa from Middle Ordovician Decorah Shale of Minnesota: Unpublished Ph.D. dissertation, University of Minnesota, Minneapolis.
- 1969, The cryptostome Bryozoa from the Middle Ordovician Decorah Shale, Minnesota: *Minnesota Geological Survey Special Publication Series SP-6*, 121 p.
- 1983, Introduction to the suborder Ptilodictyina, in Part G, Bryozoa (rev., v. 1), of Robison, R.A., ed., *Treatise on invertebrate paleontology*: Geological Society of America and University of Kansas Press, p. 453-488.
- 1984, Trepostome and cystoporate bryozoans from the Lexington Limestone and the Clays Ferry Formation (Middle and Upper Ordovician) of Kentucky: U.S. Geological Survey Professional Paper 1066-I, 105 p.
- Kay, G.M., 1928, Divisions of the Decorah Formation: *Science*, v. 67, p. 16.
- 1929a, *Rafinesquina alternata* (Shepard), a Cincinnati brachiopod [abs.]: *Geological Society of America Bulletin*, v. 40, p. 211.
- 1929b, Stratigraphy of the Decorah Formation: *Journal of Geology*, v. 37, p. 639-671.
- 1934, Mohawkian Ostracoda: Species common to Trenton faunas from the Hull and Decorah Formations: *Journal of Paleontology*, v. 8, p. 328-343.
- 1935a, Distribution of Ordovician altered volcanic materials and related clays: *Geological Society of America Bulletin*, v. 46, p. 225-244.
- 1935b, Ordovician System in the Upper Mississippi Valley, in *Paleozoic rocks of Upper Mississippi Valley, Iowa City, Iowa, to Duluth, Minnesota*: Kansas Geological Society, 9th Annual Field Conference, 1935, Guidebook, p. 281-295.

- 1937, Stratigraphy of the Trenton Group: Geological Society of America Bulletin, v. 48, p. 252-255.
- 1940, Ordovician Mohawkian Ostracoda: Lower Trenton Decorah fauna: Journal of Paleontology, v. 14, p. 234-269.
- 1953, Geology of the Utica Quadrangle: New York State Museum Bulletin 347, 126 p.
- 1968, Ordovician formations in northwestern New York: Le Naturaliste Canadien, v. 95, p. 1373-1378.
- Keenan, J.E., 1951, Ostracodes from the Maquoketa Shale of Missouri: Journal of Paleontology, v. 25, p. 561-574.
- Kendall, A.C., 1977, Origin of dolomite mottling in Ordovician limestones from Saskatchewan and Manitoba: Bulletin of Canadian Petroleum Geology, v. 25, p. 480-504.
- Kesling, R.V., and Paul, C.R.C., 1968, New species of Porocrinidae and brief remarks on these unusual crinoids: University of Michigan, Museum of Paleontology Contributions, v. 22, no. 1, 32 p.
- Knight, J.B., and others, 1960, Mollusca 1, v. 1 of Treatise of invertebrate paleontology: Geological Society of America, 351 p.
- Kobayashi, Teichi, 1934, Cambro-Ordovician formations and faunas of South Chosen; Palaeontology; Part III, Middle Ordovician faunas: University of Tokyo, Faculty of Science Journal: Sec. 2, v. 3, p. 329-520.
- Kolata, D.R., 1973, *Scalenocystites strimplei*, a new Middle Ordovician Belemnocystitid solute from Minnesota: Journal of Paleontology, v. 47, p. 969-975.
- 1975, Middle Ordovician echinoderms from northern Illinois and southern Wisconsin: Journal of Paleontology, v. 49, no. 3, suppl., pt. 2 (Paleontological Society Memoir 7), 74 p.
- 1986, Crinoids of the Champlainian (Middle Ordovician) Guttenberg Formation—upper Mississippi Valley region: Journal of Paleontology, v. 60, p. 711-718.
- Kolata, D.R., Frost, J.K., and Huff, W.D., 1986, K-bentonites of the Ordovician Decorah Subgroup, Upper Mississippi Valley: Correlation by chemical fingerprinting: Illinois State Geological Survey Circular 537, 30 p.
- Kolata, D.R., and Graese, A.M., 1983, Lithostratigraphy and depositional environments of the Maquoketa Group (Ordovician) in northern Illinois: Illinois State Geological Survey Circular 528, 49 p.
- Kolata, D.R., Huff, W.D., and Frost, J.K., 1983, Correlation of K-bentonites in the Decorah Subgroup of the Mississippi Valley by chemical fingerprinting, in Delgado, D.J., ed., Ordovician Galena Group of the Upper Mississippi Valley—deposition, diagenesis, and paleoecology: Society of Economic Paleontologists and Mineralogists, Great Lakes Section, 13th Annual Field Conference, 1983, Guidebook, p. F1-F15.
- 1984, Correlation of Champlainian (Middle Ordovician) K-bentonite beds from Minnesota to Kentucky and Tennessee: Geological Society of America Abstracts with Programs, v. 16, p. 563.
- Kolata, D.R., and Jollie, M., 1982, New anomalocystitid mitrates (Stylophora-Echinodermata) from the Champlainian (Middle Ordovician) Guttenberg Formation of the Upper Mississippi Valley region: Journal of Paleontology, v. 56, p. 631-653.
- Kraft, J.C., 1962, Morphologic and systematic relationships of some Middle Ordovician Ostracoda: Geological Society of America Memoir 86, 104 p.
- Kunk, M.J., and Sutter, J.F., 1984, ⁴⁰Ar/³⁹Ar age spectrum dating of biotite from Middle Ordovician bentonites, eastern North America, in Bruton, D.L., ed., Aspects of the Ordovician System: Palaeontological Contributions from the University of Oslo 295, Universitetsforlaget, p. 11-22.
- Ladd, H.S., 1929, The stratigraphy and paleontology of the Maquoketa Shale of Iowa, part I: Iowa Geological Survey Annual Report, v. 34, 1928, p. 305-448.
- Lane, P.D., and Thomas, A.T., 1983, A review of the trilobite Suborder Scutelluina: Palaeontological Association Special Papers in Palaeontology 30, p. 141-160.
- Levinson, S.A., 1950, The hingement of Paleozoic Ostracoda and its bearing on orientation: Journal of Paleontology, v. 24, p. 63-75.
- Levorson, C.O., and Gerk, A.J., 1972a, A preliminary stratigraphic study of the Galena Group in Winneshiek County, Iowa: Iowa Academy of Science Proceedings, v. 79, p. 111-122.
- 1972b, Revision of Galena stratigraphy: Geological Society of Iowa Field Trip Guidebook, 1972, p. 1-10.
- 1975, Field recognition of subdivision of the Galena Group within Winneshiek Co.: Iowa, Minnesota, and Wisconsin Academies of Science, Fall 1975 Gathering, Field Trip Guide, p. 1-17.
