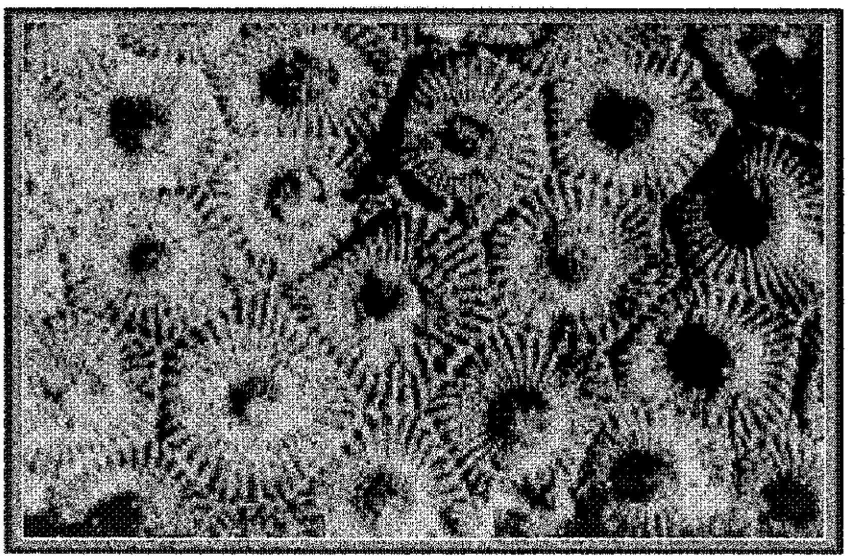
Classic Geological Exposures, Old and New, Coralville Lake and Spillway

Devonian Fossil Gorge, Merrill A. Stainbrook Preserve & Old State Quarry Preserve

Brian J. Witzke & Bill J. Bunker



Hexagonaria cedarense

Geological Society of Iowa

November 5, 1994 Guidebook 60

CLASSIC GEOLOGICAL EXPOSURES, OLD AND NEW, CORALVILLE LAKE AND SPILLWAY

Devonian Fossil Gorge, Merrill A. Stainbrook Preserve & Old State Quarry Preserve

Prepared by

Brian J. Witzke and Bill J. Bunker
Iowa Department of Natural Resources
Geological Survey Bureau
Iowa City, Iowa

November 5, 1994

Geological Society of Iowa
Guidebook 60

CONTENTS

INTRODUCTION

The summer floods of 1993 filled the Coralville Lake reservoir to capacity, and for the first time since its construction, the emergency spillway of the Coralville Dam overflowed. The torrent of water that rushed over the spillway washed away everything in its path and scoured the less indurated Quaternary sediments away, leaving a spectacular swath of exposed bedrock in its wake. A small group of Iowa City geologists, including students, university faculty, and survey personnel, had long been interested in the geology of the Coralville Lake area, but the level of public interest in the geology of the area had largely been latent. To our amazement, the surge of public interest in the geology and paleontology of the area that followed the floods was beyond anything we could have imagined. Literally hundreds of thousands of people traversed the exceptional Devonian bedrock exposures at the spillway in the year following the flood, discovering what we geologists had known all along — indeed, the Coralville Lake area is a treasure trove of information about the Devonian seas that once covered the interior regions of North America. It was gratifying to see the broad spectrum of people, both young and old, doing what we geologists had previously done in isolation — crawling around and looking at the rocks and fossils. And the visitors were fascinated with what they saw — thinking, probing, and learning from the record in the rocks laid out before them. It was thrilling to see geology become so popular. Yes, people really are interested in learning more about geology and paleontology.

Interest came from far and wide, as the national and international media spread word about the fossils exposed at the Coralville Dam. Of course, there was a certain irony in the sudden explosion of interest. While the spillway exposures are certainly exceptional, equivalent rocks and fossils had been accessible to the public all along. Miles of shoreline of Coralville Lake display Devonian fossiliferous limestone exposures, and we will visit a few of these during the course of this field trip. But it was the 1993 flood that perhaps focused public attention on the rocks — the spillway exposures, now termed the Devonian Fossil Gorge, provide a strong visual impression of the power of the floodwaters. And the summer of 1993 was also the time the blockbuster movie *Jurassic Park* was released, and the public's imagination was spurred to think about the fascinating history of life on earth. Whatever the reasons, the public interest in the local geology has been beyond anything we could have imagined.

Numerous geologic and paleontologic studies have been undertaken in the general area of present-day Coralville Lake, and some of these will be subsequently noted. In addition, previous geologic guidebooks can provide the interested reader with further information and background concerning the geology of the Coralville Lake area (Bunker and Witzke, 1987; Plocher, 1989; Day and Bunker, 1992). Additional geologic reference sections a short distance downstream from the Coralville Dam in the Coralville-Iowa City area expose equivalent strata, and geologic guidebooks for this area are also available (Witzke, 1984; Bunker and Hallberg, 1984).

Exposed rocks and sediments in the Coralville Lake area include materials from three different geologic systems: 1) Devonian aged limestone strata and minor shale (about 370 to 380 million years old); 2) Pennsylvanian aged river channel deposits, primarily sandstone and siltstone (about 310-320 million years old); and 3) more recent Quaternary aged glacial, alluvial (river), and wind-blown deposits (the last 1.5 million years or so). This guidebook primarily focuses on the Devonian strata in the region, and a general summary of Devonian paleontology and stratigraphy is presented.

IOWA'S PLACE IN THE DEVONIAN WORLD

The geography of the Devonian world was considerably different than that seen today, largely because the Earth's crust has moved and shifted in response to dynamic processes within the Earth's interior. Lithospheric plates have jossled and collided, and continents have drifted around the surface of the Earth. About 375 million years ago, at

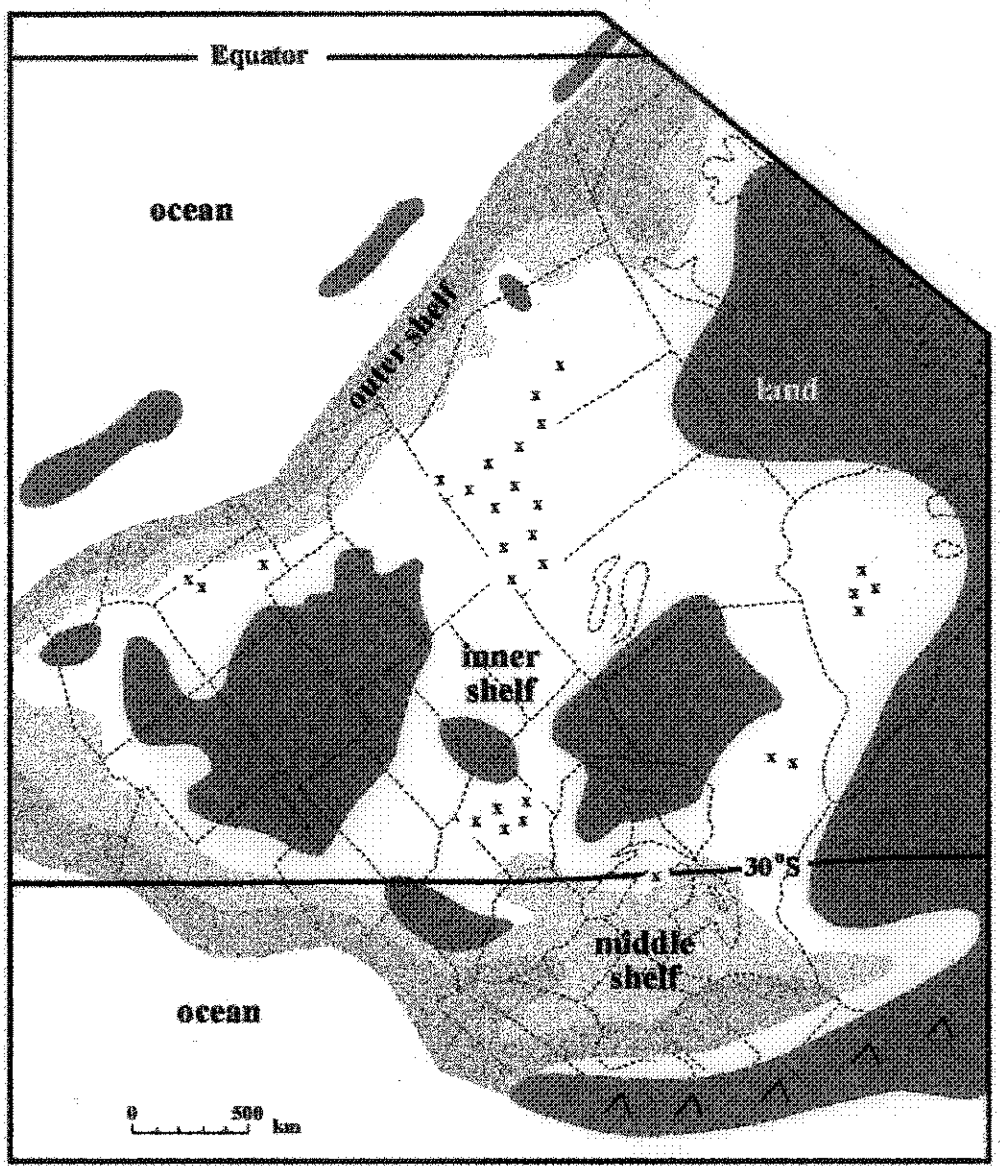


Figure 1. Paleogeographic map of the Middle Devonian Euramerican continent.

the time the lime sediments presently seen in the Devonian Fossil Gorge were deposited, the region of present-day Iowa was located in the interior of the Euramerican continent (North America and Europe cojoined) under shallow tropical seas. The continent was largely positioned at low latitudes in the southern hemisphere, with Iowa located about 25° south latitude in the warm tropics (Fig. 1).

Seaways expanded and contracted across the interior of the continent numerous times during the Devonian, with large-scale cycles of deepening and shallowing (transgression and regression) developed on the order of every 1 to 3 million years (Johnson et al., 1985; Witzke et al., 1988). In the area of eastern Iowa, some of the shallowing phases were marked by complete withdrawal of the seaway and subaerial exposure on the emergent land surface. During times of maximum seaway development, Iowa was part of a vast interior seaway that interconnected our region with areas to east (eastern U.S., Michigan), west (southwest U.S.), and north (the Dakotas and Canada). The deep ocean bordered the continent south from Iowa across present-day Arkansas (Fig. 1).

The animals and plants of the Devonian world share some distant similarities with those of the modern world, but, in general, the living organisms of the Devonian world would appear largely alien to our modern perspective. The Devonian seas teemed with marine life, but bottom dwellers, swimmers, and plankton belonged to families and orders of animals now mostly extinct. Brachiopods, crinoids, bryozoans, corals, and sponge-like stromatoporoids were the predominant bottom dwellers in the tropical seas. Primitive fish, conodont animals, and nautiloids swam the seas.

The land surface during the Devonian was notably dissimilar to that of the modern world. The familiar plants and animals of the modern landscape were largely absent from the Devonian world. Early vascular plants, including lycopods, sphenopsids, and ferns, were in the process of becoming well established on the land surface during the Devonian. A few insect groups and other terrestrial arthropods made their appearance during the Devonian, adapting to the newly evolving early terrestrial ecosystems. Terrestrial vertebrate animals (early amphibians) evolved from lung-bearing lobe-finned freshwater fish during the Devonian, and made their global debut in terrestrial and wetland environments in the Late Devonian. In other words, our distant ancestors first crawled out of the water and onto land during the Devonian.

AN INTRODUCTION TO DEVONIAN FOSSILS OF THE CORALVILLE LAKE AREA

The limestone rocks around Coralville Lake provide a fabulous glimpse of shallow marine life in the middle part of the Devonian period. While a comprehensive review of these fossils is not attempted here, a brief overview of the main groups of fossil organisms is provided to give the reader some idea of the diversity of life that inhabited the Devonian seas. More detailed studies of certain fossil groups found in the Coralville Lake area can be referenced elsewhere. However, some groups remain poorly studied, and many opportunities for further paleontologic studies still await.

The bulk of fossils seen in the Coralville Lake area represent the hard parts (shells or skeletons) of once living organisms, primarily bottom dwellers. Most of these shells and skeletons are composed of calcite (calcium carbonate), the same mineral that forms the limestone matrix in which they are enclosed. In fact, the limestone sediments themselves were probably derived primarily from the breakdown of calcium carbonate particles secreted by sea-dwelling plants and animals. That is, the limestone itself is primarily a product of biological activity. Many of the grain-rich limestones seen around Coralville Lake are composed primarily of the skeletal parts of brachiopods, crinoids, corals, or stromatoporoids — these can be simply termed "skeletal limestones."

Some animals produce hard parts that are composed of different materials, including phosphatic minerals (apatite), resistant chitin and other organic substances, or silica (quartz). In the Coralville Lake area, fossils made of these materials are considerably less common that those derived from lime-secreting organisms. Some limestone beds in the area contain common fossil burrows and tracks (also called "trace fossils"), providing evidence of animal activities in the soft sediments. Elongate burrows provide evidence of soft-bodied creatures like worms that would otherwise be unrepresented in the fossil record. Soft tissues are rarely preserved in the geologic record, but occasionally such material is preserved as carbon films or impressions in the rock. In general, the fossil record of life on earth is largely a record of skeletal hard parts.

Sponges and Stromatoporoids

Sponges (Phylum Porifera) are primitive invertebrate animals whose soft parts are supported in some groups by a skeleton composed of small mineral elements (spicules). Whole sponge fossils are not particularly abundant in the Coralville Lake area, but bowl-shaped calcareous sponges (with hundreds of small six-pointed calcite spicules) are commonly seen in strata of the upper Solon and basal Rapid members. While generally not seen as whole body fossils, isolated siliceous spicules are also commonly identified in microscopic residues or in thin section. Indirect evidence in some Devonian units in the area suggests that siliceous sponges may actually have been fairly abundant at times. The biologically-precipitated silica spicules are not geologically stable, and the siliceous material is commonly solutionally mobilized in the sediments and re-precipitated as chert. Chert-rich beds in portions of the Devonian section, especially in the upper part of the Rapid Member, may likely owe their origin to an abundance of siliceous sponge spicules in the sediments.

The stromatoporoids are an extinct group of organisms with a dense calcareous skeleton containing a microscopic maze of laminae and pillars with chambers or tubes internally. The biological relationships of the extinct stromatoporoids has been debated for many years. However, the discovery of a peculiar group of modern encrusting sponges with similar features may indicate that the stromatoporoids are an unusual group of sponges with massive calcareous skeletons. Stromatoporoids are especially abundant fossils in the Coralville Lake area, and in some beds they are the most common fossil seen (e.g., parts of the Cou Falls Member). Stromatoporoids are commonly associated with corals in biostromal (tabular "reef-like" accumulations) or coralline intervals of the upper Solon, middle Rapid, Cou Falls, Iowa City, and State Quarry members.

Two general skeletal forms of stromatoporoids are recognized: 1) small branching stick-like forms, and 2) small to large massive hemispherical and tabular forms. The branching forms are commonly broken or abraded into smaller fragments. The massive forms are commonly encrusted onto or around corals in some beds. Much of the stromatoporoid fauna in the Coralville Lake remains to be studied in detail, and its taxonomic diversity has not yet been clearly identified. Carl Stock of the University of Alabama and his students have initiated important studies of the rich stromatoporoid fauna of the Iowa Devonian.

The Corals

Fossil corals are the namesake for the Coralville Lake area. The famous geologist Louis Agassiz visited the University of Iowa in 1866 and delivered a lecture on the fossil corals of the Iowa City area. This lecture so impressed the local populace that the discovery of abundant corals at a mill site shortly thereafter prompted the new town site adjacent to the mill to be named Coralville. Coralville Dam and Coralville Lake thereby appropriately bear a label that reflects the abundance of fossil corals in the area. In fact, fossil corals are among the most conspicuous Devonian fossils to be seen in the Coralville Lake area.

The fossil corals (Phylum Cnidaria, Class Anthozoa) in the area are characterized by a calcareous skeleton which protected the soft tissues of coral animals that lived in the Devonian seas. Two extinct orders of fossil corals are recognized: 1) the tabulates, and 2) the rugosans. Tabulate corals are entirely colonial, with compound skeletons composed of numerous small corallites (the skeletal chamber secreted by individual coral polyps). The tube-like corallites display simple horizontal partitions (tabulae) that were successively added as the coral colony grew outward. Favositid tabulate corals (*Favosites, Alveolites,* and related forms) are the most abundant. The common "honeycomb coral' (*Favosites*) displays hexagonal corallites (generally < 3 mm diameter), and their colonies variably show massive to branching morphologies. The small pachyporid tabulates form small stick-like branching colonies. The auloporid corals display loosely-packed cylindrical corallites, commonly encrusting brachiopod shells or other corals.

The rugose corals include both solitary and colonial forms, whose corallites are partitioned by both horizontal tabulae as well as thin vertical plates arranged in a radial pattern (septa). Solitary rugose coral are characterized by horn- or conical cup-shaped corallites secreted by a single coral animal. Their fossils are commonly termed "horn corals" or "cup corals" to reflect their general shape. They are generally 2 to 5 cm in length, but large horn corals in excess of 20 cm are found in some beds (e.g. the Rapid biostromes). The colonial rugose corals in the Coralville Lake area are exceptionally beautiful fossils, and their massive skeletons (some in excess of 60 cm) are crowded in some beds. The common *Hexagonaria* (see cover illustration) has distinctive hexagonal corallites (about 1 cm diameter), and can be seen in many units in the area (including the upper Solon, lower to mid Rapid, lower Coralville, and State Quarry members). The spectacular *Astrobillingsa* has much larger corallites (about 3 to 5 cm), and is restricted to strata of the upper Solon Member. Some rugose corals display cylindrical corallites that are not in contact with each other, forming loosely grouped or branching forms (fasciculate rugosans); such forms are less common than the massive colonial forms.

The Bryozoans

The bryozoans (Phylum Bryozoa) are small colonial invertebrates that superficially resemble miniature colonial corals. Most fossil bryozoans in the Coralville Lake area have calcareous skeletons secreted by colonies of tiny animals (individual zooids). The abundant bryozoan fauna in the area has not been thoroughly studied, but a number of distinctive forms are recognized. The fenestellid or "lace" bryozoans secreted a skeleton with an open lace-like form of slender parallel branches and crossbars. Thin fan-like fenestellid colonies are especially prominent in parts of the Rapid Member. Small branching ribbon-like colonies (cystodictyonids) and twig-like bryozoans are also common. Some bryozoans encrust the shells of other bottom-dwelling creatures, especially brachiopods. The trepostome or "stony" bryozoans include more massive colonies of sheet-like and domal form, and are among the largest of bryozoan colonies noted in the area (some in excess of 10 cm; middle to upper Rapid Member).

The Brachiopods

The brachiopods (Phylum Brachiopoda) are among the most important and abundant groups of fossils found in the Coralville Lake area. Brachiopods are marine invertebrates whose soft parts are enclosed by two shells (valves), which in most species are composed of calcite. They superficially resemble bivalve molluscs (clams), but brachiopods are easily distinguished from clams by the inequal size and shape of the two valves and the equal-sided symmetry of each single valve. Brachiopods are among the better known Devonian fossils in the Coralville Lake area, primarily owing to the extensive studies of Merrill Stainbrook (1938a - 1943b). Stainbrook studied Devonian brachiopods from many localities in eastern Iowa, including the Coralville Lake area, and Stop 2A of this trip has been designated the Stainbrook Geological Preserve in his honor. Significant additions and updating of the brachiopod fauna of the Cedar Valley Group in eastern Iowa has been a research focus of Jed Day (Illinois State University) in more recent years (see summary paper by Day, 1992, and references therein). The interested reader is referred to the publications of Stainbrook and Day for a more thorough treatment of the spectacularly abundant and diverse brachiopod fauna in the area.

Although some brachiopod species exist in the modern oceans, brachiopods were among the dominant bottom-dwelling invertebrate animals of the Devonian seas. A number of extinct orders of brachiopods are recognized in the Coralville Lake area. The orthid brachiopods (Order Orthida) are represented primarily by the genus *Schizophoria*, an elliptical bi-convex form with fine ribbing (costae) on the exterior shell. The strophomend brachiopods (Order Strophomenida) include a variety of forms with a broad hinge area between the two valves, with one valve convex in form, the other concave. Common strophomenids include *Strophodonta* (a relatively large flattened form, finely ribbed), chonetids (small flat forms, finely ribbed), and productids (with spiny shells).

Pentamerid brachiopods (Order Pentamerida) include *Pentamerella*, a bi-convex form with coarse ribs, common in parts of the Rapid and Cou Falls members. The terebratulid brachiopods (Order Terebratulida) in the area include generally smooth-shelled forms like *Cranaena* with elongate shells. This form is most common in coral-bearing strata of the Cou Falls Member. Some specimens in the Coralville Lake area are even known to preserve faint striped bands that correspond to color markings in life. The rhynchonellid brachiopods (Order Rhynchonellida) are not especially abundant in the area, but small forms are marked by prominent coarse ribs.

The spiriferid brachiopods (Order Spiriferida) are particularly common in the Coralville Lake area, and a tremendous diverisity of forms is represented. The interior of spiriferid shells display a distinctive calcareous spiral feature (spiralia) which, in life, supported the tentacle-like feeding structures. Atrypid forms are characterized by biconvex shells with a more or less rounded outline; many show fine ribbing (e.g., *Pseudoatrypa, Neatrypa*), and some have lamellar growth ridges or spiny shells (*Spinatrypa*). Athyrid forms (*Athyris*) have bi-convex shells with small hinge areas and non-ribbed surfaces bearing fine growth ridges. Athyrid brachiopods occur through a wide range of strata in the area, and in life the athyrids apparently had a broad range of environmental tolerance (environmental generalists). Spiriferid brachiopods of the suborder Spiriferidina include a variety of distinctive forms with transverse shells (wider than long), wide hinges, and a central elevation or depression (fold and sulcus); many have prominently ribbed shells. The distinctive *Orthospirifer* has broad wing-like shells, and some of the largest brachiopod shells in the area belong to this form (up to 15 cm wide). A variety of smaller forms are also common (especially *Tylothyris, Eosyringothyris, Cyrtina, Allanella*).

Shells of inarticulate brachiopods (shells lack hinges) are generally rare, but several forms are known in the area. Some are characterized by thin phosphatic shells (not calcareous as in other brachiopods), including more or less circular orbiculoids and elongate linguloids. These phosphatic forms are most commonly encountered in the Rapid Member (but also occur in Solon and State Quarry strata). Additional more or less round calcareous shells of small inarticulates (craniids) are scattered in the Solon, Rapid, and Cou Falls members, commonly cemented to the surface of other brachiopod shells.

The Molluscs

Most molluscs (Phylum Mollusca) secrete calcareous shells composed of a variety of calcium carbonate called aragonite (interlayered with organic material). Unlike the calcite shells secreted by most other fossil groups, aragonite is not stable over geologic time, and the aragonite shells are typically dissolved away. As such, most mollusc fossils in the Coralville Lake area are represented by molds of the shell within the limestone, and not the actual fossil shell material itself. Molluscs are among the dominant bottom-dwelling animals of the shallow oceans today, but, in general, molluscs had not achieved such dominance in the Devonian seas (brachiopods, crinoids, bryozoans proportionately more abundant).

The familiar filter-feeding bottom-dwelling clams or bivalves (Class Bivalvia) are noted in many units in the Coralville Lake area, but they are never particularly common. Clam molds have been observed in strata of the Solon, Rapid, Cou Falls, and State Quarry members, and are most commonly seen in mudstone units of the State Quarry Member. The easily recognized shell molds of coiled snails or gastropods (Class Gastropoda), likewise, are occasionally seen scattered through much of the Devonian sequence in the area. Snails are primarily bottom-dwelling scavengers. However, snails are common to abundant in some units within the Iowa City Member, and some of these are quite large (to 8 cm). Apparently some snail species achieved their greatest success as scavengers in the shallow restricted nearshore and tidal flat environments represented by some beds within the upper Coralville Formation.

The rostroconchs are an extinct groups of molluscs (Class Rostroconchia) that superficially resemble the bivalves. Their two equal-sized shells were held rigidly together. Unlike other mollusc fossils in the area, rostroconch shells are not preserved as molds, but the shell material is commonly preserved displaying a distinctive powdery white appearance. Rostroconchs (*Conocardium*) are relatively common in several coral-rich biostromal units in the Coralville Lake area, particularly in the Cou Falls Member.

The cephalopods (Class Cephalopoda) include the modern squids, octopus, and nautilus. Cephalopods are advanced invertebrates with tentacles and eyes, and most are active predatory animals. Shell molds of nautiloid cephalopods are occasionally encountered in many units in the area, including the Solon, Rapid, Cou Falls, State Quarry, and Andalusia members. They are most common around Coralville Lake in a bed a short distance below the top of the Solon Member. Nautiloid shells are characterized internally by a series of chambers interconnected by a single tube (siphuncle). Like the modern chambered nautilus, the gas and liquid filled chambers can be regulated to control the animal's buoyancy. The Devonian rocks of the Coralville Lake area have produced nautiloid shell molds of straight, curved, and coiled forms; these include some of the largest invertebrate fossils in the area (commonly 20-30 cm, occasionally larger).

The Echinoderms

Echinoderms (Phylum Echinodermata) are abundantly represented in Devonian strata of the Coralville Lake area, but most echinoderms are disarticulated into their individual calcite plates. Echinoderms, which include modern starfish and sea urchins, are bottom dwelling creatures that are exclusively marine. Some lived attached to the bottom, while others were capable of moving around. Echinoderms possess a skeleton of numerous calcite plates which protect the main portion of the body (the cup or theca) and its appendages (arms and stems). Echinoderms are charcterized by a sophisticated water-circulatory system. The calcite skeleton of most echinoderms is held together by connective tissue which rapidly decays following death, resulting in the skeleton disarticulating into its individual plates on the sea bottom. However, if a living echinoderm is rapidly buried, its entire skeletal structure may be beautifully preserved in exceptional circumstances. Although generally rare, spectacular articulated echinoderm specimens are known from strata of the Rapid Member in the Coralville Lake area.

Crinoids (Class Crinoidea) are the most abundant echinoderms in the area, and their disarticulated plates comprise a significant portion of many limestone beds. In some units, crinoid debris comprises almost the entire volume of the rock (especially the crinoidal packstones and grainstones of the upper Rapid Member). Crinoids (also known as sea lilies) have a body plan that is reminiscent of a plant in containing a long stalk (stem), a basal attachment (sometimes root-like in structure), a plated head (or calyx), and arms. Individual plates that comprise the stem are called columnals. The distinctive columnals are usually circular in form, resembling small poker chips. Crinoid columnals and stem segments are recognized in virtually all limestone units in the area, with the exception of the Iowa City Member. Although some groups of crinoids are known from the modern oceans, they are generally not particularly abundant in the modern world. However, now extinct groups of crinoids achieved remarkable success in the shallow seas of the Paleozoic Era, and in some settings they were the dominant form of invertebrate life. Crinoids generally remained attached to the bottom in life, and they fed by filtering small particles out of the water with their arms.

Three extinct subclasses of crinoids are identifed from articulated specimens in the Rapid Member of the Coralville Lake area, and further information about this remarkable crinoid fauna can be referenced in Thomas (1924), Strimple (1959), and Calhoun (1983). The inadunate crinoids (Subclass Inadunata) in the area are mostly relatively small crinoids, and number of genera are recognized, especially in upper Rapid strata (*Botryocrinus, Decadocrinus, Synbathocrinus, Halysiocrinus*). The flexible crinoids (Subclass Flexibilia) have relatively simple branching arms; two genera are recognized in the Rapid Member of the area (*Eutaxocrinus, Euryocrinus*). Most camerate crinoids (Subclass Camerata) have a rigid box-like calyx, and many camerate crinoids in the Coralville Lake area are relatively large. The largest species belong to *Megistocrinus*, some with calyces up to 10 cm in diameter. The distinctive large stems and columnals of *Megistocrinus* are common in parts of the Solon and Rapid members. Other large camerate genera from the Rapid Member include *Stereocrinus* and *Melocrinites*; a new genus of large melocrinitid was collected at the Devonian Fossil Gorge and will be described later. Smaller camerates from the Coralville Lake area include *Gilberstsocrinus, Arthroacantha,* and *Hexacrinites*.

In addition to the abundant crinoids, a number of other echinoderm classes are found in less abundance in the Rapid Member of the Coralville Lake area. Plates from a late surviving member of the rhombiferan cystoids (Class Rhombifera) are scattered to common in strata of the upper Rapid Member in the area (*Strobilocystites*), and occasional globular heads (theca) are found. The rhombiferan cystoids have stems similar to those of crinoids, but commonly taper downward. Like other rhombiferan cystoids, *Strobilocystites* thecal plates can be recognized by distinctive slit-like pore structures (pore rhombs) not seen in the crinoids. Hickory-nut-shaped theca from representatives of another stalked echinoderm group, the blastoids (Class Blastoidea), are occasionally found. These blastoids (mostly *Nucleocrinus*) have five prominent grooves (ambulacra) that run the length of the theca.

Skeletal plates and occasional articulated specimens of echinoids and starfish are also recognized in Rapid strata. Articulated spiny sea urchins or echinoids (Class Echinoidea) are known from upper Rapid strata in the Coralville Lake area, and rare edrioasteroids (Class Edcrioasteroidea), disc-shaped distant relatives of the echinoids, are known. Among the rarest of fossils, articulated specimens of starfish (Class Stelleroidea, Subclass Asteroidea) and brittle-stars (Subclass Ophiuroidea) have also been identified in middle to upper Rapid strata of the Coralville Lake area.

Trilobites and Other Arthropods

Trilobites are an extinct group of arthropods (Class Trilobita), classified by some in a phylum distinct from more "normal" arthropods. Trilobites possess an exoskeleton of mineralized chitin, which in many forms is dominantly calcareous (calcite). Trilobite skeletons are divided into three parts: 1) the head or cephalon, with a central glabella and two eyes (in most trilobites); 2) a flexible thorax, consisting of a series of individual segments; and 3) a fused tail region or pygidium, generally displaying segmentation. Trilobite skeletons generally disarticulate upon death or molting into a number of discrete pieces, although cephala and pygidia are commonly identifiable even when disarticulated. Trilobites probably were mobile scavengers on the sea bottom. Trilobites are recognized in strata of the Solon, Rapid, and Cou Falls members in the Coralville Lake area, and most specimens are disarticulated. Although never abundant, trilobite material is relatively common in some beds. Rare articulated specimens are known from Solon and lower to middle Rapid strata, and beautiful complete trilobite skeletons, both flat and enrolled, are known (especially from basal Rapid beds).

Devonian trilobites in the area are relatively well studied (see descriptions and discussion in Walter, 1923, and Hickerson, 1992, and references therein). Proetid trilobites are among the commonest forms (*Crassiproetus, Dechenella*), known from Solon, Rapid, and Cou Falls members. These proetids have semi-circular convex pygidia with numerous weak segments. *Phacops* is a distinctive trilobite with large complex faceted eyes known from Solon and Rapid strata. *Greenops* pygidia are easily identified from their spiny margins. A few other trilobite genera are also noted in the Solon Member (*Scutellum, Cyphaspis, Mystrocephala*).

