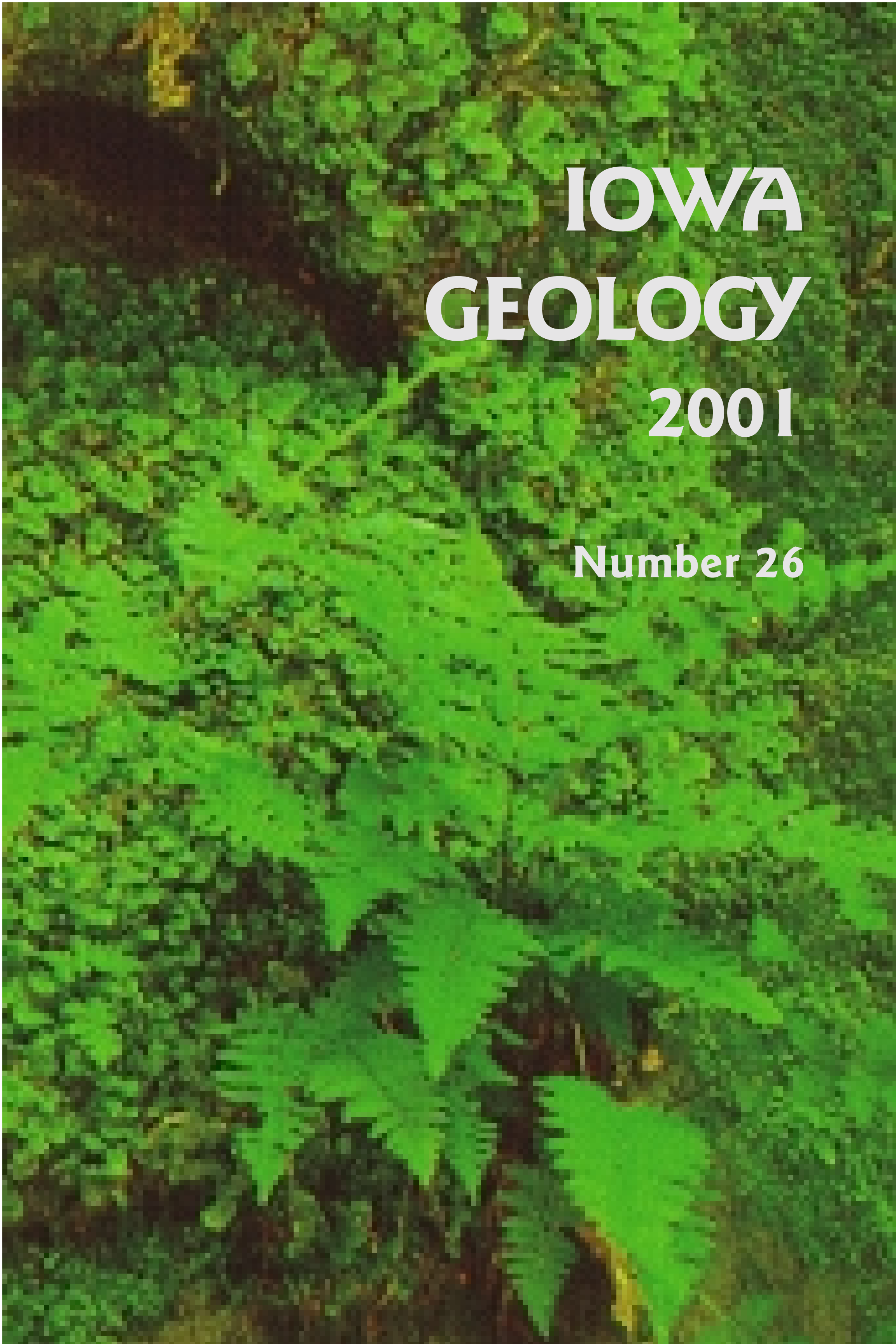

IOWA GEOLOGY 2001

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Iowa Department of Natural Resources
Jeffrey R. Vonk, Director

Geological Survey Bureau
109 Trowbridge Hall
Iowa City, Iowa 52242-1319
(319) 335-1575
www.igsb.uiowa.edu

Donald L. Koch
State Geologist and Bureau Chief

COVER

The cool moist surface of a sandstone outcrop provides favorable habitat for a lush growth of liverworts (flat plants), mosses (dark green), and ferns in Clayton County. Throughout the state, geology and ecology combine to create natural areas of great beauty and scientific interest.

Cover photo by Clay Smith

Jean Cutler Prior *Editor*
Patricia J. Lohmann *Publication Designer*

Printed on Recycled Paper

This issue is dedicated to Donald L. Koch,
retiring State Geologist of Iowa – for 42 years a researcher of fossils, rock strata & groundwater; advisor to well drillers, aggregate & gas-storage companies; leader of the Geological Survey & supporter of informative publications for Iowans.

The Age of Dinosaurs in Iowa

Brian J. Witzke

Did dinosaurs once live in Iowa? The simple and unqualified answer is "Yes, without a doubt!" But the actual evidence for dinosaurs in Iowa is limited to only a few fossils. Dinosaur fossils have been found in several states adjoining Iowa (Nebraska, Minnesota, Missouri, South Dakota), and wandering dinosaurs would have been unimpeded by these artificial boundaries.

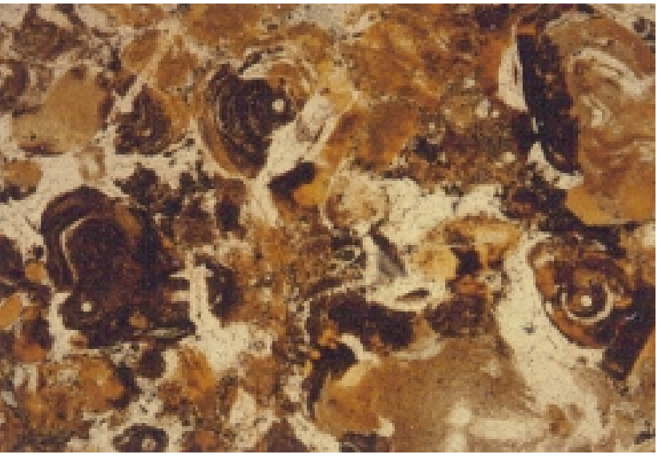
Fortuitous circumstances are needed to preserve dinosaur remains in ancient sedimentary environments. Following the death of an animal, the bones need to be buried within the sediments and protected from chemical and mechanical destruction. Many great dinosaur discoveries are associated with sediments of ancient river systems, where dinosaur bones may be preserved within floodplain and river channel deposits. The discovery of fossil bones is aided by a careful understanding of a region's geology (where to look), considerable patience (keep looking), and a significant measure of good fortune.