- 1983, Field recognition of stratigraphic position within the Galena Group of northeast Iowa (limestone facies), in Delgado, D.J., ed., Ordovician Galena Group of the Upper Mississippi Valley—deposition, diagenesis, and paleoecology: Society of Economic Paleontologists and Mineralogists, Great Lakes Section, 13th Annual Field Conference, 1983, Guidebook, p. C1-C11.
- Levorson, C.O., Gerk, A.J., and Broadhead, T.W., 1979, Stratigraphy of the Dubuque Formation (Upper Ordovician) of Iowa: Iowa Academy of Science Proceedings, v. 86, p. 57-65.
- Locke, John, 1838, Geological report: Ohio Geological Survey Annual Report 2, p. 201-286.
- Loeblich, A.R., 1942, Bryozoa from the Ordovician Bromide Formation, Oklahoma: Journal of Paleontology, v. 16, p. 413-436.
- Ludvigsen, R., 1978a, Towards an Ordovician trilobite biostratigraphy of southern Ontario, in Sanford, J.T., and Mosher, R.E., eds., Geology of the Manitoulin area: Michigan Basin Geological Society Special Paper 3, p. 73-84.
- 1978b, Middle Ordovician trilobite biofacies, southern Mackenzie Mountains, in Stelck, C.R., and Chatterton, B.D.E., eds., Western and Arctic Canadian biostratigraphy: Geological Association of Canada Special Paper 18, p. 1-37.
- 1979a, A trilobite zonation of Middle Ordovician rocks, southwestern District of Mackenzie: Canada Geological Survey Bulletin 312, 99 p.
- 1979b, Fossils of Ontario; Part I: The Trilobites: Toronto, Royal Ontario Museum, Life Sciences Miscellaneous Publications, January 1979, 96 p.
- Ludvigsen, R., Chatterton, B.D.E., 1982, Ordovician Pterygometopidae (Trilobita) of North America: Canadian Journal of Earth Sciences, v. 19, p. 2179-2206.
- Majewske, O.P., 1953, The Platteville formation: Unpublished M.S. thesis, University of Minnesota, Minneapolis.
- Marintsch, E.J., 1986, Systematic paleontology and paleoecology of trepostome Bryozoa from the Middle Ordovician Hermitage Formation of east-central Tennessee: Unpublished Ph.D. dissertation, State University of New York at Stony Brook, 358 p.
- Mather, K.F., 1917, The Trenton fauna of Wolfe Island, Ontario: Ottawa Naturalist, v. 31, p. 33-40.
- Mazzulo, J.M., and Ehrlich, Robert, 1980, A vertical pattern of variation in the St. Peter Sandstone—Fourier grain shape analysis: Journal of Sedimentary Petrology, v. 50, p. 63-70.
- 1983, Grain-shape variation in the St. Peter Sandstone: A record of eolian and fluvial sedimentation of an Early Paleozoic cratonic sheet sand: Journal of Sedimentary Petrology, v. 53, p. 105-119.
- McEwan, E.D., 1919, A study of the brachiopod genus *Platystrophia*: U.S. National Museum Proceedings, v. 56, p. 383-448.
- McKinney, F.K., 1971, Trepostomatous Ectoprocta (Bryozoa) from the lower Chickamauga Group (Middle Ordovician), Wills Valley, Alabama: Bulletins of American Paleontology, v. 60, no. 267, p. 193-337.
- 1974, Bibliography and catalogue (1900-1969) of the Trepostomata (phylum Ectoprocta): Southeastern Geology Special Publication 4, 147 p.
- Melone, T.G., and Weis, L.W., 1951, Bibliography of Minnesota geology [through 1950]: Minnesota Geological Survey Bulletin 34, 124 p.
- Miller, M.F., 1977, Middle and Upper Ordovician biogenic structures and paleoenvironments, southern Nevada: Journal of Sedimentary Petrology, v. 47, p. 1328-1338.
- 1979, Paleoenvironmental distribution of trace fossils in the Catskill deltaic complex, New York State: Palaeogeography, Palaeoclimatology and Palaeoecology, v. 25, p. 117-141.
- Miller, S.A., 1874, Monograph of the Lamellibranchiata of the Cincinnati Group: Cincinnati Quarterly Journal of Science, v. 1, p. 211-236.
- Moore, R.C., editor, 1959, Arthropoda 1, Part O of Treatise on invertebrate paleontology: Geological Society of America and University of Kansas Press, 560 p.
- 1961, Arthropoda 3, Part Q of Treatise on invertebrate paleontology: University of Kansas Press, 442 p.
- Morey, G.B., 1972, Pre-Mt. Simon regolith, in Sims, P.K., and Morey, G.B., eds., Geology of Minnesota: A centennial volume: Minnesota Geological Survey, p. 506-508.
- Morey, G.B., and Sims, P.K., 1976, Boundary between two Precambrian W terranes in Minnesota and its geological significance: Geological Society of America Bulletin, v. 87, p. 141-152.
- Morrow, D.W., 1978, Dolomitization of Lower Paleozoic burrow-fillings: Journal of Sedimentary Petrology, v. 48, p. 295-306.

- Mossler, J.H., 1985, Sedimentology of the Middle Ordovician Platteville Formation, southeastern Minnesota: Minnesota Geological Survey Report of Investigations 33, 27 p.
- 1987, Paleozoic lithostratigraphic nomenclature of Minnesota: Minnesota Geological Survey Report of Investigations 36 (in press).
- Mossler, J.H., and Hayes, J.B., 1966, Ordovician potassium bentonites of Iowa: Journal of Sedimentary Petrology, v. 36, p. 414-427.
- 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.
- Õpik, A., 1935, Ostracoda from the Lower Ordovician Megalaspis-Limestone of Estonia and Russia: Tartu Ülikool, Geologica Instituudi Toimetused (Tartu University, Geological Institute Publication) 44, 12 p.
- 1937a, Ostracoda from the Ordovician Uhaku and Kukruse Formations of Estonia: Tartu Ülikooli juures oleva Loodusuurijate Seltsi Aruanded, v. 43, p. 65-138.
- 1937b, Trilobiten aus Estland: Tartu Ülikool, Geoloogia Instituudi Toimetused (Tartu University, Geological Institute Publication) 52, p. 1-163.
- Owen, D.D., 1852, Description of new and imperfectly known genera and species of organic remains, collected during the geological surveys of Wisconsin, Iowa, and Minnesota, in Report of a geological survey of Wisconsin, Iowa, and Minnesota, and incidentally of a portion of the Nebraska Terr.: Philadelphia, Penn., p. 573-586.
- Palmer, T.J., 1978, Burrows at certain omission surfaces in the Middle Ordovician of the Upper Mississippi Valley: Journal of Paleontology, v. 52, p. 109-117.