Shrimp-like phyllocarid crustaceans (Class Crustacea, Subclass Phyllocarida) with a three-pronged tail have been noted in middle Rapid strata ("Z-beds") at the Devonian Fossil Gorge, but their chitinous exoskeleton is rarely preserved. The small ostracode crustaceans are common, but are considered under the section on microfossils.

Miscellaneous Fossils

A variety of additional invertebrate forms are identified in limestone strata of Coralville Lake area, most from extinct groups whose biological relationships remain problematic. Conularids are a group of extinct invertebrates characterized by elongate triangular or pyramidal phosphatic skeletons, most with fine transverse ribs. The biologic relations of this group are perplexing, but they are generally considered to have cnidarian affinities.

Conularids are scattered in the Solon and Rapid members, and some exceptional specimens were collected from Rapid strata ("Z-beds") at the Devonian Fossil Gorge.

The extinct tentaculites are small fossils characterized by elongate tube-like tapered calcitic shells pointed at one end and ornamented with numerous ring-like ridges and furrows. They are typically 1 to 2 cm in length. Tentaculites occur in Devonian rocks on many continents, and they were widespread and successful animals. However, their biologic relations are not known with certainty, and they have been variously allied with the molluscs or annelids (worms). Tentaculites are scattered in the Solon and Rapid members, and they are common to abundant on some bedding surfaces in the middle to upper Rapid Member (sometimes oriented in tentaculite-rich packstones in the Coralville Lake area).

Graptolites are an extinct group of small colonial invertebrates with stick-like or branching forms. Their skeleton is composed of an organic chitin-like substance. One group of lacy branching graptolites, the dendroids, are rarely identified in shaly strata of the middle Rapid Member ("Z-beds"). The graptolites are probably allied with the chordates, distant relatives of vertebrate animals.

Worms were probably common to abundant animals in the Devonian seas that covered the present-day Coralville Lake area, as evidenced by common to abundant elongate worm-like burrows. However, because worms commonly have few if any preservable hard parts, their true diversity is impossible to decipher from the fossil record. Nevertheless, chitinous jaws (scolecodonts) of polychaete worms (Pylum Annelida, Class Polychaeta) are common microfossils identified in acid residues from the Solon, Rapid, Cou Falls, Iowa City, and State Quarry members, indicating that worms were common animals on the Devonian seafloor. In addition, small calcareous spiral tubes (*Spirorbis*) encrust brachiopods or other fossils in some beds, and these were secreted by filter-feeding annelid worms.

Although a variety of plants undoubtedly inhabited the Devonian environments of the area, their body fossils are not particularly well represented. Calcareous algae and algal filaments are identified in the Little Cedar and Coralville formations (Kettenbrink and Toomey, 1975). Some primitive cyanobacteria (blue-green algae) grow in laminated mat-like bodies that bind small sediment particles into forms called stromatolites. Stromatolitic laminations are identified in some beds of the Iowa City Member. As subsequently noted, the microfossil record of plants provides a better indication of Devonian plant life in the area.

Microfossils

A tremendous variety of microfossils have been recovered from Devonian strata in the area, primarily identified in residues derived from acid treatment of the limestone. These residues are examined under a microscope to identify the contained microfossils. Organic-walled microfossils include spores and cysts of marine algae as well as a number of spores (mostly miospores $< 200\mu m$) probably derived from early terrestrial (land) plants. The terrestrial miospores (see summary by Klug, 1992) were apparently transported from nearby land areas into the shallow sea and incorporated with the marine sediments. These miospores are most abundant in strata of the Rapid Member, an interval which also contains the highest clay content (also derived from landward sources).

The chitinizoans are another group of resistant organic-walled microfossils characterized by a hollow flask-like shape. They have been recognized in Solon and Rapid strata in the area (Dunn, 1959). Chitinozoans are an extinct group (most taxa did not survive the Devonian) of uncertain biological affinities. They were probably a part of the marine plankton.

Foraminifera are single-celled marine animals (protists) enclosed within a shell of secreted mineral (usually calcite) or agglutinated particles. Microfossils of calcareous foraminifera have been identified in the Solon, Cou Falls, Iowa City, and State Quarry members (Kettenbrink and Toomey, 1975; Watson, 1974) in the Coralville Lake area. Spherical calcareous walled microfossils called calcispheres are common in some beds of the Coralville Formation. The biological affinities of calcispheres are not clearly known, but they likely represent reproductive cysts of calcareous algae.

Ostracodes are tiny bivalved crustaceans sometimes known as "seed shrimp." Two calcareous valves serve as a protective enclosure for the tiny shrimp-like creature inside. Ostracod microfossils are recognized in many of the Devonian limestone units of the Coralville Lake area, but no systematic treatment of the fauna has yet been undertaken. As noted above, chitinous jaw elements of polychaete worms are common microfossils in many beds.

Conodonts are tiny phosphatic tooth-like microfossils that are identified in all Devonian rock units of the Coralville Lake area except the Iowa City Member. The biological affinities of the extinct conodont animals have been the subject of much debate, but recently found body fossils from Scotland and Wisconsin may suggest some sort of relationship to chordates or chaetognath worms (chaetognaths also share chordate affinities). Some workers classify the conodonts as a separate phylum (Phylum Conodonta). The Scottish and Wisconsin specimens indicate that the soft-bodied conodont animals were small eel- or worm-like forms with a faintly segmented body, a central gut, and posterior fin-like structures. The phosphatic tooth-like structures are the animals' only hard parts, and each animal sported a number of distinctive phosphatic elements within the head (mouth?) region. Conodonts are known from Paleozoic and Triassic marine deposits, and their widespread habits suggest that the animals were part of the marine plankton and nekton.

Devonian conodonts in the Coralville Lake and Iowa City area have been the subject of numerous studies (see summary papers in Day and Bunker, 1992, and references therein). Conodonts are particularly useful for biostratigraphic comparisons with other Devonian strata around the world, and the age assignments of Devonian units in the Coralville Lake area were largely derived from such studies. The most diverse conodont faunas are recognized in the Solon and lower Rapid members. Conodonts are most abundant in the Rapid Member, and commonly 100 to 400 elements are recovered per kilogram of limestone. Conodont faunas are less diverse and elements are less common in overlying Coralville and State Quarry strata. The State Quarry mudstones, however, have produced some of the most perfectly preserved conodont elements known in the area.

The Fish

A variety of early fish are recognized in the Devonian limestones of the Coralville Lake area. No articulated specimens are known in the area, and our knowledge of the fossil fish fauna is primarily derived from isolated bones, teeth, dental plates, and minor bone associations. These can be compared to more complete Devonian fish fossils known from elsehwere in the world. Of note, however, articulated skulls and whole fish are known from Devonian strata in the Quad Cities and Waterloo areas (Hickerson, 1994; Schultze, 1992; Denison, 1985). The most comprehensive overview of the Devonian fish fauna in the area is provided by Eastman (1908). Virtually all fossil fish material in the area is characterized by dark brown-black or brown colors, generally in stark contrast to the lighter gray colors of the enclosing limestone.

The commonest fish fossils are bones and tooth-like plates from placoderm fish. The placoderms are an extinct group (Class Placodermi) of jawed fish with a prominent bony head region. The commonest placoderms belong to the ptyctodontids (Order Ptyctodontida), and the finely ridged dental plates of *Ptyctodus* are especially common. These dental plates are relatively flat ovoid structures seemingly adapted for crushing hard prey (not for biting and tearing). Ptyctodont plates are known from Solon, Rapid, Cou Falls, and State Quarry beds in the Coralville Lake area.

The arthrodires (Order Arthrodira) are another group of placoderms recognized in the area. Arthrodire heads were armored with thick bony plates, and some forms possessed bony spines. Based on the size of some head plates found in the Rapid Member in the area, some arthrodires reached lengths to 2 to 3 meters (see Fig. 2). These were likely the largest animals in the sea, and their sharply ridged or pointed dental plates were well suited for a predatory role. A particularly nice arthrodire plate (a median dorsal plate) was recov-

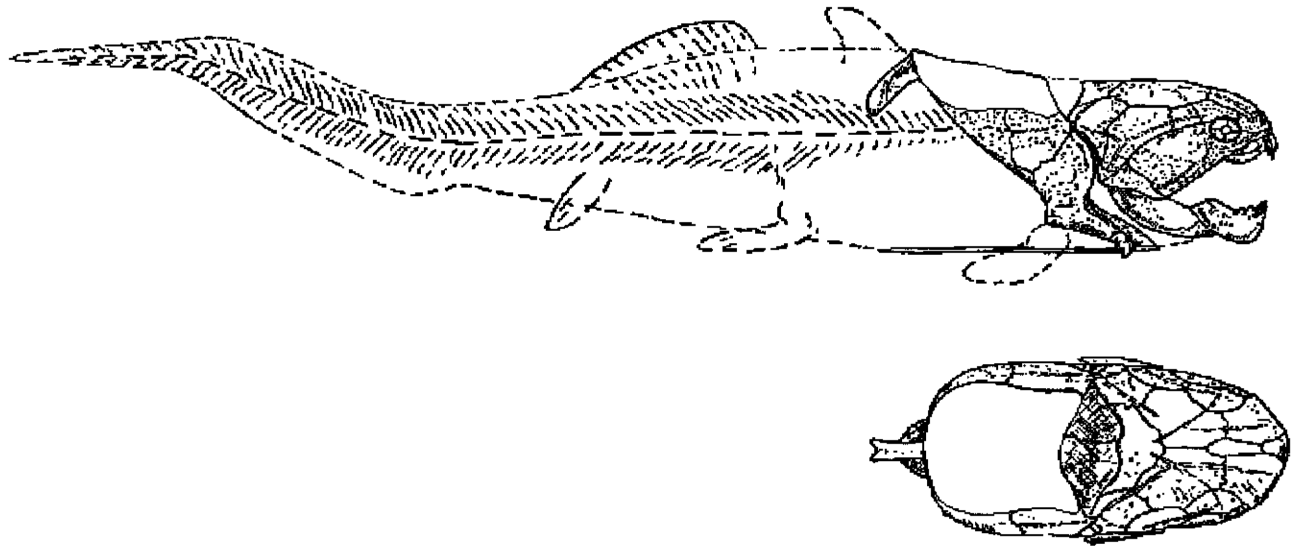


Figure 2.. Graphic depiction of giant arthrodire (placoderm) found at Devonian Fossil Gorge.

ered from middle Rapid strata ("Z-beds") at the Devonian Fossil Gorge, which is presently on display at the Coralville Lake visitor center. Additional arthrodire plates are known from Solon, basal Rapid, upper Rapid, and State Quarry strata in the Coralville Lake area.

Remains of early sharks (Class Chondrichthyes) are identified in upper Rapid and State Quarry strata in the Coralville Lake area. They are not particularly common, but cladodont shark teeth and ctenacanth shark spines have been found.

Several types of bony fish (Class Osteichthyes) are known from Devonian strata of the Coralville Lake area, primarily representatives of the lobe-finned fish (Subclass Sarcopterygii). Teeth, jaws, and spines of extinct crossopterygian lobe-finned fish are identified in the Rapid and State Quarry members, mostly from the group of onychodontids. A jaw, possibly from a rhipidistian crossopterygian fish, is also known from upper Rapid strata in the area. The crossopterygian fish include the ultimate ancestors of all terrestrial vertebrates, including mammals. Although most crossopterygians were marine, the modification of lungs and lobe-fins enabled some freshwater forms to adapt to terrestrial environments.

Another group of lobe-finned sarcopterygian fish includes the dipnoans (Order Dipnoi), or lungfish. Although a few dipnoans survive in modern ephemeral freshwater habitats, many of the Devonian lungfish were marine forms. Distinctive tooth plates with ridges or nodes are the most common dipnoan fossils in the Coralville Lake area. They are especially common in the "bone bed" units in State Quarry grainstone facies, but they are also known from mudstone units in the State Quarry Member. Dipnoans are also known from the Little Cedar Formation elsewhere in eastern Iowa.

STRATIGRAPHY AND DEPOSITION OF DEVONIAN BEDROCK UNITS IN THE CORALVILLE LAKE AREA

The Devonian bedrock geology around the Coralville Lake area includes a number of distinctive rock units that can be recognized by their general lithologies (rock types), fossil content, and relative position within the vertical sequence of strata. The composite sequence of stratigraphic units exposed in the area is graphically illustrated in Figure 3. The complete sequence is not exposed at any single locality, but all units can be visited in the

Coralville Lake area. Because the Devonian strata are not horizontal but dip at low angles in various directions (see structure contour map in Plocher and Bunker, 1989), different rock units are exposed at lake level in different areas. In general, the oldest rock units are seen north of the Lake MacBride spillway, and the youngest units are exposed in the drainage south and west of the old State Quarry. Because the State Quarry Member occupies channels incised into Coralville and Little Cedar strata, it is shown separately from the main sequence of Devonian units on Figure 3.

The development of stratigraphic nomenclature (rock unit names) in the area has a long history stretching back over 140 years of geologic study. The full history is not outlined here, but much of the existing nomenclature was developed by Keyes (1912), Stainbrook (1935, 1941a), and Witzke, Bunker, and Rogers (1988). General descriptions of individual stratigraphic units are provided in the following sections to assist the reader in recognizing various Devonian strata in the Coralville Lake area. General overviews of the Devonian stratigraphy of eastern Iowa can be found in Witzke et al., (1988) and Bunker and Witzke (1989, 1992).

MIDDLE DEVONIAN WAPSIPINICON GROUP

Pinicon Ridge Formation

Davenport Member

The Wapsipinicon Group, originally named after exposures along the Wapsipinicon River in Linn County, encompasses four formations. Only the uppermost part of the Wapsipinicon Group, the Davenport Member of the Pinicon Ridge Formation, is exposed in the Coralville Lake area (see Fig. 3). The best exposures are found on the east shore of Coralville Lake south of Twin View Heights and north of the Lake MacBride spillway (NW NW sec. 29, T81N, R6W), but their accessibility is dependent on lake levels.

The full thickness of the Davenport Member is not exposed around Coralville Lake, but nearby quarries and well penetrations indicate that the member averages about 7.5 m (25 ft) thick. Davenport strata are distinctive, consisting of prominently brecciated limestone. The limestone breccias contain abundant angular broken clasts of limestone, laminated in part, in a matrix of dense unfossiliferous limestone. These clasts vary in size (commonly 1-10 cm), but larger blocks of partially-broken laminated limestone (to 1 m) are locally entrained within the breccia. Smaller clasts (mm-size) also occur. In general, the breccias are essentially highly broken chunks of limestone cemented together. The member also contains fractures and pods filled with sandy and silty limestone, and some clasts of fossiliferous Solon Member lithologies are locally incorporated. Thin sandstone is locally present at the top of the member and locally infills fractures below. The contact between the Davenport and Solon members is abrupt, and the surface separating them is irregular. Up to 2 to 3 m of local relief is seen along the upper Davenport surface in the lake-shore exposures. Basal Solon strata lap this surface.

Limestone breccias of the Davenport Member are widely exposed across eastern Iowa, from the Quad Cities area to the Minnesota border. Evaporites beds (gypsum, anhydrite) occur with inbrecciated limestone and and dolomite strata in the Davenport Member in the subsurface to the south and west. The Davenport breccias in the outcrop belt are generally interpreted to have formed by evaporite-solution collapse processes, which were operating, at least in part, during marine deposition of the overlying Little Cedar Formation. As the soluble evaporite beds were dissolved, the volume of rock was reduced, and the intervening limestone beds became broken and jumbled as the interval collapsed.

Deposition of Wapsipinicon Group strata during the Middle Devonian (late Eifelian-mid Givetian) occurred largely in shallow-water environments inhospitable to marine life. Restricted water circulation led to hypersalinity and, at times, to the deposition of evaporite salts. The shallow restricted sea withdrew from eastern Iowa at the close of Davenport deposition.

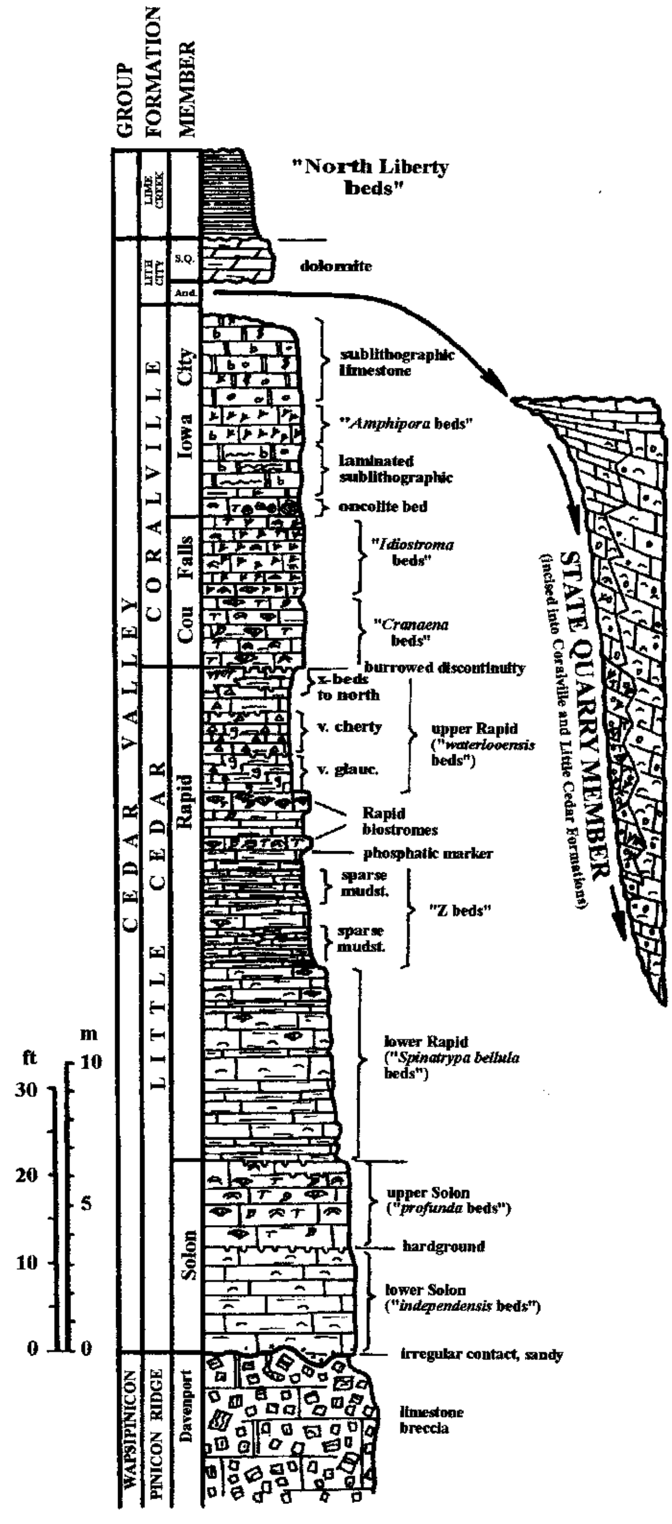


Figure 3. Composite section of the Devonian strata of the Coralville Lake area. See inside back cover for Key to symbols.

CEDAR VALLEY GROUP

Most Devonian limestone strata exposed in the Coralville Lake area belong to the Cedar Valley Group. The Cedar Valley Group in eastern Iowa was deposited in a series of broad, generally shallowing-upward cycles of marine deposition, each terminated by mudflat facies and subaerial exposure in northern and central Iowa. These large-scale cycles define the contained formations within the group, which are bounded by subaerial erosional unconformities in northern and central Iowa and by submarine discontinuity surfaces in southeastern Iowa. The Cedar Valley Group encompasses strata of late Middle and early Late Devonian age (late Givetian-early Frasnian). These strata were first termed the "limestones of Cedar Valley" in 1852, named after Devonian limestone exposures in the valley of the Cedar River. As presently recognized, the primary reference area for Cedar Valley strata, and the area of greatest study, lies in Johnson County, Iowa, especially the region around Coralville Lake and Iowa City.

Little Cedar Formation

Witzke, Bunker, and Rogers (1988) first defined the Little Cedar Formation, which in the Coralville Lake area includes strata of the Solon and Rapid members. Prior to this time, Solon, Rapid, and Coralville strata were all included under the term "Cedar Valley Formation." Regional study across Iowa clearly indicated that the Rapid Member (and its northern equivalents) and the Coralville "Member" (as previously used) are separated by a widespread discontinuity surface in eastern Iowa and a correlative erosional unconformity surface in northern Iowa. This surface serves as a convenient and important boundary that separates two large-scale cycles of regional deposition. After much deliberation, the present authors (Witzke and Bunker) concluded that these relations are best considered to reflect a formational level of stratigraphic organization for the combined Solon and Rapid members. The Little Cedar Formation derives its name from exposures along the Little Cedar River in northern Iowa (Witzke et al.,

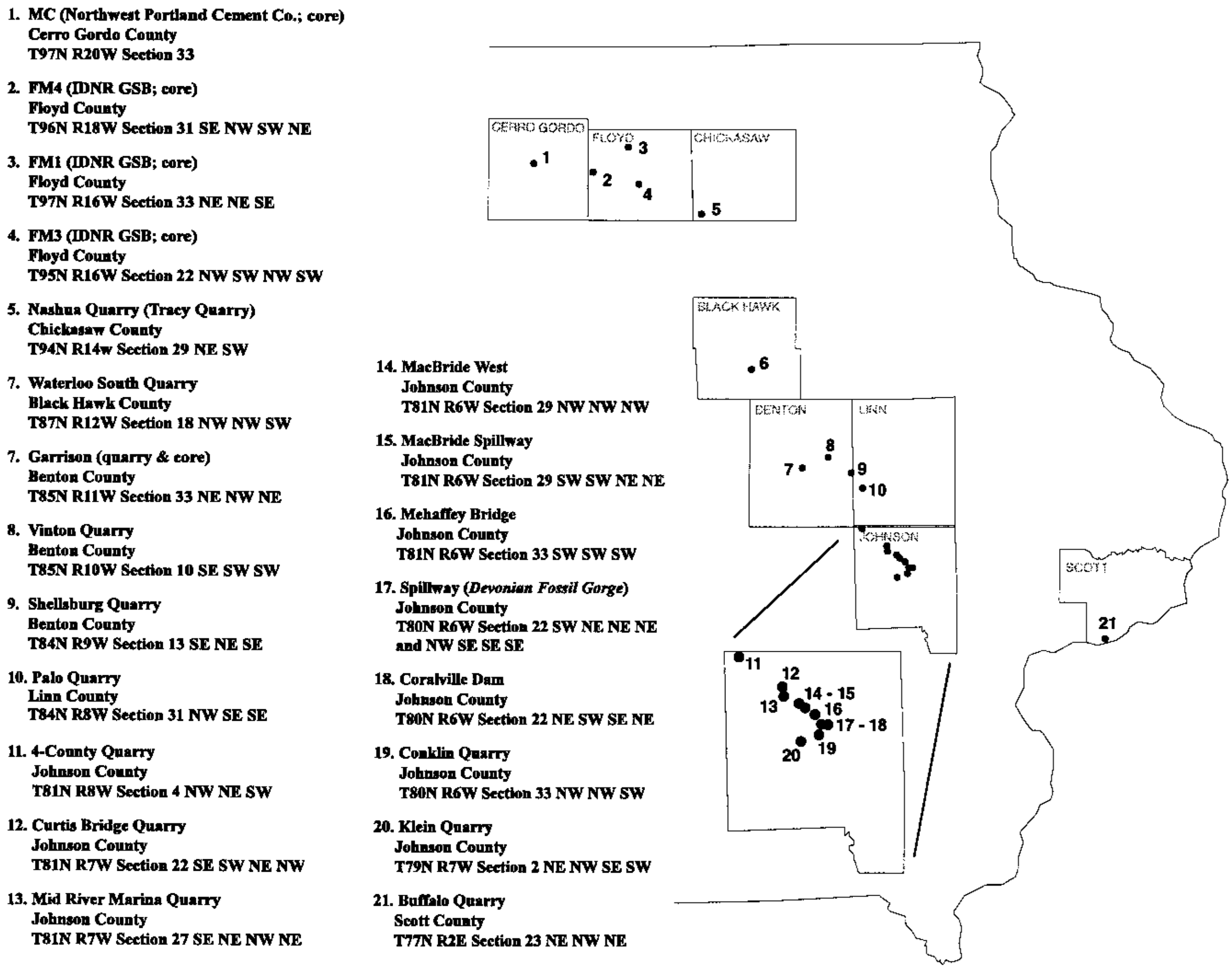


Figure 4. Map of localities across eastern Iowa used in cross-sections and illustrations within this report.

1988). The name also reflects the fact that the formation represents a smaller ("little") part of the larger Cedar Valley Group.

The Little Cedar Formation averages about 24 m (78 ft) in thickness in the Coralville Lake area. The constituent Solon and Rapid members thin to the east (Quad Cities area, Scott County), but the formation thickens northward and changes its lithologic character (Figs. 4, 5). Northward from Benton County, additional member names within the formation were introduced by Witzke et al. (1988), primarily because Solon and Rapid lithologies are not recognized in that area. Instead, dolomite-dominated lithologies characterize the formation in that area, including a thick lower fossiliferous dolomite unit (Bassett Member), an upper cherty dolomite interval (Eagle Center Member), locally an upper dolomitic shale unit (Chickasaw Shale), and an uppermost unit of laminated to brecciated dolomite and sublithographic limestone (Hinkle Member) (see Fig. 5). Hinkle strata were primarily deposited in mudflat environments, and the member contains evaporites in central Iowa. The transition between typical southeastern facies of the Little Cedar Formation (Solon and Rapid members) and typical northern facies

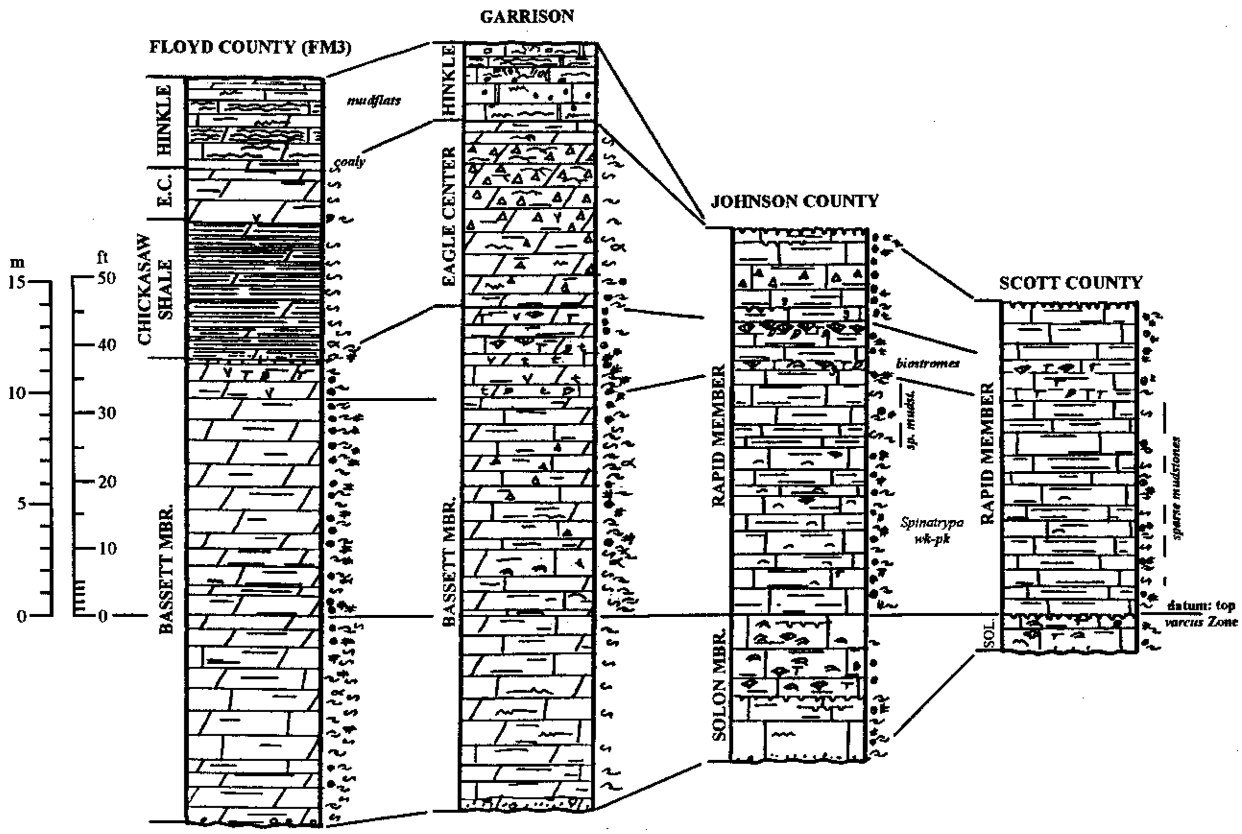


Figure 5. Cross-section of the Little Cedar Formation, northern and eastern Iowa. See Figure 4 for locality register, inside back cover for Key to symbols.

(Bassett-Hinkle members) occurs in the Benton County area northwest from the Coralville Lake area.

Solon Member

The Solon Member was originally named by Keyes (1912) for exposures at Solon, Johnson County, a short distance east of the present-day Coralville Lake area. Solon strata are well exposed along the lakeshore in the general region of the Lake MacBride spillway and in the northern area of the lake. Uppermost Solon strata can also be seen during low water at river level downstream from the Coralville Dam. The Solon Member averages about 6.5 m (21 ft) in thickness in the Coralville Lake area, but infilling of relief on the basal surface makes its thickness variable.