Dinosaurs were the dominant land animals for about 170 million years of earth history, spanning the Late Triassic, Jurassic, and Cretaceous periods. This "Age of Dinosaurs" came to a close 65 million years ago when a mass extinction ended the dinosaurs' reign. (Almost all paleontologists consider birds to be descendents of small carnivorous dinosaurs, so a segment of the dinosaur pedigree survived this extinction.) Sedimentary deposits from the Age of Dinosaurs cover extensive portions of Iowa and have real potential to yield dinosaur fossils. The Jurassic Fort Dodge Formation was deposited at the same time as strata in the American West that have produced remarkable dinosaur fossils, but no Jurassic dinosaur fossils have yet been found in Iowa. The Cretaceous formations are more widespread in Iowa, and these same formations have produced dinosaur fossils at scattered localities in the central United States.

"Dinosaur Society Hadrosaur," by natural history and wildlife artist Karen Carr, courtesy of www.TheFernleaf.com

Hadrosaurs, commonly known as duck-billed dinosaurs, occupied subtropical environments in the coastal lowlands of the central United States during the Cretaceous Period, about 100 million years ago.

Iowa's oldest Cretaceous sediments, the Dakota Formation, were deposited in ancient river systems that drained westward to an interior seaway during the middle part of the Cretaceous period, about 95 to 100 million years ago, a time of global "greenhouse" warming. Floodplains and coastal lowlands were covered with lush subtropical vegetation at that time, providing suitable habitats for dinosaurs. The first dinosaur fossil found in the Dakota Formation, a portion of a leg bone (femur), was collected in 1928 from the Missouri River bluffs near Decatur, Nebraska. This locality lies only about one mile from the Iowa border. Although this fragmentary fossil has not been assigned to a particular dinosaur species, its features are sufficient to identify it as a large ornithopod, a highly successful group of generally bipedal plant-eating dinosaurs. The proportions of this leg bone, when compared with other ornithopods, indicate a dinosaur that was about 32 feet long. This Dakota fossil likely represents an



Brian Witzke

The microscopic structure of a petrified dinosaur bone fragment from Guthrie County, Iowa, shows a once-porous network of vascular canals for blood vessels. (Enlarged 3-mm-wide view.)

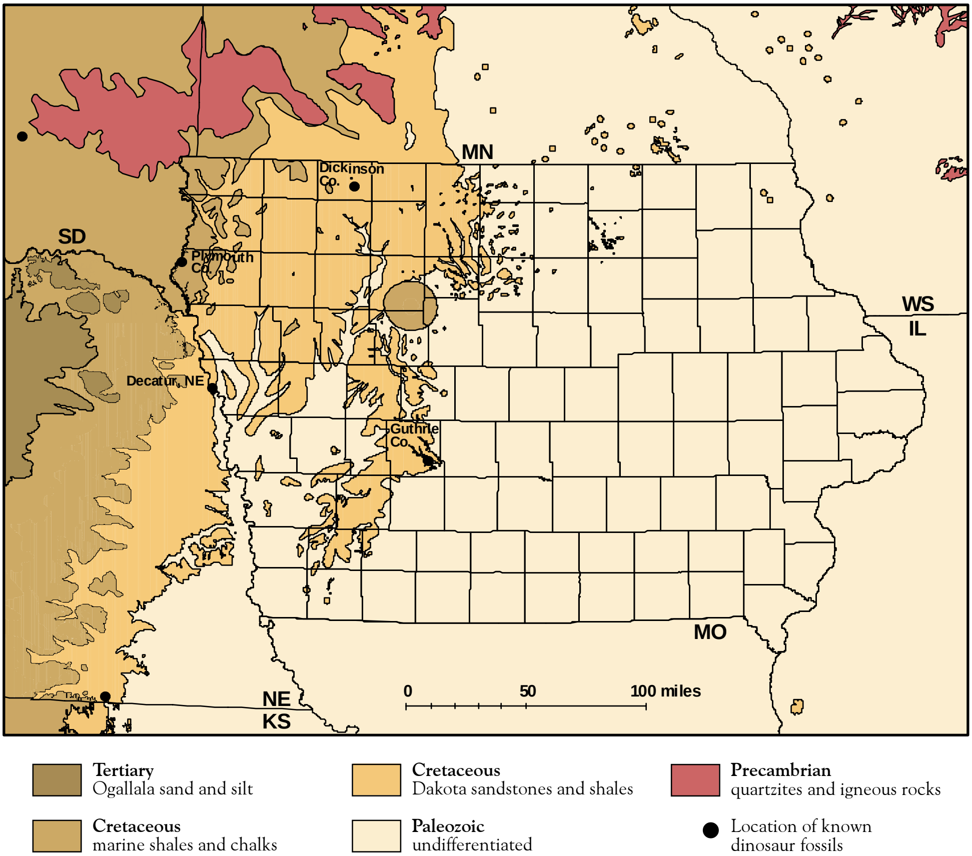
early hadrosaur. Hadrosaurs are a well-known family of "duck-billed" ornithopod dinosaurs that comprise the most abundant and diverse group of Late Cretaceous dinosaurs in North America.

Other dinosaur fossils have been uncovered from the Dakota Formation in nearby northern Kansas, eastern Nebraska, and Minnesota. A family of heavily armored ankylosaurian dinosaurs, the nodosaurids, is represented by partial skeletons of a ten-foot-long creature known as *Silvisaurus*. Additional hadrosaur bones have been found in Minnesota. Three-toed fossil footprints of ornithopod dinosaurs have been discovered recently in Dakota strata.