- Palmer, T.J., and Palmer, C.D., 1977, Faunal distribution and colonization strategy in a Middle Ordovician hardground community: Lethaia, v. 10, p. 179-199.
- Palmquist, R.C., 1969, The configuration of the Prairie du Chien-St. Peter contact in southwestern Wisconsin: An example of an integrated geological-geophysical study: Journal of Geology, v. 77, p. 694-702.
- Parker, M.C., Dorheim, F.H., and Campbell, R.B., 1959, Resolving discrepancies between surface and subsurface studies of the Maquoketa Formation of northeast Iowa: Iowa Academy of Science Proceedings, v. 66, p. 248-256.
- Perry, T.G., 1962, Spechts Ferry (Middle Ordovician) bryozoan fauna from Illinois, Wisconsin, and Iowa: Illinois State Geological Survey Circular 326, 36 p.
- Pickerill, R.K., and Forbes, W.H., 1977, *Bifungites cf. Halli* from the Ordovician (Caradocian) Trenton Limestone of the Quebec City Area: Maritime Sediments, v. 13, p. 87-92.
- Pojeta, John, Jr., 1962, The Pelecypod genus *Byssonychia* as it occurs in the Cincinnati at Cincinnati, Ohio: Palaeontographica Americana, v. 4, no. 30, p. 169-216.
- 1966, North American Ambonychiidae (Pelecypoda): Palaeontographica Americana, v. 5, no. 36, p. 129-241.
- 1971, Review of Ordovician Pelecypods: U.S. Geological Survey Professional Paper 695, 46 p.
- 1978, The origin and early taxonomic diversification of Pelecypods: Royal Society of London Philosophical Transactions, Ser. B, v. 284, p. 225-243.
- Pojeta, John, Jr., and Runnegar, Bruce, 1985, The early evolution of diosome molluscs, in Evolution, v. 10 of Trueman, E.R., and Clarke, M.R., The Mollusca: Orlando, Academic Press, p. 295-336.
- Pope, J.K., 1976, Comparative morphology and shell histology of the Ordovician Strophomenacea (Brachiopoda): Palaeontographica Americana, v. 8, no. 49, 213 p.
- Port Authority of the City of St. Paul, 1967, Topographic map of the Pickeral Lake industrial districts: Mark Hurd Aerial Surveys, Inc., November 1967 aerial photographs, scale 1:1,200.
- Prantl, Ferdinand, and Přibyl, Alois, 1947, Classification of some Bohemian Cheiruridae (Trilobitae): Prague, Národní Museum, Sborník, v. 3b, p. 1-44.
- Přibyl, Alois, and Vaněk, J., 1980, Ordovician trilobites of Bolivia: Československé Akademie Věd, Rozpravy, Rad Matematických a Přírodních Věd, Ročník 90. Sesit.
- Přibyl, Alois, Vaněk, J., and Pek, I., 1985, Phylogeny and taxonomy of Family Cheiruridae (Trilobita): Olomouc, Moravia, Palackého Univerzita, Acta. Geol.-Geog., p. 107-193.
- Quinlan, G.M., and Beaumont, Christopher, 1984, Appalachian thrusting, lithospheric flexure, and the Paleozoic stratigraphy of the Eastern Interior of North America: Canadian Journal of Earth Sciences, v. 21, p. 973-996.
- Randle, Keith, Goles, G.G., and Kittleman, L.R., 1971, Geochemical and petrological characterization of ash samples from Cascade Range volcanoes: Quaternary Research, v. 1, p. 261-282.
- Rassam, G.H., 1967, Study on the Platteville Formation of Minnesota: Unpublished Ph.D. dissertation, University of Minnesota, Minneapolis.
- Raymond, P.E., 1903, The faunas of the Trenton at the type section and at Newport, New York: Bulletins of American Paleontology, v. 17, 18 p.
- 1905, The trilobites of the Chazy limestone: Carnegie Museum Annals, v. 3, p. 328-396.
- 1910, Notes on Ordovician trilobites: Asaphidae from the Beekmantown: Carnegie Museum Annals, v. 7, p. 35-45.
- 1912, Notes on parallelism among the Asaphidae: Royal Society of Canada Transactions, 3rd Ser., v. 5, p. 111-120.
- 1913a, Description of some new Asaphidae: Ottawa, Canada, Victoria Memorial Museum Bulletin 1, p. 41-48.
- 1913b, A revision of the species which have been referred to the genus *Bathyrurus*: Ottawa, Canada, Victoria Memorial Museum Bulletin 1, p. 51-69.
- 1914, Notes on the ontogeny of *Isotelus gigas* DeKay: Harvard University, Museum of Comparative Zoology Bulletin, v. 58, p. 247-263.
- 1921, A contribution to the description of the fauna of the Trenton Group: Canada Geological Survey Bulletin 31.
- 1925, Some trilobites of the lower Middle Ordovician of eastern North America: Harvard University, Museum of Comparative Zoology Bulletin, v. 67, p. 1-180.
- Raymond, P.E., and Barton, D.C., 1913, A revision of the American species of *Ceraurus*: Harvard University, Museum of Comparative Zoology Bulletin, v. 54, p. 525-543.
- Raymond, P.E., and Narraway, J.E., 1908, Notes on Ordovician trilobites: Illaenidae from the Black River limestone near Ottawa, Canada: Carnegie Museum Annals, v. 4, p. 242-255.
- 1910, Notes on Ordovician Trilobites: Asaphidae from the Lowville and Black River: Carnegie Museum Annals, v. 7, p. 46-59.
- Reed, F.R.C., 1896a, Notes on the evolution of the genus *Cheirurus*: Geological Magazine, New Ser. 4, v. 3, p. 117-123, 161, 167.
- 1896b, The fauna of the Keisley limestone, Part I: Geological Society of London Quarterly Journal, v. 52, p. 407-436.
- Rice, W.F., 1985, The systematics and biostratigraphy of the Brachiopoda of the Decorah Shale at St. Paul, Minnesota: Unpublished M.S. thesis, University of Minnesota, Minneapolis, 141 p.
- Rigby, J.K., and Bayer, T.N., 1971, Sponges of the Ordovician Maquoketa Formation in Minnesota and Iowa: Journal of Paleontology, v. 45, p. 608-627.
- Rodriguez, J., and Gutschick, R.C., 1970, Late Devonian-Early Mississippian ichnofossils from western Montana and northern Utah, in Crimes, T.P., and Harper, J.C., eds., Trace fossils: Geological Journal Special Issues 3: Liverpool, Seel House Press, p. 17-34.
- Ross, J.R.P., 1964, Champlainian cryptostome Bryozoa from New York State: Journal of Paleontology, v. 38, p. 1-32.
- 1967, Evolution of ectoproct genus *Prasopora* in Trentonian time (Middle Ordovician) in northern and central United States: Journal of Paleontology, v. 41, p. 403-416.
