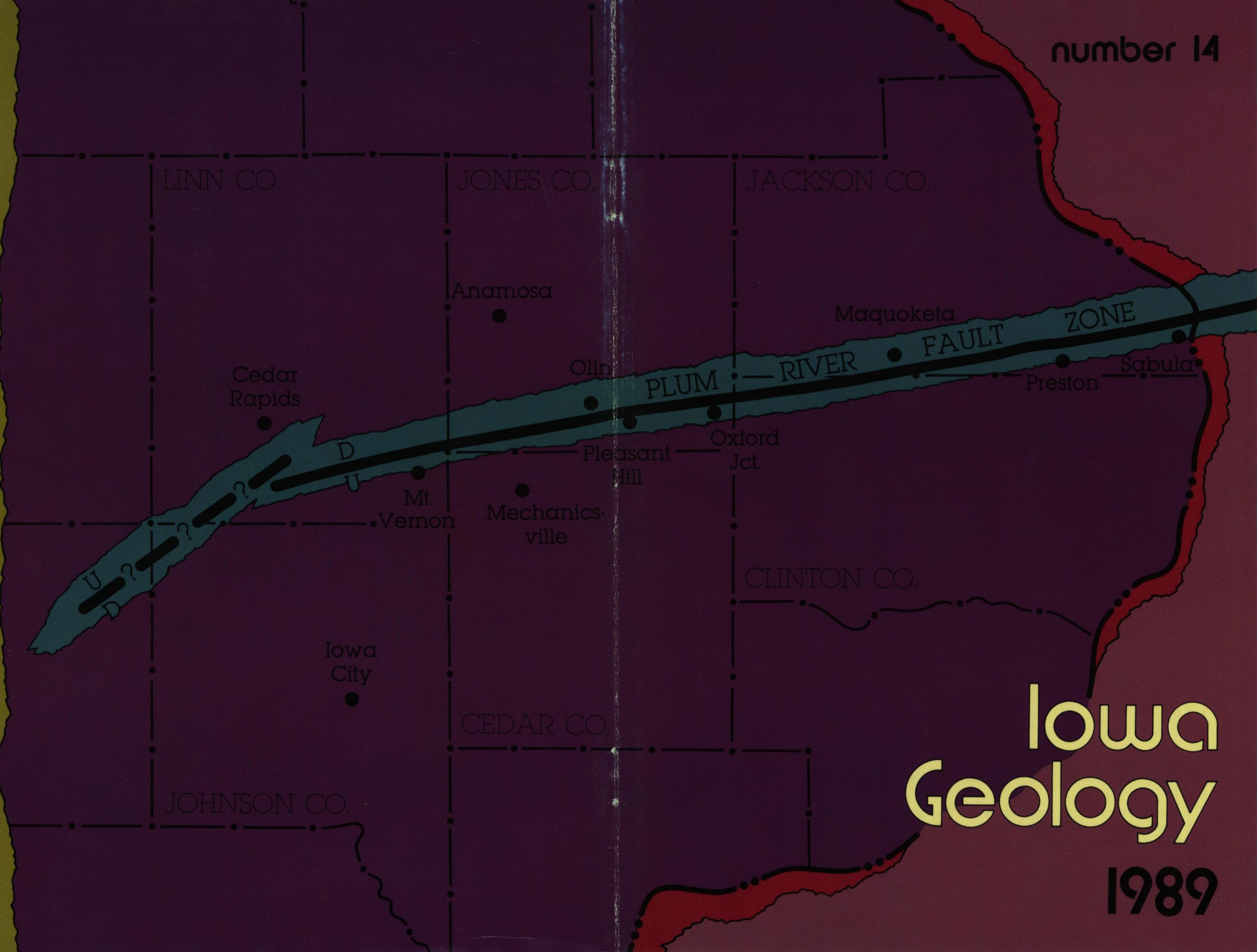
number 14

Iowa Geology

1989



Iowa Geology 1989

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Donald L. Koch
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Iowa
Department of Natural Resources

DNR

COVER:

Shifting of the Earth's crust has occurred along the Plum River Fault Zone in east-central Iowa. Today this fault poses no known seismic hazard, but it does influence the availability of groundwater resources and stone products.

Cover design and illustration by Patricia Lohmann

Jean C. Prior .... Editor
Patricia J. Lohmann .... Publications Designer, Artist

Editor's Note: I would like to thank Will Thomson, The University of Iowa Museum of Natural History, and Tim Kemmis for their generous assistance with logistics and photography at Iowa Hall.

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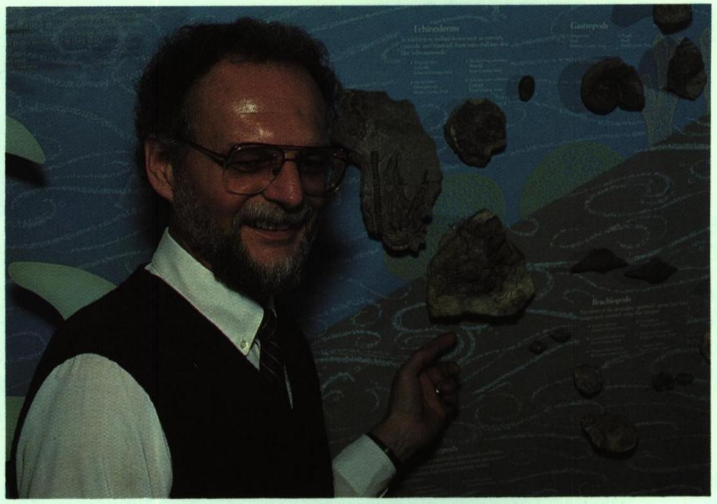


The fossil didn't look like much at first. Thinking it probably was part of a crinoid protruding from the wall of a limestone quarry, I continued to chip away with my hammer and chisel, trying to expose a little more of the specimen's interlocking skeletal plates. Complete crinoid "cups," as the plated living cavities are called, were not common in the area, but with a few more chips I would know whether to expend any more effort in the hot afternoon sun. A bit more of the rounded form came into view. The pattern was puzzling — different from most crinoid plates I had seen — but still too hidden to be certain. I pried a chunk of the surrounding rock loose (hoping not to break the fossil), carefully wrapped it to protect the exposed plates, and took it home to work on later.

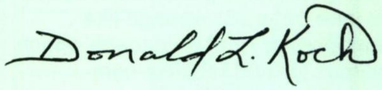
The rock lay on a table for a few days before I went back for another look. Slow, tedious work with special tools began to reveal more of the fossil. Fortunately, the covering material was different from the rest of the rock — hard, but more granular, and it could be picked off grain-by-grain. Remarkably, the fossil did seem to be a complete crinoid cup, brought to light after being buried on an Iowa seafloor over 350 million years ago. Another surprise awaited me. The plates *were* different; the entire form was different; this was a cystoid, similar to a crinoid but quite a different organism! After more painstaking work, part of a thin arm was exposed. Additional arms appeared as more rock was removed. Though it seemed too rare to expect, further excavation revealed the segmented stem was there too — not just a part, but the entire length. It ended in small, root-like expansions where it was anchored to the harder limestone knob. This was a complete cystoid, uncovered just as it lived eons ago.

Additional trips resulted in the collection of several complete cystoids from another part of the quarry where the rock was more weathered and easier to work. Not only had a new cystoid genus been discovered, but, as a bonus, other fossil forms were attached to the same limestone knobs. All were preserved where they had been part of a thriving community of organisms, until smothered by a layer of Devonian-age mud.

While this was an exceptionally rare

STATE GEOLOGIST'S VIEWPOINT

find, fossil discoveries are available to anyone who takes the time to look. After you read about Iowa's ancient seas and learn more about some of Iowa's rocks and fossils in this issue of *Iowa Geology*, look closer at those silent stones in quarries and along roadcuts or creek banks. You are sure to uncover another never-before-seen piece of earth history. Even those rare discoveries of great paleontological significance have sometimes been made by amateur collectors, even novices, who followed their curiosity.



Donald L. Koch
State Geologist and Bureau Chief

The University of Iowa Museum of Natural History

A rare colony of a new genus of Devonian cystoids was discovered by Don Koch in Floyd County. These fossils are preserved in their living positions, attached to limestone knobs on what was a shallow, eroded seafloor with moderate currents. This specimen is on permanent exhibit at Iowa Hall in The University of Iowa Museum of Natural History.