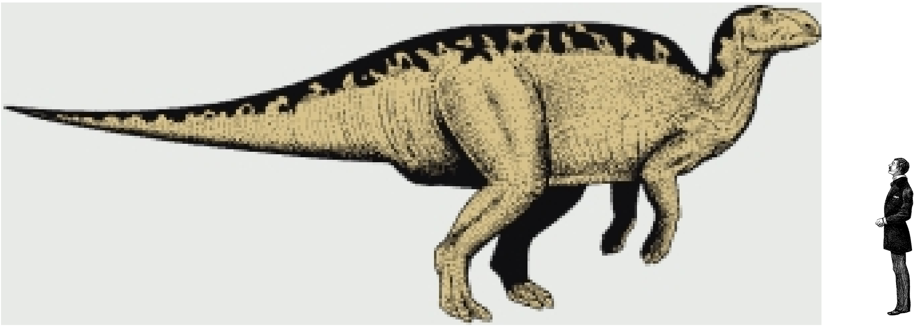
In Iowa, a fragment of fossil bone was found by the author in 1982 in ancient river gravels of the Dakota Formation in Guthrie County. The microscopic structure of this fragment (shown above) revealed densely vascularized bone, indistinguishable from that seen in typical dinosaur bone. Although not terribly impressive by itself, the Guthrie County discovery confirms that dinosaur fossils indeed occur in the Dakota Formation of Iowa.

The river deposits of the Dakota Formation were progressively flooded by marine waters as a vast interior seaway encroached eastward later in the Cretaceous, and a succession of younger shale and chalk deposits were laid down on the ancient sea bottom in western Iowa. These strata, named the Graneros, Greenhorn, Carlile, and Niobrara for-

Dinosaur-bearing Cretaceous strata in Iowa and adjoining states



mations, have yielded bones of large marine reptiles known as plesiosaurs from several localities in Iowa. In nearby areas, these same formations have also produced fossils of other extinct reptile groups including mosasaurs (giant sea lizards) and pterosaurs (large flying reptiles). Although plesiosaurs are sometimes linked with dinosaurs in the public's imagination, plesiosaurs actually represent an unrelated group of extinct marine reptiles. Long- and short-necked plesiosaurs plied the waters of the Cretaceous interior seaway with large paddle-like flippers in search of fish and other prey. The marine shales and



Fossil bone from the Dakota Formation in the Iowa area indicates that large ornithopod dinosaurs once inhabited the region. Reaching a length of 32 feet, these plant-eating giants browsed the lush subtropical forests and swamps. (Six-foot-tall human for scale.)

chalks of this seaway also yield the remains of true dinosaurs. Dinosaurs certainly did not live at sea, but occasionally a carcass would float out to sea, decay, and settle to the bottom. The discovery of dinosaur bones and teeth (of hadrosaurs and ankylosaurs) in marine strata from nearby Minnesota, South Dakota, and Kansas certainly raises the possibility of similar discoveries in western Iowa.

Long after extinction of the dinosaurs, huge continental glaciers advanced and retreated across Iowa during the "Ice Age" (the last 2.5 million years). These advancing glaciers incorporated large volumes of rock and other sediments as they moved across the continent. Much of the glacial material was derived from erosion of the Cretaceous strata that underlie large areas of the northern Great Plains. Reworked and transported Cretaceous fossils, such as plesiosaur bones and shark teeth, are sometimes found in the glacial tills and associated gravel deposits in Iowa, especially in the western part of the state. Two dinosaur bones can now be added to the list of Cretaceous fossils recovered from glacially derived gravels in Iowa, and to date these discoveries represent the best dinosaur fossils found in the state.

Charlie Gillette of Dickinson County picked up a dark-colored, 3-inch fossil bone from a load of landscaping gravel that came from a nearby gravel pit. When his uncle Jack Neuzil, a re-

Fossil dinosaur vertebrae 3 and 4 inches long have been found in Dickinson (right) and Plymouth (far right) counties, Iowa, respectively. These specimens likely came from hadrosaurs.

photos by Paul VanDorpe

tired educator and dinosaur enthusiast, saw the bone he suspected that it could be a dinosaur vertebra. His suspicions were confirmed by a leading dinosaur paleontologist, and the discovery of Iowa's first identifiable dinosaur bone was soon reported in the *Des Moines Register* (9/7/2000). The fossil is a tail vertebra from an unknown dinosaur, possibly a hadrosaur.

Following this discovery, a second dinosaur vertebra from Iowa has come to light thanks to Doris Michaelson of Bellevue. Her father, John Holdefer, had a keen eye and was fascinated by the rocks and fossils that he saw as a Materials Inspector for the Iowa Highway Commission. Sometime in the mid-1930s he picked up a fossil bone from a conveyer in a gravel pit near Akron in Plymouth County, and the bone was kept on a shelf and occasionally used as a doorstop in the family's home. In response to a recent newspaper article about dinosaurs in Iowa, Mrs. Michaelson contacted the Geological Survey Bureau and brought the bone in for identification. It is a partially weathered 4-inch dinosaur vertebra, likely from an hadrosaur.

It's only a matter of time before some lucky searcher examining Iowa's Cretaceous formations or Ice-Age gravels finds the next dinosaur fossil from Iowa. So keep looking! ❖

Monitoring Iowa's Waters

Bernard E. Hoyer photos by Ken Formanek

We require water for life, share its ownership and stewardship, benefit from its use for business and recreation, and, in order to manage it, we need water quality data. The mission of the Iowa Water Monitoring Program is to conduct an ongoing assessment of the condition of the state's surface water and groundwater resources and to report results so that appropriate information is available to guide resource management policies and decisions.

The program requires collection of reliable, objective statewide data on a continuing basis and delivery of information through various means. Key goals are a scientific description of waters, measurement of changes in quality, identification of trends, delivery of information to the public, and public involvement with their water resources.