- 1970, Distribution, paleoecology, and correlation of Champlainian Ectoprocta (Bryozoa), New York State, pt. III: Journal of Paleontology, v. 44, p. 346-382.
- 1984, Palaeoecology of Ordovician Bryozoa, in Bruton, D.L., ed., Aspects of the Ordovician System: Palaeontological Contributions from the University of Oslo 295, Universitetsforlaget, p. 141-148.
- Ross, R.J., Jr., and Naeser, C.W., 1984, The Ordovician time scale—new refinements, in Bruton, D.L., ed., Aspects of the Ordovician System: Palaeontological Contributions from the University of Oslo 295, Universitetsforlaget, p. 5-10.
- Ross, R.J., Jr., and Shaw, F.C., 1972, Distribution of the Middle Ordovician Copenhagen Formation and its trilobites in Nevada: U.S. Geological Survey Professional Paper 749, 33 p.
- Ross, R.J., Jr., and others, 1982, The Ordovician System in the United States—correlation chart and explanatory notes: International Union of Geological Sciences Publication 12, 73 p., 3 pls.
- Roy, S.K., 1941, The Upper Ordovician fauna of Frobisher Bay, Baffin Land: Chicago, Field Museum of Natural History, Geological Series Memoirs, v. 2, 212 p.
- Ruedemann, Rudolph, 1901-1902, Trenton conglomerate Rysedorph Hill, Rensselaer County, New York, in Paleontologic Papers 2: New York State Museum Bulletin 49, p. 71-94.

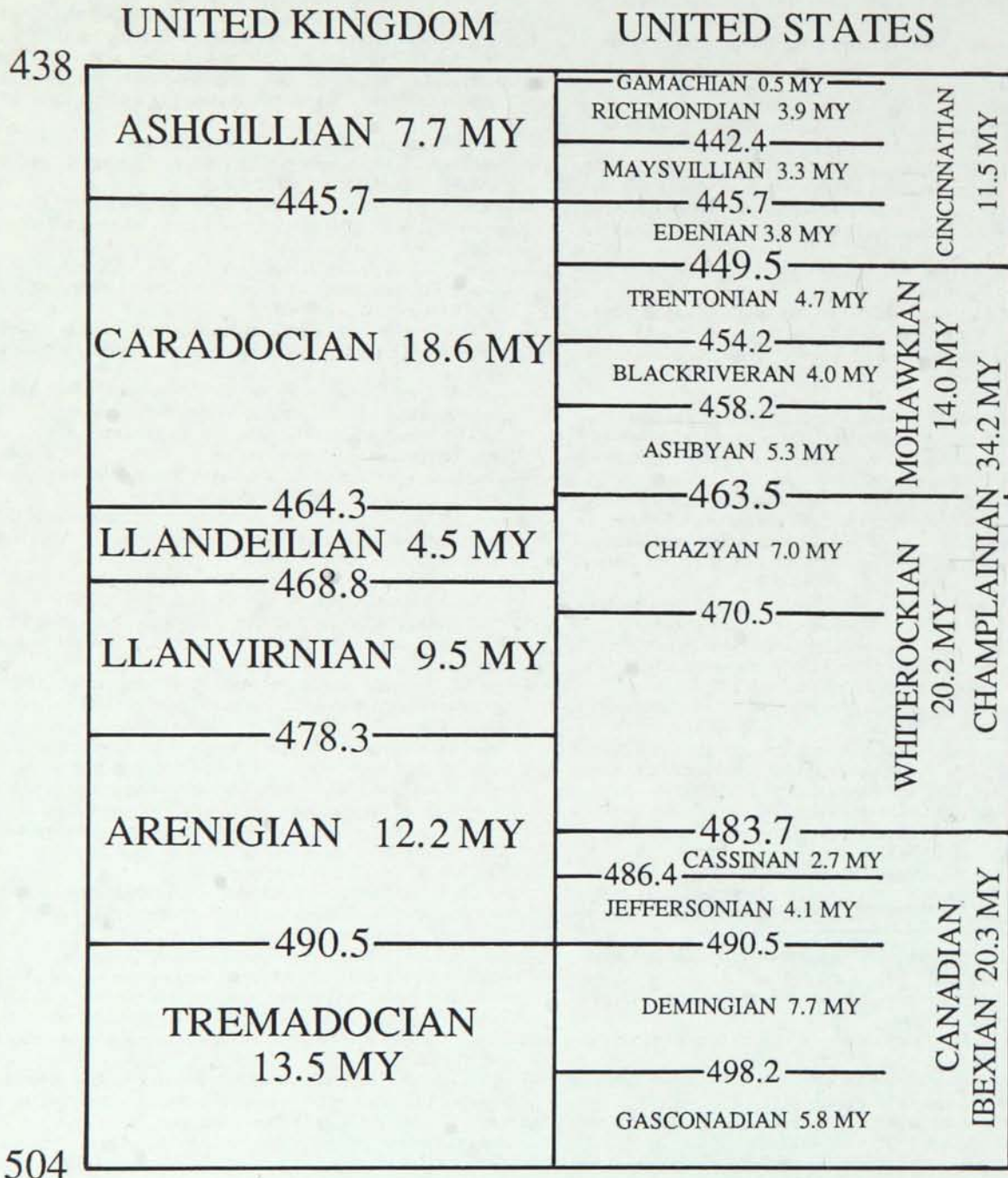
- 1934, Paleozoic rocks of the Lowville Quadrangle: New York State Museum Bulletin 296, p. 183-194.
- Russell, R.D., and Taylor, R.E., 1937, Roundness and shape of Mississippi River sand: *Journal of Geology*, v. 45, p. 225-267.
- Salmon, E.S., 1942, Mohawkian Rafinesquininae: *Journal of Paleontology*, v. 16, p. 564-603.
- Salter, J.W., 1864-1883, A monograph of British trilobites: London, Palaeontographical Society, p. 1-80, 1864; p. 81-128, 1865; p. 129-176, 1866; p. 177-214, 1867; p. 215-224, 1883.
- Samson, S.D., 1986, Chemistry, mineralogy, and correlation of Ordovician bentonites: Unpublished M.S. thesis, University of Minnesota, Minneapolis, 128 p.
- Sardeson, F.W., 1892a, Fossils in the St. Peter Sandstone: *Minnesota Academy of Natural Sciences Bulletin*, v. 3, p. 318-319.
- 1892b, The Lower Silurian formations of Wisconsin and Minnesota compared: *Minnesota Academy of Natural Sciences Bulletin*, v. 3, p. 319-326.
- 1892c, The range and distribution of the Lower Silurian fauna of Minnesota, with descriptions of some new species: *Minnesota Academy of Natural Sciences Bulletin*, v. 3, p. 326-34.