IOWA'S ANCIENT SEAS

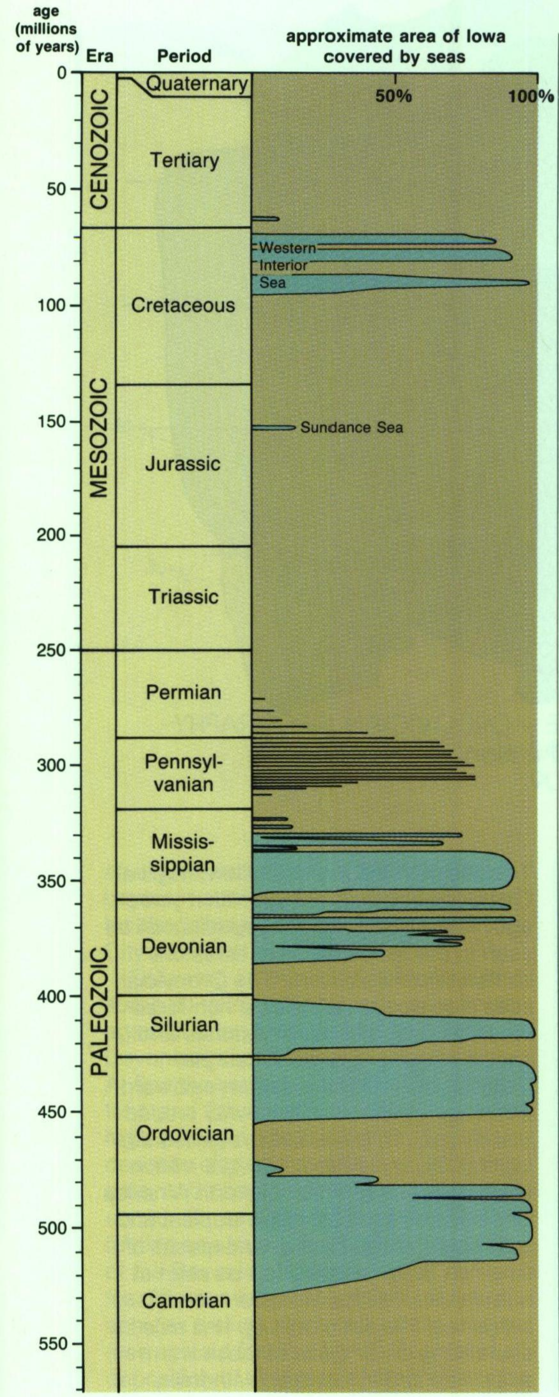
Brian J. Witzke

Iowa forms the land-locked heartland of the United States, far removed from the oceans which border our nation. In fact, central Iowa lies some 900 miles from the Atlantic, 850 miles from the Gulf of Mexico, 1,400 miles from the Pacific, and 900 miles from James Bay. Therefore, it may come as a surprise that seas once covered our state, not once, but many times. The stack of sedimentary rocks found in Iowa reveals a record of deposition on ancient sea bottoms, and the contained fossils give exceptional evidence of the varied life forms that inhabited those seas.

The water in these seas was salty, and it flowed in from the open oceans which surrounded the North American continent. Unlike the ocean basins, the seas in Iowa were much shallower. Evidence for plant photosynthesis on the seafloor is common, suggesting depths less than the effective limits of light penetration through water, typically 500 feet or less. Geologists refer to such seas as "epicontinental," meaning "on the continent." Hudson Bay is an example of a modern epicontinental sea.

It is important to realize that, although Iowa presently lies at latitudes between about 41° and 43°N in a temperate climate, Iowa occupied a position at low latitudes, at times equatorial, between about 550 to 250 million years ago. This resulted from the migration, or drift, of the North American continent through time. Therefore, many of Iowa's ancient seas were characterized by relatively warm water in subtropical and tropical settings. Deposition of lime mud and shallow-water coral reefs today is limited to latitudes no higher than about 30° to 35°. The extensive record of limestone deposits in Iowa, including abundant corals, conjures up images of clear-water subtropical seas like those seen in the modern Bahamas. The rock record also displays details of wave and tidal currents washing the seafloor; deep, quiet bottom conditions occasionally disturbed by storms; arid coastal mudflats and humid coastal swamps and deltas; and even stagnant, oxygen-depleted masses of bottom water where organic matter was preserved. Most commonly, however, Iowa's seas consisted of well-circulated water of normal marine salinity in which a host of animals and plants flourished.

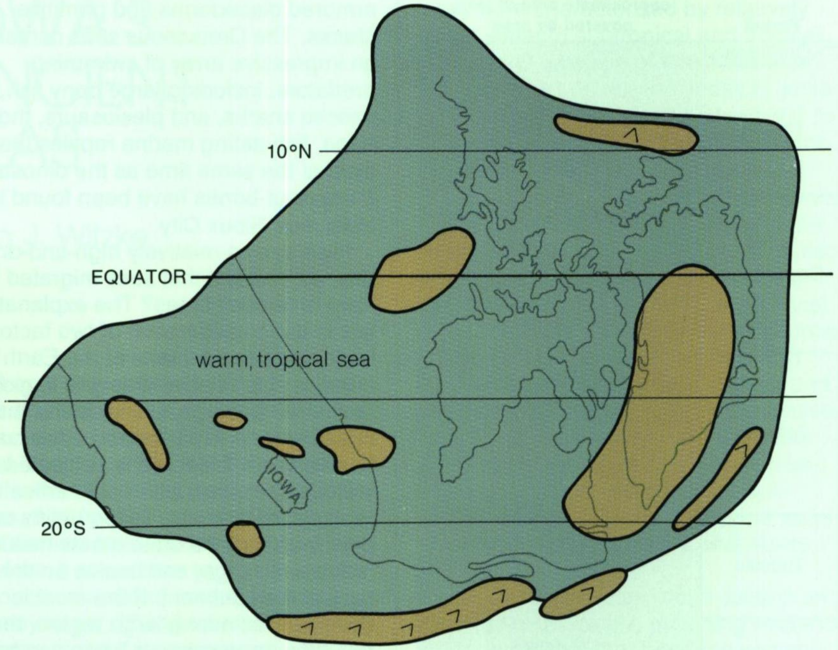
Iowa's sedimentary rocks contain an abundance of fossils, providing evidence of life forms that inhabited the ancient seas. The most abundant fossils are of organisms, most now long extinct, that lived on the sea bottom where they secreted shells or skeletons of lime and gleaned food particles from sea water or from bottom mud. Among the most important groups of these bottom-dwellers are the shelled brachiopods (see page 8), clams, and snails, and the crinoids or "sea lilies" (see inside back cover). Colonial filter-feeding animals included corals (see page 26), sponge-like stromatoporoids, and bryozoans, which sometimes formed reef-like communities. Soft-bodied worms burrowed through the sediments in search of food, and trilobites (see page 8) scavenged on the Paleozoic sea bottoms. Numerous swimming and floating creatures also inhabited the overlying waters. Microplankton formed the base of the food chain. Squid-like shelled cephalopods plied the waters of the Paleozoic and Mesozoic seas. By Devonian time, a variety of fish inhabited the seas of Iowa; most noteworthy were the armored placoderms and primitive sharks. The Cretaceous seas contained an impressive array of swimming predators, including large bony fish, advanced sharks, and plesiosaurs, those large, fish-eating marine reptiles that lived at the same time as the dinosaurs. Plesiosaur bones have been found in Iowa near Sioux City.



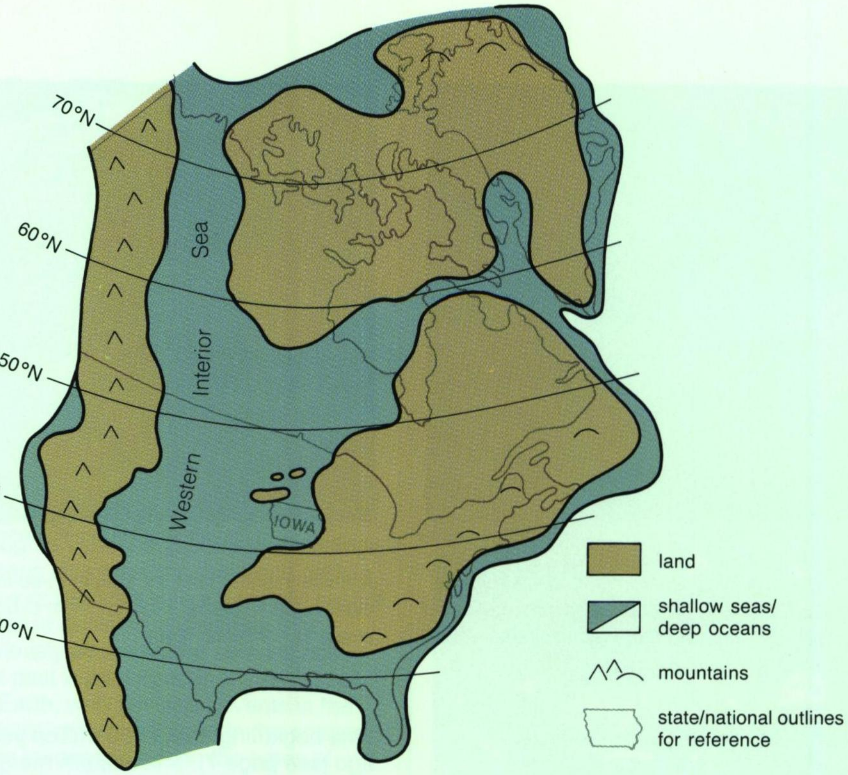
Iowa seems relatively high-and-dry today, so how is it that seas migrated into Iowa in ancient times? The explanation lies in the consideration of two factors: 1) large-scale movements of the Earth's crust, and 2) relative changes in global sea level. Geologists have found that the crust of North America and other continents is not fixed, but is subjected to various stresses that create vertical motions in the crust. These uplifts or downwarps of the crust create flexures, mountains, sags, and basins on the surface of the continent. If the crust is downwarped over a large region, the resulting depression or basin can be flooded by water from the surrounding ocean if the depression lies below global sea level and there is some connection with the open ocean. As the seas advanced into Iowa, the eroded river valleys were flooded first forming estuaries, and, as the seas continued their advance, vast areas were progressively inundated, covering Iowa and much of the interior of the continent with sea water.