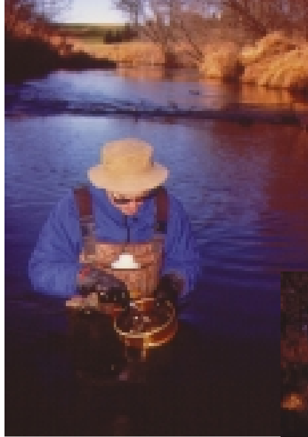
The uniqueness of this monitoring program lies in its comprehensive nature, including rivers, lakes, wetlands, and their ecological communities; groundwater from the water table to deep bedrock aquifers; and even precipitation. The program focuses on ambient water conditions. This means that all types of water resources are being looked at across the state to gain a fair and consistent appraisal of their condition. It is not concerned just with known water quality problems, or with checking on regulatory compliance – aspects of monitoring that have existed for years. It is "big picture" monitoring, and it can lead to many practical policies and management decisions. This program is growing and adapting with the strong emphasis placed on it by the Governor, the General Assembly, and a diverse coalition of other groups.

Initial emphasis has been placed on improved monitoring of Iowa's interior rivers and lakes and developing a data management system that can capture data effectively and deliver it to government and public users.

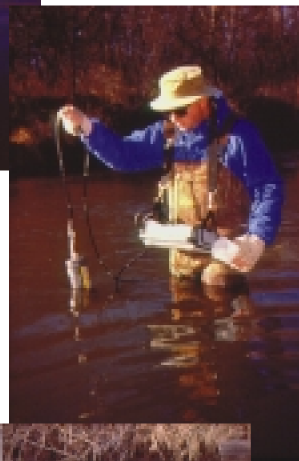
Data collection is the most important and expensive portion of the program. Iowa's interior rivers and streams plus 132 lakes are monitored for over 200 chemical, physical, and biological parameters, including pesticides, pharmaceuticals, and volatile organic compounds. All state-owned beaches are monitored for indicator bacteria groups throughout the swimming season. Groundwater is monitored from available public, private, and specially installed monitoring wells. All field and laboratory methods and techniques are recorded to insure future comparability of data for scientific analysis.

Following the sampling phase, data management, coordination, and interpretation are crucial areas of the program, as well as the production of reports for management purposes and for the public. Other agencies will be encouraged to add their data to a central clearinghouse to ensure long-term curation and widespread availability. Timely interpretation, annual as well as long-term, is essential as monitoring data accumulates through the years.

Finally, keeping Iowans informed is vital to the success of this monitoring program. Resource managers, elected officials, special interest groups, and the public need to be aware of what is done and learned. Part of this citizen involvement includes the IOWATER program, targeted at educating the public by training volunteers to monitor water resources in their home areas.



Left: Identifying small invertebrates found in streambeds provides an indicator of water quality.



Right: This device measures such water characteristics as pH, dissolved oxygen, and turbidity.

Above: Following electro-shocking, fish can be counted, identified, and examined before being released.

Monitoring Iowa's waters is a long-term investment. The program must continue uninterrupted, without gaps in data, to attain its goals and maximize its usefulness to Iowa. At the same time, the program must maintain flexibility and adjust as experience is gained and technology improves. ❖

Keeping Ahead of Groundwater Quality Questions

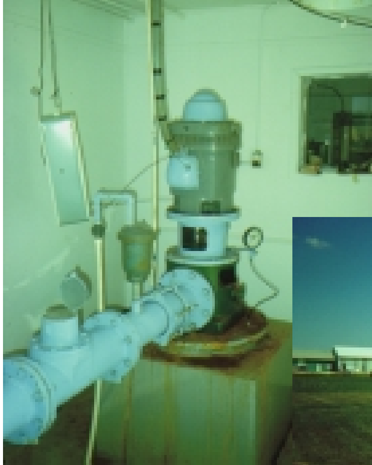
Robert D. Libra photos by Dave Conell (USGS)

For almost two decades, the Geological Survey Bureau, in partnership with the U.S. Geological Survey (USGS) and the University Hygienic Laboratory, has monitored the quality of raw untreated groundwater from individual municipal wells. The size of this effort has varied through time, with available state and federal funding. Focus of the monitoring has evolved as well, in response to changes in society's questions about the quality of our groundwater.

In the early 1980s, between 150 and 200 wells were sampled annually and analyzed primarily for "natural" constituents. These included minerals such as calcium, magnesium, bicarbonate, sulfate, iron, and manganese; the more common nutrients such as nitrate; and radioactive compounds such as radium. As various groundwater investigations began to show the presence of agricultural and other contaminants in "vulnerable" aquifers, the program emphasis shifted towards shallow aquifers, with more nutrients, pesticides, and synthetic organic chemicals added to the analyses. Environmental parameters such as organic carbon and dissolved oxygen also joined the list. The number of wells sampled increased for a time to over 200 per year, but decreased to the 45 to 90 range in the late 1990s.

Results from this cooperative monitoring network are a key part of our knowledge about the state's groundwater quality. They allow for prediction of natural and contaminant-related water quality of our major aquifers, and thus let us know whether their quality will support various uses. Is the water too hard for a boiler, or does it have too much sulfate for supplying a dairy? Would we need to purge the iron and hydrogen sulfide to make it palatable? Will the water meet public drinking water standards? Will the quality pose odor problems if used with an anaerobic lagoon?

Many such questions are known to the water supply industry. However, new questions always arise, and one of the most




Emmetsburg Municipal Well #4 is 35 feet deep and taps gravel deposits along the Des Moines River valley. The well has been sampled periodically as part of a long-standing cooperative program with the U.S. Geological Survey.

important uses of groundwater monitoring information is to supply answers for questions that haven't been asked before.

For example, nitrogen in the form of ammonia may undergo troublesome reactions during some types of water treatment, and even have a negative effect on the treatment process itself. In the past, water supply wells were rarely analyzed for ammonia, based on the "conventional wisdom" that ammonia doesn't occur in significant amounts in groundwater, unless it is grossly polluted. When a water supply did show measurable ammonia, the search was on for the contamination source. The usual suspects, such as nearby septic systems, leaking sewer lines, or livestock manure, would be rounded up, examined, and typically found innocent. Information from the groundwater monitoring was used to explain the situation. Ammonia does indeed occur naturally in high enough concentrations in some groundwaters to cause treatment problems. This occurs fairly commonly, and predictably more so in some aquifers than others. There is no contaminant source to search for.