The Solon Member in the area is characterized by fossiliferous limestone beds. The Solon dramatically thins eastward towards the Quad Cities, and is replaced northward from Benton County by fossiliferous dolomite facies of the lower Bassett Member (Fig. 6). Solon strata are commonly sandy at the base, locally incorporating reworked limestone clasts derived from the underlying Davenport

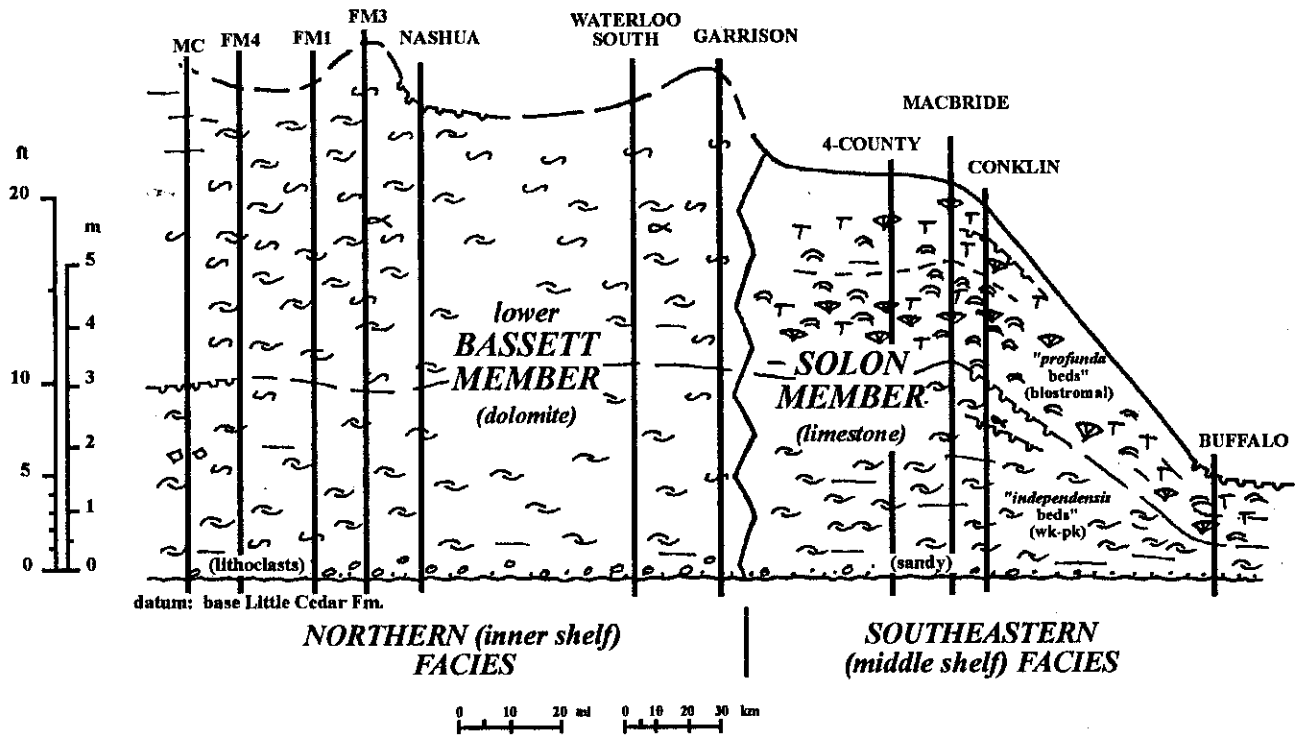


Figure 6. Cross-section of the Solon Member, Little Cedar Formation. See Figure 4 for locality register, inside back cover for Key to symbols. (abbreviations as noted for Stop 1).

Member. Lower Solon beds are commonly disrupted or partially brecciated, probably related to penecontemporaneous solution-collapse in the underlying Davenport Member.

The Solon Member was subdivided into two intervals by Stainbrook (1941a), named after characteristic fossils. The lower half or so of the member has been termed the "*independensis* beds" (Fig. 7), after the common atrypid brachiopod *Independatrypa independensis*. This interval includes medium to thick beds of fossiliferous limestone, slightly argillaceous in part; some beds are separated by thin argillaceous partings. The limestones are primarily brachiopod-rich fine packstones (with abraded grains) and crinoidal or brachiopodal wackestones and packstones. The interval contains a relatively diverse marine invertebrate fauna of brachiopods, bryozoans, crinoid debris, and scattered trilobites, but colonial corals are rare to absent. The upper part of the *independensis* interval locally contains one or more irregular hardground surfaces (lithified submarine surfaces), and a geographically persistent hardground surface typically marks the top of the interval (and an abrupt change in lithology). This surface locally displays sculpted relief of up to 15 cm.

The upper half or so of the Solon Member was termed the "*profunda* beds" by Stainbrook (1941a), after the common coral *Hexagonaria profunda*. In contrast with the lower interval, the "*profunda* beds" are characterized by coral- and stromatoporoid-rich fine packstones, biostromal in

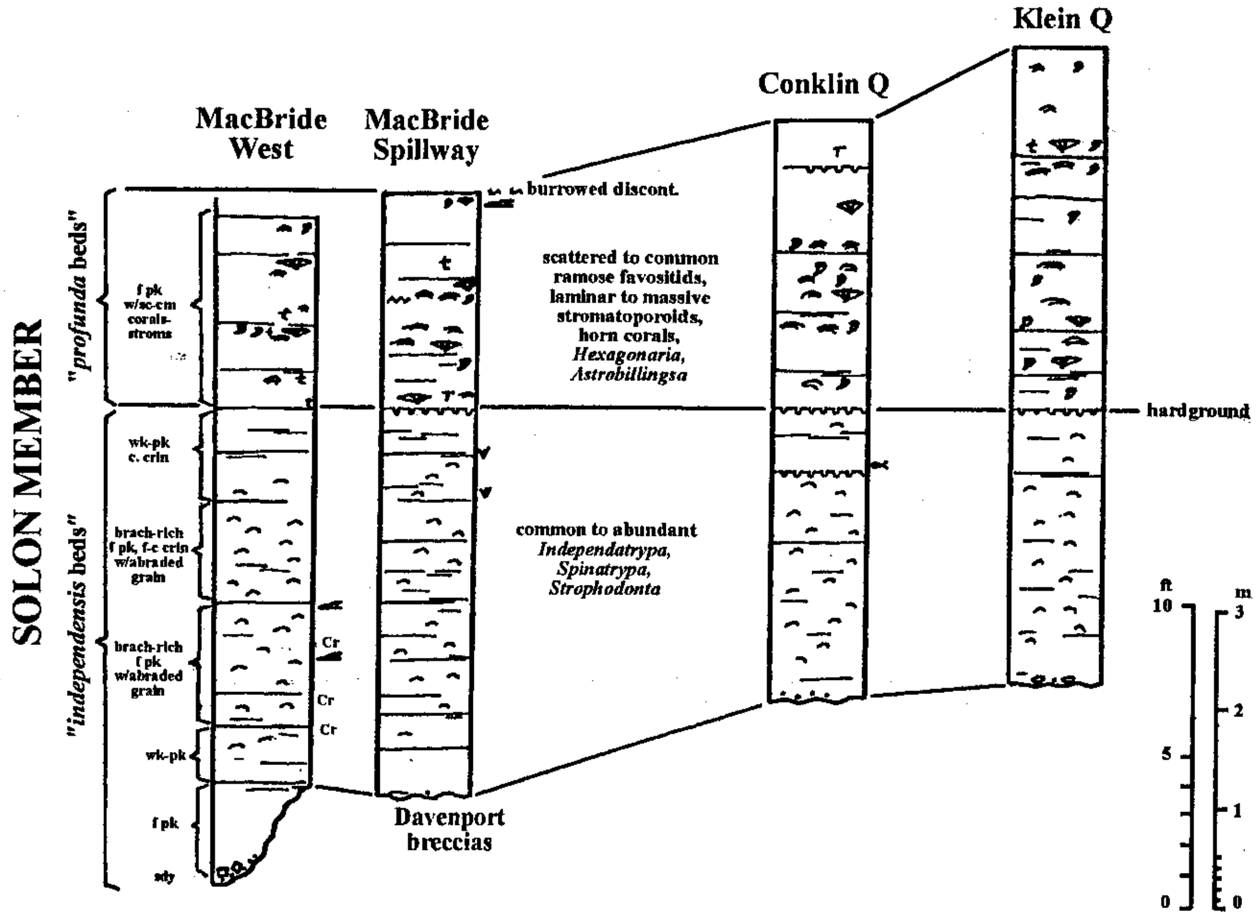


Figure 7. Cross-section of the Solon Member, Little Cedar Formation, Johnson County, Iowa. Cr - *Cranaena*-rich accumulations. See Figure 4 for locality register, inside back cover for Key to symbols. (abbreviations as noted for Stop 1).

some beds (Fig. 7). Although brachiopods occur in this upper interval, they are considerably less common than in the lower "*independensis*" interval; small crinoid debris is recognized throughout. A variety of corals occur in the upper interval, including solitary and colonial rugosans (*Hexagonaria, Astrobillingsa*), tabulates (favositid, alveolitid, auloporid, pachyporid), as well as massive, tabular, and encrusting stromatoporoids. Nautiloids and sponges are scattered in the the "*profunda* beds," and the topmost one or two beds of the interval locally contain more common nautiloids at many localities around Coralville Lake. The upper contact with overlying Rapid strata is abrupt and marked by a prominent change to more argillaceous lithologies above. The upper surface is locally marked by a prominently burrowed discontinuity.

The Solon Member was deposited in shallow marine environments that flooded the area during the first transgression of the Cedar Valley Group. The abundance of abraded grains and packstone lithologies indicate strong bottom currents on at least an episodic basis. The hardground surface that separates the two intervals within the Solon probably marks a minor hiatus in deposition, possibly coincident with a fluctuation in relative sea level. The upper interval shows a significant decline in brachiopod and conodont abundance, but a notable increase in the coral and stromatoporoid fauna. These changes are interpreted to reflect a general upward shallowing of environments during Solon deposition.

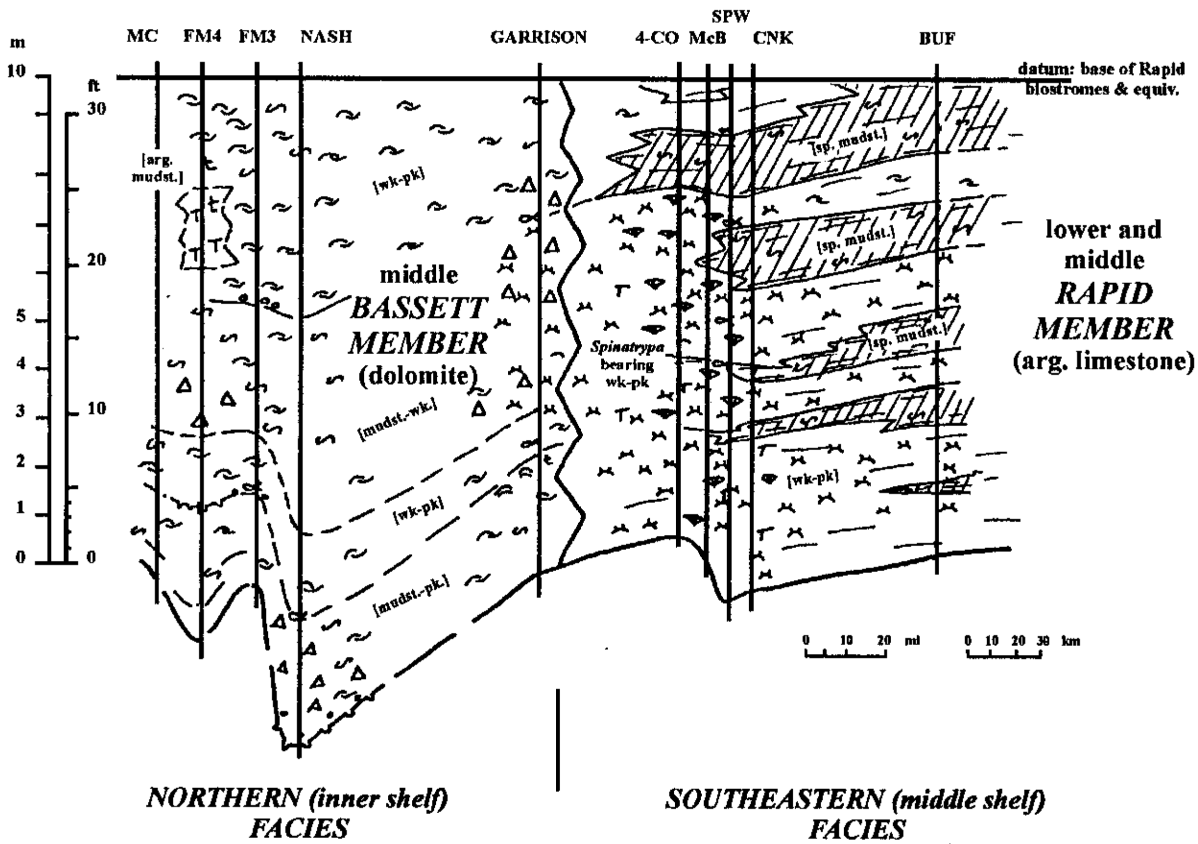


Figure 8. Cross-section of the middle part of the Little Cedar Formation, northern and eastern Iowa. NASH = Nashua; 4-CO = 4 County Quarry; McB = MacBride Spillway; SPW = Spillway; CNK = Conklin Quarry; BUF = Buffalo Quarry. See Figure 4 for locality register, inside back cover for Key to symbols. (abbreviations as noted for Stop 1).

Rapid Member

The Rapid Member was named by Keyes (1912), and the type locality for the member is located near the mouth of Rapid Creek a short distance below the Coralville Dam (Stainbrook, 1941a). The Rapid Member is dominantly an argillaceous (clay-rich) limestone, characterized by alternations of skeletal packstone and less skeletal mudstones and wackestones. Strata of the lower to middle Rapid Member incorporate progressively more intervals of sparsely fossiliferous argillaceous mudstones to the east towards the Quad Cities (Fig. 8). Northward from Benton County, these strata are replaced by less argillaceous fossiliferous dolomite facies, locally cherty to coralline (Fig. 8). Overall, however, lower to mid Rapid strata and their equivalent facies to the north maintain a similar thickness and form the most geographically homogeneous interval, both lithically and faunally, of the Cedar Valley Group.

A pair of coralline biostromes or coral-rich beds with common colonial rugosans occur above the middle part of the Rapid Member, and these persist over the extent of the member eastward to the Quad Cities (Fig. 9). The biostromes also persist northward into the Bassett Member, but the biostrome pair becomes less distinct and the fauna becomes dominated by stromatoporoids and tabulate corals in that direction (Fig. 9). Upper Rapid strata and

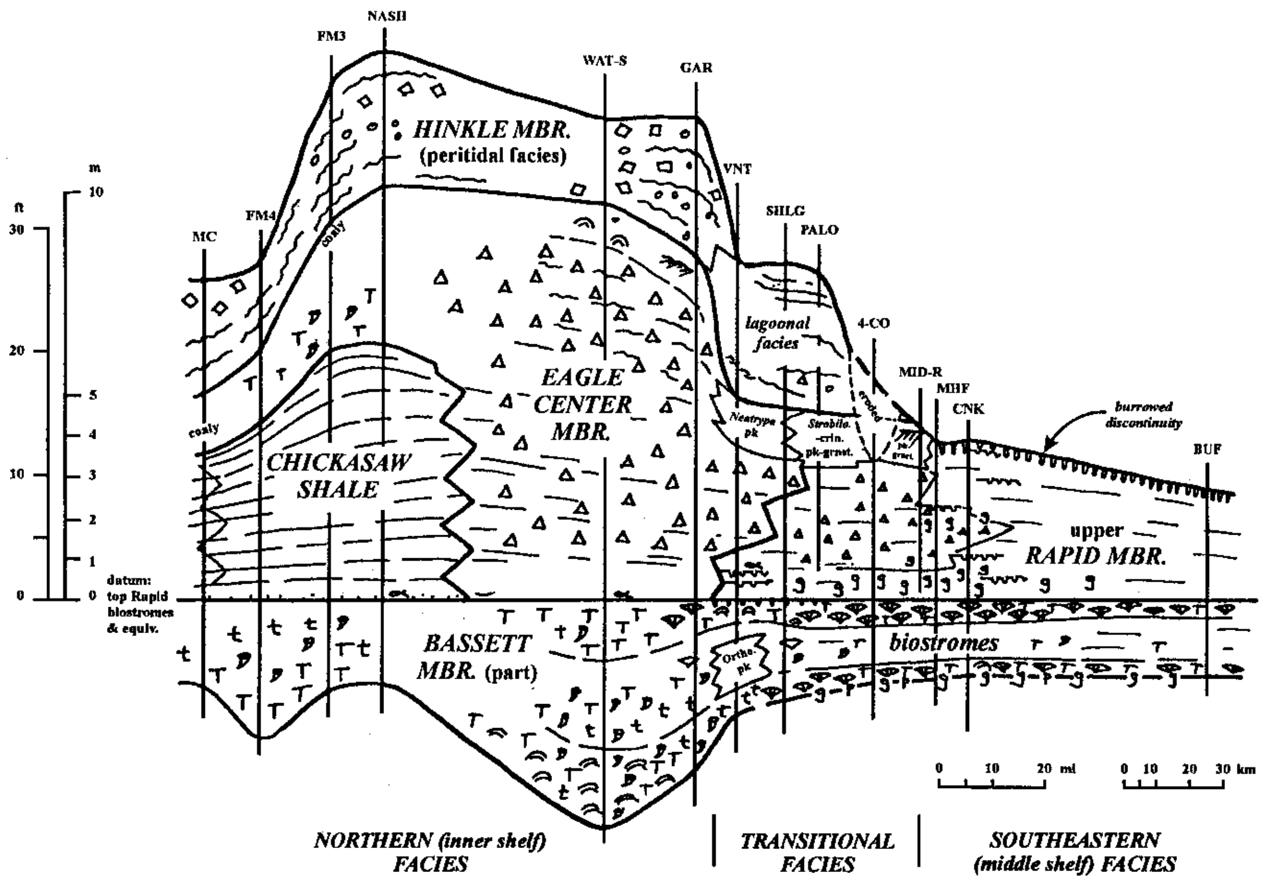


Figure 9. Cross-section of the upper part of the Little Cedar Formation, northern and eastern Iowa. NASH = Nashua; WAT-S = Waterloo South Quarry; GAR = Garrison; VNT = Vinton Quarry; SHLG = Shellsberg Quarry; 4-CO = 4-County Quarry; MID-R = Mid River Marina; MHF = Mehaffey Bridge; CNK = Conklin Quarry; BUF = Buffalo Quarry. See Figure 4 for locality register, inside back cover for Key to symbols. (abbreviations as noted for Stop 1).

their northward equivalents display significant geographic variations. Upper Rapid beds, which are cherty and glauconitic in the Coralville Lake area, thin eastward into non-cherty and slightly less skeletal lithologies in the Quad Cities area (Fig. 9). Equivalent strata thicken northward from Benton County into cherty dolomites of Eagle Center Member, dolomitic shales of the Chickasaw Shale, and are capped by lagoonal, peritidal, and mudflat facies of the Hinkle Member (Fig. 9). The top of the Rapid Member is marked at a prominent burrowed discontinuity surface across most of its extent, but a subaerial exposure surface is recognized at the same position to the north.

Rapid strata are exposed along much of the lakeshore of Coralville Lake and are particularly well displayed at the Devonian Fossil Gorge. Rapid strata are largely covered by water in the southern region of Coralville Lake. The member averages about 16 m (53 ft) in thickness in the area.

Lower Rapid Strata. The lower part of the Rapid Member in the area was termed the "*bellula* beds" by Stainbrook (1941a), named after the spiny atrypid brachiopod *Spinatrypa bellula* which is common through much of the interval (Fig. 3). The lower part of the *bellula* interval is dominated by argillaceous wackestone with some packstone beds, and sponge fossils are commonly seen near its base in the Coralville Lake area. The bulk of the *bellula*

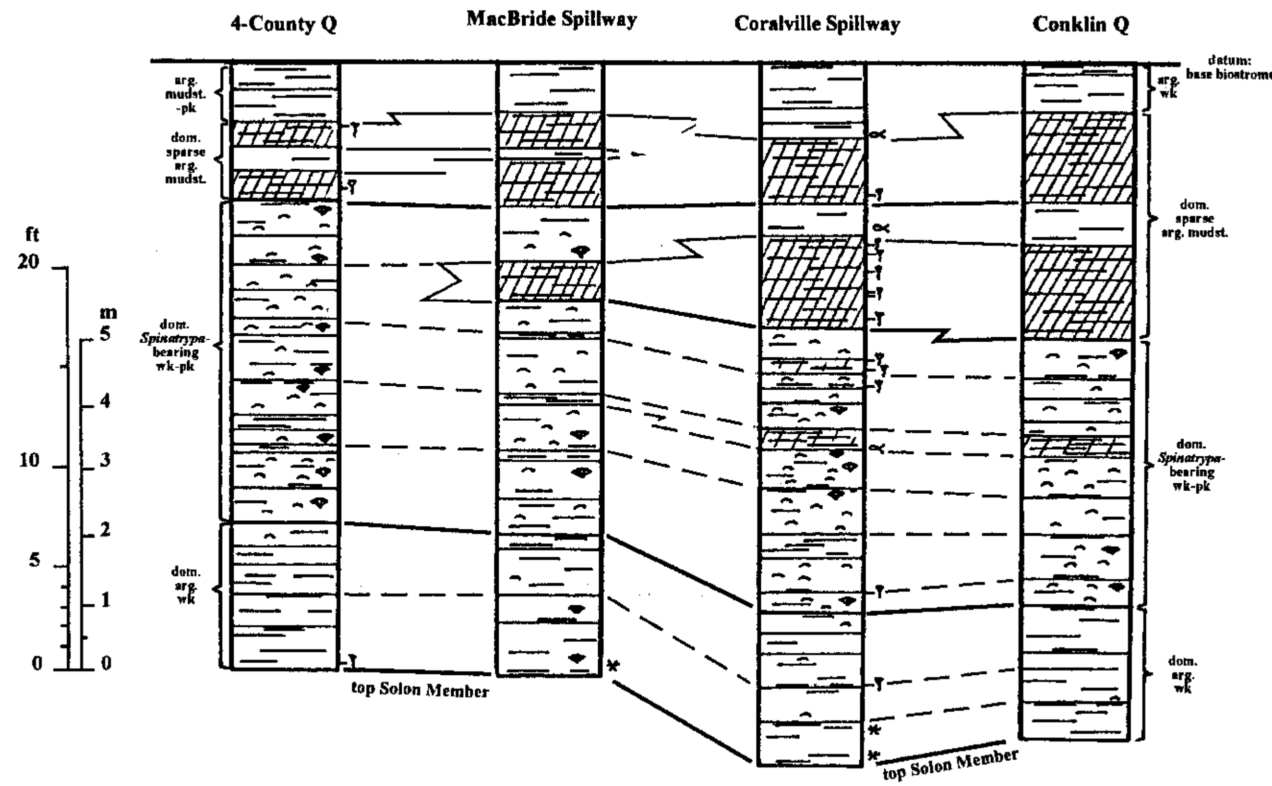


Figure 10. Cross-section of the lower and middle Rapid Member, Little Cedar Formation, Johnson County, Iowa.. See Figure 4 for locality register, inside back cover for Key to symbols. (abbreviations as noted for Stop 1).

interval is marked by repetitive couplets of brachiopod-rich packstones and thinner more argillaceous wackestones and mudstones. The packstone units show lateral variations in thickness, and many beds contain scattered corals especially in their upper parts.

The packstone and wackestone units of the "*bellula* beds" contain an abundant and diverse marine fauna, among the richest found in the Cedar Valley Group. Brachiopods, crinoid debris, and bryozoans are particularly common, and trilobites become moderately common in the upper part. Articulated crinoids are found in some of the more argillaceous units, especially in the lower and upper parts of the interval. These strata average about 6 m (20 ft) in thickness in the area (Fig. 10).

Middle Rapid Strata ("Z-beds"). The middle part of the Rapid Member above the *bellula* interval in the Coralville Lake area includes two very distinctive lithologic intervals: 1) a lower interval dominated by sparse skeletal burrowed argillaceous mudstones, and 2) an upper interval of crinoidal packstones and coral-rich biostromes. These strata in the middle Rapid were termed the "*Pentamerella* beds" by Stainbrook (1941a), but this term is not particularly appropriate. The brachiopod *Pentamerella* does occur in the uppermost mudstones and in the biostromal interval, but it is not common; in fact, we have found *Pentamerella* to more common in the underlying "*bellula* beds." In addition, we have failed to find any *Pentamerella* through most of the mudstone interval above the "*bellula* beds" in the Coralville Lake area, indicating its general scarcity (or even absence) through much of the so-called "*Pentamerella* beds" interval. Because a prominent lithologic and faunal break separates these strata, we prefer to label the two intervals independently. The lower mudstone-dominated interval is here informally termed the "Z-beds" in honor of Zawistowski's (1971) recognition of these strata. The upper part is simply termed the Rapid biostrome interval.

Zawistowski (1971) recognized the lithologic uniqueness of the argillaceous mudstone-dominated interval in the middle Rapid of the area, and he informally termed this the "key bed." However, more than one bed occurs, and these interfinger with thin skeletal wackestones to packstones in the area. The mudstone-dominated interval is further split in the middle part by a persistent skeletal wackestone to packstone bed in the Coralville Lake area, and it is capped by a more brachiopod-rich skeletal limestone (Fig. 10). We will simply label the interval of mudstones and associated skeletal limestone beds the "Z-beds"; these beds are bounded below by the interval of *Spinatrypa*-bearing packstones and above by the Rapid biostromes. The sparse argillaceous mudstones (limestones) of the "Z-beds" are a distinctive burrowed lithology, characterized by a general paucity of skeletal material. However, thin horizons within these mudstones display beautifully-preserved invertebrate fossils, including brachiopods, bryozoans, and moderately common articulated crinoids. Small chonetid brachiopods are locally common within this interval. Certain rare fossils are also identified, including conularids and phyllocarid crustaceans.

The "Z-beds" are replaced northward by *Spinatrypa*-bearing limestones and dolomites (Fig. 8), and a few *Spinatrypa* specimens are known from the lower interval in the Coralville Lake area. The "Z-beds" persist eastward to the Quad Cities area (Fig. 8). The "Z-beds" average about 4 m (14 ft) in thickness in the Coralville Lake area, and the cumulative thickness of mudstone beds generally decreases northward within the lake area (Fig. 10).

Middle Rapid Strata (Rapid biostromes). The Rapid biostrome interval contains a pair of remarkably persistent and distinctive coral-rich units. The corals are partially silicified at many localities around Coralville Lake. The two biostromal units are separated by intervening strata of crinoidal packstones with common to abundant pachyporid and horn corals, brachiopods, and bryozoans. The entire interval averages about 2 m (7 ft) in thickness. The lower biostrome includes a thin argillaceous unit at its base, with a sharp basal contact; this is enriched in sand-sized glauconite and phosphate particles. This forms a "phosphatic marker horizon" in the area (Fig. 11). The lower biostrome itself contains an abundance of tabulate and rugose corals, some of which are overturned. Stromatoporoids, dominantly encrusting forms, are notably more common than in the upper biostrome. The matrix is primarily a fine to coarse skeletal packstone, with scattered brachiopods, bryozoans, and crinoid debris.

The upper biostrome grades upward from underlying strata, showing a general upward increase in coral abundance. The upper part of the biostrome is characterized by dense concentrations of *Hexagonaria* throughout the Coralville Lake area, and at some localities the upper surface shows irregularly mounded relief due to concentrations of large *Hexagonaria* colonies. Additional corals and rare stromatoporoids are noted, but overall the upper biostrome is dominated by *Hexagonaria*, some overturned. The matrix is primarily an argillaceous wackestone to packstone, locally with concentrations of crinoid material or brachiopods between the densely packed corals.

Upper Rapid Strata. Stainbrook (1941a) termed the upper Rapid interval above the biostromes the "*waterlooensis* beds," named after the large atrypid brachiopod *Neatrypa waterlooensis*. This label may not be particularly appropriate, and this species is not ubiquitous throughout these strata, and the species ranges upward into lower Coralville strata. We will simply label strata above the biostromes as the upper Rapid interval. The base of the upper Rapid interval sharply overlies the underlying Rapid biostrome, and these basal strata infill and lap the irregular upper surface of biostrome. Upper Rapid limestone strata are partially dolomitized at some localities around Coralville Lake. Upper Rapid strata average about 3.7 m (12 ft) thick in the central and southern areas of Coralville Lake, but the interval increases to about 4.8 m (16

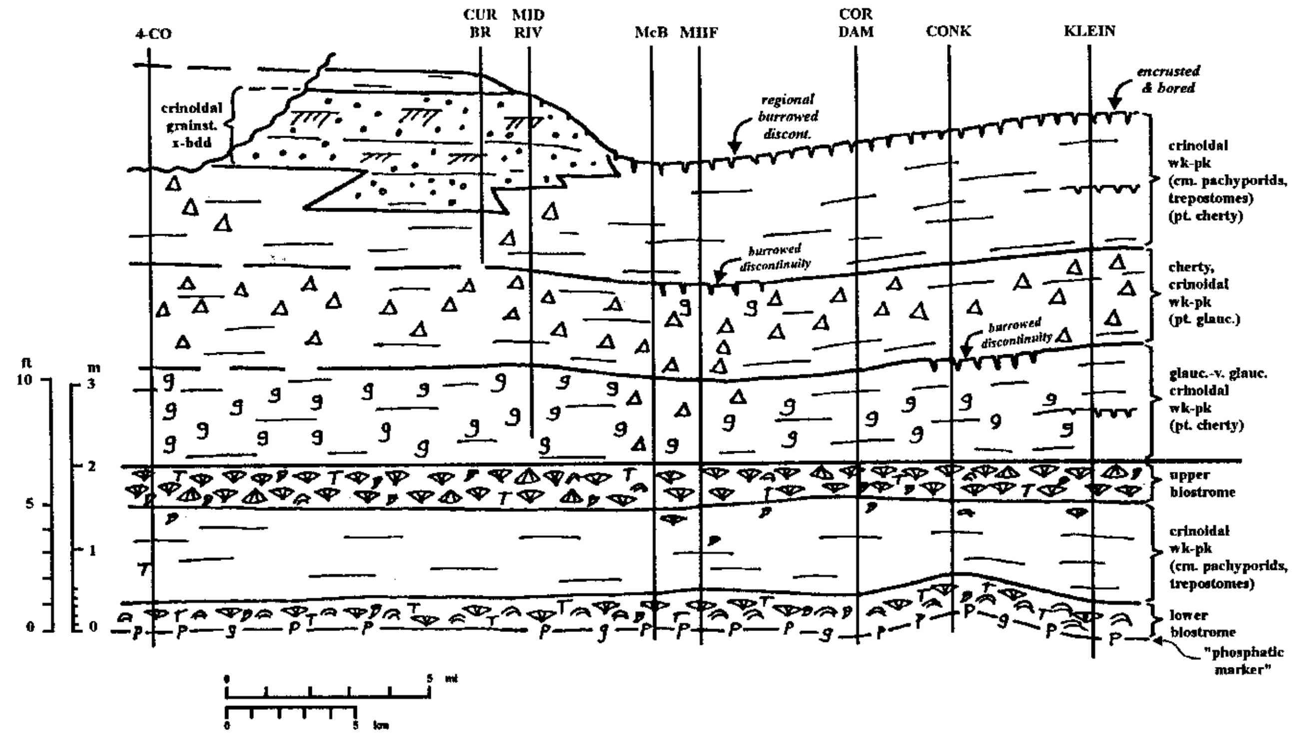


Figure 11. Cross-section of the upper Rapid Member, Little Cedar Formation, Johnson County, Iowa. 4-CO =4-County Quarry; CUR BR = Curtis Bridge; MID RIV = Mid River Marina; McB = MacBride Spillway; MHF = Mehaffey Bridge; COR DAM = Coralville Dam; CONK = Conklin Quarry. See Figure 4 for locality register, inside back cover for Key to symbols. (abbreviations as noted for Stop 1).

ft) in the Curtis Bridge area in the northwestern part of Coralville Lake.