Crustal movements in the ocean basins, especially at the mid-ocean ridges, could displace large volumes of water, potentially raising sea level and flooding continental lowlands. Likewise, the waxing and waning of continental ice sheets significantly modify the volume of water in the oceans. For example, the melting of the North American and European continental glaciers, especially about 12,000 years ago, raised sea level approximately 300 to 400 feet, flooding large areas of former land.

The record of ancient seas in Iowa dates back to when continental crust first



LATE – ORDOVICIAN GEOGRAPHY
440 million years ago



LATE – CRETACEOUS GEOGRAPHY
90 million years ago

formed the "basement" to what was to become the state of Iowa, beginning about 2.5 billion years ago. This Precambrian history is recorded by rocks now largely buried deep beneath the surface and spans the time from about 600 to 2,500 million years ago. Although this history has not been worked out in detail, various rocks in Iowa record the presence of shallow seas and volcanic islands fringing ancient ocean margins at that time. Sediments deposited in the ancient Precambrian seas include the distinctive pink quartzite seen at Gitchie Manitou State Preserve in northwest Iowa.

The better-known history of seas in Iowa begins in the Paleozoic Era (see page 5), a time when the shells of sea-dwelling animals first became abundant. Trilobites thrived in the shallow, tropical Cambrian seas some 500 million years ago. These early marine deposits can be seen in the sandstone and limestone bluffs of northeast Iowa. The Ordovician seas (see above) also left a rich fossil record exposed in the limestones and shales of eastern Iowa. When the Ordovician seas withdrew, an eastward-draining network of valleys was eroded across eastern Iowa. Seas returned during the Silurian period (400-425 million years ago), when much of North America was covered by clear-water tropical and subtropical seas. Extensive deposits of lime-rich Silurian rocks can be seen at numerous localities in eastern Iowa. Large reef-like structures up to a mile in diameter grew at times in these warm seas. As the Silurian seas withdrew, eastern Iowa became a restricted embayment in which the familiar laminated building stone from the Anamosa-Stone City area was deposited.

Following an erosional episode lasting some 20 to 25 million years, seas once again flooded Iowa during the Middle Devonian, about 385 million years ago. At first the seaway was restricted in extent, and the water was characterized by high salinity and evaporation. Extensive deposits of gypsum salts formed at that time, and now are an important economic resource for the state. Fluctuating sea levels during the remainder of the Devonian left deposits of fossiliferous limestone, shale, and gypsum, as well as signs of surface erosion (see cystoid fossil, page 3). Extensive deposition of lime also characterized the Mississippian seas, which covered much of Iowa about 330 to 360 million years ago. The bluffs and cliffs of fossiliferous limestone along the Mississippi River near Burlington and Keokuk form part of the classic geologic reference area from which the Mississippian Period derives its name.

The repeated rise and fall of sea level during the Pennsylvanian was caused by prolonged glacial activity in the southern hemisphere between about 275 and 350 million years ago. Iowa was flooded at least 45 times during this geologic period alone. These alternating episodes of marine and terrestrial deposition stacked seams of coal and layers of river mud between marine deposits of limestone and dark shale.

The record of Permian sedimentation

Paul VanDorpe

A selection of fossil brachiopods, abundant bottom-dwelling marine organisms, collected from Devonian rocks of eastern Iowa.

The University of Iowa Museum of Natural History

A fossil trilobite, with its typical three-lobed, oval-shaped external skeleton, from Ordovician strata in northeast Iowa.

has been lost to erosion in Iowa; however, the presence of marine limestones and shales of this age near the Iowa-Nebraska state line indicates that Permian seaways did expand into Iowa. There is no evidence that seaways encroached into Iowa during the latest Permian through early Mesozoic, from about 150 to 260 million years ago. It seems likely that Iowa was dry land during this time, experiencing a prolonged period of erosion as the continent migrated progressively northward across subtropical latitudes.

Economically important deposits of gypsum of Late Jurassic age occur around the Fort Dodge area, and were probably deposited in a marginal marine basin under arid climatic conditions. This area apparently occupied a position near the eastern margin of an extensive Late Jurassic seaway (the "Sundance Sea"; see page 5) that trended across the western U.S. and whose deposits are known from adjacent Nebraska. The extensive "Western Interior Sea" expanded eastward into Iowa during Cretaceous time beginning about 100 million years ago (see page 7). The eastern margin of this seaway expanded and contracted several times during the Late Cretaceous, and marine shales and chalks remain as evidence of this last documented invasion of seas into Iowa. Evidence for the final influx of shallow seas into the central U.S. about 60 million years ago is found in adjacent South Dakota, where Early Tertiary marine shales occur. This sea may have extended into Iowa, but subsequent erosion has removed all deposits along what would have been the eastern margin of that sea.

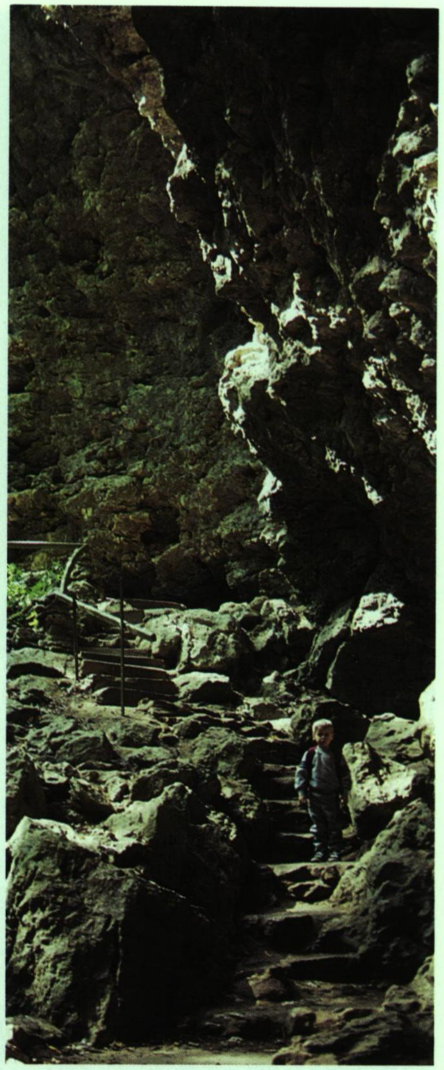
The expansion and contraction of seas across central North America has a long and recurring history. It seems reasonable to suggest that these marine environments may one day, in the far distant future, return again to the heartland. □

STATE PARKS:
CROSSROADS WITH THE GEOLOGIC PAST

Jean C. Prior

Visitors to Iowa's state parks follow road signs and trail markers to guide them through a variety of picturesque settings, perhaps little realizing that each park is also a crossroads with a geologic past of immense duration and variety that previously occupied the same space. That past is packaged in the depths of the Earth, with the latest events in the geologic record still seen in the shapes of the landscape and in the types of materials exposed at the land surface.

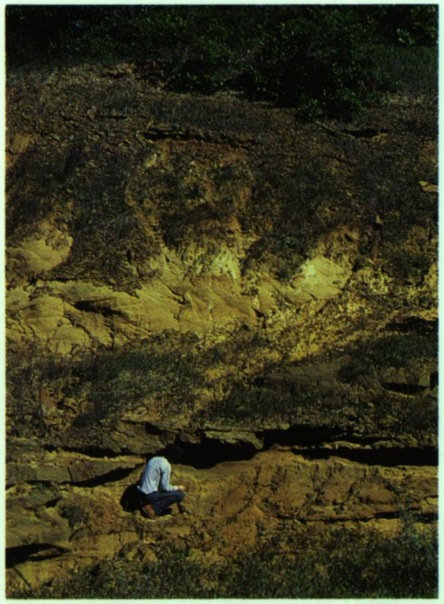
In some of Iowa's state parks, these landscapes and materials reflect the passage of glaciers, the accumulation of wind-blown deposits, or the sculpture of flowing water. For example, state parks in the lakes region of north-central Iowa contain abundant wetland habitats often surrounded by irregular, knobby hills composed of the stony debris left behind by melting glacial ice. Parks along Iowa's western border are nestled in steeply pitched hills carved from wind-deposited silt, the product of fine-grained glacial outwash blown from the Missouri Valley below. Still other parks are located on flat-floored valleys, landscape corridors excavated by flowing rivers and underlain by their water-sorted deposits. South-central Iowa parks are set in billows of well-drained hills and often contain artificial lakes that store water in the network of drainageways that have dissected and reshaped these old glacial plains.



Greg Ludvigson

Massive outcrops of weathered Silurian dolomite contribute to the rugged beauty of Maquoketa Caves State Park in Jackson Co.

Those state parks, however, where bedrock is exposed reach much farther back in geologic time and bring visitors into direct contact with the remains of



Greg Ludvigson

Above: Iron-stained, Cretaceous sandstones near Springbrook State Park in Guthrie County exhibit patterns characteristic of river deposits. Right: Dolomite bluffs at Bellevue State Park in Jackson County contain lime deposited in warm, clear, Silurian seas.