Other such questions are being raised. Researchers are coming to realize that relatively low concentrations of phosphorus impact stream and lake environments, so we need to assess the natural background levels in groundwater feeding streams and lakes. Also, there has been a long discussion about lowering the drinking water standard for arsenic. What would be the impact on Iowa water suppliers if this happens? Beyond answering the questions we know about, we need to continue keeping our monitoring efforts a step ahead – collecting answers before the questions are asked. ❖

Baseflow

WHERE GROUNDWATER MEETS SURFACE WATER

Keith E. Schilling photo by J.R. Olson

It's late summer and it hasn't rained in a month. The lawn has turned brown and farm fields are dry and cracking. Yet a trip down to the nearby stream channel finds flowing water. What you are witnessing is the interplay between groundwater and surface water. Groundwater seepage into a stream channel is called *baseflow*. During most of the year, stream flow is composed of both groundwater discharge and land surface runoff. When groundwater provides the entire flow of a stream, *baseflow conditions* are said to exist.

Groundwater discharges into streams when the water table (top of groundwater saturation) rises above the streambed. Perennial streams flow because groundwater remains above the streambed throughout the year. You may notice some streams flow only part of the year, generally from spring to midsummer, or only during wet periods. These intermittent streams occur when the water table rises above or falls below the base of a stream channel in response to wet or dry weather. During extended dry periods, the water table falls below the streambed. Only after rainfall has replenished the groundwater supply does the water table rise sufficiently to intersect the streambed and resume baseflow discharge.

The amount of baseflow a stream receives is closely linked to the permeability of rock or soil in the watershed. For example, the Floyd River in northwest Iowa flows through a watershed composed of clayey glacial till and silty loess. Based on a 12-year record of stream gaging (1987-1999), each square mile of land in its watershed produced an average of 3.7 inches of baseflow discharge. On the other hand, the Upper Iowa River in northeast Iowa, flowing through a watershed consisting of fractured limestone and dolomite, had more than twice the baseflow discharge (8.0 inches per square mile).

Baseflow is an important consideration when evaluating the health of a stream. Arguably, the most important

Streams continue to flow during extended dry periods because of contributions from groundwater. Such baseflow conditions affect water temperature, aquatic life, and delivery of pollutants to streams.

factor regarding the fate of aquatic organisms in surface water is the amount of sustainable flow in the channel. Streams with adequate baseflow can sustain fish and tiny aquatic organisms during prolonged dry periods. Since groundwater temperatures are nearly uniform year-round, groundwater discharge also provides a measure of temperature stability in surface water. Streams in northeast Iowa, home to several indigenous trout species, owe their temperate conditions to contributions from baseflow and spring discharge. However, in some cases, discharge of pollutants in baseflow may have detrimental effects on surface water quality. Nitrate-nitrogen, a common pollutant in Iowa's streams, is delivered primarily through groundwater discharge as baseflow or tile drainage (a type of modified baseflow). Point-source impacts are especially noticeable when a stream's flow consists nearly entirely of baseflow (see photo above).

Ultimately it is the relationship between surface water and groundwater during baseflow periods that may help solve some of Iowa's water quality issues. Monitoring surface water quality when flow consists entirely of baseflow can be used to identify and locate sources of pollution. In turn, these pollution sources can be addressed at their origin so that baseflow water quality improves over time. We can all understand the need for quality baseflow in our streams, especially during a hot Iowa summer. ❖

Topographic Relief Map of Iowa

James D. Giglierano
Jean C. Prior

This soaring view of Iowa's terrain shows the unevenness, or relief, of the land surface. Particularly noticeable are the large number of rivers within the state and the directions in which they flow. Using river alignments, can you follow the Missouri-Mississippi drainage divide along its length in Iowa?

The amount of topographic relief and the patterns of stream dissection are related to underlying geologic materials. In northeastern Iowa, sedimentary bedrock at the land surface sharpens and steepens the landforms. In far western Iowa, adjacent to the level Missouri River valley, rise the intricate blufflands of the silt-dominated Loess Hills. Fresh glacial drift deposited just 14,000 to 12,000 years ago across north-central Iowa yields level terrain, only a few well-developed rivers, and a landscape scored with curved ridges of glacial moraines. In contrast, drainage networks are well established across the much older glacial deposits of southern Iowa (over 500,000 years old), and extensive erosional sculpture is evident.

This computer-generated map is based on a grid of land surface eleva-

tions artificially illuminated from the northwest. The intriguing view reveals a variety of physical shapes and features, as well as broader landscape patterns. These clearly demonstrate remarkable differences in Iowa's terrain from one part of the state to another. ❖

THE GEOLOGY OF
Pikes Peak State Park

Brian Witzke and Ray Anderson photos by Clay Smith

The northeast Iowa area around Pikes Peak State Park in Clayton County is one of the most beautiful and interesting regions of Iowa. Its precipitous rock bluffs record a geologic history beginning over 500 million years ago. Various plant and animal communities have inhabited the region, shifting and evolving with climatic and cultural changes. The long history of its Native American residents is symbolized by the large number of mounds along ridge tops, many shaped as animal effigies. The arrival of Father Marquette and Louis Joliet in the region in 1673 opened a rich, new phase of regional history. French hunters, trappers, and miners were among the early historic residents. The region became a part of the United States with the purchase of the Louisiana territory in 1803, and was explored by Zebulon Pike shortly thereafter. Military forts were built, towns established, and roads constructed. In 1837, Alexander McGregor established a ferry across the Mississippi River. McGregor's Landing was located at the site of the town that now bears his name. The Pikes Peak area was owned by McGregor, and, as a favorite family picnic spot, it was protected from being logged for firewood to feed the hungry

riverboat boilers. Ownership of the area passed down through McGregor's relatives, until it was given as a gift to the federal government. The property was later conveyed by Congress to the State of Iowa and became Pikes Peak and Point Ann state parks in 1935. Since settlers had never been allowed on the land, Pikes Peak today probably appears much as it did hundreds of years ago.