The upper Rapid interval in the area can be generally subdivided into three units of subequal thickness (Fig. 11). These units are locally marked at their top by hardground surfaces or burrowed discontinuities. The lowest unit is notably glauconitic, and glauconite grains impart a greenish cast to the beds at some localities. It is dominantly a crinoidal wackestone to packstone, and it becomes cherty northward within the Coralville Lake area. The middle unit is of similar lithology, but it is generally less glauconitic and notably more cherty. The upper unit commonly lacks chert except to the northwest, and its upper portion includes noteworthy beds of crinoidal grainstone and packstone, crossbedded in part, in the area of Curtis Bridge and Mid-River Marina (see Plocher, 1989) and locally in the Sugar Bottom area. These grainstones contain rhombiferan cystoid plates, similar to equivalent units in Benton County.

The upper Rapid interval contains an abundant and diverse invertebrate fauna of brachiopods, crinoids, bryozoans, pachyporid corals, and other fossils. Exceptional accumulations of articulated crinoids (especially *Melocrinites nodosus*) and echinoids have been recovered from these strata in the Coralville Lake area. The top of the Rapid Member is marked by a prominent and persistent burrowed discontinuity surface. This irregular surface, commonly with burrow penetrations extending downward 10 to 15 cm, is infilled with limestone of the overlying Coralville Formation. The upper discontinuity surface becomes less distinct above the crossbedded grainstone beds.

Deposition of the Little Cedar Formation

The Little Cedar Formation records a general cycle of marine transgression and regression (seaway deepening and shallowing), as interpreted by Witzke et al. (1988). The seaway initially encroached across the subaerial exposure surface at the top of the Davenport Member, burying this surface with marine deposits of the basal Solon Member. A prominent shallowing event is recorded at the top of the Rapid Member, which in northern and central Iowa culminated in the progradation of mudflat environments and subaerial exposure. In the northern area of Coralville Lake, this shallowing event is marked by cross-bedded grainstone deposits,.which formed in shallowing shoal-water environments. These grainstones were then subjected to subaerial exposure and freshwater influx as the sea withdrew to the southeast (see Plocher, 1989). Southeastward of the area, shoal-water environments are not identified in the upper Rapid, and shallow-marine environments may have persisted across southeastern Iowa at the end of Little Cedar deposition.

Although the Little Cedar sequence forms a general transgressive-regressive cycle of deposition, this cycle does not simply represent a symmetric deepening and shallowing of the sea. Smaller-scale fluctuations of relative water depth are also interpreted for the deposition of the Little Cedar Formation, as graphically shown on Figure 12. Minor deepening events are interpreted at the position of condensed units (enriched in phosphatic and glauconitic material) or starved surfaces (hardgrounds, discontinuities).

However, interpretations of the magnitudes of changes in relative water depth during the deposition of the Little Cedar Formation have been both difficult and controversial. Which units were deposited in the deepest water environments? Which in the shallowest environments? Varying interpretations have been put forward, and one version is presented here. There is, of course, no direct way to evaluate absolute water depths in ancient seas, but indirect sedimentologic and paleontologic evidence may be of use. The deepest environments in the Little Cedar Formation were at or near the limits of storm wave activity, possibly near the upper limits of the pycnocline in a stratified sea. These environments were inhabited by trilobites that possessed eyes, suggesting that light was capable of penetrating to the bottom. Based on the limits of storm currents and light penetration in the modern seas, it seems likely that water depths never exceeded more than about 30 to 60 m (100-200 ft) (see discussion by Brett et al., 1993). Water depth would have been considerably less for much of Little Cedar deposition. Nevertheless, water depths were sufficient to maintain an effective thermohaline circulation and normal-marine salinities throughout its deposition.

The Solon Member is interpreted to record a general deepening and shallowing of the sea. The upward loss of benthic faunal diversity and a dramatic decline in conodont abundance is consistent with environmental stress associated with shallowing. The upward shift from diverse brachiopod-crinoid-bryozoan faunas into stromatoporoid and coral communities has been associated with depositional shallowing in other Devonian settings in North America and Europe. Upper Solon strata also show significant local and regional facies variations, a trend most commonly associated with relatively shallow environments (deeper environments show more geographic homogeneity). In addition, strata temporally equivalent to the Solon Member in northern Missouri are known to shallow upward into mudflat facies (Woodruff, 1990).

Basal Rapid strata abruptly overlie the Solon, and this significant change in sedimentation is interpreted to reflect overall depositional deepening. The shift from abraded grain packstones to more mud-rich wackstones is certainly consistent with a decrease in bottom agitation associated with deepening. The return to diverse brachiopod-rich benthic associations (and loss of stromatoporoid-rich associations) and a dramatic increase in conodont abundance are consistent with overall depositional deepening. Rapid strata and their equivalents in Missouri and western Illinois are known to onlap and overstep older Devonian units, which is highly suggestive of regional seaway deepening and geographic expansion. In addition, strata equiva-

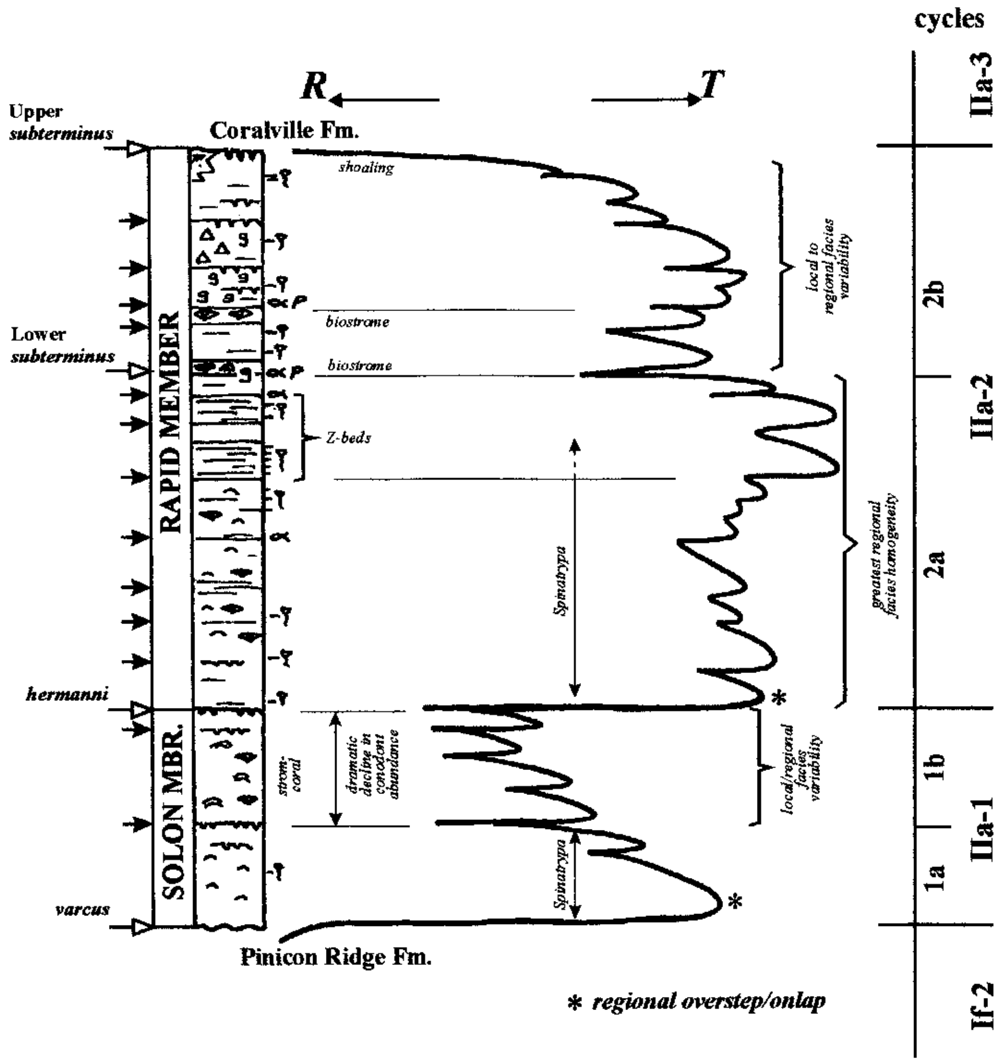


Figure 12. Interpreted sea-level curve for the Little Cedar Formation. Solid arrows show position of condensed units (phosphatic, glauconitic) and starved surfaces (hardgrounds, discontinuities), which are interpreted to mark minor deepening events. Open arrows mark the position of regionally significant transgressive surfaces or condensed units, which also correspond to the base of conodont zones as noted. R = regression, T = transgression. Numbered cycles modified from Johnson et al., 1985.

lent to the basal Rapid (lower *hermanni* conodont Zone) in the Appalachian Basin also record significant depositional deepening, marking a shift from skeletal limestone deposition below and deeper-water anoxic black shale deposition above.

Packstone and wackestone lithologies in the lower Rapid generally contain proportionately less abraded grain material than seen in the lower Solon, and the lower Rapid is interpreted to have been deposited in generally less agitated environments. Packstone beds in the lower Rapid show large-scale bedforms interpreted to reflect amalgamated sedimentation near average storm wave base (see Stop 1 discussion). These units interbed with quieter-water mudstones and wackestones.

The deepest relative water depths during deposition of the Little Cedar Formation are interpreted for the "Z-beds." The dominance of mud-rich lithologies suggests a general absence of current winnowing in relatively quiet-water environments. The paucity of normal shelly benthos from these mud-rich intervals is interpreted to reflect benthic oxygen stress associated with a stratified water colum, with increasing bottom oxygenation in a northwestward (landward) direction. The preservation of exceptional articulated crinoids at multiple horizons within the mudstones would not be expected in shallow-water settings, where normal wave current or storm current activity would readily disarticulate the crinoid remains. Such exceptional preservation in other areas has been attributed to distal mud influx from gradient currents triggered by episodic storms at depths at or below storm wave base. By contrast, articulated crinoid accumulations are absent in the more abraded Solon lithologies.

An additional line of evidence suggests that the Rapid mudstones represent deeper-water facies than the skeletal packstone units. Sparse mudstones increase in thickness and abundance in an offshore direction (east and south), and are replaced by packstones in an onshore (north and west) direction (Fig. 8). If the mudstones represent shallowing deposits, the opposite relationship should be displayed. Minor shallowing is indicated in the upper "Z-beds" with the return of skeletal wackestone-packstone deposition and a diverse brachiopod-rich fauna.

The phosphatic and glauconitic marker bed at the base of the Rapid biostrome interval is interpreted to represent a condensed unit associated with renewed marine transgression. The widespread nature of the biostrome horizons are suggestive of broadly uniform conditions, possibly associated with transgressive episodes. Upper Rapid strata are interpreted to record several small-scale cycles of deepening and shallowing, marked by a starved transgressive surface at their base (discontinuity surface). Glauconitic enrichment in the lower beds is suggestive of overall slow sedimentation associated with transgressive sedimentation. Storm current activity is evident by numerous packstone units and lenses within the upper Rapid, some preserving articulated crinoid accumulations. The upper Rapid sequence, as noted above, shallows upward to shoal-water facies, with regional subaerial exposure to the north. This shallowing phase terminates the broad-scale Little Cedar cycle of deposition.

Coralville Formation

Keyes (1912) first proposed the Coralville as a stratigraphic unit within the Cedar Valley Limestone. Stainbrook (1941a) designated the type section at the Conklin Quarry in Coralville a short distance downstream from the Coralville Dam. Although Stainbrook recognized the Coralville as a member, Witzke et al. (1988) elevated the Coralville to formation status containing two lithologically distinct members, the Cou Falls and Iowa City (Fig. 3). Of note, Keyes (1912) also recognized two stratigraphic units within the interval that Stainbrook (1941a) subsequently identified as the Coralville Member, and the present usage acknowledges Keyes' two-part stratigraphic subdivision of this interval, albeit under different names.

The Coralville Formation is well exposed throughout much of the Coralville Lake area, but it is absent in the area of Lake MacBride-Twin View Heights and portions of the northern lake area. The formation forms the highest bedrock in much of the area, except in the area of State Quarry exposure. The most complete Coralville sections in the area reach thicknesses to about 14 m (45 ft), but it is thinner at most localities owing to sub-State Quarry and sub-Quaternary erosion. A general summary of Coralville stratigraphy in the Coralville Lake area is given by Bunker and Witzke (1989). It is certainly appropriate that strata of the *Coralville* Formation are so well exposed along the shores of *Coralville* Lake.

Cou Falls Member

The Cou Falls Member was formally named by Witzke, Bunker, and Rogers (1988), with its designated type locality located adjacent to Coralville Lake at the abandoned Mid River Marina Quarry, southeast of the village of Cou Falls. The member is characterized by fine abraded grain packstones with common to abundant corals and stromatoporoids through much of the sequence, biostromal in part. The member is replaced northward in Benton County by fossiliferous dolomites of the Gizzard Creek Member. Stainbrook (1941a) and Kettenbrink (1973) subdivided the Cou Falls interval into two units: 1) a lower "*Cranaena* zone," named after a common brachiopod; and 2) the upper "*Idiostroma* beds," named after the abundant branching stromatoporoids that characterizes much of the unit. These subdivisions are partly artificial, as *Cranaena* ranges through the entire Cou Fallls interval, and *Idiostroma*-bearing lithologies are gradational or interbedded in the middle part of the member at many localities. The Cou Falls Member averages about 6 m (20 ft) in thickness in the Coralville Lake area.

The "*Cranaena* zone" contains scattered thin shaly and dark carbonaceous partings. and the interval sharply overlies the burrowed discontinuity surface at the top of the Rapid Member. The unit contains an abundant marine fauna typified by colonial (*Hexagonaria*) and solitary rugosans, favositids, and massive stromatoporoids. Brachiopods are abundant in some beds (see Day, 1992). Crinoid debris, common rostroconchs, rare bryozoans, moderately common trilobite material, and other fossils are also noted.

The "*Idiostroma* beds" contain an abundance of branching stromatoporoids, mostly fragmented, as well as massive stromatoporoids, favositids, rugosans (solitary and *Hexagonaria*, especially in the lower part). Crinoid debris decreases in abundance upward, and brachiopod diversity also decreases upward. Rostroconchs, gastropods, and a few other fossils also occur. The upward faunal change probably reflects a transition from normal-marine to more euryhaline environments. The relative abundance of *Idiostroma* varies between localities, and branching stromatoporoids do not occur through the entire interval at all localities. The upper contact with the Iowa City Member can generally be drawn at the position of the lowest sublithographic limestone bed or oncolitic interval, or above the highest *Idiostroma*. At some localities the boundary separating the two members is more gradational, and upper *Idiostroma*-bearing strata may have a matrix that is sublithographic in part.

Iowa City Member

Witzke et al. (1988) named the Iowa City Member after exposures on the campus of the University of Iowa downstream from the Coralville Dam. This interval was previous named the Lucas Member by Keyes (1912), but this name was preoccupied as a stratigraphic term in Ohio. The member is characterized by a diverse array of lithologies, and complex lateral facies variations are displayed in the area. The following limestone lithologies are recognized: 1) pelleted mudstones, generally with dense "sublithographic" textures (breaks with glass-like fracture, resembles dense limestones once used in the preparation of lithographic plates), commonly faintly laminated with "birdseye" structures (small calcite-filled voids); 2) pelleted mudstones to packstones containing ramose favositid corals and/or branching stromatoporoids (primarily *Amphipora*); 3) intraclastic and brecciated lithologies; 4) mudstones and packstones with abundant gastropods and oncolites (rounded clasts with concentrically-laminated stromatolitc coatings). Mudcracks and irregular internal sediment fills occur locally. The various lithologies are interpreted as peritidal, mudflat, and shallow restricted-marine facies. The Iowa City Member reaches maximum thicknesses to about 8 m (26 ft) in the area.

A "gastropod-oncolite bed" (Kettenbrink, 1973) is recognized in the lower Iowa City Member at many, but not all, localities in the area. The middle part of the member is generally characterized by abundant fragmented branching stromatoporoids (the "*Amphipora* beds" of Kettenbrink, 1973), but this unit contains only scattered stromatoporoids at some localities. *Amphipora* also occurs locally in the upper strata. Invertebrate fossils are generally rare in the Iowa City Member, especially in the "sublithographic" units, but stromatoporoids, favositids, and gastropods are common to abundant in some beds. Brachiopods (*Athyris*), ostracodes, rostroconchs, and calcareous algae are noted.

Multiple subaerial exposure surfaces, sometimes with minor erosional relief, are recognized within the Iowa City Member at various localities. These surfaces are primarily developed within the "sublithographic" units, but these are not laterally persistent throughout the Coralville Lake area. The Iowa City Member is well developed at localities north and west of Iowa City, and it includes evaporite facies in central Iowa. However, the member disappears only a few miles east and south of Iowa City in the subsurface, where the entire Coralville Formation is characterized by fossiliferous lithologies of the Cou Falls Member. These relations indicate that the Coralville Lake and Iowa City area lies very close to the margin of extensive mudflat and peritidal carbonate facies (Iowa City Member), which are replaced in an offshore direction (southeast) by more open-marine facies. The erosional surface beneath the State Quarry Member cuts across and truncates underlying strata of the Coralville Formation.

Deposition of Coralville Formation

Widespread marine transgression flooded the subaerial surface at the top of the Little Cedar Formation, coincident with starved sedimentation along the discontinuity surface developed in more offshore settings to the southeast. This marine transgression initiated deposition of the Cou Falls Member in the area. Depositional environments were relatively shallow, and active bottom currents abraded much of skeletal material into fine fragments. Normal-marine faunas inhabited the bottom environments, but an upward decline in faunal diversity, and the loss of some stenohaline groups (echinoderms, bryozoans, trilobites), suggests that bottom environments became progressively more stressed (probably salinity-related) as the environments shallowed. This upward-shallowing trend culminated in sedimentation of restricted nearshore and mudflat facies (Iowa City Member).

The complex facies of the Iowa City Member are interpreted to have been deposited in a mosaic of shallow restricted nearshore, in part intertidal, and mudflat environments. Periodic subaerial exposure of mudflat facies within the Iowa City Member is indicated by abundant desiccation features. These environments advanced southeastward across the area as the seaway withdrew from the region. However, mudflat facies did not prograde southeastward beyond the area of Iowa City, and the exposures in Johnson County represent the marginal region of mudflat deposition, with more open-marine deposition a short distance offshore.

The entire Coralville Formation is interpreted to form a general transgressive-regressive cycle of sedimentation. It generally shallows upward through the interval, although a minor transgressive pulse apparently flooded the mudflat environments during deposition of the "*Amphipora* beds." The final withdrawal of the sea from the area resulted in widespread subaerial exposure and erosion. Erosional incision proceeded to down-cut as base levels continued to drop during later stages of regional regression. This erosional phase cut deep erosional channels (to 25 m depth) in the Coralville Lake area, locally incising through Coralville and upper Rapid strata. These erosional valleys became the first sites for subsequent sedimentary infilling as marine environments once again transgressed the area during the next cycle of Devonian sedimentation (the State Quarry Member, Lithograph City Formation).

Lithograph City Formation

The Lithograph City Formation was named by Witzke et al. (1988) to include strata of the next major cycle of Devonian sedimentation within the Cedar Valley Group of Iowa. It derives its name from the former town of Lithograph City in northern Iowa, where high-quality lithographic engraving stone was quarried during World War I. The formation includes two members in the Coralville Lake area, the State Quarry and Andalusia members, but additional members are included in northern Iowa. The formation overlies a submarine discontinuity surface in southeast Iowa, but it overlies a subaerial exposure surface at all localities north and west of Iowa City. The formation spans the Middle-Upper Devonian boundary and encompasses several smaller-scale sedimentary cycles. Strata of the Lithograph City Formation in the Coralville Lake area are entirely of latest Middle Devonian age, but younger units are included within the formation at other localities in eastern Iowa.

State Quarry Member

The "State Quarry limestone" was named by Calvin (1897) for exposures in the area of the old State Quarry along the shores of present-day Coralville Lake. It was included as a member within the Lithograph City Formation by Witzke et al. (1988). The member is, as far as known, restricted entirely to Johnson County. Its best exposures are found in the area of Coralville Lake, stretching from the Mehaffey Bridge area southward to its eroded edge about 1 mile (1.6 km) south of the old State Quarry. The member overlies an unconformity surface and infills deeply eroded channels cut into underlying strata. The State Quarry Member variously overlies strata of the Iowa City, Cou Falls, or Rapid (lower to upper) members. It reaches thicknesses to about 15 m (50 ft) or slightly greater. The sub-State Quarry unconformity displays about 25 m (80 ft) of total relief in the area, and the total thickness of the member, if preserved, would probably approach or equal this value. Various workers have described the rocks and fossils of the member in this area, but the report by Watson (1974) contains the best descriptive information on the interval. Day (1992) updated and revised the abundant brachiopod fauna contained within the member.

The State Quarry Member displays a remarkable variety of limestone lithologies in a relatively small area, with various facies characterizing different regions of the channel-filling sequence. The thickest State Quarry sections are located in the central areas of the channel-filling sequence, where the member is dominated by skeletal and intraclastic packstones and grainstones, some displaying cross-bedding. Many of the grainstones contain abundant brachiopods, commonly disarticulated to abraded. Crinoidal packstones and grainstones also occur. Some facies contain abundant reworked corals and stromatoporoids, many of which appear to have been derived from the erosion of Cou Falls strata. Many of the limestones are pelleted, and brachiopod-rich pellet packstones are common in the upper parts of the channels. Although much internal variation is evident, the coarsest grainstone lithologies are generally found in the lower parts of the member, with finer packstones to mudstones in the upper part.

Skeletal grainstones with scattered to common fish bones and teeth plates (placoderms, dipnoans, shark) are locally noted in the lower parts of member, and these have been termed "bone beds" by Watson (1974). Some of this bone material may be reworked from the Rapid Member, but many fish taxa appear to be indigenous to the State Quarry. Abrupt lithologic breaks are recognized at one or more positions within the State Quarry Member which probably represent minor discontinuities within the channel-filling sequence At the old State Quarry, several shallowing-upward intervals capped by mudstones are recognized (see Stop 3 discussion). It is probable that several episodes of channel-filling sedimentation are represented within the member. The channel-filling sequence is capped by mudstones and skeletal wackestones, and mudstones interbed with packstones and grainstones near the channel margins.

Marginal facies of the State Quarry Member, as well as capping strata in more central positions, are characterized by flaggy-bedded relatively unfossiliferous mudstones. Chert nodules are common in these beds. The mudstones are slightly burrowed, and well-preserved brachiopods (especially *Allanella, Hadrorhynchia*) and conodonts are recovered from these beds. Upper strata about one-half mile south of the old State Quarry locally include dolomitic skeletal wackestones. These beds may mark an upward transition into dolomites of the Andalusia Member, but, except as noted below, younger Devonian bedrock units are now largely eroded in the area. The State Quarry Member is unconformably overlain by Pennsylvanian or Quaternary detrital sediments at all localities.

Andalusia Member

The Anadalusia Member was defined by Bunker et al. (1986) and Witzke et al. (1988) to include fossiliferous dolomites and dolomitic limestones within the Lithograph City Formation of southeastern Iowa and adjacent areas. The member overlies a discontinuity surface developed on top of the underlying Coralville Formation. The Andalusia

Member is recognized in the subsurface a short distance east of Iowa City in Johnson County (Mid-America Pipeline terminal), where it overlies State Quarry-like skeletal lithologies. Skeletal-moldic dolomites (with crinoid debris and atrypid brachiopods) were also encountered above the level of the Iowa City Member in engineering cores taken at the site of the Pappajohn Building directly across from the Geology Department on the campus of the University of Iowa. These dolomites are probably assignable to the Andalusia Member.

Additional exposures of dolomite within the Lithograph City Formation of Johnson County are also recognized along a stream drainage located between North Liberty and Coralville Lake (NE sec. 7 to NW sec. 8, T80N, R6W). These dolomite exposures were first noted by Youngquist (1947) and Müller and Müller (1957), who suggested that they may be a dolomitic unit within the State Quarry or Cedar Valley. Bunker and Witzke (1989) tentatively assigned these beds to the Anadalusia Member. The dolomite unit in this area probably does not excede 4 or 5 m (13-16 ft) in thickness, and it overlies an eroded surface on the Iowa City Member. The contact is not well exposed. State Quarry skeletal limestones (intraclastic grainstones) are identified above the Iowa City Member at slightly lower elevations a short distance downstream.

The medium-bedded dolomites in this area are dense and slightly argillaceous. They are only sparsely fossiliferous, but scattered to common horizontal burrows are present. We acquired a small collection of fossil molds from these beds, including crinoid debris, nautiloids, bivalves, and brachiopods (*Allanella allani, Strophodonta*; Day, 1994, personal communication). The occurrence of *Allanella* clearly allies these beds with the Lithograph City Formation (see Day, 1992), consistent with previous interpretations based on stratigraphic position and lithology. These dolomite strata are disconformably overlain by Devonian shales of the Lime Creek Formation.

Deposition of Lithograph City Formation

Watson (1974) considered the State Quarry Member to have been deposited contemporaneously with that of the Cou Falls and Iowa City members. Studies of State Quarry strata in the Coralville Lake area make this interpretation unlikely, as the State Quarry cuts across and erosionally bevels these underlying strata. In addition, biostratigraphic studies of conodonts and brachiopods indicate that the State Quarry entirely post-dates the Cou Falls. Our studies of Cedar Valley stratigraphy indicates, instead, that the Lithograph City Formation, with which the State Quarry Member is included, represents a large-scale transgressive-regressive cycle of deposition that post-dates the Coralville cyle across the Iowa area (Witzke et al., 1988). The State Quarry is interpreted to record the initial phases of this transgression that infilled erosional channels incised near the shelf margin of the Iowa City Member. As the seaway encroached northwestward, the pre-existing erosional channels in the area became flooded with marine waters, and State Quarry deposition was initiated.

Watson (1974) interpreted the grain-rich facies of State Quarrry Member as tidal-channel deposits. His depositional interpretation remains compelling, although the influence of storm processes should also be considered. Storm surges and their associated offshore geostrophic flows may also have been capable of concentrating currents within the State Quarry channels. The tidal and/or storm currents were vigorous enough to winnow mud and transport and abrade skeletal material. Brachiopods, crinoids, and other fauna inhabited the channels, and their skeletons became concentrated in the grain-rich sediments. Additional reworked clasts of limestone and fossils (especially corals and stromatoporoids) were probably derived from erosion in the channel walls, and these are most abundant in the lower portions of the channels incised below the level of the Coralville Formation.

With continuing marine transgression, the channels became filled with sediment, and currents were reduced as the environments deepened. The seaway then encroached across the exposed surface of the Iowa City Member outside the channels, marking regional expansion of the seaway and the initiation of Andalusia Member deposition in the area. More uniform and quieter-water mud-rich sedimentation occurred within the geographically-expanded sea.

The subsequent history of Cedar Valley sedimentation in the Iowa region, which is preserved in northern Iowa, was largely lost to erosion in the Coralville Lake area. The seas withdrew from Iowa following the close of Cedar Valley deposition, and a long period of erosion ensued, several million years in duration. The eroded landscape of Cedar Valley strata was buried by the next marine transgression, which marked the initiation of Lime Creek deposition in the region.

UPPER DEVONIAN LIME CREEK FORMATION

"North Liberty Beds"

A series of discontinuous exposures of greenish-gray noncalcareous shale are found disconformably above dolomite strata of the Andalusia Member in a stream drainage located between North Liberty and the Coralville Lake (NE sec. 7 and NW sec. 8, T80N, R6W). Thin brown shales are located near the base. The exposed shale interval is only about 4 m (13 ft) thick, but nearby well penetrations indicate that the shale unit reaches thicknesses to about 23 m (75 ft) in the area. This shale interval has been informally termed the "North Liberty beds," which has been studied by Youngquist (1947), Müller and Müller (1957), and Bunker and Witzke (1989). Shales of the "North Liberty beds" are relatively soft, and plastic when wet. No shelled invertebrate fossils have been identified, although spores and conodonts are recovered from the interval. The shale lithology, stratigraphic position, and contained conodont fauna indicate that the unit should be assigned to the Lime Creek Formation, an Upper Devonian shale-dominated interval that is widely distributed in the Iowa region.

The Lime Creek Formation is best known in its type region of northern Iowa, where it includes a lower green-gray shale member (Juniper Hill Shale), a middle calcareous shale and limestone unit (Cerro Gordo Member), and an an upper limestone (Owen Member). Thinner but equivalent strata in southeast Iowa are included in the Sweetland Creek Shale. Additional exposures of Lime Creek strata are known in the area, including shale at Iowa City (above the Coralville Member; see Witzke, 1984) and Cerro Gordo Member lithologies near Middle Amana, Iowa County, west of Coralville Lake. Stratigraphic leaks and karst fills of Lime Creek shales within older Devonian and Silurian strata are also known in the area (sometimes called "Independence Shale"). The green-gray noncalcareous shale lithologies of the "North Liberty beds" as well as the contained conodont fauna indicate equivalence of these beds with the Juniper Hill Shale Member.

The Lime Creek Formation was deposited during a large-scale transgression and regression of the sea across the Iowa area. Interpretations of Lime Creek deposition are provided by Witzke (1987). The lower shales of the Lime Creek Formation were probably deposited in relatively quiet-water environments with dysoxic bottom conditions (oxygen stressed).

ACKNOWLEDGEMENTS

We wish to express are thanks to the many people who have participated in and/or worked on the fossils and rocks of the Coralville Lake area and Spillway. In particular Orrin Plocher, Greg Ludvigson, Brian Glenister, Jean Prior, Jed Day, Bob Pyle, and Blaine Phillips. We also wish to thank the Army Corps of Engineers for the help and support during our work on the Spillway. Additionally, we would like to thank Ray Anderson and our many other colleagues in the Iowa City area for their support and encouragement during our studies of the rocks and fossils of the Coralville Lake area.

STOP 1. CORALVILLE DAM EMERGENCY SPILLWAY, OVERFLOW CHANNEL: DEVONIAN FOSSIL GORGE

ROCK HAMMERS AND FOSSIL OR ROCK COLLECTING ARE NOT ALLOWED.
Please preserve the rocks and fossils for all to enjoy.