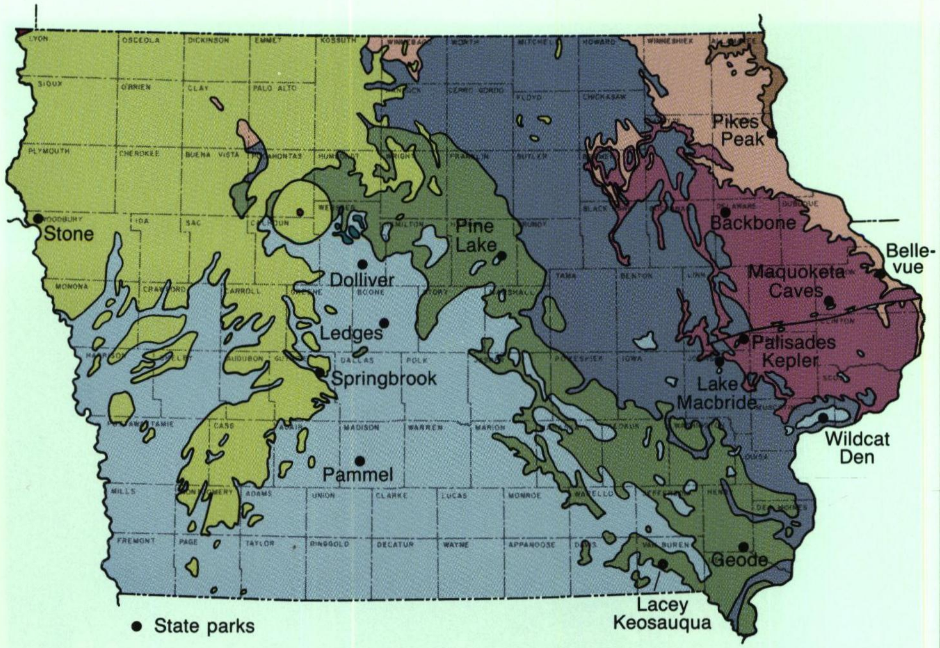
those ancient bodies of tropical sea water described in the previous article. Though Iowa's land surface may appear topographically modest, a result of its glacial past, the rocks beneath these gentle contours are not. They are warped, tilted, fractured, and eroded with an overall incline downward to the southwest, toward basin centers in Kansas and Oklahoma. What this particular structural framework does for park visitors across Iowa is to reveal not just the remains of the last marine environment to submerge Iowa, but to display a whole sequence of ancient environments that span geologic time from about 90 million years to 500 million years ago — an impressive interval of earth history.

The influence of bedrock, whatever its age, on a state park is always eye-catching. In many such parks across Iowa, the surrounding landscape starts out in low-relief uplands, dominated by rounded shapes contoured from easily eroded glacial-age clays, silts, and sands. Continuing further into the park, the terrain drops quickly into wooded valleys whose rivers have carved deeply enough to expose the bedrock beneath. These strata, especially the more resistant limestone, dolomite, and sandstone, change the whole visual and ecological setting to one of abrupt slopes, rocky bluffs and ledges, and cooler and more moist habitats.

Beginning in western Iowa and traveling east and north, visitors to state parks see sedimentary bedrock formations of increasingly older age. It is that structural dipping of the sequence of strata to the southwest, combined with extensive periods of subsequent erosion that beveled the surface of these inclined layers, that continues to keep older and older rock units within reach of the land surface. The banded appearance seen on the state's bedrock geology map (page 12) reflects the pattern caused as each deeper, and older, stratigraphic unit extends farther northeast beyond the one above it.

The uppermost bedrock exposed in Stone State Park in Woodbury County contains clam-rich, thin-bedded, chalky limestones of the Cretaceous-age Greenhorn Formation. These 90-million-year-old marine deposits were left by the eastward migration of a major inland seaway that extended back to a mountain range in the western states. In Guthrie County, older portions of this Cretaceous record are exposed in the Springbrook State Park vicinity (see photo above). Colorful, reddish-brown sandstones seen here were deposited in stream channels that drained southwesterly toward the advancing Cretaceous coastline. These deposits, about 100 million years old, belong to the

Greg Ludvigson



Dakota Formation and show interesting cross-stratifications of sand and gravel, occasional plant fossils, and perhaps, someday, Iowa's first convincing dinosaur remains.

Continuing to the east, Dolliver State Park in Webster County and Ledges State Park in Boone County display still older, 300-million-year-old rocks of Pennsylvanian age. The geologic record of this time interval is characterized by cycles of marine and terrestrial environments that left behind alternating deposits of limestones and dark shales, with interbedded coals and sandstones. The thick sandstones in these two particular parks represent river-channel deposits that were building in a southwesterly direction across a coastal delta. These environments where the river met the sea were unstable and frequently shifted position as continental glaciation in the southern hemisphere caused repeated world-wide fluctuations in sea level. Pammel State Park in Madison County contains a better look at the alternating limestone and shale deposits that reflect some of these global changes in water depth.

The entire sequence of Pennsylvanian rocks in Iowa has been eroded back to the southwest, many miles from where they once were present. Erosional outliers, or isolated remnants of these rocks, still occur at scattered locations well to the east of the main deposits. The prominent sandstone bluffs in Pine Lake State Park in Hardin County and Wildcat Den State Park in Muscatine County mark two of these notable Pennsylvanian outlier locations.

At Lacey-Keosauqua State Park in Van Buren County and Geode State Park in Henry County, the Des Moines River and the Skunk River have eroded their respective valleys deep enough to expose this region's Mississippian-age strata. These rocks, about 350 million years old, are dominated by fossiliferous carbonate deposits formed on shallow

marine shelves in sea water rich with lime-secreting organisms such as crinoids (see inside back cover). Increased quantities of mud washed into these seas at times and are marked today by deposits of shale, some of which contain the highly prized, crystal-lined geodes, Iowa's state rock.

Limestone in the vicinity of Lake Macbride State Park in Johnson County belongs to the 385-million-year-old Cedar Valley Formation. This Devonian-age carbonate represents still older, warm, shallow seas and tidal shoreline environments that contained abundant fish, brachiopods (see page 8), and corals (see page 26).

Moving northeast, Palisades-Kepler State Park in Linn County, Maquoketa Caves State Park in Jackson County (see photo, page 9), and Backbone State Park in Delaware County show the increasing effects of bedrock on the scenery within state parks. These frequently visited parks are formed from resistant Silurian-age dolomites approximately 420 million years old. The massive dolomites seen in each of these parks exhibit abundant fossil colonial corals and reef structures, which indicate warm, clear water and uniformly shallow sea bottoms.

At Bellevue State Park in Jackson County (see photo, page 11) the exposed bluffs include durable Silurian dolomites in the upper vertical cliffs and older, less-resistant Ordovician-age shale at the base of the slope. Ordovician strata completely dominate the landscape at Pikes Peak State Park in Clayton County. Here, 450-million-year-old sandstones, shales, and dolomites reflect the deposition of sand, mud, volcanic ash, and lime in offshore marine shelf environments that gradually deepened over time.

The oldest rocks exposed in any state park also occur at Pikes Peak, just at river level, near the base of the massive bluff that overlooks the Mississippi Valley. These 500-million-year-old rocks belong to the Jordan Sandstone, a formation of well-rounded quartz grains with sweeping arcs of cross-stratification showing the direction of shallow marine currents. Exposures of these and older Cambrian strata continue northward into Allamakee County.

Many visitors take in Iowa's state parks on a weekend afternoon for a spring picnic, some summer shade, or a look at the fall colors. These areas offer additional attractions, for each park is also a place that records in its rocky scenery the events from a distant geologic past. Each park visited is a crossroads in time, a place to pause and consider what other environments and events have occupied that space and how they have influenced what is seen there today. □