- 1896a, The Galena and Maquoketa series, pt. I: *American Geologist*, v. 18, p. 356-368.
- 1896b, The Saint Peter sandstone: *Minnesota Academy of Natural Sciences Bulletin*, v. 4, p. 64-88.
- 1897a, The Galena and Maquoketa series, pt. II: *American Geologist*, v. 19, p. 21-35.
- 1897b, The Galena and Maquoketa series, pt. III: *American Geologist*, v. 19, p. 91-110.
- 1897c, The Galena and Maquoketa series, pt. IV: *American Geologist*, v. 19, p. 180-190.
- 1899, A new cystocrinoidean species from the Ordovician: *American Geologist*, v. 24, p. 263-276.
- 1902, On the deceptive fossilization of certain pelecypod species and on the genus *Eurymya*: *American Geologist*, v. 30, p. 39-45.
- 1907, Galena Series: *Geological Society of America Bulletin*, v. 18, p. 179-194.
- 1908, Discoid crinoidal roots and *Camerocrinus*: *Journal of Geology*, v. 16, p. 239-254.
- 1924, Habit of an Ordovician pelecypod: *Pan-American Geologist*, v. 42, p. 345-356.
- 1925, Ordovician Crinoidea (Minnesota): *Pan-American Geologist*, v. 43, p. 55-68.
- 1926, Pioneer re-population of devastated sea-bottoms: *Pan-American Geologist*, v. 46, p. 273-288.
- 1927, Shoreline of Galena Seas: *Pan-American Geologist*, v. 46, p. 331-342.
- 1928, Derivation of the Calceocrinidae: *Pan-American Geologist*, v. 49, p. 35-46.
- 1939a, *Carabocrinus* and species making: *Pan-American Geologist*, v. 71, p. 27-38.
- 1939b, Early pelecypod *Cyrtodonta* in Minnesota: *Pan-American Geologist*, v. 71, p. 337-346.
- 1939c, Early pelecypod *Vanuxemia* in Minnesota: *Pan-American Geologist*, v. 71, p. 283-293.
- Schmidt, E.A., 1941, Studies in Böhmisches Caradoc (Zahoran-Stufe); I. Ostrakoden aus den Bohdalec-schichten und über die Taxonomie der Beyrichiacea: *Senckenbergische Naturforschende Gesellschaft Abhandlungen* 454, 87 p.
- Schopf, T.J.M., 1966, Conodonts of the Trenton Group (Ordovician) in New York, southern Ontario, and Quebec: *New York State Museum and Science Service Bulletin* 405, 105 p.
- Schuchert, Charles, 1897, A synopsis of American fossil Brachiopoda including bibliography and synonymy: *U.S. Geological Survey Bulletin* 87, 464 p.
- 1913, Brachiopoda, in Zittel, K.A. von (Eastman, C.R., trans. and ed.), *Textbook of paleontology*, v. 1 (2nd ed.): London, Macmillan, p. 355-420.
- Schuchert, Charles, and Cooper, G.A., 1932, Brachiopod genera of the suborders Orthoidea and Pentamerioidea: *Peabody Museum of Natural History Memoirs*, v. 4, p. 1-270.
- Schuchert, Charles, and LeVene, C.M., 1929, Brachiopoda (Generum et genotyporum index et bibliographia), in *Fossilium Catalogus 1, Animalia*, pars 42: Berlin, Junk, 140 p.
- Schwartz, G.M., and others, eds., 1956, *Guidebook for field trips: Geological Society of America, Annual Meeting, Minneapolis, Minnesota, 1956*.
- Seilacher, A., 1964a, Biogenic sedimentary structures, in Imbrie, J., and Newell, N., eds., *Approaches to paleoecology*: New York, John Wiley, p. 296-316.
- 1964b, Sedimentological classification and nomenclature of trace fossils: *Sedimentology*, v. 3, p. 253-256.
- 1967, Bathymetry of trace fossils: *Marine Geology*, v. 5, p. 413-428.
- Sellwood, B.W., 1970, The relation of trace fossils to small scale sedimentary cycles in the British Isles, in Crimes, T.P., and Harper, J.C., eds., *Trace fossils: Geological Journal Special Issues 3*; Liverpool, Seel House Press, p. 477-504.
- Shaw, A.B., 1964, *Time in stratigraphy*: New York, McGraw-Hill, 365 p.
- Shaw, F.C., 1968, Early Middle Ordovician Chazy trilobites of New York: *New York State Museum Memoir* 17, 163 p.
- 1974, Simpson Group (Middle Ordovician) trilobites of Oklahoma: *Journal of Paleontology*, v. 48, no. 5, pt. 2, 54 p.
- Shaw, F.C., Fortey, R.A., 1977, Middle Ordovician facies and trilobite faunas in North America: *Geological Magazine*, v. 114, p. 409-496.
- Sheehan, P.M., and Schiefelbein, D.R.J., 1984, The trace fossil *Thalassinoides* from the Upper Ordovician of the eastern Great Basin: Deep burrowing in the early Paleozoic: *Journal of Paleontology*, v. 58, p. 440-447.
- Shepard, C.U., 1838, *Geology of upper Illinois*: *American Journal of Science*, v. 34, p. 134-161.
- Shimer, H.W., and Shrock, R.R., 1944, *Index fossils of North America*: New York, Wiley, 827 p.
- Shinn, E.A., 1977, Sedimentary accretion along the leeward southeast coast of Qatar Peninsula, Persian Gulf, in Purser, B.H., ed., *The Persian Gulf*: New York, Springer-Verlag, p. 199-209.
- Shourd, M.L., and Levin, H.L., 1976, *Chondrites* in the Upper Plattin Subgroup (Middle Ordovician) of eastern Missouri: *Journal of Paleontology*, v. 52, p. 260-268.
- Simpson, G.G., 1944, *Tempo and mode in evolution*: New York, Columbia University Press, 237 p.
- Simpson, S., 1957, On the trace fossil *Chondrites*: *Geological Society of London Quarterly Journal*, v. 112, p. 475-499.
- Sims, P.K., Card, K.D., Morey, G.B., and Peterman, Z.E., 1980, The Great Lakes Tectonic Zone—a major crustal structure in central North America: *Geological Society of America Bulletin*, v. 91, p. 690-698.
- Sinclair, G.W., 1944, Some Ordovician trilobites from Ontario: *Toronto, Royal Canadian Institute Transactions*, v. 25, p. 15-20.
- 1946, Some species of *Platystrophia* from the Trenton of Ontario and Quebec: *Palaeontographica Americana*, v. 3, no. 20, 16 p.
- 1947, Two examples of injury in Ordovician trilobites: *American Journal of Science*, v. 245, p. 250-257.
- Sloan, R.E., 1956, Hidden Falls Member of Platteville Formation, Minnesota: *American Association of Petroleum Geologists Bulletin*, v. 40, p. 2955-2966.