In July of 1993, water from Coralville Lake flowed over its emergency spillway for 28 days, and carved a 15-foot deep gorge through a former campground area. When the waters receded a fossilized snapshot of the sea floor from about 375 million years ago (Middle Devonian) was exposed by the raging flood waters. Exposures of Devonian limestone in eastern Iowa are typically limited to vertical quarry faces, roadcuts, and cutbanks. The new spillway exposures provided a rare treat to see broad bedding plane surfaces, many of which show spectacularly abundant fossils. Although the spillway exposures are certainly of special interest for local geologists, the public interest in the rocks and fossils has been astounding. To date in excess of 200,000 visitors have made the trek across the fossiliferous exposures, and hundreds of people continue to visit the site every day. Numerous school groups from across eastern Iowa have taken advantage of the learning opportunities afforded and the area has become an outdoor natural science laboratory for many. Because of the special interest, Iowa DNR geologists prepared a short hand-out to assist the visitor in interpreting the rocks and fossils, and the Army Corps has printed in excess of 50,000 copies for distribution. The influx of visitors began almost immediately after the overflow event ceased. The numbers increased dramatically following a news release that appeared in numerous newspapers nationwide (and Europe and Japan also) as well as a Paul Harvey broadcast, the NBC Nightly News, and CNN. Conveniently located a few miles north of Interstate 80, visitors from across the US as well as overseas have stopped at the spillway to marvel at the newly created exposures of Middle Devonian strata.

Remarkably, the half-mile long channel below Coralville Dam is not alone. In at least two other places, the 1993 floods exposed major fossil beds. (1) At Saylorville Dam, the emergency spillway also overflowed, deepening a gorge first cut in 1984. The Pennsylvanian exposure is mainly amid dangerous cliffs and ledges, however access is limited. (2) At Tuttle Creek Reservoir near Manhattan, Kansas, a stair-stepped series of Permian exposures of shellfish and a few prehistoric shark fossils have also drawn thousands of visitors. However, it is the Coralville area, the oldest of the three, that seems to have caught the public's imagination. Perhaps part of the interest was sparked by the 1993 summer movie *Jurassic Park*, although dinosaurs didn't appear until approximately 165 million years after the Devonian Period.

Most visitors say that they would like to see the area preserved as it is today. In February 1994, the locality was appropriately named Devonian Fossil Gorge.

The Devonian Fossil Gorge provides a unique opportunity to examine strata of the Rapid Member (Cedar Valley Group, Little Cedar Formation) along expansive bedding plane surfaces. Although these strata are well exposed at other localities in eastern Iowa, the broad surfaces at Stop 1 provide the finest look at the member known in the area. When these surfaces were first exposed immediately after the overflow event, the contained fossils were beautifully displayed, and their distribution was tabulated. Rare and exceptionally preserved fossils were collected in the fall of 1993 in order to protect them from damage or vandalism, especially beautifully articulated crinoid specimens and an exceptional bone plate from an armored fish (arthrodire; see Fig. 2). Some of these fossils are presently on display at the Army Corps visitor center near the east end of the dam, and others are under study or preparation at the University of Iowa, Dept. of Geology and the Iowa DNR-Geological Survey Bureau.

Fossils are still evident in abundance at Stop 1, but the traffic of hundreds of thousands of visitors has taken its toll, and some of the bedding surfaces are weathered and abraded obliterating some of the fossils. Nevertheless, visitors are encouraged to get down on hands and knees and take a close look at the abundance of brachiopod, crinoid, bryozoan, coral, and other fossils still well displayed. Some beds are abundantly fossiliferous, but others beds contain only sparse fossils (especially units 15 and 17, Fig. 13A, B).

The lowest bedrock strata exposed belong to the upper Solon Member, which can be seen in the downstream reaches of the gorge near its junction with the Iowa River. These beds are only visible when river levels are low, and are displayed in a series of large subparallel faulted blocks with small-scale displacements along their margins. The Solon is a massive limestone with fragmented fossil debris; coral fossils are common. The basal part of the overlying Rapid Member is marked by a change in lithology, notably more argillaceous (clay-bearing) than the underlying Solon beds.

The bulk of the lower Rapid Member is characterized by repetitive alternations of thick hard brachiopod-rich limestone beds (most 30-60 cm) and thinner sparsely fossiliferous softer argillaceous limestone intervals. Spiny atrypid brachiopods (*Spinatrypa*, includes *S. bellula* and *S. mascula*) are characteristic, but many other fossils are noted, especially crinoid debris. The hard limestones commonly contain scattered corals in their upper parts. The hard limestones show lateral variations in composition and thickness, and packstone lenses and large-scale bedforms are displayed. These are interpreted to represent sedimentary structures generated by episodic storm currents. The argillaceous limestone interbeds are more sparsely fossiliferous, but a variety of fossils are recognized on bedding surfaces, including common trilobite debris (especially units 10,12,13, Fig. 13A, B). The argillaceous beds were deposited under quieter and less agitated conditions than the thicker and more skeletal beds with which they interbed. Articulated crinoids occur in some of the argillaceous beds, apparently smothered by mud influx associated with distal storm currents.

Above the *Spinatrypa*-bearing lower Rapid interval, an especially interesting unit of sparsely fossiliferous argillaceous (clay-rich) limestone is noted. These beds (units 15-17, Fig. 13A) were distinguished as the "key beds" by Zawistowski (1971), and are here informally termed the "Z-beds." The bulk of these beds are relatively unfossiliferous, except for scattered to common burrow mottles. However, bedding surfaces within the interval contain scattered to common fossils, and some of the finest and best preserved fossils observed at the Devonian Fossil Gorge were found within the "Z-beds." These include some spectacular articulated crinoid specimens, as well as oriented accumulations of crinoid stem segments. Dense clusters of large brachiopods (*Orthospirifer*) and surfaces rich in small chonetid brachiopods are noted. A more fossiliferous interval within the "Z-beds" (unit 16, Fig. 13A, B) also produced a beautiful median dorsal plate of a large arthrodire placoderm (fish). Conularid clusters and a phyllocarid crustacean were found within the sparse mudstones at this site. The mud-rich sediments of the "Z-beds" were deposited in relatively quiet bottom environments, but distal storm currents episodically smothered the bottom, burying delicate crinoids and other fossils in the mud.

Unit 18 (Fig. 13A) is an argillaceous limestone generally resembling the "Z-beds," but the unit contains brachiopods in greater abundance. The presence of certain brachiopods (*Athyris, Eosyringothyris*) contrasts with underlying beds. This unit is sharply overlain by a widespread shaly re-entrant (base unit 19, Fig. 13A) containing glauconite and phosphatic grains.

The overlying coral biostromes of the Rapid Member are particularly well displayed at the

Devonian Fossil Gorge. These coral-rich beds do not form coral reefs in the strict sense of the word, as reefs are mounded build-ups formed by the skeletons of reef-dwelling organisms. Instead, these coral-rich beds form tabular geometries that extend over great lateral distances, and they do not display mounded reef-like bodies. For this reason they are termed coral "biostromes" to connote their widespread tabular form. The lower biostrome (unit 19, Fig. 13A, B) includes an abundance of corals (*Favosites* ["honeycomb coral"], horn corals, and *Hexagonaria* [large hexagonal corallites]), some encrusted by stromatoporoids (sponge-like animals). The lower biostrome is best seen in upper strata along the east side of the site. The upper biostrome (unit 22, Fig. 13A, B) is more densely packed with corals, primarily *Hexagonaria.* The upper biostrome is best displayed on the east side of the gravel road that runs along the east side of Devonian Fossil Gorge, and also in the far northwest corner of the site. Some corals are overturned, apparently by strong currents and/or scavengers. Intervening beds (units 20-21, Fig. 13A, B) between the two biostromes contain an abundance of crinoid debris along with many other fossils, including small branches of pachyporid corals.

There is much to see at the Devonian Fossil Gorge, and we encourage trip participants to carefully examine the various beds for fossils and sedimentary features. Many other geologic features are also displayed at the site. The following itinerary is recommended:

1) Take a look at the many limestone beds, and see how many fossils you can identify. Lower strata are rich in brachiopods. Careful examination should reveal trilobite material in the interbedded argillaceous limestones (especially units 10-13, Fig. 13A, B). Overlying sparsely fossiliferous strata (the "key beds" or "Z-beds") contain common burrow mottles, and some bedding surfaces are rich in crinoid material and brachiopods. The coral biostromes are particularly spectacular.

2) The limestone beds in the Devonian Fossil Gorge are disrupted by numerous small-scale faults and fractures. Strata show a gentle northwestly dip in the northwestern area of the gorge. Immediately below the concrete margin of the spillway apron, a series of northeasterly-trending faults (high-angle reverse faults) have disrupted the limestone beds. Vertical displacements are small, but one fault shows unit 15 (Fig. 13A) juxtaposed against middle to upper *Spinatrypa* beds, indicating a displacement of 2 or 3 m. The fault surfaces are slickensided (grooved parallel to the direction of movement), and additional sub-horizontal slickensided surfaces indicate additional relative movements parallel to bedding surfaces. Other subparallel faults and fractures transect the site, marking a complex of stepped blocks and disrupted strata. A series of subparallel faults and fractures also disrupts the lower reaches of the Devonian Fossil Gorge.

Although many of the faults and fractures trend in a general northeasterly direction, others cut across at various directions. Fault breccias are recognized at several places, which incorporate angular blocks of varying sizes. The most dramatic fault breccia is found along the southeastern margin in the downstream area of the gorge, where a meter-wide fault zone incorporates blocks from various stratigraphic levels including dense limestone blocks derived from the Davenport Member of the Wapsipinicon Group. The complex structure of the site is presently being studied and mapped by students under the direction of Jim Faulds (Univ. Iowa). The origin of these various structures is not known with certainty. Some may be related to movements accompanying evaporite solution-collapse of underlying Wapsipinicon Group strata (which is known to be contemporaneous in part with deposition of the Little Cedar Formation). Other structural movements may relate to later-stage regional tilting and compression across eastern Iowa, possibly coincident with a phase of late Mississippian to early Pennsylvanian structural reorganization.

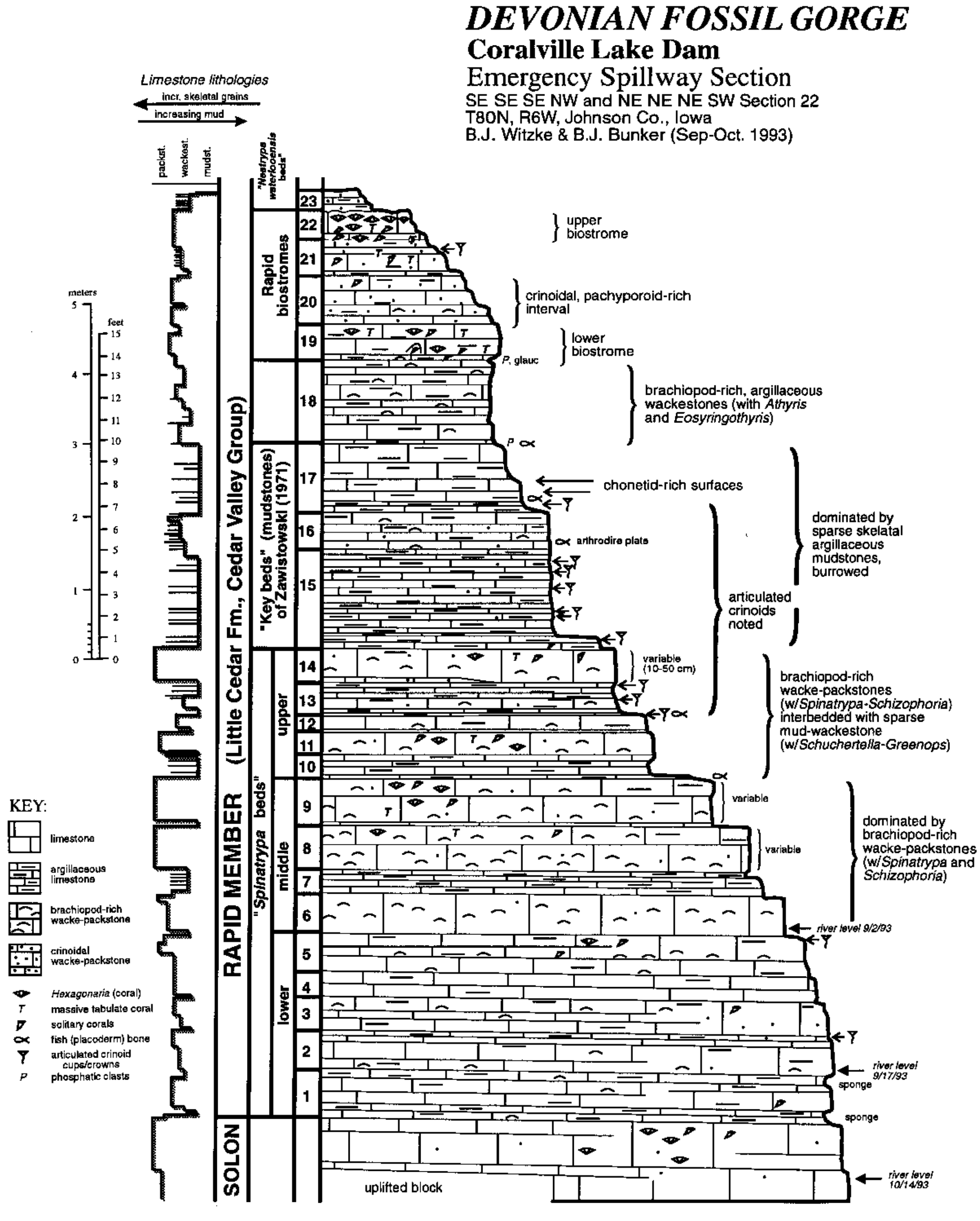


Figure 13A. Graphic section of the rocks exposed at the Devonian Fossil Gorge.

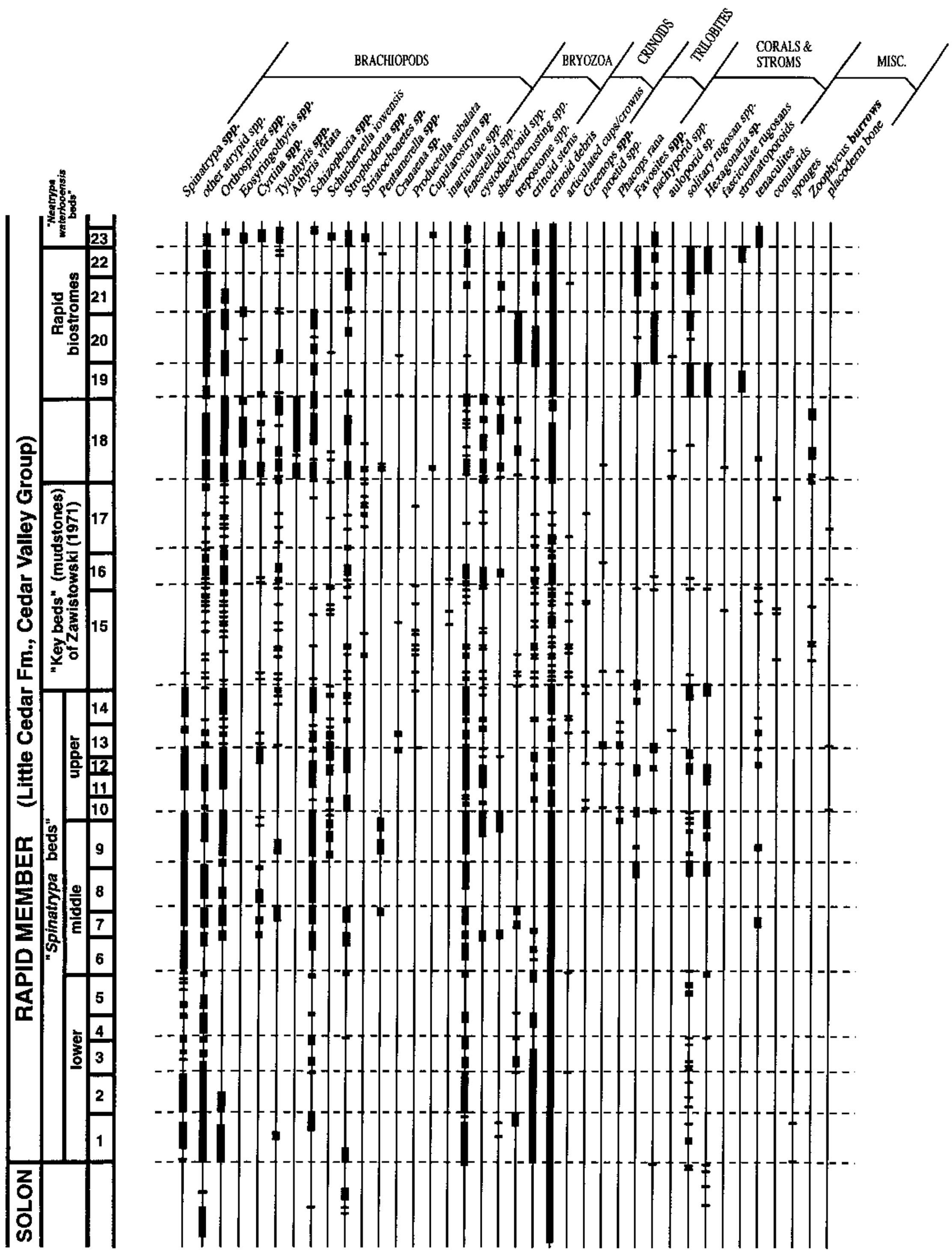


Figure 13B. Chart showing the ranges of fossils exposed at the Devonian Fossil Gorge.

3) The magnitude of the spillway overflow event during the summer of 1993 is dramatically displayed at the Devonian Fossil Gorge. The margins of the former asphalt roadway which once transected the site is clearly evident, although all evidence of the campground that once existed at the site is now removed. Before the 1993 floods, there was no limestone bedrock exposed at this site, and the overlying Quaternary sediments were scoured away down to the bedrock surface during the flood. One small remnant of Quaternary sediments remains near the center of the upper reaches of the gorge; a large block of limestone apparently deflected the floodwaters, preserving a mound of softer sediments on its downstream side.

Large blocks of limestone were plucked by the floodwaters and transported as a bedload which further scoured the bedrock. The direction of movement is evident by a series of subparallel grooves on some of the bedrock surfaces (particularly in the softer "Z-beds"), which formed by the chatter and movement of limestone blocks. An accumulation of large blocks, many stacked in imbricated fashion, is preserved along the outer bend about half way down the gorge. Some of these blocks are immense, providing clear evidence of the transport power of the floodwaters. The largest blocks measure in excess of 2 m in length and weigh up to 5 tons. A plume of smaller limestone blocks and limestone gravel, derived by flood scour within the gorge, was deposited below the mouth of the gorge and extends for a few hundred meters down the Iowa River (evident during low water).

4) An interesting section of Quaternary sediments is displayed along the margins of the gorge above the limestone bedrock. The unusual basal brown to black sediments (dark stained with manganese and iron minerals) incorporate resistant silicified Devonian fossil fragments derived by solution of the underlying limestone bedrock. The sub-Quaternary bedrock surface is solutionally sculpted in places, forming a network of solutional channels, grooves, and potholes. Many visitors have incorrectly concluded that the sculpted surfaces were formed by the action of the recent floods, but these surfaces are clearly buried and infilled with Quaternary sediments along the margins of the gorge indicating an older origin. Limestone slowly dissolves by normal rainwater and below acidic soils, and the convoluted surfaces were formed by such karstic (solutional) processes. Small-scale ancient stream channels are incised into the limestone bedrock in the lower reaches of the gorge, and these are filled with Quaternary sediments.

CORALVILLE DAM, EMERGENCY SPILLWAY SECTION
DEVONIAN FOSSIL GORGE
SE SE SE NW and NE NE NE SW sec. 22, T80N, R6W, Johnson Co., Iowa
Brian J. Witzke and Bill J. Bunker; measured Sept.-Oct. 1993.

Abbreviations used: mudst. (mudstone; sparsely fossiliferous to unfossiliferous limestone); wk (wackestone; matrix-dominated limestone with scattered to common skeletal grains); pk (packstone; skeletal-rich fossiliferous limestone, skeletal grains are packed, in contact); grainst. (grainstone; limestone composed entirely of skeletal grains, no muddy matrix, usually with calcite cements); arg. (argillaceous; limestone matrix contains clay minerals).

MIDDLE DEVONIAN
CEDAR VALLEY GROUP; LITTLE CEDAR FORMATION
RAPID MEMBER

Unit 23. Crinoidal wk-pk, very crinoidal in upper part, beds 5-10 cm, sl. glauc.; arg. partings, capped by 1 cm arg. mudst.-wk; *Megistocrinus* stems; brachiopods (*Strophodonta, Tylothyris, Cyrtina, Orthospirifer, Eosyringothyris,* atrypids, *Schizophoria, Schuchertella,* rhynchonellid, chonetids), fenestellid bryozoans, pachyporid corals in lower part, tentaculites scattered to common. Lower contact irregular, conforms to coral surfaces in underlying unit. Basal part of "*Neatrypa waterlooensis*" beds [25 cm].

Unit 22. *Hexagonaria*-rich biostrome, densely packed coral heads; arg. wk-pk matrix, matrix decreases upward (to < 10% at top), matrix with crinoidal stems and debris (*Megistocrinus* stems in pockets), brachiopods (atrypids, *Tylothyris, Strophodonta, Pentamerella*), fenestellid bryozoans; abundant corals, *Hexagonaria* packed in upper part, *Hexagonaria* mostly 10 to 30 cm diameter (to 60 cm), some overturned, *Hexagonaria* smaller in basal part (< 20 cm); scattered small branching to globular favositids, rare massive *Favosites* (to 15 cm) especially in lower part; scattered pachyporid corals; common to abundant horn corals (to 15 cm); stromatoporoids rare (massive forms to 15 cm noted). Upper surface irregular with 5 to 10 cm relief conforming along coral heads; irregular arg. surface 5-10 cm above base conforms to coral heads. Upper Rapid biostrome [40-45 cm].

Unit 21. Arg. wk with stringers of crinoidal pk; basal 7 cm is arg. to shaly brachiopod wk (*Orthospirifer, Tylothyris, Eosyringothyris, Schizophoria,* rare crinoid debris and trepostome bryozoans); upper beds show upward increase in corals and decrease in crinoidal debris; crinoidal pk stringers with oriented stems (to 10 cm, mostly southeastward orientations), *Megistocrinus* cup noted 35 cm above base of unit; scattered brachiopods (atrypids, *Orthospirifer, Strophodonta*); scattered encrusting trepostome bryozoans in middle part, scattered fenestellids in lower part; harder bed 7-32 cm above base with horizontal burrows; scattered horn corals (to 8 cm), pachyporids, and small favositids in lower part; upper 20 cm shows upward increase in horn coral abundance and size (to 18 cm), scattered *Favosites* (to 12 cm, some overturned), scattered *Hexagonaria* near top; grades into biostrome above. [50 cm].

Unit 20. Crinoidal wk-pk, slightly arg., in beds 10 to 15 cm; top bed shows upward shift to brachiopodal wk-pk, more arg. near top; thin arg. mudst. locally 17 cm above base of unit; lower half of unit shows general upward increase in crinoidal debris, including oriented stems (stems to 6 cm, southeast and northeast orientations noted); pachyporid corals (to 5 cm) scattered to common through most of unit, rare horn corals through, scattered small favositids (to 5 cm) in lower half, auloporid-encrusted brachiopod noted near middle of unit; large massive to branching trepostome bryozoans are scattered but conspicuous (to 4 cm in lower third, 8-11 cm in upper two-thirds of unit, cap-shaped forms to 4 cm in top bed); brachiopods scattered, more common near top and base (atrypids, *Orthospirifer, Tylothyris, Eosyringothyris, Strophodonta, Schuchertella, Schizophoria, Cranaena*). [68 cm].

Unit 19. Coral biostrome, resistant ledge former with thin arg. reentrant in basal 7 cm, two subequal beds above; basal 7 cm is crinoid-brachiopod wk with pk lenses, common sand-sized glauconite and phosphatic material (phosphatic "marker bed"), pk burrow fills noted, brachiopods (atrypid, *Cyrtina, Tylothyris, Strophodonta, Schizophoria*), crinoid debris (semi-articulated camerate cup noted), scattered corals (horn corals to 7 cm, *Hexagonaria* to 16 cm, favositids to 5 cm), irregular thin shale parting at base. Lower ledge (18 to 21 cm thick) is biostrome with f-c pk matrix, arg. streaks scattered through, matrix with crinoid debris (14 cm crinoid stem noted), brachiopods are very rare (atrypid noted), corals common to abundant (part silicified) includes *Hexagonaria* (10-30 cm), ramose favositids (to 6 cm), massive *Favosites* (up to 40 x 15 cm), horn corals; some corals overturned; stromatoporoid coatings on some corals, rarer massive forms (to 10 cm). Upper ledge (20 to 21 cm), biostromal wk-pk, lower 3-8 cm is crinoidal pk, less crinoidal upward; scattered brachiopods (atrypids, *Orthospirifer, Schizophoria*), scattered fenestellid bryozoans; corals less common than below, scattered *Hexagonaria* (to 12 cm), small favositids, massive *Favosites* (to 25 cm), horn corals. [49 cm].

Unit 18. Argillaceous skeletal mudst to wk with intervals of arg. wk-pk (6-30, 45, 67-84, and 113-117 cm above base), brachiopod wk-pk (whole-shell to broken shell), other skeletal material (crinoid, bryozoan) is scattered to rare; crumbly weathering. Possible hardground surface 45 cm above base. Basal 1 to 3 cm is laterally distontinuous skeletal pk with phoshatic clasts (2 to 10 mm) and scattered fish plates and spines (2-3 cm) horizontal burrows scattered to common through unit, *Zoophycus* burrows noted in lower to middle parts. Brachiopods dominated by atrypids, *Cyrtina, Tylothyris, Athyris, Orthospirifer, Eosyringothyris, Strophodonta, Schizophoria*; rarer brachiopods include indet. rhynchonellid, *Schuchertella, Pentamerella* (lower part), chonetids (basal bed and 56 cm above base), *Cranaena* (near top); local concentrations of large *Orthospirifer* (especially in basal 5 cm, and 30-45 cm above base), shells to 12 cm. Crinoid debris is scarce, includes *Megistocrinus* columnals, star-shaped columnal noted in lower beds. Bryozoans are scattered and rare in all beds, includes branching cystodictyonids and fenestellids; scattered massive to encrusting trepostomes (2 to 4 cm diameter) in some beds. Lower 60 cm locally with rare scattered fasciculate rugosan and auloporid corals, tentaculites, proetid trilobites. [1.17 m].

Unit 17. Argillaceous mudstone, sparsely skeletal with horizontal burrows scattered through; more burrowed in upper half with scattered *Zoophycus* burrows; scattered rare skeletal material in mudstone includes crinoid and fenestellid debris, brachiopods (*Orthospirifer* [to 12 cm], *Cyrtina*, small chonetids, productids). Unit contains laterally discontinuous thin skeletal-rich horizons (sparse wk to pk): 12 cm above base with articulated crinoid material (melocrinitid cup, arms); 22 cm above base, wk-pk, abundant small chonetids (*Striatochonetes*), other brachiopods (atrypids, *Orthospirifer, Tylothyris, Strophodonta*), sparse crinoid debris, fish plate; 45 cm above base, pk, abundant small chonetids, scattered crinoid debris and cystodictyonid bryozoans, other brachiopods as noted above; 47 cm above base, wk, brachiopods (*Orthospirifer, Tylothyris, Strophodonta*), crinoid stem (8 cm), cystodictyonid bryzoans, trilobite pygidia (*Greenops*); 65 cm above base, scattered *Orthospirifer*, conularids;

69 cm above base, scattered large *Orthospirifer, Schizophoria,* chonetids. Unit forms upper part of Zawistowski's (1971) "key beds," here informally included in the upper "Z-beds." [94 cm].

Unit 16. Argillaceous skeletal wk to pk, minor arg. mudst., scattered horizontal burrows; packstones occur as discontinuous lensatic stringers up to 3 cm thick, in starved bedforms to 75 cm wide, broken to whole-shell skeletal material; unit top forms prominent irregular and extensive bench surface. Basal 11 to 15 cm, pk stringers in wk, brachiopods (*Orthospirifer* [to 12 cm], *Tylothyris, Cyrtina, Strophodonta,* atrypids, orbiculoids), fenestellids, scattered pachyporid (to 8 cm) and solitary corals, crinoid debris (stems to 14 cm), scattered phosphatic clasts (to 5 cm), giant arthrodire plate (20 cm) recovered in upper part; top of basal unit may be hardground surface. Upper 41 cm, common pk stringers through, includes some arg. mudst. in upper part, sheet-like trepostome (to 8 cm) and fenestellid bryozoans common to abundant in lower part; crinoid debris includes oriented stems (southeast) and root system (lower part); brachiopods (*Orthospirifer, Tylothyris, Strophodonta*); rare proetid trilobite pygidia; single fasciculate rugose coral (3-4 mm corallites) noted on top surface. This unit forms a geographically widespread skeletal-rich interval within the sparsely fossiliferous "Z-beds." [52 cm].

Unit 15. Dominated by argillaceous mudstone, sparsely skeletal, in beds 3 to 20 cm, flaggy bedded in part horizontal burrows scattered to common, *Zoophycus* burrows noted (especially 56 to 66 cm above base). Mudstones are interspersed with thin laterally discontinuous skeletal-rich surfaces (wk-pk), some with oriented crinoid stems and articulated crinoid material; camerate crinoids dominate (*Megistocrinus,* undescribed melocrinitid), but inadunates and flexibles (including *Euryocrinus*) also occur. Articulated crinoids noted at 10, 18, 50, 56, 86, 118, 127 cm above base; oriented crinoid stems noted at 10, 18, 41 (to 10 cm, south-southeast), 50, 56 (to 30 cm, southeast), 86 (northwest and north-northeast), 127 (stems to 30 cm) cm above base of unit; crinoidal material is laterally segregated into areas variably displaying disarticulated debris, oriented stem segments, articulated to semi-articulated cups and arms, and rarely whole crinoids with stem-cup-arms (roots are absent). Skeletal-rich surfaces display other fossil material in varying abundance including brachiopods (*Orthospirifer, Tylothyris, Cyrtina,* atrypids, *Strophodonta, Leptostrophia, Schuchertella, Striatochonetes, Schizophoria,* spiny productids, lingulids, orbiculoids), bryozoans (fenestellids, cystodictyonids, branching and encrusting trepostomes [to 4 cm]), trilobites (proetids, *Greenops, Phacops*), rare corals (small tabulates [to 2 cm], pachyporids, *Favosites* [single specimen 67 cm above base], *Hexagonaria* [single specimen 67 cm above base], cup corals, fasciculate rugosans), conularids, and tentaculites. Dense clusters of large *Orthospirifer* shells (whole shells to 16 cm) are locally noted (41, 86, 118 cm above base of unit). An unusually dense cluster of 22 conularids was collected in the basal 18 cm. The argillaceous mudstones are largely unfossiliferous (except for burrowing), but scattered specimens of brachiopods (especially *Orthospirifer,* small chonetids, orbiculoids), fenestellids, conularids, and phyllocarid crustaceans have been noted. Unit is gradational above; sharp basal contact. Unit 15 is the primary unit of Zawistowski's (12971) "key beds" (here termed the "Z-beds"). [1.40 m].