UNDERGROUND COAL MINES
OF THE DES MOINES AREA

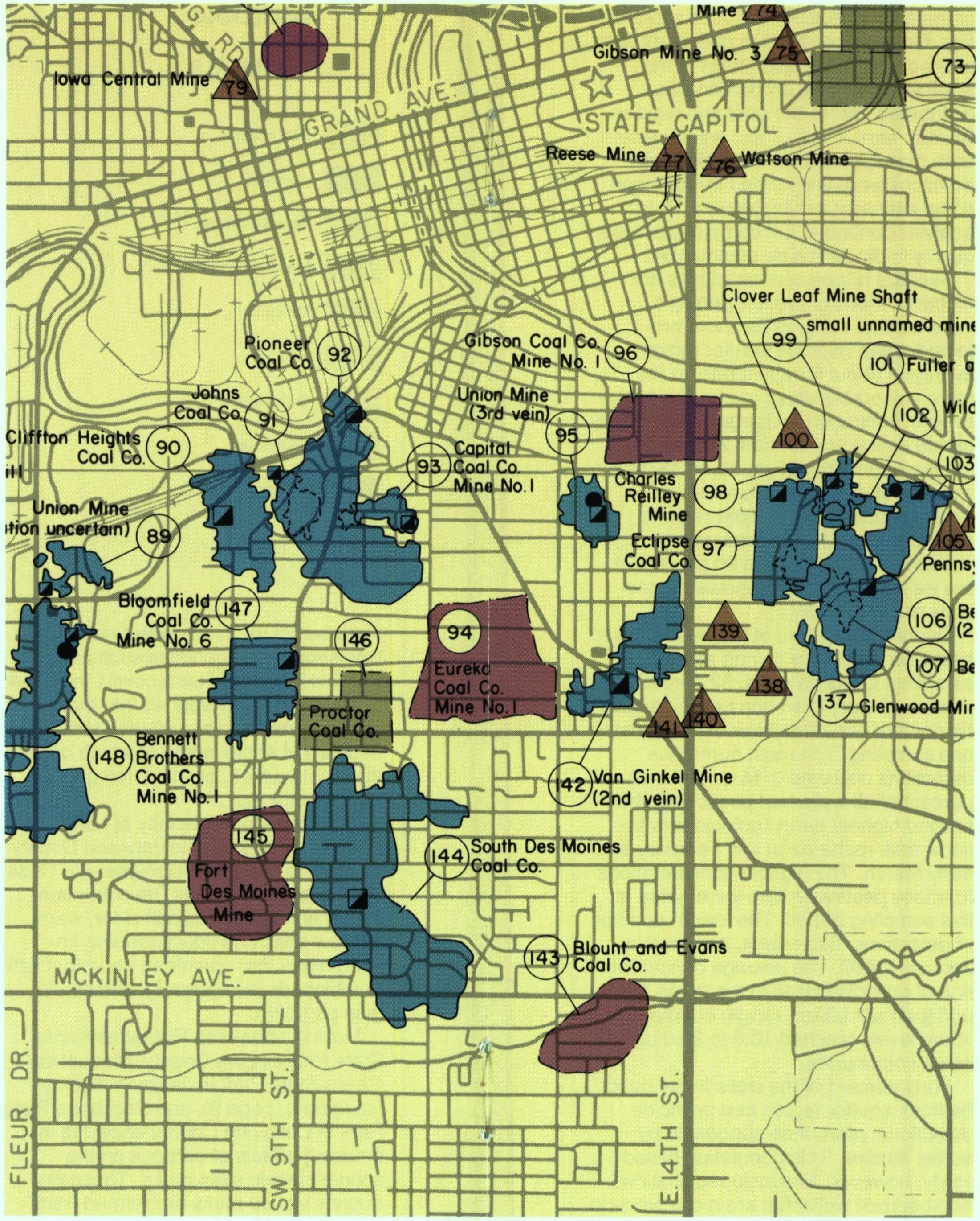
Mary R. Howes
Matthew A. Culp

Des Moines was once the center of a thriving coal industry, although little visible evidence remains today. Underground mines in Des Moines and surrounding Polk County produced 51 million tons of coal between 1865 and 1947, ranking second in overall production in Iowa behind Monroe County.

Mining started in the mid-1840's when coal was quarried from outcrops along the Des Moines River within the city. Peak production in the county reached almost 2 million tons in 1917 and employed nearly 3,000 miners. By 1945 only four mines remained in operation, and in 1947 the last underground mine, in the Urbandale area, ceased production.

A recent study by the Geological Survey Bureau located 160 of the 222 underground coal mines which, according to historical records, operated in the Des Moines metropolitan area. A portion of the map delineating the boundaries of these abandoned mines is illustrated here. These boundaries were determined from restored mine maps, mine inspectors' files, and lease maps. Each of these sources provided a different level of accuracy in documenting mine location and extent. The remaining 62 mines cannot be located at all because of incomplete mining records.

Individual mines range in size from a few tens of square feet to more than 1,000 acres. In geologically favorable areas, mines were often developed on adjoining properties, so impacted areas cover several square miles. Multiple-level mining was also practiced. Most mines had vertical shaft entrances, and the coal was extracted using room-and-pillar methods. Mining was done by hand, although draft animals and steam engines also were used.



MINE LOCATION KEY

- Boundaries from restored maps; known location and extent
- vertical entrance
- slope entrance
- air shaft
- Boundaries from mine inspectors' maps; known location, approx. extent
- Boundaries from lease maps; known location, approx. extent
- Boundaries unknown; approx. location, unknown extent
- Areas with multi-level mining

The distribution of the mined areas reflects the geologic irregularity of the coal deposits. The coal seams are not continuous across the area and their thickness and quality are not consistent. These conditions result from complex environments of deposition in which these Pennsylvanian-age, Cherokee Group coals were formed.

This map, soon available as part of a GSB publication on abandoned coal mines and geology of the Des Moines area, is useful for planning commercial or residential development, for mitigating land subsidence problems that occur in the Des Moines area because of underground mine collapse, and for estimating remaining coal reserves. □

WATER QUALITY RESULTS:

FLOYD-MITCHELL COUNTIES

George R. Hallberg
Robert D. Libra

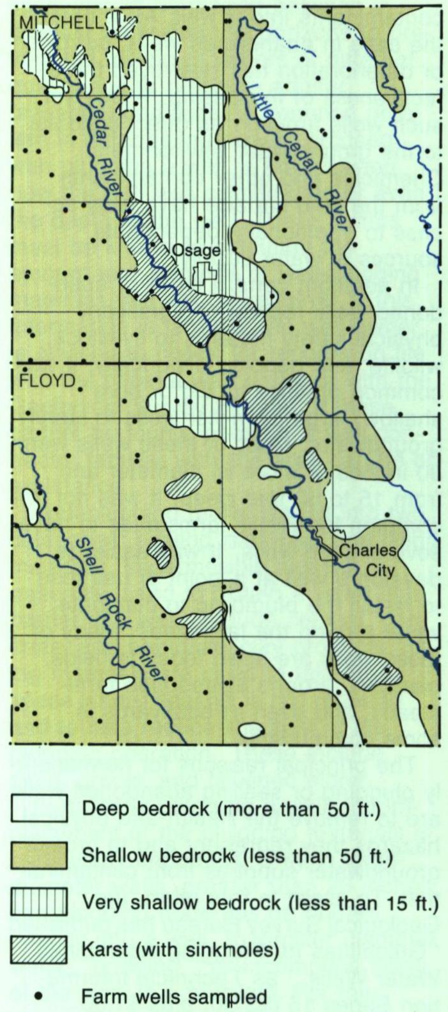
Since 1982 the Department of Natural Resources has been studying the occurrence of nitrates and pesticides in groundwater supplies in Floyd and Mitchell counties. These northeastern Iowa counties were selected because: 1) they are underlain by regionally important bedrock aquifers that supply nearly all rural residents with drinking water; 2) they are intensively farmed; and 3) the variable thickness of clay-rich glacial till that covers the bedrock provides different levels of protection from surface contamination. In general, as the thickness of the glacial till increases, so does the time it takes for recharge waters and contaminants from the surface to enter the aquifer. During studies in 1982-83, four geologic regions were defined on the basis of till thickness and underlying limestone characteristics in order to assess water quality impacts from land surface activities (see map).

An expanded effort, from February 1986 to January 1987, was initiated as a cooperative study between the DNR and the Department of Preventive Medicine at The University of Iowa and was supported by the EPA's Office of Pesticide Programs. This study involved a systematic, quarterly sampling of 10 percent (184 sites) of the well-water supplies of the farm population of these two counties. On average, there is one study farm and well per 4.5 square miles in the area, with the sites proportionately distributed across the geologic regions. At each farm, the well and water-system, farm management and chemical-use practices were inventoried through personal interview and inspection. Data analysis continues but some of the water quality findings can be summarized.

Average nitrate concentrations are higher in areas of greater geologic vulnerability. Wells in the more protected, deep bedrock aquifer region averaged about 5 mg/l nitrate; in the more vulnerable areas marked by higher rates of infiltration recharge, the average nitrate concentration from all wells increased from 25 mg/l, to 32, to 43 mg/l, from the shallow aquifer, to the very shallow aquifer, to the karst regions, respectively. In these three most vulnerable regions, 60 to 90 percent of the wells sampled also showed detections of pesticides.

Overall, 60 percent of the wells showed pesticide detections during at least one sampling. Of those wells, 52 percent contained more than one pesticide, and 64 percent had detections in more than one sampling. The most numerous detections occurred in May, when 42 percent of all wells had pesticides; the second highest period coincided with snow-melt recharge in late February and early March. The highest concentrations for many pesticides also were noted in this sampling period. The lowest number of detections, 29 percent, occurred in January, 1987. The average concentration of pesticides was in the 0.1 to 1.0 ug/l (part per billion) range; but maximum levels reached 10.0 to 20.0 ug/l for some compounds.

Forty percent of the wells in the deep bedrock aquifer region had pesticide detections, more than suggested by earlier studies. This population-based study, however, also included shallow, non-bedrock wells that are more prone to contamination. Many of the wells with pesticides are also from the edges of the deep aquifer areas, and may have less protection than previously thought. Other sites recorded problems with spills or handling accidents. Additionally, over 70 percent of the counties' agricultural drainage wells are in the deep aquifer region, and these may be affecting water wells. Completing the analysis for these variables will provide further insights into defining the distribution of groundwater contaminants.



The herbicide atrazine was the most commonly detected pesticide, comprising 25 percent of sample detections and in 43 percent of all wells. The herbicides alachlor, metribuzin, and metolachlor grouped as the second most common, ranging from 6 to 9 percent of sample detections in 13 to 19 percent of the wells. These herbicides were present in all sampling periods, as were two insecticides, carbofuran (and/or metabolites) and chlorpyrifos. These insecticides comprised only 1 to 2 percent of the total sample detections.