An instructive and picturesque succession of geologic strata is wonderfully displayed within Pikes Peak State Park. The downcutting of the Mississippi River valley has exposed a number of geologic formations in bold cliffs and steep ravines. The oldest rock formation exposed in the area is the Jordan Sandstone, which outcrops at Point Ann at the north end of the park. The sandstone, about 100 feet thick, was deposited during the latter part of the Cambrian Period, about 505 million years ago, as beach and near-shore sands of a slowly advancing and retreating sea. The Jordan

Above: The highest bluffs at Pikes Peak are underlain by massive Paleozoic-age dolomites of the Galena Group. They provide panoramic views of the Mississippi River valley and its confluence with the Wisconsin River – the spot where French explorers Marquette and Joliet first saw the Upper Mississippi Valley in 1673.

Far left: Water splashes over Bridal Veil Falls, a resistant ledge of 460-million-year-old dolomite of the Platteville Formation (Ordovician).

Sedimentary bedrock outcrops form bold bluffs throughout Pikes Peak. These rock strata vary in their resistance to weathering and erosion. The result can be rough-textured ledges overhanging smooth-textured recesses. (Prairie du Chien dolomite shown here.)

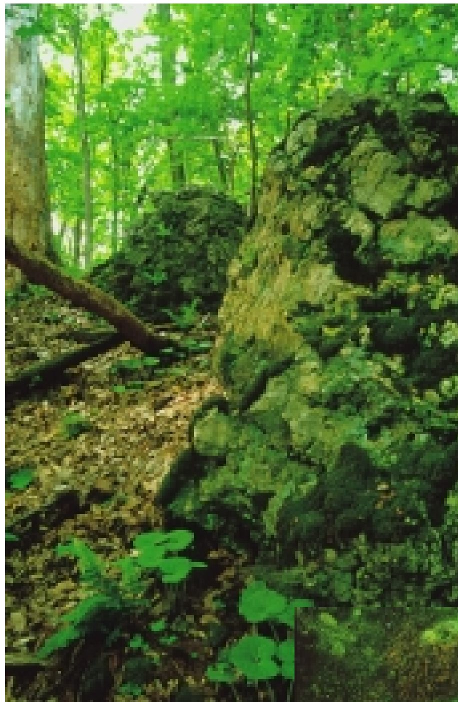
Sandstone is an important aquifer, providing water to wells across much of eastern Iowa, including wells for drinking water at Pikes Peak.

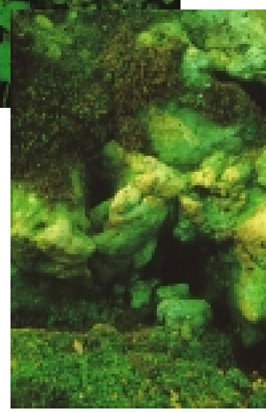
Above the Jordan Sandstone is the Ordovician-age Prairie du Chien Group, named for the nearby city of Prairie du Chien, Wisconsin. These strata include a succession of dolomites with minor sandstone and shale, which reaches thicknesses up to 220 feet in the park. The erosionally resistant dolomite forms bluffs, exposed at Prairie du Chien and northward throughout much of the Upper Mississippi Valley to the Twin Cities. The dolomite layers were originally deposited as lime sediments in a shallow tropical sea that covered much of the interior of North America between about 490 and 505 million years ago. These sediments were subjected to later chemical replacement by dolomite.

The Prairie du Chien seas eventually withdrew from the interior of North America during later stages of the Early and Middle Ordovician, beginning a remarkably long period of erosion that continued for 25 million years. This erosional period was characterized by extensive weathering of the landscape, the cutting of deep river valleys, and the production of a network of caves and sinkholes, known to penetrate up to 350 feet deep in areas of eastern Iowa. As the seas again returned to the area, the deep valleys were filled with sand and shale, and a remarkably homogeneous interval of fine quartz sandstone was deposited across the region. This upper blanket of sandstone and the underlying valley-fill succession of variably colored sandstone and shale comprise the St. Peter Sandstone. The lower unit is of special interest in the area of Sand Cave in the park, where iron staining has produced rich colors, with reds, oranges, browns, and purples coursing through a mostly buff- to white-colored matrix of quartz sand (see p. 21).

Directly above the St. Peter Sandstone, lies the gray-green Glenwood Shale. Only about four to five feet thick in the park, the shale is soft and easily erodible, so it is typically not well exposed in the park's wooded ravines. The clay sediments that formed the Glenwood Shale were deposited very slowly in a shallow seaway, probably far from shore.

The Platteville Formation, a 45-foot-thick succession of limestone and dolomite strata, is exposed in the upper slopes in Pikes Peak State Park. It represents lithified sediments deposited in a broad tropical sea, which supported a diversity of shelled bottom-dwelling





Prairie du Chien dolomite forms broad-shouldered outcrops on hillslopes (above), and tiny grottos within its weathered surface (inset right). In contrast, water wears the St. Peter Sandstone into smoothly contoured slopes (left).

animals. The unit can be most easily viewed along the park's boardwalk, where a small creek cascades over a resistant dolomite ledge to create Bridal Veil Falls.

The uppermost rock interval exposed at Pikes Peak is the Galena Group, composed of the basal Decorah and the overlying Dunleith formations. The Decorah Formation is a succession of shale and limestone. The shales, typically greenish-gray in color, include spectacular lenses of brachiopod fossils. Interestingly, these shales also include thin but widespread layers of altered volcanic ash derived from distant eruptions near present-day Virginia. The clay shales and embedded ash deposits are soft and easily weathered, so they are not well exposed in the park.

Above the Decorah, however, the massive Dunleith Formation forms the highest cliffs and ledges within the park. These resistant dolomite and limestone beds are well displayed at the main Mississippi River scenic overlook and in old quarry workings within the park. The Dunleith contains almost no shale and is dominated by dolomite, which displays a considerable quantity of nodular chert ("flint"). This formation reaches thicknesses of 80 feet in the park and forms cliffs along the Mississippi River valley southward to the Dubuque area.