Unit 14. Skeletal packstone, slightly arg., extensively exposed massive ledge former; diffuse internal layering of brachiopod valves (single valves, variably convex down or up) in abraded-grain brachiopod-crinoid pk; general upward increase in crinoid content, becoming crinoidal pk in top 10 cm (with crinoid stems). Basal 9-12 cm is laterally discontinuous crinoidal wk-pk, forms starved megaripple bedform approximately 1 m in length; laterally expressed as crinoidal pk lens, capped by thin mudst.; basal interval disappears laterally, downlapped by overlying bed. Main ledge is brachiopod-rich crinoidal pk; variable thickness, thins southward; brachiopods (common *Spinatrypa* and *Schizophoria*; less abundant *Orthospirifer*, atrypids, *Tylothyris, Strophodonta, Schuchertella,* productids), scattered fenestellid bryozoans (especially in lower to middle part); upper one-third with scattered corals including horn corals (2-10 cm), *Favosites* (to 11 cm), *Hexagonaria* (to 7 cm). Unit 14 shows significant lateral variations in thickness; thickest (47 cm) along northern edge (structural flexure with northern dip), northwest-trending axis of thickening; thins southward (15-30 cm) into less skeletal wk-pk; lateral changes in thickness and lithology suggest that the Unit 14 packstones form a large-scale bedform tens of meters in extent. This is the uppermost unit of the so-called "*Spinatrypa* beds." [15-47 cm].

Unit 13. Sparsely fossiliferous argillaceous mudst. to arg. skeletal wk; thin wk-pk lenses in lower half; unit in thin beds (2-10 cm), some surfaces extensively exposed at site. Sparse mudst. with horizontal burrows and arg. partings. Lower half with discontinuous skeletal lenses 1-3 cm thick (wk-pk), some displaying megaripple bedforms, and thin skeletal concentrations along bedding surfaces; brachiopods (common *Spinatrypa, Orthospirifer* [to 8 cm], *Schuchertella, Schizophoria,* atrypids[probably *Pseudoatrypa*]; scattered *Cyrtina, Tylothyris, Cranaena*); bryozoans (fenestellids, cystodictyonids); crinoid debris, including oriented stems (with north-south and east-west orientation), rare star-shaped columnals, and rare articulated cups and crowns (*Megistocrinus*, inadunates); scattered to common trilobite pygidia and cranidia (*Greenops, Phacops,* proetids); scattered to common tentaculites (to 3 mm); scattered auloporid (to 3 cm) and pachyporid corals; scattered fish bones near base (to 3 cm). Upper half lacks pk lenses, but some bedding surfaces with scattered to common skeletal concentrations (wk); brachiopods (as noted, including *Orthospirifer* to 9 cm); bryozoans (fenestellids, cystodictyonids; trilobites (includes coiled complete *Phacops*); crinoid debris, including oriented stems (to 10 cm; part with east-west orientation) and articulated *Megistocrinus* cup near top of unit; scattered tentaculites. [40 cm].

Unit 12. Skeletal wk, slightly arg., thin skeletal pk stringers internally; massive ledge former. Basal 6 to 8 cm is thin skeletal mudst. to wk., arg.; thins laterally to arg. parting; scattered to common fossils; brachiopods (*Spinatrypa, Orthospirifer, Pseudoatrypa, Tylothyris, Eosyringothyris, Schizophoria, Schuchertella,* productid); crinoid debris, some oriented stems (southeast); fenestellid and cystodictyonid bryozoans; common trilobite debris (*Greenops, Phacops*, proetids); scattered tentaculites; scattered fish plates (to 2 cm). Main ledge with brachipod-rich stringers (fauna as noted), crinoid debris (including 25 cm stem in upper part) and star-shaped columnal; scattered cup corals. [20-25 cm].

Unit 11. Brachiopod-rich wk-pk, crinoidal; massive ledge former; brachiopods concentrated in diffuse bands internally (whole shells and convex-up single valves); upward increase in crinoidal debris, with thin crinoidal pk lenses in upper part. Brachiopods (*Spinatrypa, Pseudoatrypa, Orthospirifer, Schizophoria, Strophodonta, Schuchertella*); scattered branching and fenestellid bryozoans; some oriented crinoid stems noted (*Megistocrinus*); upward increase in solitary corals (scattered to common); top 10 cm with scattered *Favosites* (to 6 cm) and pachyporids. Unit thickens along margin of small-scale fault at north end of exposure, more coral-rich (includes *Favosites* and *Hexagonaria* [to 30 cm]); fault dies out vertically (suggests displacement contemporaneous with deposition). [35 cm; may reach 60 cm along faulted margin].

Unit 10. Sparse skeletal mudst. to wk, arg., includes crinoidal pk stringers in top 8 cm; bedded 2 to 10 cm, flaggy in part, recessive unit. Arg. mudst. with horizontal burrows; scattered to common skeletal material concentrated along some bedding surfaces, forming thin wk stringers; brachiopods (common *Schizophoria, Spinatrypa, Pseudoatrypa, Orthospirifer, Tylothyris, Strophodonta, Schuchertella*); scattered bryozoans (fenestellids, cystodictyonids, rare trepostomes [to 3 cm]); scattered crinoid debris, including some stem segments (to 10 cm); scattered to common trilobite debris (*Greenops, Phacops*, proetids); rare small pachyporids; scattered fish spines and plates noted at base (to 2 cm). Crinoidal pk stringers in upper part with brachiopods (*Schizophoria, Schuchertella*), fenestellids, crinoid stems. Thin shale parting at top. [35 cm].

Unit 9. Skeletal wk-pk, slightly arg., brachiopod and crinoid rich; massive, in one to two beds. Lower 7 cm is brachiopod pk (single valves, convex up), common brachiopods (*Schizophoria, Spinatrypa, Orthospirifer*), large crinoid debris upward; minor shale or arg. parting at base (mudst.-wk), *Orthospirifer* (to 10 cm) noted. Basal 15 cm is locally more arg. and recessive (arg. wk), thin irregular beds, thickness varies laterally; common brachiopods near base (as noted), scattered fenestellids; capped by arg. mudst. Main wk-pk ledge with broken grains, some whole-shell brachiopods, common small crinoid debris, basal 3 cm is discontinuous crinoidal pk (with long stem segments), crinoid stems locally at top; unit shows lateral variation in relative abundance of crinoid and brachiopod debris, less brachiopods to south; brachiopods (common *Schizophoria, Spinatrypa*; also *Orthospirifer, Pseudoatrypa, Cyrtina, Tylothyris, Strophodonta, Pentamerella*); bryozoans (fenestellids, cystodictyonids, encrusting trepostomes); rare tentaculites; rare trilobite debris (*Phacops*); inverted *Favosites* (9 cm) noted 18 cm above base; upper half (especially top 14-23 cm) with scattered corals, including horn corals, *Favosites*, and *Hexagonaria* (to 30 cm). [64 cm].

Unit 8. Skeletal wk-pk, slightly arg., brachiopod and crinoid rich; primarily massive, in one to two beds (minor bedding break near middle), locally weathers into irregular beds 10-30 cm thick. Skeletal grains fragmented to whole, scattered to common whole-shell brachiopods; brachiopod valves concentrated into thin layers internally (convex-up valves near base), laterally variable concentrations; common to abundant crinoid debris, scattered stem segments (including *Megistocrinus*). Brachiopods dominated by *Schizophoria* and *Spinatrypa* (to 3 cm, some preserving spines); also *Pseudoatrypa, Cyrtina, Strophodonta*; scattered fenestellids. Top 30 cm varies laterally between burrow-mottled pk-wk (with coarser skeletal material concentrated in pockets or burrow networks) and crinoidal or brachiopod rich wk-pk; corals scattered to common, including horn corals (to 6 cm), pachyporids, favositids, and *Hexagonaria* (7-45 cm, some inverted). Unit is laterally variable; notably more arg. with flaggier bedding to east, skeletal mudst.-wk, with fine arg. laminations, brachiopods (as noted), rarer crinoid debris, scattered fenestellids, corals absent. Lateral variations in thickness and lithology suggest that the packstone beds form large-scale tabular bedforms that grade laterally into more argillaceous and less skeletal facies over tens of meters. [62 cm; thickens to 83 cm in southern exposure].

Unit 7. Skeletal mudst. to wk, slightly arg. to arg.; thinly bedded (1 to 8 cm), recessive unit, top 1-2 cm is shaly reentrant, locally benched; mudst. dominated, with fossiliferous wk (approaching pk in places) variably in lower to middle parts. Arg. mudst., sparsely fossiliferous, faintly laminated in places; bedding surfaces internally with scattered to common skeletal material, including brachiopods (*Spinatrypa, Schizophoria, Orthospirifer* [to 8 cm], *Tylothyris*, atrypids), bryozoans (fenestellids, trepostomes), crinoid debris. Brachiopod and crinoid-bearing wk lenses with brachiopods (as noted, plus *Strophodonta, Cyrtina, Pentamerella*), bryozoans (fenestellids, trepostomes), crinoid debris and stems, scattered tentaculites, spirorbid encrusting brachiopod. [35 cm].

Unit 6. Skeletal wk-pk, slightly arg., massive, single bed, prominent bench at top. Crinoidal debris, m-c debris (especially upper half); crinoid stem segments noted in middle part (7 cm) and near top (to 10 cm, oriented north-south). Brachiopod fragments and valves scattered to common through, especially in middle and upper parts; common *Schizophoria, Spinatrypa, Orthospirifer* (to 6 cm), *Cyrtina,* atrypids, *Strophodonta.* Scattered bryozoans include fenestellids (fronds to 5 cm) and sheet-like trepostomes (to 5 cm). [54 cm].

Unit 5. Skeletal wk-pk, slightly arg., massive to medium bedded (minor bedding breaks 14 cm below top and 23 cm above base). Brachiopod-rich horizons internally, brachiopods fragmented to whole valves; includes common *Spinatrypa, Schizophoria, Pseudoatrypa.* Scattered to common crinoid debris; scattered fenestellids. Scattered corals in upper part; horn corals, *Hexagonaria* (to 10 cm). Unit becomes more arg. upward; top 6 cm is more recessive, arg. mudst.-wk, brachiopods (as noted), crinoid debris (includes stem segments, large *Megistocrinus* cup [5.5 cm diameter]), scattered fenestellids. [58-63 cm].

Unit 4. Skeletal wk, slightly arg., in two subequal beds. Brachiopod and crinoid debris scattered to common; brachiopods fragmented to whole shell (includes *Spinatrypa, Schizophoria, Pseudoatrypa*); crinoid debris and stem segments; scattered bryozoans (fenestellids, trepostromes). [31-34 cm].

Unit 3. Skeletal wk, slightly arg., grades upward to brachiopod-rich wk-pk, thin arg. mudst. at top; minor bedding breaks every 7-15 cm. Lower half with common crinoid debris (including stem segments), scattered indeterminate brachiopods, scattered trepostome bryozoans. Upper half more brachiopod-rich, wk-pk, common *Spinatrypa, Schizophoria,* crinoid debris, scattered branching trepostome bryozoans; top 10 cm with scattered corals including horn corals (to 9 cm) and *Hexagonaria* (to 15 cm). [44-46 cm].

Unit 2. Fine skeletal wk-pk (mostly wk), arg.; ledge former, minor bedding breaks (16 cm below top, 18 cm above base), weathers into irregular beds (1-4 cm). Scattered to common crinoid debris (including stem segments), scattered to common brachiopods (*Spinatrypa, Orthospirifer, Pseudoatrypa, Schizophoria*; some large whole-shell atrypids preserve spiralia internally); scattered small cup corals; scattered to common fenestellid bryozoans. Top surface more arg., with abundant brachiopods (as noted), scattered fenestellid and branching trepostome bryozoans, scattered crinoid debris (including stems and articulated *Megistocrinus* cups). [57 cm].

Unit 1. Arg. wk and fine skeletal wk to wk-pk; lower 20 cm and upper 13 cm are arg. reentrants, thinly bedded (1-4 cm); middle 37 cm is single bed, weathers into irregular beds (2-6 cm). Lower 20 cm is arg. wk, scattered to common crinoid debris (including stem segments), scattered fenestellids, brachiopods (*Orthospirifer, Tylothyris, Strophodonta,* atrypids), scattered trilobite debris (*Phacops*), sponge at base (*Astraeospongia*). Middle 37 cm, fine skeletal wk-pk, slightly arg., scattered to common crinoid debris (including *Megistocrinus* stems), scattered to common brachiopods (large atrypids, *Spinatrypa, Orthospirifer, Tylothyris, Schizophoria*), scattered bryozoans (fenestellids, cystodictyonids, sheet-like trepostomes), scattered small cup corals, sponge (*Astraeospongia,* 13 cm diameter, top of interval). Upper 13 cm, arg. wk and wk-pk; common crinoid debris (including stem segments), scattered brachiopods (atrypids, *Schizophoria*), bryozoans (fenestellids, branching trepostomes). Basal contact sharp; base of Rapid Member. [70 cm].

SOLON MEMBER

Fine skeletal pk and wk-pk; generally massive, in beds 20 to 60 cm, locally weathers into thinner irregular beds; some bedding breaks marked by arg. streaks. Scattered crinoid and brachiopod debris, fragmented; part very crinoidal, rare brachiopod valves. Brachiopods (*Schizophoria, Strophodonta, Orthospirifer,* atrypids); scattered bryozoans (fenestellids, sheet-like and branching trepostomes [to 5-10 cm]); rare sponges (*Astraeospongia*; to 8 cm); scattered to common corals (horn corals [2-9 cm], *Hexagonaria* [most 5-10 cm, some to 15-20 cm], scattered pachyporids). Solon strata are visible primarily during low water in the lowest reaches of the emergency spillway washout adjacent to the Iowa River. Solon beds are also seen within a complex of fault-bounded tilted blocks in the lower reaches of the spillway washout during low water. Thicknesses of Solon strata measured in individual blocks varies from 40 to 65 cm; composited Solon thickness of exposed beds is difficult to evaluate, probably about 1 to 1.5 m total.

We will depart the spillway parking area, and procede east over the Coralville Dam, then north to the Mehaffey Bridge area. Distances given are in miles.

0.0 Leave spillway; procede east over Coralville Dam.

0.4 Coralville Lake outlet below; exposures of Little Cedar Fm., Rapid Member, and Coralville Formation, Cou Falls and Iowa City members.

0.6 Procede east; visitor center parking to left.

2.1 Turn left on NE Newport Road.

4.9 Turn left on NE Sugar Bottom Road.

7.4 Bear left on Sugar Bottom Road.

10.5 Turn left on NE Mehaffey Bridge Road.

10.9 Stop 2A roadcut; park along right shoulder area; pull forward (west) as far as possible. Be cautious along the roadway; this can be a busy highway.

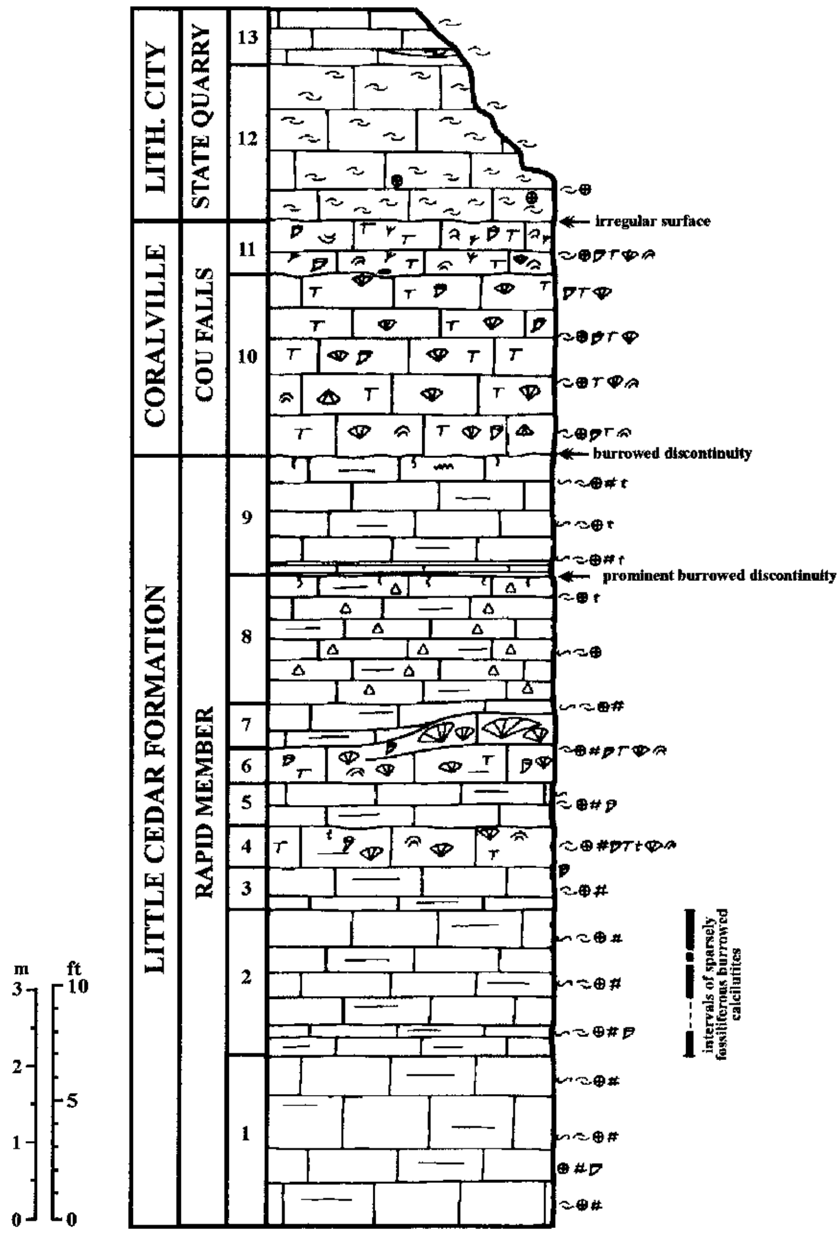


Figure 14. Graphic section of the rocks exposed at Mehaffey Bridge (Merrill A. Stainbrook Geological Preserve; T81N R6W Section 33 SW SW SW). See Figure 4 for locality register, inside back cover for Key to symbols.

STOP 2A. MEHAFFEY BRIDGE ROADCUT; MERRILL A. STAINBROOK GEOLOGICAL PRESERVE

PLEASE DO NOT USE ROCK HAMMERS OR COLLECT FOSSILS OR ROCKS.

The Mehaffey Bridge roadcut section provides trip participants the opportunity to examine limestone strata which occur stratigraphically above the beds exposed at Stop 1. The section exposed here encompasses strata of the upper Rapid Member as well as units of the Coralville and Lithograph City formations. Underlying units, which include the Rapid biostromes, "Z-beds," and the upper *Spinatrypa* beds, can be accessed along the lakeside exposures which lie immediately north of the roadcut section. These strata are disrupted by a zone of high-angle reverse faults with up to 3 m of relative displacement; fault breccias are locally developed.

Upper Rapid strata are characterized by cherty and glauconitic beds in its lower portion (unit 8, Fig. 14). Prominent burrowed discontinuity surfaces are displayed at the contact between units 8 and 9 (Fig. 14) as well as at the top of the member. The contact between the Little Cedar and Coralville formations is marked by an abrupt change in lithology, with Coralville lithologies deeply penetrated along burrow networks into the uppermost Rapid. Only the lower portion of the Coralville Formation (the lower half of the Cou Falls Member) is exposed in the roadcut; it is characterized by an abundance of corals and stromatoporoids. The upper part of the Cou Falls includes abundant branching stromatoporoids (*Idiostroma*).

The overlying beds of the State Quarry Member (Lithograph City Fm.) lie unconformably above an eroded surface; upper Coralville strata have been erosionally removed in this area. The State Quarry beds are dominated by brachiopod-rich packstones and grainstones, crossbedded in part. The upper beds can be accessed above the roadcut on the south side; these include lime mudstones with common brachiopods (*Independatrypa*). Oddly brecciated fabrics are seen along the bedrock surface.

The eroded surface of the State Quarry Member is beautifully incised with glacial striations, best seen on the surface of a bedrock knob in the upper bench area. These striae are oriented N 60-70° W (measured by Bill Bunker and Jean Prior, 1989), indicating glacial movement in a general east-southeastly direction. Glaciers advanced across the region during several episodes of pre-Illinoian glaciation (early to middle Pleistocene time). Although now largely overgrown, glacial till and loess overlie the bedrock surface at the site.

The exceptional bedrock exposures and glacial striae in the area of Stop 2A are included within a geological preserve established by the State Preserves Board in 1969. It encompasses 33 acres of land, and is named in honor of Merrill A. Stainbrook, whose important studies of Devonian paleontology and stratigraphy in the region are duly noted. ***COLLECTING IS NOT PERMITTED.***

Additional comments by Jean C. Prior: The Coralville Reservoir, a flood-control project of the U.S. Army Corps of Engineers, was completed in 1958, and in 1960 Congress authorized the construction of Mehaffey Bridge to replace an earlier, turn-of-the-century bridge over the Iowa River. During excavations to re-route a segment of the County Road at the east end of the bridge, a unique combination of geological features was exposed. A new roadcut exposed beds containing exceptional marine fossils, and, just above and southeast of the roadcut, removal of about 50 feet of loess and glacial drift revealed glacial grooves carved into the surface of the limestone bedrock.

Prominent on the excavated bench just above the roadcut is a knob of Devonian limestone shaped and smoothed by glacial action. This rock surface is further etched with fine parallel grooves and striations that indicate a NW to SE direction of Pre-Illinoian (over 500,000-year-old) ice movement across the area. The striated rock surface extends beneath much of the site and presently is covered with about 21 inches of glacial drift. The ice-inscribed surface also is seen along the top edge of the roadcut; however, preservation of the striations is more delicate and weathering is taking its toll. This site contains the only permanently exposed glacial grooves in the State of Iowa.

Beneath the glacially inscribed bedrock surface, and along the adjacent roadcut, excellent exposures of richly fossiliferous marine limestones of the 375 million-year-old (Devonian) Cedar Valley Group can be examined. Included (from bottom to top) are the upper beds of the Rapid Member of the Little Cedar Formation, the coral-stromatoporoid biostrome of the Cou Falls Member of the Coralville Formation, and the skeletal calcarenites of the State Quarry Member of the Lithograph City Formation, the unit in which the glacial striations are preserved. This site probably contains the best single (and accessible) exposure of these three formations, which are recognized for the exceptional quantity of fossil organic remains which compose them. Included are an excellent bioherm, an excellent burrowed sea floor, and excellent coral heads.

In 1969, nearly 33 acres of land encompassing these diverse geological features, which are of exceptional scientific and educational value, were dedicated by the State of Iowa as the Merrill A. Stainbrook Geological Preserve. The research of Professor Stainbrook, an Iowa native, contributed substantially to our knowledge of the Cedar Valley Group fossil faunas. The University of Iowa has a long-term lease with the U.S. Army Corps of Engineers (owner) to coordinate management, monitoring, and interpretation of the site, in concert with the State Preserves Advisory Board. The Department of Geology, particularly the work of Brian F. Glenister, was instrumental in getting the site into the State Preserve System, has a strong tradition of contributing to site maintenance, and continues to make frequent visits to the area with classes and research scientists.

MEHAFFEY BRIDGE SECTION, MERRILL A. STAINBROOK GEOLOGICAL PRESERVE

SW SW SW sec. 33, T81N, R6W, Johnson Co., Iowa

(Largely based on a section measured by B.J. Witzke, B.J. Bunker, and J.E. Day, 1985; originally published in Bunker and Witzke, 1987; supplemented with additional notes by Witzke and Bunker, 1994.)

Merrill A. Stainbrook Geological Preserve. (Roadcut encompasses units 7-13; units 1-6 are accessible in exposures bordering Coralville Lake immediately north of the roadcut section; bedrock surfaces of units 12-13 in the upper bench area south of the roadcut display a striated glacial pavement.) Elevation of the bedrock surface at the top of the roadcut is approximately 748 ft (244 m) (sea level datum).

MIDDLE DEVONIAN
CEDAR VALLEY GROUP
LITHOGRAPH CITY FORMATION
STATE QUARRY MEMBER

Unit 13. Skeletal mudst.-wk, scattered brachiopods; burrowed pk-grainst. locally at top (brachiopods, crinoid debris, *Idiostroma*), brecciated in part (irregular clasts to 10-20 cm), locally (far northeast exposure) an atrypid packstone is developed 8 to 20 cm above base of unit; lower contact slightly irregular; *Independatrypa, Schizophoria.* [70 cm].

Unit 12. Skeletal pk-grainst., brachiopod-rich, scattered crinoid debris; small intraclasts; disconformable below (5 cm relief along exposure), locally with low-angle cross-beds; *Variatrypa, Cranaena*, scattered rostroconchs, gastropods. [2.0 m].

CORALVILLE FORMATION
COU FALLS MEMBER

Unit 11. Biostrome, skeletal pk; abundant stromatoporoids and corals, some overturned; intraclastic near base, irregular basal surface; *Idiostroma* (branching stromatoporoids), hemispherical stromatoporoids, branching *Favosites*, pachyporid corals, horn corals, *Cranaena.* [70 cm].

Unit 10. Biostrome, skeletal pk; abundant corals and stromatoporoids, many overturned; brachiopods (*Neatrypa*) common near base, *Psuedoatrypa* and other brachiopods above; encrusting and hemispherical stromatoporoids, *Favosites*, pachyporids, horn corals, *Hexagonaria, Conocardium*; irregular burrowed discontinuity surface at base. [2.3 m].

LITTLE CEDAR FORMATION
RAPID MEMBER

Unit 9. Arg. skeletal wk-mudst., some pk lenses and stringers, burrowed; discontinuity surface at top (sharp break from mudst. below to Coralville pk above), vertical burrows infilled with Coralville lithologies extend downward locally to 20 cm; basal 11 to 15 cm with two prominent shale partings; abundant crinoid debris (including *Megistrocrinus*), bryozoans (including cystodictyonids), scattered pachyporid corals, large *Neatrypa waterlooensis, Orthospirifer, Tylothyris, Cranaena* (upper part), *Strophodonta, Schizophoria*, other brachiopods. [1.5 m].

Unit 8. Arg. skeletal wk-pk, burrowed; prominent discontinuity surface at top with abundant vertical burrows to 10 cm; scattered to abundant nodular chert (smooth to chalky), nodules 1 to 30 cm; glauconitic, very glauconitic in upper part; abundant crinoid debris, scattered small to large brachiopods including *Orthospirifer* and *Neatrypa*, pachyporid corals near top. [1.7 m].

Unit 7. Arg. skeletal wk with lenses and stringers of pk; oversteps upper surface of underlying biostrome; shaley to very argillaceous at top; small *Favosites* and horn corals near base; crinoid debris (including *Megistocrinus*), bryozoans, *Orthospirifer, Tylothyris, Schizophoria, Pseudoatrypa, Athyris, Cranaena, Pentamerella*. [27 to 70 cm].

Unit 6. Biostrome, slightly arg., skeletal wk-pk; shaley parting at top; biostrome varies laterally, where thickest includes massive accumulations of large *Hexagonaria*; crinoid debris, fenestellid bryozoans, horn corals, *Favosites*, alveolitids, encrusting stromatoporoids, *Pseudoatrypa, Tylothyris, Strophodonta, Cranaena, Gypidula, Pentamerella*. Equivalent to unit 22 at Stop 1. [40 to 85 cm].

Unit 5. Arg. skeletal wk-pk, burrowed, shaley at top; crinoid debris (including *Megistocrinus*), bryozoans (including fenestellids and cystodictyonids), horn corals at top, *Orthospirifer, Pseudoatrypa, Strophodonta, Schizophoria*. Equivalent to units 20-21 at Stop 1. [70 cm].

Unit 4. Biostrome, arg. skeletal wk-pk; *Favosites*, alveolitids, pachyporids near top, *Hexagonaria*, horn corals, hemispherical stromatoporoids, crinoid debris, *Orthospirifer, Pseudoatrypa*. Equivalent to unit 19 at Stop 1. [50 cm].

Unit 3. Arg. skeletal mudst. to wk-pk at top; crinoid debris, bryozoans (including fenestellids), *Orthospirifer, Pseudoatrypa, Schizophoria*, horn corals at top. Shaley re-entrant at base is glauconitic and phosphatic. Equivalent to unit 18 at Stop 1. [53 cm].

Unit 2. Sparsely fossiliferous to unfossiliferous arg. mudst., contains lenses or stringers or arg. skeletal wk to pk; extensively burrow-mottled throughout; fossiliferous horizons include crinoid debris (including *Megistocrinus*), bryozoans (including fenestellids), strophomenids, *Orthospirifer, Tylothyris, Pseudoatrypa, Schizophoria*, chonetids (upper part); lower part locally includes horn corals and *Hexagonaria* (to 30 cm). Equivalent to the "Z-beds," units 15-17 at Stop 1. [1.9 m].

Unit 1. Arg. skeletal wk to pk, interbedded with thinner recessive arg. mudst.-wk, burrowed; crinoid debris (including *Megistocrinus*), bryozoans (including fenestellids and cystodictyonids), horn corals in lower part, *Phacops, Spinatrypa bellula, Pseudoatrypa, Orthospirifer, Tylothyris, Schizophoria*. Equivalent to units 9-14 at Stop 1. [2.2 m].

STOP 2B. MEHAFFEY BRIDGE SOUTH, CORALVILLE LAKE SHORE — DEVONIAN AND PENNSYLVANIAN CHANNEL-FILL DEPOSITS

FOSSIL AND ROCK COLLECTING IS NOT ALLOWED IN THE CORALVILLE LAKE AREA WITHOUT PRIOR PERMISSION OF THE ARMY CORPS OF ENGINEERS.

We will proceed downstream from Mehaffey Bridge along the eastern shore of Coralville Lake. Depending on lake levels, we will traverse the shoreline edge or, alternatively, follow the wooded bluff margin above the limestone exposures that trend south from the bridge. Stretches of loose blocky limestone talus will be encountered, so ***please be cautious of your footing and the safety of others***.

An instructive series of Devonian limestone exposures is displayed along the eastern shore of Coralville Lake and its tributary inlets between Mehaffey Bridge and the Sugar Bottom area (see map, Fig. 15). Exposures of the State Quarry Member display a variety of limestone lithologies (including fossiliferous grainstones and cherty mudstones) which unconformably overlie a deeply eroded surface which cuts across strata of the Coralville Formation and Rapid Member (see cross-section, Fig. 16). State Quarry strata display a general channel-filling geometry, with coarse fossiliferous grainstones occupying the deeper and more central portions of the channel, and more sparsely fossiliferous mudstones in marginal and capping positions. The exact course of the State Quarry channel is not known with certainty, but our field studies indicate that it roughly parallels the valley of the Iowa River, with a secondary system to the east in the valley of "Indian Creek" (an unnamed creek valley including the Indian Cave archaeological site).