The results of this study show that the concentration of nitrate is an indicator of the probability of pesticide occurrence. The proportion of wells with pesticide detections increases as the nitrate concentration increases. However, 14 percent of the wells with non-detectable nitrate concentrations (less than 1.0 mg/l) did have pesticides. Studies have shown that denitrification (a microbial process) may remove nitrate but not pesticides from the groundwater. Additionally, local point sources of pesticides, from commercial sites or from farm spills, do not necessarily coincide with similar point sources of nitrogen. Six percent of the farmers interviewed in this study indicated pesticide-handling problems have occurred on their farms.

The residents of Floyd and Mitchell counties have made a major contribution to the understanding of the state's groundwater contamination problems. The ongoing analysis of the data collected in this region will continue to provide further insights into solving these problems, as Iowa strives to balance efficient agricultural production with the protection of water resources. □

PLUGGING ABANDONED WELLS

Donivan L. Gordon

Among the many issues raised in regard to protecting Iowa's groundwater quality is that of abandoned wells. These are water wells that are no longer in use or are in such poor condition that continued use is unsafe or impractical. Such wells are liabilities which threaten our drinking water supplies, health, and safety.

Prior to 1985 we had no real idea of how many abandoned wells there were in Iowa, only that they were numerous. Information tabulated from a well inventory, conducted by county assessors in 1983 and 1984, showed that there were at least 21,775 abandoned wells in the state. Only about 60 percent of the inquiry cards distributed were returned. If these represented an accurate statistical sample, then the total number of abandoned wells could exceed 36,000. Additionally, in 1900 there were nearly 225,000 inhabited farmsteads in Iowa. Today only half of these are still occupied. This fact, coupled with other known types of abandoned wells, suggests a total number of abandoned wells exceeding 100,000.

Abandoned wells undoubtedly occur in each of Iowa's 99 counties; they probably connect to every principal aquifer in the state; and they vary considerably in design and depth. Wells are constructed with a casing that is supposed to function as a sanitary barrier to the movement of contaminants into a well. As is often the case in abandoned wells, corrosion or deterioration has destroyed the effectiveness of the casing. Worse yet, such wells function as direct conduits to the groundwater environment. Chemicals and other contaminants from the land surface have easy access to traditionally dependable sources of water supply.

In addition, certain types of abandoned wells represent significant physical safety hazards to livestock, wildlife, and people. Historically, it was common practice to dig or bore shallow, large-diameter wells to supply groundwater. Most of these wells were 30 inches or more in diameter and from 15 to 50 feet deep. It was not uncommon for single farmsteads to have several such wells. It was easier to develop a well at a point of use than to install the plumbing to distribute water around the farmstead. Many of these wells are seen today in fields, pastures, around abandoned farmsteads, and even in backyards in some communities.

The principal reasons for permanently plugging or sealing abandoned wells are to remove the health and physical hazards they represent and to protect groundwater supplies from contamination. To assist in this effort, the Geological Survey Bureau has published "Guidelines for Plugging Abandoned Water Wells," as Technical Information Series 15 ($2.00, plus $1.00 post./hand.). This publication covers the recommended plugging methods and materials to meet the different situations that Iowa well owners can expect to encounter.

Ideally, an abandoned well should be plugged in a manner that will essentially restore the hydrologic integrity of the well site to its condition before the well was completed. This means using materials and methods that will prevent any surface water drainage into the well. Also, effective seals should be placed between individual water-bearing horizons to prevent the mixing of waters of different quality and to preserve aquifer pressure conditions. A common problem in determining how to proceed with plugging a well is not knowing how the well was constructed or even the depth of the well. These factors must be known to calculate the amount and volumes of well-plugging materials that will be required. If this information is lacking, the well owner is advised to check for records on file with the original well driller or with the Geological Survey Bureau. If these cannot be found, possibly a well contractor familiar with the area can be of assistance.

Well-plugging materials fall into two categories: sealing materials and filling materials. Impermeable sealing materials, used to obtain a water-tight barrier in a well, include cement, concrete, and bentonite clay products. Filling materials are used to take up space where sealing is not required and to help reduce the cost of the plugging operation. These include sand, gravel, and crushed stone.

In properly plugging a well, the implacement of the plugging materials is particularly important. Only in large-diameter wells, greater than 28 inches, can plugging materials be poured directly into a well. In smaller diameter wells, "bridging," or incomplete filling of the well, is a problem. For this reason it is not recommended that concrete be poured into a well with standing water. Also, cement and aggregate can separate and prohibit an effective seal. It is recommended that bentonite and cement sealants be introduced into wells by means of a device known as a "tremie pipe." This pipe should extend to the bottom of the well with the filling material pumped in from the bottom upward; the tremie pipe is gradually raised as the hole fills. This is the recommended procedure for most small-diameter, cased wells. Because of the specialized equipment required to seal a well in this manner, the work should only be done by a registered well driller.

Jean Prior

As a final note, it is especially important to properly seal abandoned wells in proximity to new replacement wells, particularly if the two wells tap the same source of supply. In such contexts, an abandoned well can be a receptor of contaminants which move via the aquifer during pumping directly into nearby wells. To protect your investment and your neighbor's investment in a water supply — plug your abandoned wells. □

PLUM RIVER FAULT ZONE

Greg A. Ludvigson

Devastating earthquakes, such as those recently experienced in Soviet Armenia and Mexico City, are obvious and newsworthy effects of geologic faults. Within the United States, many people also are aware of the periodic activity along the San Andreas and kindred fault systems in southern California. Fewer people may realize that the most violent earthquakes to shake North America since European settlement occurred in the midcontinent during 1811 and 1812, near New Madrid in southeastern Missouri. Some eastern Iowans have felt the tremors of lesser midwestern earthquakes in recent decades. Few people are probably aware that geologic faults are known to exist in Iowa. Even though the Earth's crust here in the continent's midsection is quite resistant to deformation, and is generally considered the most stable of geologic realms, geologists recognize that the midcontinent crust is broken by several significant fault systems.

Faults in Iowa generally have received little attention. There is a lack of topographic expression of bedrock faults on the Iowa landscape, as compared to the dramatic example of the Front Range along the Golden Fault in Colorado. The subdued topography indicates that no major recent movement has occurred along the faults in our state. The widespread cover of glacial deposits across Iowa further complicates matters by obscuring the bedrock geology, making detection and interpretation of faults difficult. Finally, although data are scant, there is no current information to suggest that geologic faults in Iowa pose any significant seismic hazard.

Geologic faults are linear to curving belts of deformed rock along which differential movements of the Earth's crust have taken place. These features are host to unusual geologic phenomena that can subtley record important aspects of an area's geologic history. Faults display a wide range of effects, from microscopic dislocations in the structure of individual mineral crystals to major boundaries in the Earth's crust. They record the failure and deformation of earth materials from stresses that build up in the crust. Rocks can be deformed by compression, stretching, extension, or shearing. Shearing, the angular distortion between the opposing rock masses, is the mechanism that distinguishes most faults. Detailed studies of the rock products of faulting have shown that both plastic flow of solid earth materials and brittle cracking are the processes usually involved in movements along major fault systems.

The Plum River Fault Zone of eastern Iowa and northwestern Illinois, while ancient in origin, has been recognized by geologists only since the mid-1970's. Geologists from the state geological surveys of Iowa and Illinois were aware of the peculiar geology in the area by the early 1890's. Rock strata to the south of the fault zone have been uplifted several hundred feet relative to those on the north. Since the range of land surface elevations is the same on both sides of the fault, the fault separates crustal blocks that are eroded to different stratigraphic levels, and thus different age strata are exposed on opposing sides of the fault (see photo, page 21). For many years, the structure was known as the Savanna-Sabula Anticline, in reference to the river towns in Illinois and Iowa where this feature crosses the Mississippi Valley. The long-held interpretation of the structure as an anticlinal fold, or upward bending of rock strata, was modified because of detailed field studies in Illinois. Corresponding field work in Iowa showed that the fault zone extends westward much further into Iowa than was previously believed. The fault system terminates to the south of Cedar Rapids in Linn County, although subtle evidence suggests that related rock deformation may extend farther to the southwest into the Amana Colonies in Iowa County.

The Iowa portion of the Plum River Fault Zone was first investigated during regional groundwater studies of the bedrock aquifers in east-central Iowa. It was recognized then, that the fault zone can impact the local availability of groundwater from these aquifers. This occurs because the "normal" layering of sedimentary bedrock units is physically rearranged in the area of the fault. Thus, the very existence of regionally persistent bedrock aquifers is in question near the fault. Additionally, the mechanical and chemical processes by which the rocks were deformed can alter their water-bearing characteristics. Zones of closely-spaced fractures in limestone have the capacity to yield abundant water supplies, provided that these networks are not closed by fracture-filling mineral growths. The grinding of rocks along a fault into powder-sized fragments has the effect of reducing the permeability of those rocks, creating barriers to groundwater flow (see photo, page 22).

Greg Ludvigson

Looking south across the sag marking the fault trace in Jones County, gray Devonian rocks in the foreground are exposed at the same elevation as the much older, brown Silurian rocks in the distant quarry.

The geometric complexity of the Plum River Fault Zone, and the interplay of these other factors, can make the exploration for groundwater supplies a difficult proposition in the vicinity of the fault. Local effects of the fault zone have complicated the development of municipal water supplies in several Iowa communities, including Mount Vernon and Oxford Junction.