The modern Pikes Peak State Park landscape, dominated by steep bluffs, is the product of dramatic sculpting of the bedrock strata and deep incision by the Mississippi River. The floor of the Mississippi bedrock channel lies some 300 feet below the modern river level. This deeper level of down-cutting was likely related to episodes of continental glaciation during the last 2.5 million years, when vast ice sheets were present in the Northern Hemisphere, lowering global sea level up to 400 feet, and increasing the gradient of the Mississippi River. Then, as the ice sheets began to melt, huge volumes of meltwater and sediment moved down the Mississippi Valley and other drainageways scouring and deepening the valley. As sea levels progressively rose once again, the sediment-laden meltwaters deposited large volumes of sand and gravel within the valley.

Pikes Peak State Park, perched high on the bluffs overlooking the Mississippi River in Clayton County offers an irresistible combination of natural beauty, colorful history, and informative geologic exposures. It rates as one of Iowa's greatest natural treasures. ❖

from SANDSTONE *to* SAND PAINTINGS

Well-rounded grains of nearly pure quartz sand compose the St. Peter Sandstone. This formation is up to 200 ft thick in the Pikes Peak region, and its massive beds stand out among the bluffs and steep-walled ravines. Of special interest in its lower portion are dramatic reddish-orange swirls and bands of iron-oxide cements (photo, right). These colors were imparted by mineralized groundwater moving through the porous sandstone.

Captivated by the array of colors at Pictured Rocks or Sand Cave, as the site is known, Andrew Clemens, an 1880s resident of McGregor, created exquisite, three-dimensional sand paintings in bottles. During his 20s and 30s, he created intricate designs and pictures by layering loose sand into drug jars, color by color, upside down through their narrow openings. Completed artworks were sealed with wax and inverted. Shown left are two sides of one jar, with George Washington astride a white horse on one side, and two Native Americans, the State Seal of Iowa (including motto), and a steamboat on the other. Note Clemens' signature in the red sand below the boat.

Adapted from: Wagasky, Rashelle, 1997. *One in a Million.* Iowa Heritage Illustrated, State Historical Society of Iowa, Spring, 1997, p. 48-49. Also, Anderson, R.R. and Bunker, B.J. (eds). 2000. *The Natural History of Pikes Peak State Park, Clayton County, Iowa.* Geological Society of Iowa, Guidebook 70, Nov. 2000, 139 p.

Photo above by Ray Anderson.

Photo left courtesy of State Historical Society of Iowa – Des Moines. Photographer: Chuck Greiner.

Keokuk Water Works
ITS GEOLOGICAL FOUNDATIONS

Jean C. Prior and Robert M. McKay
photos by Paul VanDorpe and Robert M. McKay

There is often more than meets the eye in a municipal water supply. This is especially true of the city of Keokuk, Iowa, and its water works. Sandwiched between the Mississippi River's flow on one side and 345 million-year-old limestone bluffs on the other, the city's state-of-the-art water plant is expanding and is literally anchored to its geological foundations. With its special geologic setting and the city's interest in educating the community about its drinking water supply, Keokuk's Municipal Water Works has put out the welcome mat for visitors to tour this fascinating facility.

This Iowa stretch of the Mississippi River has attracted geological interest for well over 150 years. The final sweeping curves in the state's eastern border between Burlington and Keokuk are formed by bluffs of massive limestone, and the rapids at Keokuk were a noted obstacle to early exploration and travel by river. J.N. Nicollet writes, "In 1838 Congress ordered a survey of the rapids, which was entrusted to Captain R[obert] E. Lee of the corps of engineers (and later Civil War General). By his estimate, the length of the rapids is eleven miles, with a fall of twenty-four feet. Here the Mississippi tumbles over ledges of blue limestone which are at all times more or less covered with water and through which many crooked channels have been worn." *

These exposures of resistant bedrock are assigned to the Mississippian Subsystem, one of the basic divisions of geologic time recognized throughout the world. In fact, Mississippian-age strata were so-named in the geologic literature of the late 1800s for this Iowa segment of the Mississippi River valley. To geologists, these rock outcrops are the starting point for the definition of strata of this age.

The lime-rich sedimentary rocks actually had their origins 345 million

Keokuk Water Works, barely visible beyond Lock and Dam #19 on the far shore, is dwarfed by the broad expanse of the Mississippi River. Its width was scoured by the erosive action of glacial meltwaters that periodically flooded the valley over 9,000 years ago. Sweeping curves along the valley are defined by limestone bluffs of Mississippian age, a term of geologic time recognized worldwide and named for this segment of the Mississippi Valley between Keokuk and Burlington.

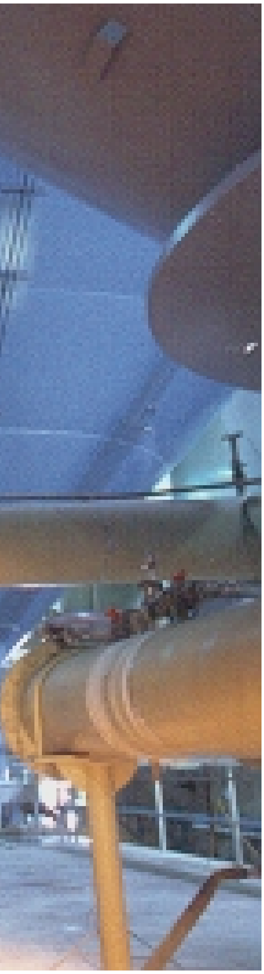
years ago in shallow tropical seas that submerged the continent's interior, including Iowa. The rocks bear fossil remains of abundant marine organisms that inhabited these warm seas, an environment resembling the clear waters of the Florida Keys today. Lime sediments were precipitated from seawater and also were produced biologically as animals such as corals, crinoids, brachiopods, and snails built their skeletal shelters.

The Mississippi River itself appeared much later in time, likely originating with south-bound glaciers that periodically gripped the midcontinent in sub-Arctic cold between 2.5 million and 10,000 years ago. Bedrock promontories, such as here at Keokuk, were left standing as the river gradually deepened its valley, especially during the later chapters of the state's Ice Age history. Episodes of glacial melting, especially between about 100,000 and 9,000 years ago, sent meltwater floods surging down the Mississippi, scouring the valley floor still deeper, and then partially backfilling the gorge with thick deposits of

sand and gravel.