- 1959, An occurrence of *Desmograptus cancellatus* in the Stewartville dolomite of Minnesota: *Journal of Paleontology*, v. 33, p. 680-681.
- 1972, Notes on the Platteville Formation, Minnesota, in Webers, G.F., and Austin, G.S., leaders, *Field trip guidebook for Paleozoic and Mesozoic rocks of southeastern Minnesota*: *Minnesota Geological Survey Guidebook Series 4*, p. 43-53.
- 1986, Tectonics, biostratigraphy and lithostratigraphy of the Mohawkian and Cincinnati of the upper Mississippi Valley [abs.]: *Geological Society of America Abstracts with Programs*, v. 18, p. 324.
- Sloan, R.E., and Austin, G.S., 1966, *Geologic map of Minnesota*. St. Paul sheet: *Minnesota Geological Survey*, scale 1:250,000.
- Sloan, R.E., and Weiss, M.P., 1956, The Ordovician rocks of southeastern Minnesota, in Schwartz, G.M., and others, eds., *Lower Paleozoic geology of the upper Mississippi Valley*: *Geological Society of America, Annual Meeting, Minneapolis, Minnesota, 1956, Guidebook for field trip no. 2*, p. 96-110.
- Slocum, A.W., 1913, New trilobites from the Maquoketa beds of Fayette County, Iowa: *Chicago, Field of Museum of Natural History Publication, Geological Series*, v. 4, p. 43-83.
- Snyder, Jeremy, and Bretsky, P.W., 1971, Life habits of diminutive molluscs in the Maquoketa Formation (Upper Ordovician): *American Journal of Science*, v. 271, p. 227-251.
- Spivey, R.C., 1939, Ostracodes from the Maquoketa Shale of Missouri, Upper Ordovician, of Iowa: *Journal of Paleontology*, v. 13, p. 163-175.

- Stasko, L.E., 1974, Trace fossils of the Middle Ordovician Platteville Formation (McGregor Member) in southwestern Wisconsin: Unpublished M.S. thesis, University of Wisconsin, Madison.
- Stauffer, C.R., 1935a, The conodont fauna of the Decorah Shale (Ordovician): *Journal of Paleontology*, v. 9, p. 596-620.
- 1935b, Conodonts of the Glenwood beds: *Geological Society of America Bulletin*, v. 46, p. 125-168.
- Stauffer, C.R., and Thiel, G.A., 1941, The Paleozoic and related rocks of southeastern Minnesota: *Minnesota Geological Survey Bulletin* 29, 261 p.
- Stone, D.J., 1980, The geology of the upper Dunleith Formation (Prosser Member, Galena Formation) of Middle Ordovician age in southeastern Minnesota: Unpublished M.S. thesis, University of Minnesota, Duluth.
- 1983, Lithostratigraphy of the upper Dunleith Formation (Ordovician) in southeastern Minnesota, in Delgado, D.L., ed., *Ordovician Galena Group of the Upper Mississippi Valley—deposition, diagenesis, and paleoecology*: Society of Economic Paleontologists and Mineralogists, Great Lakes Section, 13th Annual Field Conference, 1983, Guidebook, p. E1-E6.
- Swain, F.M., 1962, Early Middle Ordovician Ostracoda of the eastern United States; part II, Leperditellacea (part), Hollinacea, Kloedenellacea, Bairdiacea and Superfamily uncertain: *Journal of Paleontology*, v. 36, p. 719-744.
- Swain, F.M., Cornell, J.R., and Hansen, D.L., 1961, Ostracoda of the families Aparchitidae, Aechminidae, Leperditellidae, Drepanellidae, Eurychiliniidae, and Punctaparchitidae from the Decorah Shale of Minnesota: *Journal of Paleontology*, v. 35, p. 345-372.
- Swartz, F.M., 1936, Revision of the Primitiidae and Beyrichiidae with new Ostracoda from the Lower Devonian of Pennsylvania: *Journal of Paleontology*, v. 10, p. 541-586.
- Sweet, W.C., 1984, Graphic correlation of upper Middle and Upper Ordovician rocks, North American Midcontinent Province, USA, in Bruton, D.L., ed., *Aspects of the Ordovician System: Palaeontological Contributions from the University of Oslo* 295, Universitetsforlaget, p. 23-35.
- Sweet, W.C., and Bergström, S.M., 1976, Conodont biostratigraphy of the Middle and Upper Ordovician of the United States Midcontinent, in Bassett, M.G., ed., *The Ordovician System—a symposium: Palaeontological Association*, p. 121-151.
- 1984, Conodont provinces and biofacies of the Late Ordovician, in Clark, D.L., ed., *Conodont biofacies and provincialism: Geological Society of America Special Paper* 196, p. 69-87.
- Szmuc, E.J., Osgood, R.G., and Meinke, D.W., 1976, *Lingulichnites*, a new trace fossil genus for lingulid brachiopod burrows: *Lethaia*, v. 9, p. 163-167.
- Templeton, J.S., and Willman, H.B., 1952, Central northern Illinois: Tri-State Geological Field Conference, 16th Annual, Dixon, Illinois, 1952, Guidebook; also Illinois State Geological Survey Guidebook 2, 47 p.
- 1963, Champlainian Series (Middle Ordovician) in Illinois: *Illinois State Geological Survey Bulletin* 89, 260 p.
- Thiel, G.A., 1935, Sedimentary and petrographic analysis of the St. Peter Sandstone: *Geological Society of America Bulletin*, v. 46, p. 559-614.
- 1937, Petrographic analysis of the Glenwood beds of southeastern Minnesota: *Geological Society of America Bulletin*, v. 48, p. 113-122.
- Thompson, W.H., Jr., 1959, The conodonts of the Platteville Formation of southeastern Minnesota: Unpublished M.S. thesis, University of Minnesota, Minneapolis.
- Titus, R., 1986, Fossil communities of the upper Trenton Group (Ordovician) of New York State: *Journal of Paleontology*, v. 60, p. 805-824.
- Tripp, R.P., 1962, Trilobites from the "confinis" Flags (Ordovician) of the Girvan District, Ayrshire: *Royal Society of Edinburgh Transactions*, v. 65, p. 1-40.
- 1965, Trilobites from the Albany division (Ordovician) of the Girvan district, Ayrshire: *Paleontology*, v. 8, p. 577-603.
- Tripp, R.P., and Evitt, W.R., 1981, Silicified Lichidae (Trilobita) from the Middle Ordovician of Virginia: *Geological Magazine*, v. 118, p. 665-677.
- Trowbridge, A.C., 1917, The origin of the St. Peter Sandstone: *Iowa Academy of Science Proceedings*, v. 24, p. 171-175.