The earth movements responsible for the formation of the Plum River Fault Zone occurred in the distant geologic past. The origins of the structure probably date back nearly two billion years, when most of the continental crust in the Iowa area was formed. As with many fault systems in the continental interior, periodic episodes of deformation in the shallow sedimentary rocks of the Plum River Fault Zone resulted from reactivated movements of the older, buried fault systems along the weakened continental crust. Microscopic studies of deformed rocks exposed in the fault have identified multiple episodes of rock deformation that were subsequently healed by the precipitation of distinctive assemblages of mineral cements (see photo, page 23). A variety of these cements have been found, notably the carbonate minerals calcite and dolomite; the silicate mineral quartz; the sulfide minerals pyrite, marcasite, galena, and sphalerite; the sulfate mineral barite; and the oxide minerals goethite and pyrolusite. Small galena deposits were mined for lead from localities near the fault zone during the 19th century, but they have long since been abandoned.

These mineral assemblages were emplaced during or shortly following separate episodes of movement in the development of the fault system. This concept was developed through microscopic studies of the rocks and by geochemical studies of the mineral cements. The minerals were precipitated from ancient groundwaters of varying composition that once saturated the rocks along the fault zone. These chemical environments at the time of deformation and cementation determined not only which groups of minerals were deposited, but also controlled their trace-element and isotopic chemistry. The movements of these mineral-rich groundwaters were influenced by the regional episodes of deposition and erosion that formed the sedimentary rock sequence in Iowa (see "Iowa's Ancient Seas," page 4). Evidence now shows that deformation along the Plum River Fault Zone occurred during the Ordovician, Silurian, Devonian, and probably the Mississippian periods of geologic time.

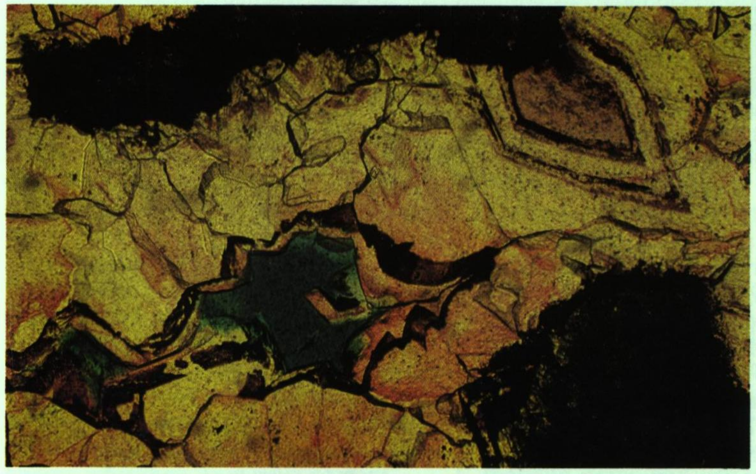
Research results indicate that the last significant movements along the Plum River Fault Zone occurred about 300 million years ago, partly overlapping with the deposition of Early Pennsylvanian sedimentary rocks across eastern Iowa. Later, about 260 million years ago, minor cracking of the rocks bordering the fault occurred during a brief episode in which hot subsurface brines flowed into the continental interior from a rising mountain belt along the southern margin of North America. The lead deposits along the Plum River Fault Zone apparently formed during this time.

While the Plum River Fault Zone is probably the best studied of the fault systems in Iowa, other faults also have been the focus of geologic research. The Thurman-Redfield Structural Zone of southwest Iowa is a complex fault and fold system that resulted from rejuvenated movements of buried faults along the Midcontinent Rift System. The Fort Dodge Fault is known from exposures along the Des Moines River valley, from underground mine workings, and from drillhole data in Webster County. Some of these geologic structures along the rift system have been drilled for commercial use as underground natural-gas storage facilities. These include installations at Redfield and Dallas Center in Dallas County, and Vincent in Webster County. Drillhole data from Decorah in Winneshiek County also suggest the presence of a fault system whose configuration remains poorly known. There are other localities in Iowa where faults are suspected but have not been investigated.

The economic importance of geologic faults in Iowa results from their influence on the distribution and availability of natural resources, including stone products and underground water supplies. Geologic faults are also known to be associated with concentrations of metallic mineral and petroleum deposits in many areas, although the prospects in Iowa are poorly known. From a scientific viewpoint, geologic faults in Iowa and the rest of the midcontinent remain mysterious in many respects. Where are they; what are their regional patterns of occurrence, their histories of movement, and what processes triggered deformation in the stable continental interior? What, if any, degree of seismic hazard is posed by these structures? These are questions that can only be addressed by further geologic studies. □

Paul VanDorpe

Grinding along the fault has broken this Silurian dolomite into angular fragments, later cemented with calcite and iron oxides.



Greg Ludvigson

Zones of color in these microscopic calcite crystals (yellow) record periodic episodes of mineral growth from ancient groundwaters that flowed through the fault-fractured rocks (black: iron-oxide; blue: epoxy; 2 mm field-of-view).

IOWA'S CEMENT INDUSTRY

Robert M. McKay

The cement industry in Iowa is geographically restricted to four sites, but these sites account for about one-third of the total value of non-fuel mineral production in the state. In 1987 these four plants produced and marketed 22 million tons of masonry and portland cement valued at 104.5 million dollars. Lehigh Portland Cement Company and Northwestern States Portland Cement Company both operate plants at Mason City in Cerro Gordo County. Davenport Cement Company operates a plant near Buffalo in Scott County, and Monarch Cement Company in Des Moines grinds cement clinker, an intermediate product, received from another facility in Humboldt, Kansas. In 1986, these plants accounted for 2.3 percent of the national production of cement.

The majority of cement produced in Iowa and worldwide is called "portland cement." This product consists of finely ground powder composed of limestone and clay which, when mixed with water, makes a binding paste for masonry mortar and construction concrete that will harden or "set" to an insoluble, rock-like solid. The name "portland cement" was coined by its inventor Joseph Aspdin, a brick layer and mason from Leeds, England. He patented this process of making artificial stone in 1824 and named it for the well-known building stone quarried from the nearby Isle of Portland, a peninsula in southern England.

The raw materials used in the production of portland cement consist principally of limestone and clay, resources which occur abundantly in Iowa. Calcium-rich limestones and clay-rich glacial deposits are utilized as these raw-mix sources. Production begins with quarrying and crushing the stone and clay, followed by a dry-process blending of these materials in specified proportions. After preheating the blended mix to about 1600°F, the mixture enters the top end of a slightly inclined, coal- or gas-fired rotary kiln where the mix temperature continues to rise to 2500°F.

Temperature-driven chemical reactions occur at various times during this firing process. Carbon dioxide and water are driven from the limestone and clay minerals at lower temperatures, while reactions between the elements of calcium, oxygen, aluminum, and silica take place at higher temperatures where partial melting and liquidization also occur. This latter phase generates the final cement compounds (calcium silicates and aluminates) which combine into black, glistening nodules of various sizes. This material is known as "portland cement clinker." After the clinker drops from the kiln and cools, it is ground with a small percentage of gypsum (calcium sulfate) to a fine powder. This final product is then readied for shipping via rail, barge, or truck.

Portland cement has been produced in Iowa since the beginning of this century. The industry has grown steadily in the volume of production even though the number of plants has remained about the same. Modern portland cements are manufactured in large, multimillion-dollar industrial plants capable of producing several thousand tons of cement per day (see photo). Nearly all construction concrete used today incorporates portland cement as its basic binding ingredient. Various "types" of cement can be produced to meet needed project-design engineering specifications.

Courtesy, Davenport Cement Company

Devonian limestone quarried along the Mississippi Valley is converted into various portland cements at this modern industrial facility, the Davenport Cement Company — Buffalo Plant.

Significant trends in the industry in Iowa, as well as nationally, include acquisition by overseas' interests and efforts to increase production and energy efficiency. Two Iowa cement plants (Lehigh and Davenport), which account for approximately 55 percent of the state's finished grinding capacity, are owned by Western European firms. While the U.S. cement industry has made progress in energy efficiency and productivity, it continues to rank low in energy efficiency when compared to other industrialized nations.