Exposures of Rapid Member strata are abruptly terminated between Localities 3 and 4, and massive blocky talus and cliffs of fossiliferous State Quarry limestone lithologies become prominent. Bold faces of State Quarry strata at Locality 4 are the main target of this excursion, where trip participants are encouraged to carefully examine these exceptional exposures. Lower strata (see Fig. 17) are richly fossiliferous, containing an indigenous fauna of brachiopods and crinoid debris as well as abundant reworked corals and stromatoporoids. Many of the corals are rounded, and may have been derived in part from erosion of coral-rich beds in the Coralville Formation. Small rounded limestone clasts are also abundant. These beds are crossbedded in part, and large stylolites (jagged horizontal solutional surfaces) cut through the massive beds. Dark fragments of fish bone, generally abraded or rounded, are scattered to common (primarily in units 2 and 3).

Upper brachiopod-rich strata (unit 5) are less massive and lack the abundant corals and stromatoporoids seen in the lower units. State Quarry exposures to the south (Locs. 6-8) generally contain fewer corals and stromatoporoids and bone fragments than seen at Locality 4, and the southern exposures are dominated by brachiopod and crinoid-rich grainstones. Trip participants are encouraged to examine the exposures between Localities 6 and 7, but time will probably not permit visitation of Locality 8 which lies south of a lake embayment. Units of the Rapid Member are erosionally truncated beneath the State Quarry beds in the southern area, and more than 4 m of erosional relief is displayed. The fossiliferous State Quarry grainstones and packstones are capped by cherty mudstones, best seen at localities 7 and 8 (visible are float in the northern sections). A high-angle reverse fault with about 1.2 m of displacement cuts across State Quarry and Rapid strata at Locality 6. Strata are roughly horizontal, but southward dips are particularly evident south of the fault.

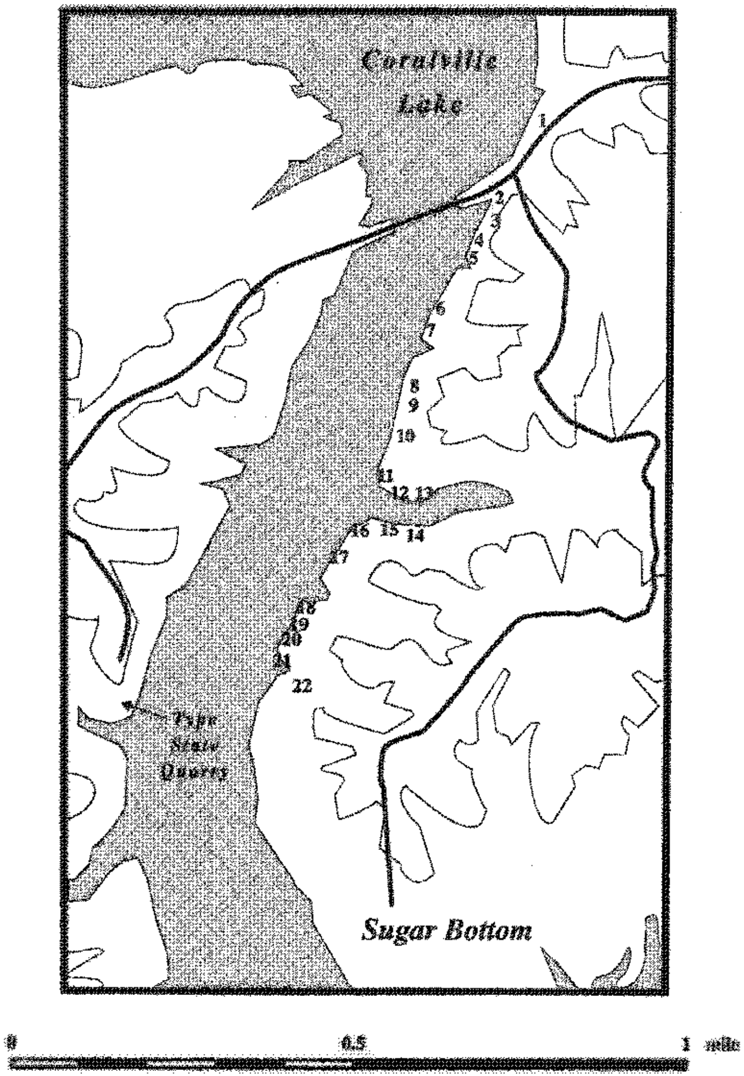


Figure 15. Locality map of the area between Mehaffey Bridge (1) and the type State Quarry in the Coralville Lake area, Johnson County, Iowa.

Erosional remnants of channel-filling sandstones and siltstones of Pennsylvanian age cut into the Devonian limestone at a number of places in the Coralville Lake area. Pennsylvanian channels can be seen at Localities 3 and 4 in the area of Stop 2B. The channels are filled with fine- to medium-grained sandstone, siltstone, and mudstone, in part cemented with iron oxides. These deposits are of fluvial origin (river deposits). Reworked brachiopods and other Devonian fossils are scattered in the sandstone, derived by local erosion of the limestone bedrock. The various stratigraphic units displayed in this area document multiple episodes of erosional channeling in the region: 1) Devonian limestone-filled channels of the State Quarry Member; 2) Pennsylvanian sandstone and siltstone-filled channels; 3) Pleistocene alluvial deposits which incise the bedrock; and 4) the modern river valley of the Iowa River and its tributaries.

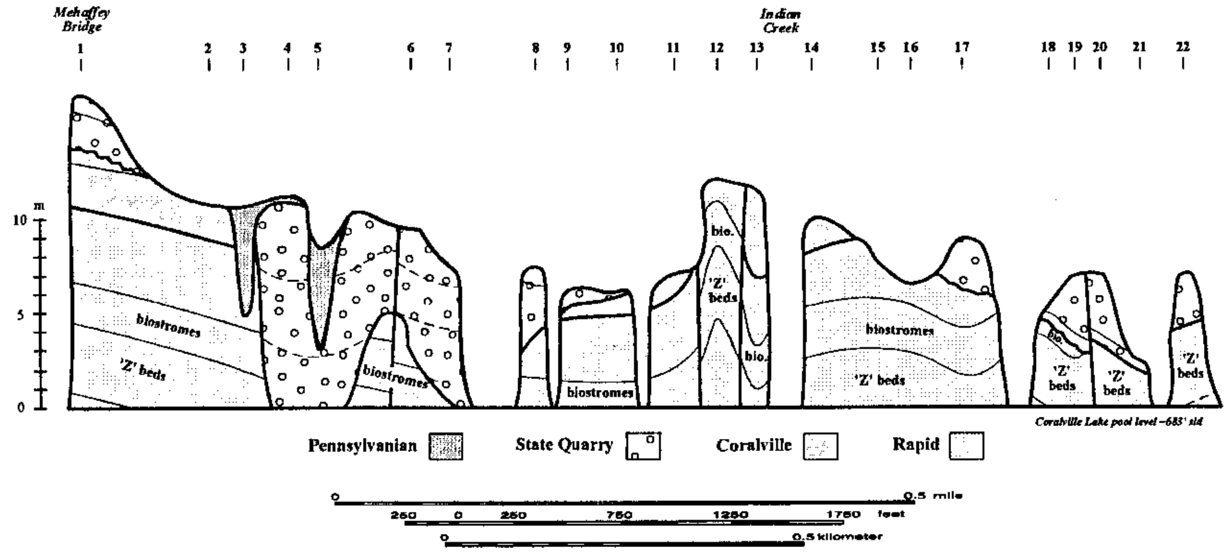


Figure 16. Cross-section showing the erosional cut-out of the State Quarry channel into the lower Rapid, Johnson County, Iowa. See Figure 15 for localities.

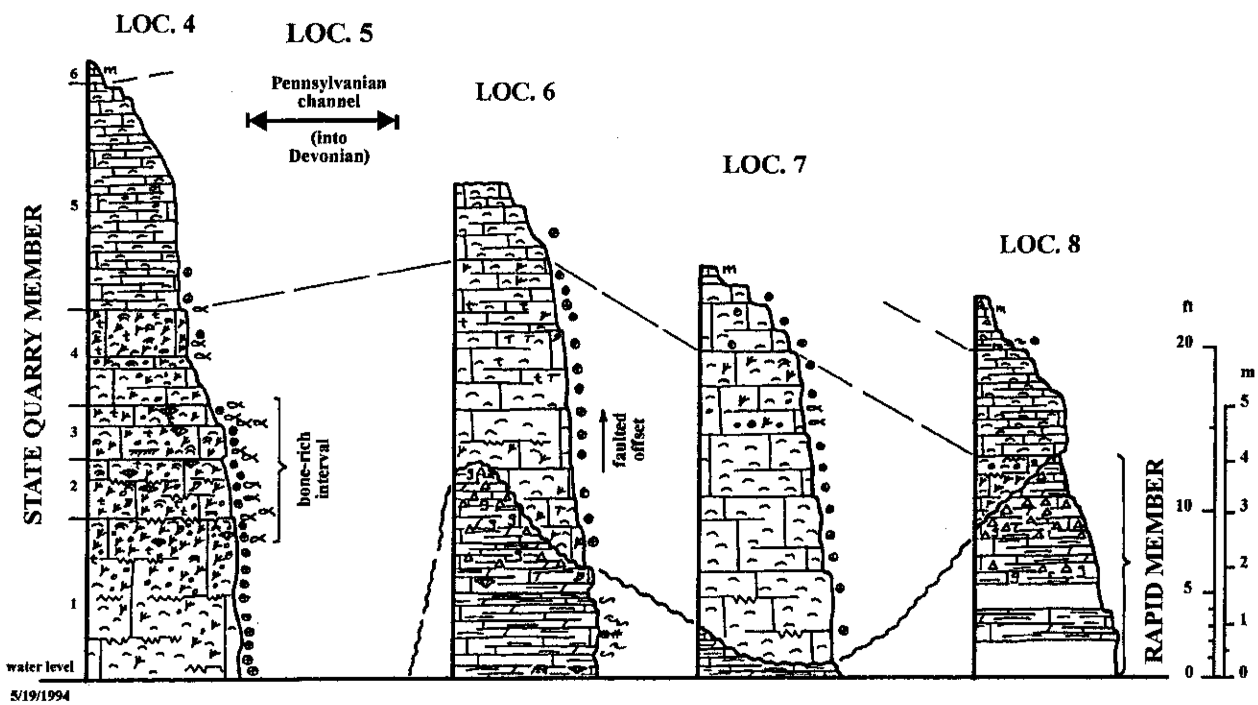


Figure 17. Cross-section of State Quarry Member, Lithograph City Formation, Johnson, County, Iowa. See Figure 15 for localities, inside back cover for Key to symbols.

MEHAFFEY BRIDGE SOUTH; east bank of Coralville Lake
Unit descriptions for Locality 4, NW NW NW NW sec. 4, T81N, R6W, Johnson Co., Iowa.
Supplemental sections: Loc. 6, SW NW NW NW sec. 4;
Loc. 7, NE SE NE NE sec. 5;
Loc. 8, SE SE NE NE sec. 5.
Brian J. Witzke and Bill J. Bunker; measured May, 1994.

MIDDLE DEVONIAN
CEDAR VALLEY GROUP, LITHOGRAPH CITY FORMATION
STATE QUARRY MEMBER

Unit 6. Sparsely skeletal mudst., flaggy bedded; nodular chert bands; scattered brachiopods (*Hadrorhynchia, Allanella, Athyris*), crinoid debris; branching stromatoporoids and thamnoporid corals locally at base (Loc. 6 only). This unit is primarily represented by scattered to abundant float and scree above the prominent ledges of pk-grainst.; mudst. beds in place at Locs. 6 and 7, sharp basal contact. At Loc. 6 a thin mudst. interval (10-20 cm) drapes underlying beds, southward dips; mudst. is sharply overlain (irregular contact) by a fine brachiopodal pk-grainst. bed (to 25 cm) which infills irregularities; pk-grainst. laterally truncates underlying mudst. bed. Flaggy, cherty mudstone beds best exposed at Loc. 7 and southward towards Stop 4. [maximum thickness about 1.4 m; 40 cm in place, additional 1.0 m of float and scree above].

Unit 5. Brachiopod-rich grainst. and pk-grainst., weathers into irregular beds (6-25 cm); primarily fine to medium grained; abraded skeletal debris, brachiopod-enriched skeletal stringers; common pellets and small intraclasts, scattered larger lithoclasts to 1 cm (lower part). Brachiopod valves vary in size, small forms dominate upward; fauna dominated by *Pseudoatrypa, Allanella, Athyris*, with rare *Cranaena, Spinatrypina.* Crinoid debris scattered to common, abundant near base. Unit 5 is similar to south (Locs 6-8), but is generally more crinoidal, locally with scattered favositids; thinner to south, capped by unit 6 mudst., mudst. may share facies relations with upper unit 5 grainst. to north. [4.25 m at Loc. 4; 1.3-2.0 m at Locs. 7-8].

Unit 4. Stromatoporoid- and brachiopod-rich grainst., porous, common voids; generally in massive thick beds (to 90 cm thick), stylolitic in part; common to abundant small intraclasts. Abundant branching stromatoporoid grains (*Idiostroma*), scattered to abundant massive stromatoporoids (to 4 cm; especially upward), scattered to common *Favosites* (to 5 cm; especially upward). Common to abundant brachiopod valves (mostly *Pseudoatrypa*), most abundant in lower part; crinoid debris. Scattered fish bone fragments (ptyctodonts) in upper half, including top surface. Upper contact sharp, gradational lower contact. Unit includes more crinoidal debris, including coarse columnals, in southern sections (Locs. 6-8), generally fewer *Idiostroma* and corals; unit laps erosional surface on Rapid Member at Loc. 8. [1.8 m at Loc. 4; 1.5 m at Locs. 6-7; 0-80 cm at Loc. 8].

Unit 3. Stromatoporoid-rich grainst., intraclastic; massive ledge former, slopes back in upper part. Common brachiopods (dominantly *Pseudoatrypa*), abundant reworked grains of branching (*Idiostroma*) and massive stromatoporoids, common reworked corals (favositids, *Hexagonaria* to 12 cm, horn corals); crinoid debris. Scattered to common fish bone (placoderm, dipnoan), most abundant along bedding surface 63 cm above base. Unit 3 changes character to south (Locs. 6-7), not clearly recognized; bone-rich aspect disappears, fewer corals and stromatoporoids, interval dominated by brachiopod-rich grainst., common crinoidal debris (including coarse columnals), brachiopods (*Pseudoatrypa, Athyris, Allanella, Cranaena,* *Eleutherokomma*). [1.05 m at Loc. 4; not differentiated to south].

Unit 2. Stromatoporoid-rich grainst., upward to pk-grainst., intraclastic, scattered lithoclasts (including mudst. lithologies to 2 cm); massive ledge former, thick beds (40-70 cm), common stylolites. Abundant branching stromatoporoid grains (*Idiostroma*), reworked massive stromatoporoids (to 7 cm); common reworked corals (horn corals, *Favosites, Hexagonaria* [in upper half], scattered chaetetids (middle part); fine to medium crinoid debris through; common to abundant brachiopods (primarily Pseudoatrypa), forms packed accumulations near top. Scattered to common fish bone (ptyctodonts and other placoderms, dipnoans), particularly in lower part. Unit is replaced to south by brachiopod-rich pk-grainst., scattered coarse crinoid debris, scattered *Idiostroma*, favositids. Re-entrant at top. [1.1 m at Loc. 4].

Unit 1. Crinoidal to stromatoporoid-rich pk-grainst.; massive, thick beds, prominent stylolite surfaces scattered through. Lower 2.1 m is dominant a medium to coarse grained crinoidal pk-grainst., slightly porous, common to abundant brachiopods (part abraded grain; dominantly *Pseudoatrypa*), especially in upper part; abundant intraclasts and small mudst. lithoclasts; branching stromatoporoid grains (*Idiostroma*) increase upwards, abundant in upper part. Upper 85 cm, stromatoporoid-rich grainst., rounded *Idiostroma* grains, massive stromatoporoids (to 5 cm); fine to coarse crinoid debris; abundant small intraclasts and lithoclasts; scattered to abundant brachiopods (*Pseudoatrypa*), packed in top 5-10 cm; reworked corals scattered to common (*Favosites, Hexagonaria*, horn corals); scattered fish bone in middle to upper parts; prominent stylolitic bedding surface at top. Unit 1 absent to south, apparently laps unconformity on top of Rapid Member. [2.95 m measured to water level at Loc. 4].

LITTLE CEDAR FORMATION
RAPID MEMBER

State Quarry Member unconformably overlies strata of the Rapid Member to the south (Locs. 6-8). Primarily dolomitic limest., arg., cherty and glauconitic in upper part; Rapid biostromes in lower part. Includes strata equivalent to units 4-8 at Stop 2A and units R5-R9 at Stop 4. [4.0 m exposed at Loc. 6, laterally truncated by State Quarry beds; 4.1 m at Loc. 8, part covered].

The return trek to the cars is most easily accomplished by walking through the woods above the limestone exposures.

11.0	Procede west across Mehaffey Bridge.
11.9	Turn left on Rice Ridge Lane NE.
12.0	Bear right on Rice Ridge Lane.
12.2	Road dead-ends. Park along right side of road; do not block residential driveways. The pathway that leads into the State Quarry Preserve procedes south from the dead-end.

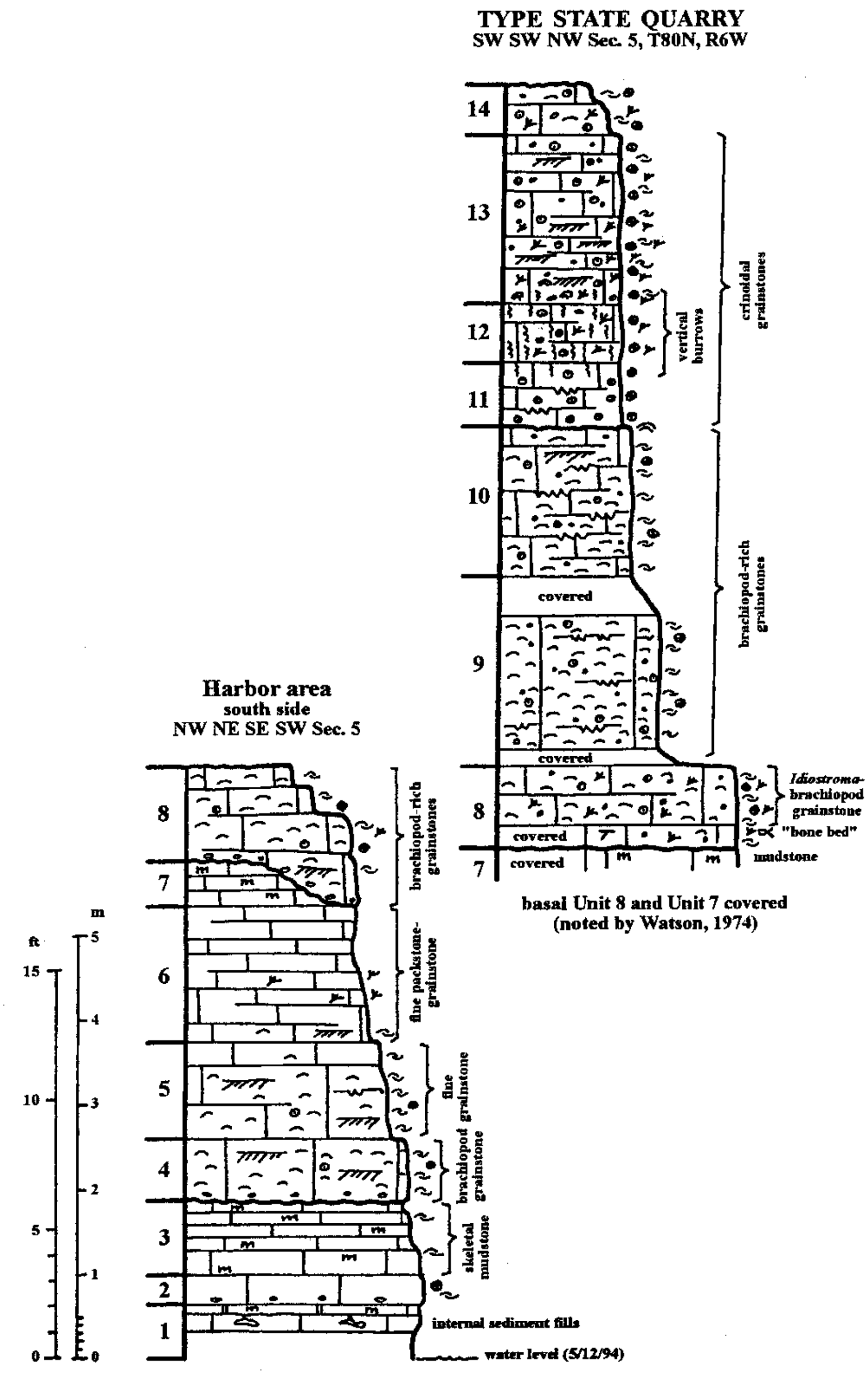


Figure 18. Graphic section of the type State Quarry Member, Lithograph City Formation, Johnson County, Iowa. See inside back cover for Key to symbols.

STOP 3. THE OLD STATE QUARRY — TYPE SECTION OF THE STATE QUARRY MEMBER

ROCK HAMMERS AND FOSSIL OR ROCK COLLECTING ARE NOT PERMITTED IN THE STATE QUARRY PRESERVE. Please be cautious along the quarry walls.

We will procede down the footpath into the old State Quarry, which is a designated state geological preserve. This quarry area has a long and interesting history of quarrying activity, and it has been known under several names including the State Quarry, the Old Capitol Quarry, North Bend Quarry, and the Penn Quarry. This quarry area (as well as a series of small quarries stretching along the bluffline 0.3 miles (0.5 km) to the south and a small quarry area to the north) provided dimensioned building stone used in the construction of the Iowa Territorial Capitol in Iowa City in the early 1840s. Quarrying continued until about the turn of the century, providing high quality stone for building foundations, bridge abutments, and other construction. The State Capitol building in Des Moines (begun 1871) contains foundation stone quarried at this site. The site is designated the type locality for the State Quarry Member (Lithograph City Formation), originally named the "State Quarry limestone" by Calvin (1897).

The base of State Quarry Member is not evident at Stop 3, but the notable thickness of the member and its lateral relations indicate that the site occupies a position in the central area of the main State Quarry channel, probably incised into strata of the lower Rapid Member. Additional strata of the lower State Quarry Member below the level of the old State Quarry can be seen along the south side of the adjacent harbor area (Fig. 18). Surprisingly, these lower strata were not recognized in any previous study of the type State Quarry area, but it is evident that the base of the quarry section lies some distance above the base of the member. The lower beds contain brachiopods characteristic of the State Quarry Member (units 2-5), including *Pseudoatrypa rugatula* and *Allanella allani.*

Several general fining-upward sequences are recognized within the member (units 2-3, 4-7, 8-10). Each sequence is marked by an irregular base, with erosional incision noted at the base of unit 8. The lower part of each sequence is marked by brachiopod-rich grainstones containing abraded grains and rounded intraclasts or lithoclasts Reworked coral and stromatoporoid material also occurs, especially in unit 8, which also contains fish bone material. The lower grainstones in each fining-upward sequence commonly show low-angle cross-bedding and planar laminae, indicative of vigorous current activity during deposition. Maximum size of brachiopod and other grains decreases upward in each sequence, and more mud-rich strata (wackestones and mudstones) are recognized in the upper parts of the first two sequences (units 3, 7). Unit 10 lacks mudstones, but a crude fining upward sequence is still displayed.

The preservation of several fining-upward sequences indicates changing environmental conditions during deposition, possibly related to small-scale variations in water depth. The upward decrease in maximum grain size and the upward increase in mud indicates decreasing bottom current activity during deposition. The sharp irregular to erosional base of each sequence marks the resumption of vigorous bottom current activity. The top of unit 10 is also slightly irregular and locally encrusted with stromatoporoids; this surface may represent a discontinuity (hiatus in sedimentation), and there is a notable change in lithology above.

The upper part of the State Quarry section (units 11-14) contrasts with underlying units

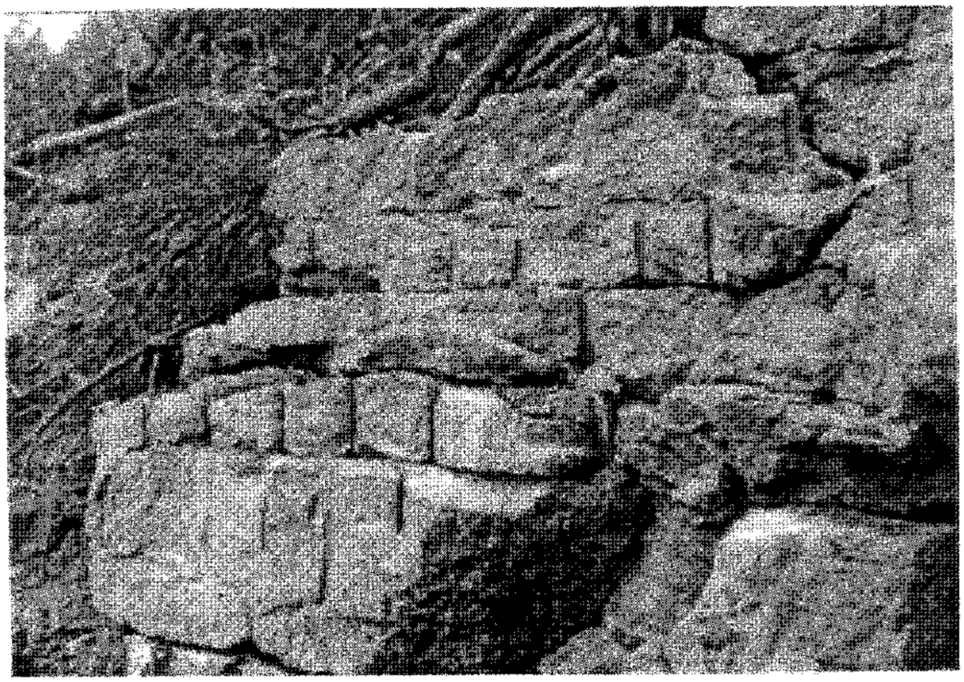


Figure 19. Shown are a series of hand-drilled holes in the State Quarry Limestone.

in containing an abundance of crinoid debris and a general paucity of brachiopod shells. Low-angle cross-beds are noted in the grainstones, and stromatoporoid grains and pebbles and lithoclasts/intraclasts are common in some beds. An unusual burrowed interval (unit 12 and adjacent) is of note, which displays an abundance of vertical and sub-vertical penetrative burrows.

Additional comments by Jean C. Prior: The Old State Quarry Geological Preserve occupies 8.5 acres along the western margin of Coralville Lake, a U.S. Army Corps of Engineers flood-control project along the Iowa River valley north of Iowa City. This site was designated as a State Preserve in 1969 in recognition of its historic and geologic significance. In fact, Old State Quarry and a smaller quarry site in the near-vicinity are in the process of being nominated to the National Register of Historic Places.

Though flooded periodically, the limestone beds at the quarry are still accessible, primarily during periods when water levels are at or below normal pool level along the adjacent reservoir. The locality is accessible by boat, or by foot along a wooded path leading from the end of a private access road through a housing development (Rice Ridge Road). Based on photographs taken by State Geologist Samuel Calvin during the late 1880s, the primary quarry site has changed little in the past one-hundred years. Evidence of 19th century hand-quarrying activities can still be seen in the form of physical artifacts such as hand-drilled holes, "feathers" - used to line the holes, and wedges - hammered between the feathers to split the stone into blocks (Fig. 19).

STATE QUARRY PRESERVE AND ADJACENT HARBOR AREA
West side of Coralville Lake
SW SW NW SE sec. 5 and NW NE SE SW sec. 5, T80N, R6W, Johnson Co., Iowa
Brian J Witzke and Bill J. Bunker; measured May 1994

MIDDLE DEVONIAN
CEDAR VALLEY GROUP; LITHOGRAPH CITY FORMATION
STATE QUARRY MEMBER (type section)

Unit 14. Crinoidal-brachiopodal pk-grainst., thin to medium bedded (4-10 cm). Lower 35 cm is abraded-grain brachiopodal to crinoidal pk-grnst., branching stromatoporoid grains, scattered pachyporid grains (to 2 cm); *Pseudoatrypa* noted. Upper 25 cm is fine to coarse crinoidal pk, thinner bedded; scattered brachiopod grains. Unit slopes back above main quarry face into woods above. [60 cm].

Unit 13. Crinoidal grainst., fine to medium crinoid debris, minor coarse crinoid debris (fine to coarse in top 45 cm), scattered stromatoporoid grains (common in lower 15 cm), small sand-size intraclasts through; medium to thick bedded (10-45 cm), part massive, weathers in part into irregular discontinuous beds (10-20 cm). Lower 42 cm, one bed; lower 15 cm is crinoid-stromatoporoid (*Idiostroma*) grainst., common stromatoporoid grains and pebbles, scattered vertical burrows (as in unit 12), scattered gastropods; stromatoporoid grains through interval, scattered brachiopods (increasing upward), low-angle cross-stratification in middle part. Middle 1.16 m, massive quarry face, weathering into irregular beds, fine to medium crinoidal grainst. (minor coarse crinoid debris), scattered stromatoporoid grains (to 4 cm at 45 cm above base of interval), rare to scattered brachiopod grains; lower half with multiple sets of low-angle cross-strata (5-10 cm thick; coarse skeletal material along laminae). Upper 45 cm, similar to below, fine to coarse crinoid grainst., contains coarser lens associated with low-angle cross-stratification; top 15 cm with more common brachiopod grains (atrypids), laterally with common stromatoporoid and pachyporid grains. [2.03 m].

Unit 12. Burrowed grainst., fine to medium crinoid debris, small intraclasts, scattered larger lithoclasts, common stromatoporoid grains and pebbles (increasing upward; to 2-3 cm). Abundant vertical to subvertical burrows throughout (3-11 cm long), especially in upper 55 cm. Massive ledge former; weathers into irregular beds (7-25 cm). [70 cm].

Unit 11. Crinoidal grainst., fine to coarse crinoid debris, pelleted and intraclastic; crudely fining upward; scattered to rare brachiopods (primarily in upper half, *Pseudoatrypa*), scattered stromatoporoid grains (some to 2-3 cm, 15-25 below top). Horizontal laminations internally; top 5 cm with vertical to subvertical burrows (as in unit 12); stylolitic surfaces scattered through. Massive ledge former, in 2 to 3 beds; sharp basal contact. [74 cm].