- Turner, B.R., and Benton, M.J., 1983, Paleozoic trace fossils from the Kufra Basin, Libya: *Journal of Paleontology*, v. 57, p. 447-460.
- Twenhofel, W.H., and others, 1954, Correlation of the Ordovician formations of North America: *Geological Society of America Bulletin*, v. 65, p. 247-298.
- Ulrich, E.O., 1879, Descriptions of new genera and species of fossils from the Lower Silurian about Cincinnati: *Cincinnati Society of Natural History Journal*, v. 2, p. 8-39.
- 1886a, Remarks on the names *Cheirocrinus* and *Calceocrinus*, with descriptions of three new generic terms and one new species: *Minnesota Geological and Natural History Survey Annual Report* 14, for the Year 1885, p. 104-113.
- 1886b, Report on the Lower Silurian Bryozoa with preliminary descriptions of some of the new species: *Minnesota Geological and Natural History Survey Annual Report* 14, for the Year 1885, p. 57-103.
- 1889, Contributions to the micro-paleontology of the Cambro-Silurian rocks of Canada, pt. 2: *Canada Geological Survey*, p. 48-57.
- 1890a, New Lamellibranchiata, no. 1, containing descriptions of new species of *Modiolopsis*: *American Geologist*, v. 5, p. 270-284.
- 1890b, New Lamellibranchiata, no. 2, on two new genera and six new species: *American Geologist*, v. 6, p. 173-181.
- 1890c, New Lamellibranchiata, no. 3, descriptions of new species with remarks on others: *American Geologist*, v. 6, p. 382-389.
- 1890-1891, New and little known American Paleozoic Ostracoda: *Cincinnati Society of Natural History Journal*, v. 13, p. 104-137, 1890; p. 173-211, 1891.
- 1892a, New Lower Silurian Lamellibranchiata, chiefly from Minnesota rocks: *Minnesota Geological and Natural History Survey Annual Report* 19, for the Year 1890, p. 211-248.
- 1892b, New Lamellibranchiata, no. 4, descriptions of one new genus and eight new species: *American Geologist*, v. 10, p. 96-104.
- 1892c, New Lamellibranchs (Ordovician, Minnesota, Wisconsin): *American Geologist*, v. 9, p. 96-108.
- 1893, On Lower Silurian Bryozoa of Minnesota: *Minnesota Geological and Natural History Survey Final Report*, v. 3, pt. 1, p. 96-332. [Published under separate cover in 1893. The entire volume was published in 1895.]
- 1894a, The Lower Silurian Lamellibranchiata of Minnesota: *Minnesota Geological and Natural History Survey Final Report*, v. 3, pt. 2, p. 475-628. [Published under separate cover in 1894. The entire volume was published in 1897.]
- 1894b [1897], The Lower Silurian Ostracoda of Minnesota: *Minnesota Geological and Natural History Survey Final Report*, v. 3, pt. 2, p. 629-693.
- 1911, Revision of the Paleozoic systems: *Geological Society of America Bulletin*, v. 22, p. 281-680.
- Ulrich, E.O., and Bassler, R.S., 1908, New American Paleozoic Ostracoda: Preliminary revision of the Beyrichiidae, with descriptions of new genera: *U.S. National Museum Proceedings*, v. 35, p. 277-340.
- 1923, Silurian: *Maryland Geological Survey*, 794 p.
- Ulrich, E.O., and Cooper, G.A., 1942, New genera of Ordovician brachiopods: *Journal of Paleontology*, v. 16, p. 620-626.
- Utgaard, John, 1983, Systematic descriptions for the order Cystoporata, in Part G (rev. v. 1), *Bryozoa*, of Robison, R.A., ed., *Treatise on invertebrate paleontology: Geological Society of America and University of Kansas Press*, p. 358-439.
- Vigrass, L.W.M., 1971, Depositional framework of the Winnipeg Formation in Manitoba and eastern Saskatchewan, in Turnock, A.C., ed., *Geoscience studies in Manitoba: Geological Association of Canada Special Paper* 9, p. 225-234.
- Walcott, C.D., 1875, New species of trilobite from the Trenton limestone of Trenton Falls, New York: *Cincinnati Quarterly Journal of Science*, v. 2, p. 347-349.
- 1876, Descriptions of new species of fossils from the Trenton limestone: *New York State Museum of Natural History, Annual Report* 28, p. 93-98.
- 1877, Descriptions of new species of fossils from the Chazy and Trenton limestone: *New York State Museum of Natural History Annual Report* 31, p. 66-71. [Published under separate cover in 1877. The entire volume was published in 1879.]
- Walter, O.T., 1927, Trilobites of Iowa and some related Paleozoic forms: *Iowa Geological Survey Annual Reports*, v. 31, 1923 and 1924, p. 167-390.
- Warshauer, S.M., 1981, *Cincinnati* concha, *Pseudoprimitiella* and *Edenopsis*; new generic names for Ordovician ostracodes: *Journal of Paleontology*, v. 55, p. 885-893.

- Warshauer, S.M., and Berdan, J.M., 1982, Palaeocopid and Podocopid Ostracoda from the Lexington Limestone and Clays Ferry Formation (Middle and Upper Ordovician) of central Kentucky: U.S. Geological Survey Professional Paper 1066-H, 80 p.
- Webers, G.F., 1961, A study of the conodonts of the Dubuque formation of Minnesota: Unpublished M.S. thesis, University of Minnesota, Minneapolis.
- 1966, The Middle and Upper Ordovician conodont faunas of Minnesota: Minnesota Geological Survey Special Publication Series SP-4, 123 p.
- 1972, Paleoecology of the Cambrian and Ordovician strata of Minnesota, in Sims, P.K., and Morey, G.B., eds., *Geology of Minnesota: A centennial volume*: Minnesota Geological Survey, p. 474-484.
- Weiss, M.P., 1953, The stratigraphy and stratigraphic paleontology of the upper Middle Ordovician rocks of Fillmore County, Minnesota: Unpublished Ph.D. dissertation, University of Minnesota, Minneapolis, 615 p.
- 1954a, Corrosion zones in carbonate rocks: *Ohio Journal of Science*, v. 54, p. 289-292.
- 1954b, Feldspathized shales from Minnesota: *Journal of Sedimentary Petrology*, v. 24, p. 270-274.
- 1954c, Notes on some Middle Ordovician fossils from Minnesota: *Journal of Paleontology*, v. 28, p. 427-429.
- 1955, Some Ordovician brachiopods from Minnesota and their stratigraphic relations: *Journal of Paleontology*, v. 29, p. 759-774; correction, v. 30, 1956, p. 219.
- 1957, Upper Middle Ordovician stratigraphy of Fillmore County, Minnesota: *Geological Survey of America Bulletin*, v. 68, p. 1027-1062.
- 1958, Corrosion zones: A modified hypothesis of their origin: *Journal of Sedimentary Petrology*, v. 28, p. 486-489.