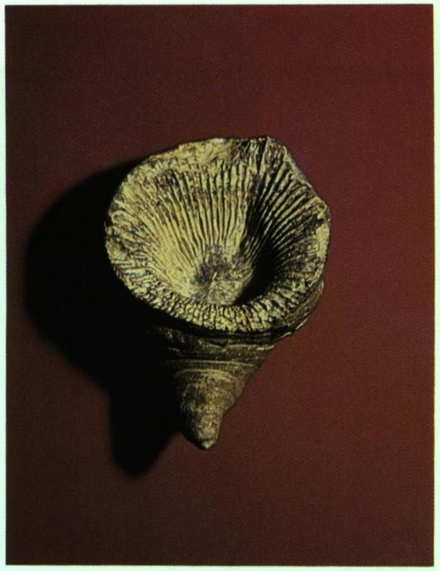
The continued growth of the north-central United States construction markets, combined with Iowa's raw materials, geographic position, and innovative plant operations, ensures that the cement industry in Iowa will endure well into the next century. □

FOSSIL CORALS IN IOWA

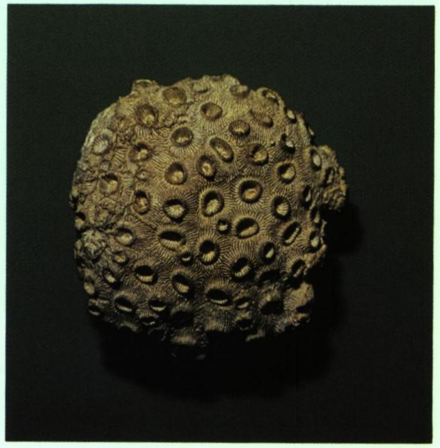
Brian J. Witzke

Corals are marine animals that live today in the world's oceans and seas. None are known from freshwater. They secrete a hard skeleton of lime (calcium carbonate), which provides protection for the animal's soft tissues. Corals feed on small food particles, especially algae, in the surrounding water by means of tentacles, and they are incapable of movement across the sea floor. Many species are colonial in habitat, that is they grow as a group of individual animals bound together within a shared skeletal mass and descended from a single founding individual. Other corals are solitary, living as a single animal that secretes its own individual skeleton. The skeleton of an individual coral is termed the "corallite," and it is generally circular or polygonal in outline. Corals form a group of animals (Class Anthozoa) assigned to the Phylum Cnidaria (formerly Coelenterata) which also includes the sea anemones, hydrozoans, and jellyfish. The body plan of the cnidarians is among the simplest known among all multicellular animals.

Because corals have a hard and readily preservable skeleton, they are abundantly represented in Iowa's fossil record. They occur in rocks of Middle Ordovician through Upper Pennsylvanian age, which spans an interval of time from about 290 to 450 million years ago. They are most commonly found in limestones that were deposited in warm, shallow, tropical and subtropical seas that



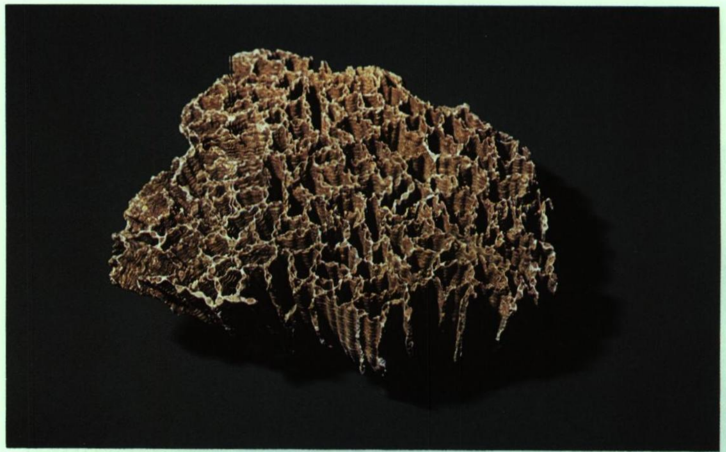
Paul VanDorpe



Paul VanDorpe

Warm, shallow, tropical seas were home to these rugose corals which secreted protective skeletons of lime. Both solitary (above) and colonial forms (below) occur as fossils in Iowa's Devonian strata.

periodically covered our state. At times, especially during portions of the Silurian and Devonian period, corals and associated colonial sponge-like animals



Paul VanDorpe

The "chain coral," as it is known by collectors, has a distinctive colonial form. Each individual skeleton of this Silurian-age tabulate coral also displays internal horizontal partitions.

known as stromatoporoids formed dense thickets and reef-like features on the shallow Iowa sea floor.

Many of Iowa's corals are of exceptional beauty and are among the most commonly collected fossils in our state. These fossils include solitary and colonial forms of the Order Rugosa and colonial forms of the Order Tabulata, both now long extinct (see photos). Most rugose corals have medium to large corallites (typically 1/4 to 3 inches in diameter) that display internal vertical partitions ("septa") which radiate towards the edge of the corallite. By contrast, the tabulate corals typically have smaller corallites (less than 1/4 inch), with septa reduced or absent. The skeletons of tabulate corals generally display a much simpler construction than those of rugose corals, although table-like horizontal partitions ("tabulae") are typically present in individual corallites.

Tabulate corals are always colonial, and the distinctive form of many of their skeletons is reflected by the names given them by fossil collectors (e.g., "honeycomb coral", "chain coral"). Popular names given to solitary rugose corals also reflect their distinctive shapes (e.g.,"cup", "horn", "button", and "square" corals). Colonial rugose corals are especially attractive fossils, and some of these have been cut and polished for decorative curios and jewelry, primarily specimens collected from Devonian and Mississippian rocks of southeast Iowa. Curios were crafted from the abundant fossil corals found in the Iowa City area and sold by local artisans, especially during the 1840's through 1890's. When a famous Swiss geologist, Louis Agassiz, visited the University of Iowa in 1866 and delivered a lecture entitled "Coral Reefs of Iowa City", it had such an impact on some local residents that a new town site a few miles to the northwest was named Coralville for the rich accumulations of fossil corals found there.

Fossil corals form an intriguing part of the geologic history of our state, a history whose study provides challenges and insights of both practical and academic concern. □

SELECTED SURVEY PUBLICATIONS

WATER QUALITY MONITORING OF THE NISHNABOTNA RIVER ALLUVIAL SYSTEM
DNR-Geological Survey Bureau Open-File Report 88-1, 60 pages, by Carol A. Thompson and Paul E. Van Dorpe (1988). An evaluation of water-quality data with particular reference to nitrate and pesticides. Price $3.00, plus $1.00 post./hand.

GUIDELINES FOR PLUGGING ABANDONED WATER WELLS
DNR-Geological Survey Bureau Technical Information Series 15, 46 pages, by Donivan L. Gordon (1988). A summary of information on the state's abandoned wells, including recommendations on well-plugging materials and methods for properly sealing typical abandoned wells in Iowa. Price: $2.00, plus $1.00 post./hand.

NEW PERSPECTIVES ON THE PALEOZOIC HISTORY OF THE UPPER MISSISSIPPI VALLEY: AN EXAMINATION OF THE PLUM RIVER FAULT ZONE
DNR-Geological Survey Bureau Guidebook Series 8, 251 pages, edited by Greg A. Ludvigson and Bill J. Bunker (1988). A guidebook for the 18th Annual Field Conference of the Great Lakes Section, Society of Economic Paleontologists and Mineralogists held on Oct. 1-2, 1988. A collection of research articles and field guide. Price: $10.00, plus $1.25 post./hand.

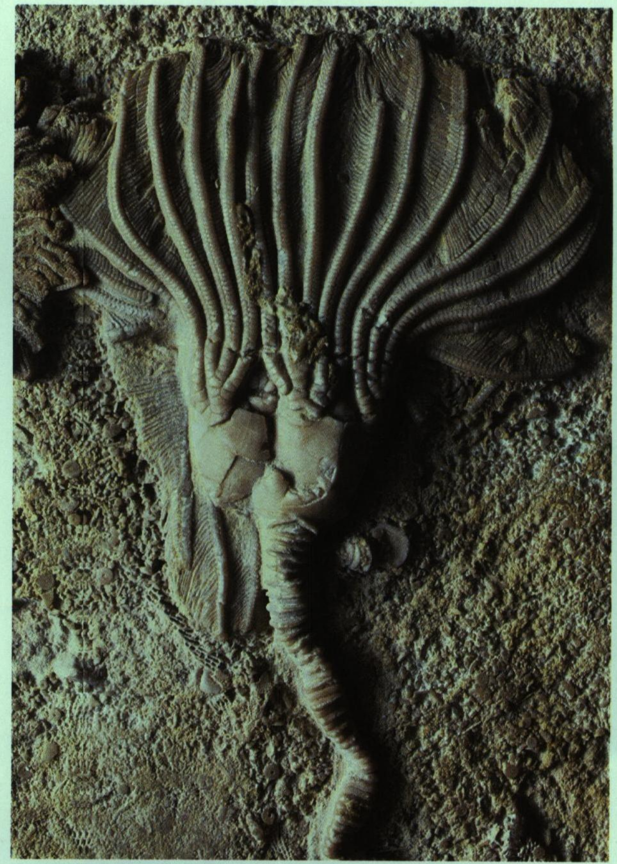
County Groundwater Reports: These compilations of available data summarize the distribution, accessibility, yield, and quality of surficial and rock aquifers. Price of each: $1.00, plus $.50 post./hand.

GROUNDWATER RESOURCES OF GRUNDY COUNTY
DNR-Geological Survey Bureau GWR-38, 35 pages, by Carol A. Thompson (1988).

GROUNDWATER RESOURCES OF HARDIN COUNTY
DNR-Geological Survey Bureau GWR-42, 37 pages, by Carol A. Thompson (1988).

GROUNDWATER RESOURCES OF MADISON COUNTY
DNR-Geological Survey Bureau GWR-61, 26 pages, by Jean C. Prior (1988).

GROUNDWATER RESOURCES OF WARREN COUNTY
DNR-Geological Survey Bureau GWR-91, 26 pages, by Jean C. Prior (1988).



Drake Hokanson/The University of Iowa Museum of Natural History

Fossil crinoids ("sea lilies") are among the most beautiful of Iowa's fossils. This specimen is from the world-famous crinoid locality at LeGrand in Marshall County.