The most significant event in the river's modern history has been construction and maintenance of a nine-foot navigation channel and its accompanying lock and dam system built to facilitate commerce throughout the region. Lock and Dam #19 is situated right outside the Keokuk Water Works, and its operation and river traffic add considerable interest to visitors.

But the story is not complete. In 1877, citizen William Stripe's concern for safe drinking water led him to found a private company known as the Keokuk Waterworks. Its purpose was to gather



Mississippi River water is pumped through a network of pipes into massive cone-shaped clarifiers where sediment and dissolved minerals are removed from the swirling water. Keokuk's expanded, state-of-the-art water plant includes a 12-ft-high portion of the 345 million-year-old Mississippian limestone bluff along one entire interior wall of the 300-ft-long building.

and treat Mississippi River waters for distribution to citizens and industries of the prospering city. In 1938 the company was purchased by the City of Keokuk, and a new treatment building was constructed, with further improvements in subsequent decades. Then, in 1995, on the same piece of ground, an entirely new treatment plant was begun as a phased replacement of the older facilities.

The first important issue was location. The site on the Mississippi River still looked good over 100 years later because it already had functioning river-intake pipes and underground settling tanks that could be converted to clean water storage. In order to construct the new building on top of the 1979 settling tanks, engineers designed a pillar anchored into underlying bedrock to support the weight of a new 1.3 million-pound re-carbonation unit.

Construction at the existing site also entailed excavating into the steep bedrock bluff to create more space. Contractors removed about 200,000 cubic feet of rock and cut a stair-step into the bluff so that massive cone-shaped water clarifiers and softeners would have a solid foundation. Phase I of the new facility is complete, and includes a 14 million-gallon-per-day treatment process. With an eye to future expansion, the pipes and space are in place to add new filters and more clarifying and softening cones as needed.

Excavation into the valley bluff exposed two of the local Mississippian bedrock formations, the upper part of the Keokuk Limestone and the lower portion of the overlying Warsaw Formation, a more shaley interval. Both rock units, particularly the Warsaw, are widely known for the spectacular crystal-lined geodes that are embedded in the clayey dolomite.

Though geodes are known from many localities around the world, one of the most famous collecting regions occurs within a 35-mile radius of Keokuk. Rock collectors commonly refer to these specimens as "Keokuk geodes," and in 1967 the Iowa General Assembly declared the geode as the official "State Rock." These roughly spherical masses of silica-rich minerals separate easily from their host rock. The most prized specimens have hollow interiors lined with pointed crystals of quartz and other minerals. They can range in size from that of a walnut to a basketball.

The geode-laden rock bluff was so interesting that it was decided to incorporate a portion of the bluff into the water plant's long west wall. About 9 feet of geode-bearing dolomite is well exposed along the driveway outside the new plant (see photo, p. 27), and the rock wall then continues some 300 feet along the entire length of the building's interior where the wall stands 12 feet high (see photo, p. 24). Smaller, less accessible exposures of Warsaw Formation are present behind the building.

Today's Keokuk Water Works is situated against a bluff of limestone significant in the history of the country's geological investigations, a bluff of sedimentary rock detailing a 345-million-year-old history of ancient seas and their inhabitants. It overlooks a younger valley that was host to torrents of glacial meltwater floods several thousand years ago, and whose modern descendant, the Mississippi River, flows past the front door, providing Keokuk and its residents with their drinking water supply.

The Keokuk Municipal Water Works recognizes its unique geography and geology. They have incorporated the bedrock, the bluffs, the valley, the river, and the lock and dam into their plant design. Inside the plant, the ancient geode-laced Mississippian strata form a striking visual counterpoint to the modern array of piping, tanks, valves, massive cones, catwalks, and computerized operations that organize and treat the river's water into a municipality's water supply (see photo p. 24).

Keokuk Water Works encourages public tours of their plant. They know these visits can increase the public's understanding not only of their local drinking water supply and its quality but

Layers of geode-bearing clayey dolomite, examined above by geologist Robert McKay, add great visual and educational interest to the Keokuk Water Works, both inside and outside the plant. The geodes, Iowa's official "State Rock," are lined with quartz (chalcedony, upper left) and calcite on quartz (lower right).

awareness of broader regional and state water supply issues as well. In this scenic setting, that awareness includes a unique reminder that we depend on and interact daily with geological resources and geological processes past and present. ❖

* Lewis, Henry. 1967 (originally published in German in 1854). *The Valley of the Mississippi Illustrated.* Minnesota Historical Society, p. 219. Quote from J.N. Nicollet's 1843 *Report Intended to Illustrate a Map of the Hydrographical Basin of the Upper Mississippi River.* 26th Congress, 2nd session. Senate Documents, no. 237 – serial 380, p. 24, 26.

COMMON GROUND

In the field of ecology, the base upon which an organism lives is called its substrate. Geology is about substrates, and includes earth materials that support plant and animal communities. These two fields are literally knit together by their common ground.

Examples include Pikes Peak where bedrock substrates provide exquisite microhabitats (see cover) as well as expansive rock-bound blufflands. In other substrate settings, Iowa's Water Monitoring Program counts on tiny creatures that cling to the bottom of rocks in streambeds to tip off investigators about stream health and water quality. The permeability of rock and soil substrates affects the groundwater contribution to a stream's baseflow and to cool water essential for some aquatic life. Dinosaur fossils bring the dimension of time to life's substrates, providing insight into the ecology of prehistoric environments. In the photo at right, a gravel substrate hosts a shoot of heat-generating skunk cabbage as it emerges through the last icy coatings of winter.

Throughout Iowa, the base upon which all life exists – our geological substrates and deeper geological infrastructure – consists of silty glacial clays, wind-blown silt and sand, river gravel and sand, as well as limestone, dolomite, sandstone, and shale bedrock. These underlying foundations affect our state's agricultural productivity. Their engineering characteristics affect building construction, and their value as mineral and aggregate resources affects our economy. Their porosity affects both how well we contain waste buried in the ground, and at the same time how well we protect the quality of our drinking water supplies – the quality of Iowa's human ecology.

Jean Cutler Prior
Editor

Clay Smith

Hanging Bog State Preserve, Linn County.