Unit 10. Brachiopod-rich grainst., abraded grains (brachiopod valves primarily convex-up, some convex down, *Pseudoatrypa*), fine to coarse crinoid debris, fine intraclasts and stromatoporoid grains (microscopic). Coarsest grains show crude fining upward aspect; largest shells in lower part, larger shells generally absent in upper part; some low-angle cross-stratification noted in places. Massive ledge former, weathers into irregular beds 15-30 cm; stylolitic surfaces scattered through. Upper surface slightly irregular, possible discontinuity, locally encrusted with tabular stromatoporoids (to 15 cm diameter). Old steel quarry wedges were still embedded in unit 10 early in 1994, but some souvenir hunter removed these in September, 1994. [1.75 m].

Unit 9. Brachiopod-rich grainst.; groundmass of abraded grains, fine crinoid debris and intraclasts, minor fine stromatoporoid grains; larger brachiopod valves (primarily *Pseudoatrypa*) concentrated in horizontal layers, most valves are convex-up (some convex-down); brachiopods best preserved in bottom part; shells part silicified. Prominent massive ledge former; common stylolitic surfaces. Basal 20 cm and upper 45 cm are presently covered intervals. [2.2 m].

Unit 8. Stromatoporoid-brachiopod grainst., abraded grains, crinoid debris common (especially in lower part of quarry section); sand-sized intraclasts, lower 10 cm in harbor area incorporates larger lithoclasts (to 2 cm) of unit 7 lithologies; scattered to common abraded branching stromatoporoid grains (*Idiostroma*), rare coral debris; abundant brachiopods (primarily *Pseudoatrypa* and *Allanella*, rare *Hadrorhynchia*, others), single valves mostly convex-up. Basal 25 cm is now covered in main quarry area; this interval was included as the "bone bed" by Watson (1974), who noted branching and massive stromatoporoid grains, abraded colonial corals (*Hexagonaria*, *Favosites*), brachiopod grains, and fish debris (placoderms, dipnoans) in a crinoidal grainst. groundmass. Unit 8 is primarily a brachiopod-rich grainst. along the south side of the harbor area; with lithoclasts and coral-stromatoporoid debris in the basal part; irregular basal contact, incises through unit 7 below; south-dipping cross-beds in lower part. Massive ledges, weathers into irregular beds 6 to 25 cm. [varies laterally, 95 cm to 1.35 m].

Unit 7. Skeletal mudst. to wk, fine skeletal debris along bedding surfaces, some discontinuous fine pk lenses in lower part; unit grades upward to mudst. (calcilutite); upper part very fractured; irregular erosional upper contact. Slope former, in weathered beds 7-15 cm; presently visible only in harbor area. A calcilutite (mudst.) bed was noted below unit 8 in the main quarry area by Watson (1974); now covered in that area. [55 cm].

Unit 6. Fine skeletal pk-grainst., finer than below; ledge former, weathers into irregular beds (2-15 cm). Lower beds display planar to low-angle cross-laminations; scattered macroscropic brachiopod and branching stromatoporoid (*Amphipora?*) grains in lower to middle parts. Upper beds grade upward to fine skeletal wk, gradational above. [1.6 m].

Unit 5. Fine grainst., abraded grain, fragmented brachiopods, finer grains than below, generally fining upwards; brachiopods dominated by *Pseudoatrypa*, scattered crinoid debris. Small-scale tabular cross-stratification; some trough cross-beds (troughs 1 m long, 10 cm depth). Exposed in stepped ledges, sloping back upwards, minor stylolites; prominent bedding style change above. [1.15 m].

Unit 4. Brachiopod-rich grainst., medium to coarse grained, common brachiopods (primarily *Pseudoatrypa*) and crinoid debris, packed brachiopod concentrations along some laminae (laterally variable; valves mostly convex-up). Lower 15 cm with lithoclasts of underlying lithologies, scattered abraded solitary corals. Unit with low-angle (to 15°) cross-bedding. Single bed, massive ledge; irregular sharp contact at base. [70 cm].

Unit 3. Skeletal mudst. to wk; scattered brachiopods (primarily *Allanella*); in thin beds (3-7 cm); highly fractured (probably secondary). Break in slope 25 cm above base, more thinly bedded above; top 12 cm partly covered; irregular surface at top. [87 cm].

Unit 2. Fine pk to grainst., abraded grains; scattered small to large brachiopods (*Pseudoatrypa, Allanella*), crinoid debris, scattered intraclasts or lithoclasts; calcite void and fracture fillings; ledge former. [36 cm].

Unit 1. Poorly exposed limestone beds; upper 30 cm in two beds, lower bed is a calcitic crystalline limestone with internal sediment fills, upper 8-10 cm is dense sublithographic limestone (mudst.), flaggy beded; basal 35 cm (to water level 5/10/1994) is mostly covered, limestone noted. [65 cm, includes basal covered interval].

12.2 Depart parking area. *Carefully and cautiously turn around and return to highway.*

12.5 Intersection with Mehaffey Bridge Road, county highway F28. Depending on weather conditions, time, and motivation, two options present themselves at this point. We will either turn left and procede to the GSI banquet site at the Westfield Inn, or we will turn right and make one more geologic stop in the Sugar Bottom area.

OPTION 1: Procede to GSI banquet site.

12.5 Turn left.
14.4 Turn right on Penn St. in North Liberty.
14.9 Stop. Turn left on Highway 965.
17.9 Continue past Oakdale campus entrance (Iowa DNR-Geological Survey Bureau facility located here).
18.5 Stop light. Turn left; entrance to Westfield Inn.

OPTION 2: Procede to Stop 4, Sugar Bottom area.

12.5 Turn right.
13.4 Cross Mehaffey Bridge.
13.5 Turn right; entrance to Sugar Bottom Recreation Area. Follow road to campground entrance area. We will probably park vehicles in the area adjacent to the water tower. We will walk westward through the woods, then downhill to the limestone exposures along the east side of Coralville Lake (Stop 4).

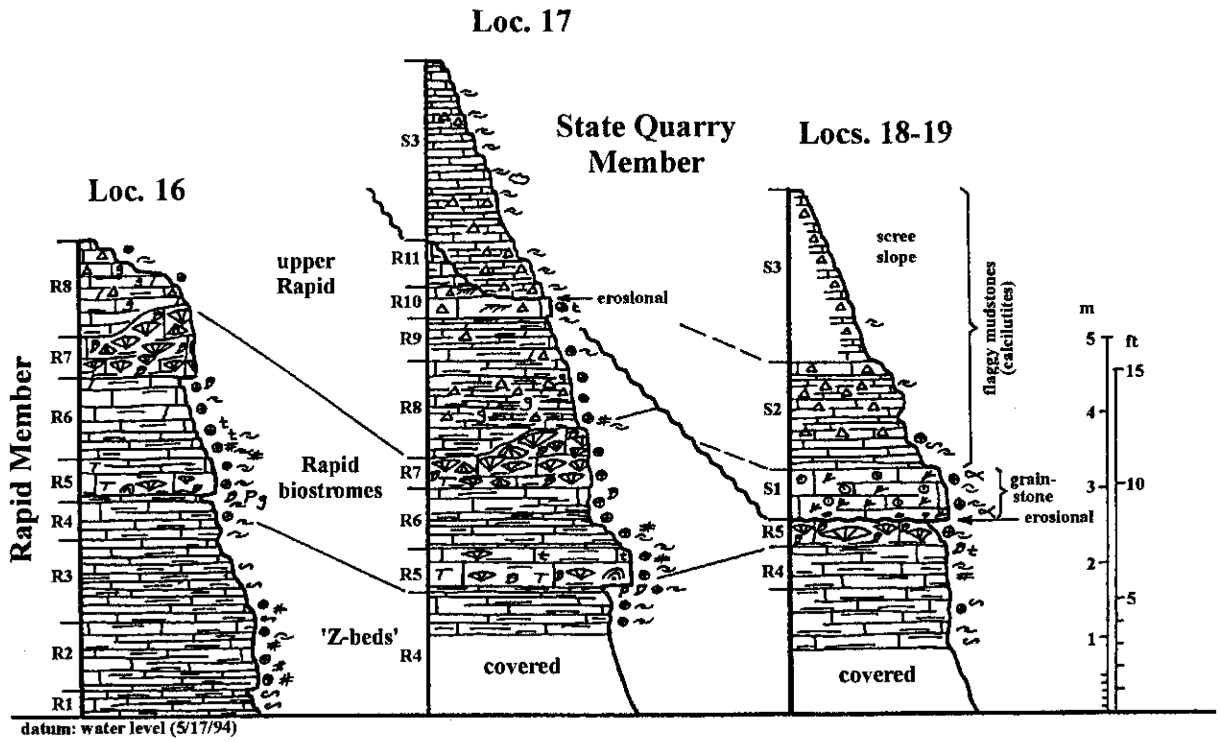


Figure 20. Cross-section of the State Quarry Member, Lithograph City Formation, Johnson County, Iowa. Section is located along Coralville Lake, south of the mouth of "Indian Creek." See Figure 15 for localities, inside back cover for Key to symbols.

STOP 4. SUGAR BOTTOM AREA — STATE QUARRY MUDSTONES OVER RAPID MEMBER

We will examine a mudstone-dominated limestone facies of the State Quarry Member at this stop, which contrasts with the grainstone-dominated facies seen at the previous stops. The mudstone facies dominates in more marginal areas of the State Quarry channels. These mudstones are generally flaggy bedded, and bands of nodular chert are common. Fossils are relatively rare in these beds. Faint burrow mottles are noted. The contained fauna is different than seen at previous stops, with scattered complete brachiopod shells characterized by *Hadrorhynchia* and *Allanella*. Crinoid material is rare, and occasional bivalve (clam) molds are encountered.

Our focus will be in the area of Localities 18 and 19 (Fig. 20), where mudstone strata are underlain by a relatively thin but prominent bed of brachiopod-bearing crinoidal grainstone at the base of the State Quarry Member. This lower bed contains reworked corals and stromatoporoids, and fish bone is scattered. The stromatoporoids and corals (silicified in part) are reworked from subjacent beds of the Rapid biostrome and display an unusual dark color. The basal grainstone occupies only the deepest erosional level on the sub-State Quarry surface, and mudstone strata lap higher portions of the upper Rapid Member to the north (Locality 17). If time permits we will visit Locality 17, where the State Quarry Member is entirely represented by cherty mudstone facies.

Strata of the Rapid Member are erosionally truncated beneath the State Quarry beds at Stop 4. The State Quarry overlies upper Rapid strata at Locality 17, and the first Rapid biostrome is erosionally beveled beneath the basal State Quarry grainstone at Locality 19. The highest beds of the Rapid are seen to the north, where the Rapid biostromes are beautifully exposed. The upper biostrome displays minor relief along its upper surface, which conforms to large masses of *Hexagonaria*. The corals are partially silicified and display an unusual dark-stained coloration. The upper Rapid includes cherty and glauconitic strata, with a thin cross-bedded crinoidal grainstone noted near the top.

Localities 18 and 19 show some interesting structural features in the Devonian bedrock. A reverse fault cuts across the strata in the central area, with about 2.1 m of vertical offset noted (upthrown to south). Adjacent to the lake embayment at the northern extremity of Locality 18, strata of the Rapid Member show relatively steep dips (up 25° to the southwest).

Stop 4 provides an informative look at distinctive mudstone facies developed in the marginal areas of the State Quarry channels. The abundance of mud indicates that depositional conditions were relatively quiet. More vigorous bottom currents, capable of winnowing mud and transporting coarse skeletal grains, is characteristic of the central channel areas. Watson (1974) interpreted the central channels to be the locus of vigorous tidal current activity. Mudstone facies became dominant as the channels were infilled, possibly at a time of progressive deepening associated with northward transgression of the expanding seaway (Lithograph City Fm.; T-R cycle IIb of Johnson et al., 1985). The exposures at Stop 4 have not been previously described, and were not included in Watson's (1974) otherwise comprehensive study of the State Quarry Member in the Coralville Lake area.

EAST SIDE OF CORALVILLE LAKE, SUGAR BOTTOM AREA
Mouth of "Indian Cave Creek" south to inlet west of Sugar Bottom water tower
Loc. 16, NW SE SE NE sec. 5; Loc. 17, SE SW SE NE sec. 5; Locs. 18/19, NE NE SE sec. 5, T80N, R6W, Johnson Co., Iowa.
Brian J. Witzke and Bill J. Bunker; measured May 1994.
Composite description of rock units.

MIDDLE DEVONIAN
CEDAR VALLEY GROUP, LITHOGRAPH CITY FORMATION
STATE QUARRY MEMBER

Unit S3. Sparsely skeletal mudst., flaggy bedded; nodular chert bands, especially in lower part (Loc. 17 with cherty bands 15 cm, 40 cm, 62 cm, 2.0 m, 3.1 m above base of unit), chert is white to brown, smooth to chalky. Scattered brachiopods, whole shell, part silicified (especially in upper part), primarily *Hadrorhynchia* and *Allanella*; packed brachiopod concentrations along some bedding surfaces (especially basal beds, also 2.4 m above base [with *Spathella* bivalves]). Sharply overlies upper Rapid strata at Loc. 17, lower 65 cm laps underlying erosional surface. Represented by scree slope above unit S2 at Loc. 19. [3.9 m at Loc. 17; 2.3 m scree slope at Loc. 19].

Unit S2. Sparsely skeletal mudst., flaggy bedded, lower 40 cm with scattered fine pk stringers; nodular chert bands (45-50 cm, 80 cm, 1.0 m, 1.1 m, 1.3 m above base of unit at Loc. 19). Scattered brachiopods, primarily *Hadrorhynchia* and *Allanella*; rare crinoid debris (crinoid stem 40 cm above base); some beds display faint horizontal burrow mottles (pk-filled burrows 30 cm above base). Unit S2 at Loc. 19 marked by sharp basal contact. [Loc. 19, 1.4 m].

Unit S1. Crinoidal grainst., fine to medium grained; ledge former, weathers into beds 3 to 10 cm. Abraded to whole-shell brachiopods, primarily *Pseudoatrypa* and *Hadrorhynchia*. Scattered dark-colored stromatoporoid grains; reworked *Hexagonaria* in basal part (part silicified, derived from underlying strata). Scattered fish bone (placoderm, dipnoan), especially in basal part. Sharp base. [Laterally variable thickness at Locs. 18-19, overlies units R5 or R4; 70 cm thick, thins laterally].

LITTLE CEDAR FORMATION
RAPID MEMBER

Unit R11. Skeletal wk, arg., crinoid debris, brachiopods (large *Neatrypa, Orthospirifer*), pachyporid corals, burrows. Fractured beds and blocks of upper Rapid strata (with some float of lower Coralville lithologies) are exposed along the north edge of Loc. 17; overlain by flaggy mudstones of the State Quarry Member; interval is erosionally truncated southward beneath State Quarry beds. [0-65 cm].

Unit R10. Skeletal pk-grainst. Lower 26 cm, fine to coarse crinoidal grainst., pachyporids noted; low-angle cross-stratification, grades laterally into crinoidal pk; scattered chert nodules in pk; directly overlain by unit S3 in south part of Loc. 17 where top is an irregular corroded and pitted surface. Upper 17 cm, fine skeletal pk, stringers of coarse pk; low-angle cross-stratification; partially silicified, chert nodules near middle; grades laterally into skeletal wk; erosional top, interval is truncated northward at Loc. 17 beneath State Quarry beds. This unit is equivalent to the cross-bedded grainstones at Curtis Bridge and Mid-River Marina in the northwestern area of Coralville Lake. [23-43 cm].

Unit R9. Dolomitic limest., arg., skeletal wk-pk. Lower 15 cm, skeletal wk, scattered brachiopod and crinoid debris, scattered chert nodules. Upper 23 cm, fine skeletal pk, chert noudles. Unit is poorly exposed at Loc. 17; small ledges in upper part. [56 cm].

Unit R8. Skeletal wk-pk, arg., dolomitic (especially at Loc. 16); glauconite grains scattered through most of unit (grains to 1mm). Nodular chert bands in middle to upper part, smooth to chalky, some nodules are chertified skeletal pk. Crinoid debris scattered to common, part silicified, includes scattered stem segments; scattered brachiopods (atrypids, *Orthospirifer*); scattered bryozoans (fenestellids and trepostomes in lower part); scattered burrows. Lower 35 cm laps onto irregular surface of underlying biostrome (unit R7), pinches out against mounded coral heads below. Lower beds equivalent to unit 23 at Stop 1. [90-125 cm].

Unit R7. *Hexagonaria*-rich biostrome; slightly arg. pk matrix; abundant *Hexagonaria*, increasing in size and abundance upward, packed in upper part, some overturned, part silicified; scattered horn corals, especially in lower part; scattered *Favosites*. Irregular upper surface conforms to underlying coral heads; locally mounded in upper part, thickens 30-45 cm over lateral distances of 3 m; overlying unit laps thicker portions of biostrome. Equivalent to unit 22 at Stop 1. [Loc. 16, 50-95 cm; Loc. 17, 39-70 cm].

Unit R6. Crinoidal wk-pk and arg. wk; irregular beds 2-10 cm in lower half, harder and more dolomitic in upper half. Lower half skeletal wk-pk, crinoid debris and stems common, scattered to common pachyporid corals, brachiopods (atrypids, *Orthospirifer, Tylothyris, Strophodonta, Schuchertella*), bryozoans (fenestellids, trepostomes [to 5-15 cm at 15-20 cm above base]). Upper half less skeletal, arg. wk with more skeletal rich stringers, crinoid debris, brachiopods (atrypids, *Orthospirifer*), horn coral near top. Equivalent to units 20-21 at Stop 1. [Loc. 17, part covered, ?85 cm; Loc. 16, 1.1 m].

Unit R5. Skeletal wk-pk, slightly arg. to arg., coral-rich biostrome in part; ledge former in two beds with basal shaly re-entrant. Basal 9 cm, arg. to shaly skeletal wk-pk, crinoid debris, brachiopods (atrypids, *Orthospirifer, Schizophoria*), horn corals, pachyporids; glauconite and phosphatic grains. Lower ledge (30-32 cm thick), coral biostrome with wk-pk matrix; scattered to common crinoid debris, brachiopods (atrypids); common corals include ramose favositids, massive *Favosites* (to 25 cm), *Hexagonaria* (to 30 cm, rarely to 60 cm), horn corals; some corals are encrusted with massive stromatoporoids; corals are part silicified, commonly with dark gray rinds or coatings. Upper ledge (19-24 cm thick), slightly arg. to arg. wk, arg. parting at base; biostromal in part, fewer corals than below, dominantly ramose favositids (especially in lower part), also horn corals, *Hexagonaria* (to 35 cm), and pachyporids; crinoid debris, brachiopods (atrypids, *Orthospirifer, Strophodonta*), bryozoans (fenestellids, trepostomes [at base]). Unit R5 is laterally truncated beneath State Quarry strata at Locs. 18-19. Equivalent to unit 19 at Stop 1. [58-65 cm].

Unit R4. Skeletal mudst. to wk, arg. to very arg., shalier and less fossiliferous in lower part, recessive, irregular bedded; scattered to common whole-shell brachiopods (atrypids, *Orthospirifer, Tylothyris, Athyris, Schizophoria*), scattered crinoid debris (including stem segments), rare fenestellid bryozoans. Equivalent to unit 18 at Stop 1. [60-70 cm].

Unit R3. Mudst., arg. to very arg., sparsely skeletal; burrows, scattered crinoid debris, scattered brachiopods (atrypids, *Orthospirifer*), rare cystodictyonid bryozoans. Upper "Z-beds." Equivalent to unit 17 at Stop 1. [1.0 m].

Unit R2. Skeletal wk-pk and mudst.-wk, arg., skeletal-rich stringers, less skeletal upward; ledge former. Fine crinoid debris (stems in lower part), bryozoans (fenestellids, cystodictyonids), scattered brachiopods (atrypids), burrows. This is the more skeletal-rich interval in the middle "Z-beds," equivalent to unit 16 at Stop 1. [90 cm].

Unit R1. Mudst., arg. to very arg., sparse skeletal, largely unfossiliferous; scattered to common burrows. Basal beds at Loc. 16; lower "Z-beds." Equivalent to the upper part of Unit 15 at Stop 1. [35 cm exposed to water level at Loc. 16].

This ends the day's geologic tour. We will trek eastward through the woods and return to the vehicles. Return to the Mehaffey Bridge area, and follow Option 1 roadlog to North Liberty and the Westfield Inn. The Highway 965/Interstate-80 interchange lies a short distance to the south. Alternatively, north-bound travelers can access Interstate-380 west of North Liberty. Thanks for coming. Have a safe journey home!

REFERENCES

Beinert, Richard J., 1968, Development report of Coralville Reservoir geological preserve by Mehaffey Bridge, and State Quarry Geological Preserve: Iowa State Advisory Board for Preserves, Development Series Report 1, Iowa City, 40 p.

Brett, C. E., Boucot, A.J., and Jones, B., 1993, Absolute depths of Silurian benthic assemblages: Lethaia, v. 26, p. 25-40.

Bunker, B.J., and Hallberg, G.H., 1984, Underburden - Overburden, An examination of Paleozoic and Quaternary strata at the Conklin Quarry near Iowa City: Geological Society of Iowa, Guidebook 41, 81 p.

Bunker, B.J., and Witzke, B.J., 1989, The Coralville and Lithograph City formations of the Coralville Lake area: Geological Society of Iowa, Guidebook 51, p. 37-46.

Bunker, B.J., and Witzke, B.J., 1987, Cedar Valley Formation of the Coralville Lake area, Iowa: Geological Society of America Centennial Field Guide - North-Central Section, p. 113-117.

Bunker, B.J., and Witzke, B.J., 1992, An upper Middle through lower Upper Devonian lithostratigraphic and conodont biostratigraphic framework of the Midcontinent Carbonate Shelf area, Iowa: *in* Day, J., and Bunker, B.J., editors, 1992, The stratigraphy, paleontology, depositional and diagenetic history of the Middle-Upper Devonian Cedar Valley Group of central and eastern Iowa: Iowa Department of Natural Resources, Geological Survey Bureau, Guidebook Series No. 16, p. 3-25.

Bunker, B.J., Witzke, B.J., and Day, J.E., 1986, Upper Cedar Valley stratigraphy, north-central Iowa, Lithograph City Formation: Geological society of Iowa, Guidebook No. 44, 41 p.

Calhoun, S.H., 1983, Echinoderms of the Devonian Cedar Valley Limestone in Iowa: M.S. thesis, University of Iowa, Iowa City, Iowa, 153 p.

Calvin, S., 1897, The State Quarry Limestone: Proceedings of the Iowa Academy of Sciences, v. 4, p.16-21.

Day, J., 1992, Middle-Upper Devonian (Late Givetian-Early Frasnian) brachiopod sequence in the Cedar Valley group of central and eastern Iowa: *in* Day, J., and Bunker, B.J., editors, 1992, The stratigraphy, paleontology, depositional and diagenetic history of the Middle-Upper Devonian Cedar Valley Group of central and eastern Iowa: Iowa Department of Natural Resources, Geological Survey Bureau, Guidebook Series No. 16, p. 53-105.

Day, J., and Bunker, B.J., 1992, The stratigraphy, paleontology, depositional and diagenetic history of the Middle-Upper Devonian Cedar Valley Group of central and eastern Iowa: Iowa Department of Natural Resources, Geological Survey Bureau, Guidebook Series No. 16, 195 p.

Denison, R.H., 1985, A new ptyctodont placoderm, *Ptyctodopsis*, from the Middle Devonian of

Iowa: Journal of Paleontology, v. 59, p. 511-522.

Dunn, D.L., 1959, Devonian chitinozoans from the Cedar Valley Formation in Iowa: Journal of Paleontology, v. 33, p. 1001-1017.

Eastman, C.R., 1908, Devonian fishes of Iowa: Iowa Geological Survey, Annual Report, v.28, p. 29-386.

Hickerson, W., 1992, Trilobites from the Late Givetian Solon Member, Little Cedar Formation of eastern Iowa and northwestern Illinois: *in* Day, J., and Bunker, B.J., editors, 1992, The stratigraphy, paleontology, depositional and diagenetic history of the Middle-Upper Devonian Cedar Valley Group of central and eastern Iowa: Iowa Department of Natural Resources, Geological Survey Bureau, Guidebook Series No. 16, p. 123-141.

Hickerson, W., 1994, Ptyctodontid placoderms? from the upper Spring Grove Member of the Pinicon Ridge Formation: Geological Society of Iowa, Guidebook 59, p. 45-53.

Johnson, J.G., Klapper, G., and Sandberg, C.A., 1985, Devonian eustatic flucations in Euramerica: Geological Society of America Bulletin, v. 96, p. 567-587.

Kettinbrink, E,C., 1973, Depositional and post-depositional history of the Devonian Cedar Valley Formation, east-central Iowa: unpublished Ph.D. dissertation, University of Iowa, 191 p.

Kettinbrink, E.C., and Toomey, D.F., 1975, Distribution and paleoecological implications of calcareous forminifera in the Devonian Cedar Valley Formation of Iowa: Journal of Foraminiferal Research, v. 5, p. 176-187.

Keyes, C.R., 1912, Sundry provincial and local phases of the general geologic section of Iowa: Proceedings of the Iowa Academy of Science, v. 19, p. 147-151.

Klug, C.R., 1992, Distribution and biostratigraphic significance of miospores in the Middle-Upper Devonian Cedar Valley Group of Iowa: *in* Day, J., and Bunker, B.J., editors, 1992, The stratigraphy, paleontology, depositional and diagenetic history of the Middle-Upper Devonian Cedar Valley Group of central and eastern Iowa: Iowa Department of Natural Resources, Geological Survey Bureau, Guidebook Series No. 16, p. 111-121.

Müller, K.J., and Müller, E.M., 1957, Early Upper Devonian (Independence) conodonts from Iowa, Part I: Journal of Paleontology, v. 31, p. 1069-1108.

Plocher, Orrin W., 1989, Geologic reconnaissance of the Coralville Lake area: Geological Society of Iowa Guidebook 51, Iowa City, p. 109-112.

Plocher and Bunker, 1989, A geological reconnaissance of the Coralville Lake area: Geological Society of Iowa, Guidebook 51, p. 1-9.

Schultze, H.-P., 1992, A new long-headed dipnoan (Osteichthyes) the the Middle Devonian of Iowa, USA: Journal of Vertebrate Paleontology, v. 12, p. 42-58.

Stainbrook, M.A., 1935, Stratigraphy of the Devonian of the Upper Mississippi Valley: Kansas Geological Society, Guidebook 9th Annual Field Conference, p. 248-260.

Stainbrook, M.A., 1937, New echinoderms from the Devonian Cedar Valley Formation of Iowa: American Midland Naturalist, v. 18, p. 899-904.

Stainbrook, M.A., 1938a, *Atrypa* and *Stropheodonta* from the Cedar Valley beds of Iowa: Journal of Paleontology, v. 12, p. 229-256.

Stainbrook, M.A., 1938b, Pentameridae of the Cedar Valley beds of Iowa: American Midland Naturalist, v. 19, p. 723-739.

Stainbrook, M.A., 1940a, Orthid brachiopods of the Cedar Valley limestone of Iowa: American Midland Naturalist, v. 23, p. 482-492.

Stainbrook, M.A., 1940b, *Prismatophyllum* in the Cedar Valley beds of Iowa: Journal of Paleontology, v. 14, p. 270-284.

Stainbrook, M.A., 1940c, *Elytha* in the Cedar Valley beds of Iowa: American Midland Naturalist, v. 24, p. 414-420.

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

Stainbrook, M.A., 1941b, Terebratulacea of the Cedar Valley beds of Iowa: Journal of Paleontology, v. 152, p. 42-55.

Stainbrook, M.A., 1942, Brachiopoda of the Cedar Valley beds of Iowa, Inarticulata, Phynchonellacea, and Rostrospiracea: Journal of Paleontology, v. 16, p. 604-619.

Stainbrook, M.A., 1943a, Strophomenacea of the Cedar Valley Limestone of Iowa: Journal of Paleontology, v. 17, p. 39-59.

Stainbrook, M.A., 1943b, Spiriferacea of the Cedar Valley Limestone of Iowa: Journal of Paleontology, v. 17, p. 417-450.

Strimple, H.L., 1959, Crinoids from the Missourian near Bartlesville, Oklahoma: Oklahoma Geological Survey, Oklahoma Geology Notes, v. 19, p. 115-127.

Thomas, A.O., 1924, Echinoderm of the Iowa Devonian: Iowa Geological Survey, Annual Report, v. 29, p. 385-550.

Walter, O.T., 1923, Trilobites of Iowa and some related Paleozoic forms: Iowa Geological Survey, Annual Reports, 1923 and 1924, with accompanying papers, v. 31, p. 167-389.

Watson, M.G., 1974, Stratigraphy and environment of deposition of the State Quarry Limestone, Johnson County, Iowa: unpublished M.S. thesis, University of Iowa, 140 p.

Witzke, B.J., 1984, Geology of the University of Iowa campus area, Iowa City, Iowa Geological Survey, Guidebook No. 7, 76 p.

Witzke, B.J., 1987, Models for circulation patterns in epicontinental seas applied to Paleozoic facies of the North American craton: Paleoceanography, v. 2, p. 229-248.

Witzke, B.J., Bunker, B.J., and Rogers, F.S., 1988, Eifelian through Lower Frasnian stratigraphy and deposition in the Iowa area, central Midcontinent, U.S.A.: *in* McMillan, N.J., Embry, A.F., and Glass, D.J., editors, Devonian of the World, Canadian Society of Petroleum Geologists, Memoir 14, Proceedings of the Second International Symposium on the Devonian System, Calgary, Volume I: Regional Syntheses, p. 221-250.

Woodson, M.L., 1990, Middle and Upper Devonian (Givetian-Famennian) conodont biostratigraphy and lithostratigraphy in the subsurface of northeastern Missouri: unpublished M.S. thesis, University of Iowa, 239 p.

Youngquist, W.L., 1947, A new Upper Devonian conodont fauna from Iowa: Journal of Paleontology, v. 21, p. 95-112.

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

KEY

Major Lithologies:

- limestone
- "sublithographic" limestone (micritic or pelletal)
- irregularly bedded limestone
- coral or stromatoporoid-rich limestone (biostrome)
- laminated limestone
- highly fractured to brecciated brecciated or intraclastic
- shale partings argillaceous

Other lithologic modifiers:

- hardground surface
- stylolites
- b "birdseye"
- v vuggy
- c calcite void fill
- P phosphate
- g glauconitic
- m mudstone
- sandy
- intraclasts, lithoclasts
- cross-bedded
- △ chert
- "stromatactis" structures
- voids or fractures filled with laminated internal sediment

Fossils:

- digitate stromatoporoids ("*Idiostroma, Amphipora*")
- hemispherical or laminar stromatoporoids
- T colonial tabulate corals (favositids)
- t small tabulate corals
- colonial rugose corals (*Hexagonaria*)
- solitary rugose corals
- ⊥ overturned corals and stromatoporoids
- brachiopods
- # bryozoans
- gastropods
- bivalves
- ⊕ crinoid debris
- ⊙ crinoidal limestone
- trilobites
- fish teeth, plates
- plant debris
- burrows
- nautiloids

Geological Society of Iowa
109 Trowbridge Hall
Iowa City, Iowa 52242-1319