- Weiss, M.P., and Bell, W.C., 1956, Middle Ordovician rocks of Minnesota and their lateral relations, in Schwartz, G.M., and others, eds., *Lower Paleozoic geology of the upper Mississippi Valley*: Geological Society of America, Annual Meeting, Minneapolis, Minnesota, 1956. Guidebook for field trip no. 2, p. 55-73; road logs, p. 96-110.
- Wetzel, A., and Aigner, T., 1986, Stratigraphic completeness: Tiered trace fossils provide a measuring stick: *Geology*, v. 14, p. 234-237.
- Whitfield, R.P., 1878, Preliminary descriptions of new species of fossils from the lower geological formations of Wisconsin: *Wisconsin Geological Survey Annual Report for the Year 1877*, p. 50-89.
- 1882, Paleontology, in *Geology of Wisconsin*, v. 4: Wisconsin Geological Survey, pt. 3, p. 161-363.
- 1886, Notice of geological investigations along the eastern shore of Lake Champlain . . . with descriptions of the new fossils discovered: *American Museum of Natural History Bulletin* 1, p. 293-348.
- 1895, Republication of descriptions of fossils in the Hall collection in the American Museum of Natural History: *American Museum of Natural History Memoir* 1, p. 39-74.
- Whitney, J.D., 1862, Stratigraphical geology, in Hall, James, and Whitney, J.D., Report on the geological survey of the state of Wisconsin: Albany, N.Y., printed by the authority of the legislature of Wisconsin, v. 1, p. 140-193.
- Whittington, H.B., 1941, Silicified Trenton trilobites: *Journal of Paleontology*, v. 15, p. 492-522.
- 1949, *Dolichoharpes* and the origin of the harpid fringe: *American Journal of Science*, v. 247, p. 276-285.
- 1950, Sixteen Ordovician genotype trilobites: *Journal of Paleontology*, v. 24, p. 531-565.
- 1952, A unique remopleurid trilobite: *Harvard University, Museum of Comparative Zoology, Breviora* 4, 9 p.
- 1953, North American Bathyruridae and Leioestegiidae (Trilobita): *Journal of Paleontology*, v. 27, p. 647-678.
- 1954, Ordovician trilobites from Silliman's Fossil Mount: *Geological Society of America Memoir* 62, p. 119-150.
- 1956, Silicified Middle Ordovician trilobites: The Odontopleuridae: *Harvard University, Museum of Comparative Zoology Bulletin* 114, p. 155-288.
- 1959, Silicified Middle Ordovician trilobites: The Remopleuridae, Trinucleidae, Raphiophoridae, Endymioniidae: *Harvard University, Museum of Comparative Zoology Bulletin* 121, p. 371-496.
- Whittington, H.B., and Evitt, W.R., 2nd, 1954, Silicified Middle Ordovician trilobites: *Geological Society of America Memoir* 59, 137 p.
- Williams, A., and Rowell, A.J., 1965a, Brachiopod anatomy, in Part H, Brachiopoda, of Moore, R.C., ed., *Treatise on invertebrate paleontology*: Geological Society of America and University of Kansas Press, p. H6-H57.
- 1965b, Classification, in Part H, Brachiopoda, of Moore, R.C., ed., *Treatise on invertebrate paleontology*: Geological Society of America and University of Kansas Press, p. H214-H237.
- Williams, A., and Wright, A.D., 1963, The classification of the "*Orthis testudinaria* Dalman" group of brachiopods: *Journal of Paleontology*, v. 37, p. 1-32.
- 1965, Orthida, in Part H, Brachiopoda, of Moore, R.C., ed., *Treatise on invertebrate paleontology*: Geological Society of America and University of Kansas Press, p. H299-H359.
- 1970, Shell structure of the Craniacea and other calcareous inarticulate Brachiopoda: *Palaeontological Association Special Papers in Palaeontology* 7, 51 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.
- Willman, H.B., and others, 1975, *Handbook of Illinois stratigraphy*: Illinois State Geological Survey Bulletin 95, 261 p.
- Wilson, A.E., 1947, Trilobites of the Ottawa formation of the Ottawa-St. Lawrence Lowland: *Canada Geological Survey Bulletin* 9.
- Winchell, N.H., 1881, New Brachiopoda from the Trenton and Hudson River formations in Minnesota: *Minnesota Geological and Natural History Survey Annual Report* 9, for the Year 1880, p. 115-122.
- 1886, New species of fossils: *Minnesota Geological and Natural History Survey Annual Report* 14, for the Year 1885, p. 313-318.
- Winchell, N.H., and Schuchert, Charles, 1892, Preliminary descriptions of new Brachiopoda from the Trenton and Hudson River groups of Minnesota: *American Geologist*, v. 9, p. 284-294.
- 1895, The Lower Silurian Brachiopoda of Minnesota: *Minnesota Geological and Natural History Survey Final Report*, v. 3, pt. 1, p. 333-474.
- Winchell, N.H., and Ulrich, E.O., 1895, Historical sketch of investigation of the Lower Silurian in the Upper Mississippi Valley: *Minnesota Geological and Natural History Survey Final Report*, v. 3, pt. 1, p. ix-liv.
- 1897, The Lower Silurian deposits of the upper Mississippi province: A correlation of the strata with those in the Cincinnati, Tennessee, New York and Canadian provinces, and the stratigraphic and geographic distribution of the fossils: *Minnesota Geological and Natural History Survey Final Report*, v. 3, pt. 2, p. lxxxiii-cxxviii.
- Winter, J., 1977, Stabile Spurenelemente als Leit-Indikatoren einer tephrostratigraphischen Korrelation (Grenzbereich Unter/Mittldevon, Eifel, Belgien): *Newsletters on Stratigraphy*, v. 6, p. 152-170.
- Witzke, B.J., 1980, Middle and Upper Ordovician paleogeography of the region bordering the Transcontinental Arch, in Fouch, T.D., and Magathan, E.R., eds., *Paleozoic paleogeography of the west-central United States—West-Central United States Paleogeography Symposium 1*: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, p. 1-18.
- Wright, L.D., 1977, Sediment transport and deposition at river mouths: A synthesis: *Geological Society of America Bulletin*, v. 88, p. 857-868.
- Young, F.P., Jr., 1943, Black River stratigraphy and faunas: *American Journal of Science*, v. 241, p. 141-166, 209-240.

AN ORDOVICIAN TIME SCALE

Robert E. Sloan
 Department of Geology and Geophysics
 University of Minnesota, Minneapolis, MN, 55455



This time scale was generated from Sweet's 1984 CSS, Kunk and Sutter's T-3 date of 454.2, 438 Ma for the O/S boundary, 504 for the C/O boundary, Hintze's 1952 Ibex sections, and Ross and others, 1982.

