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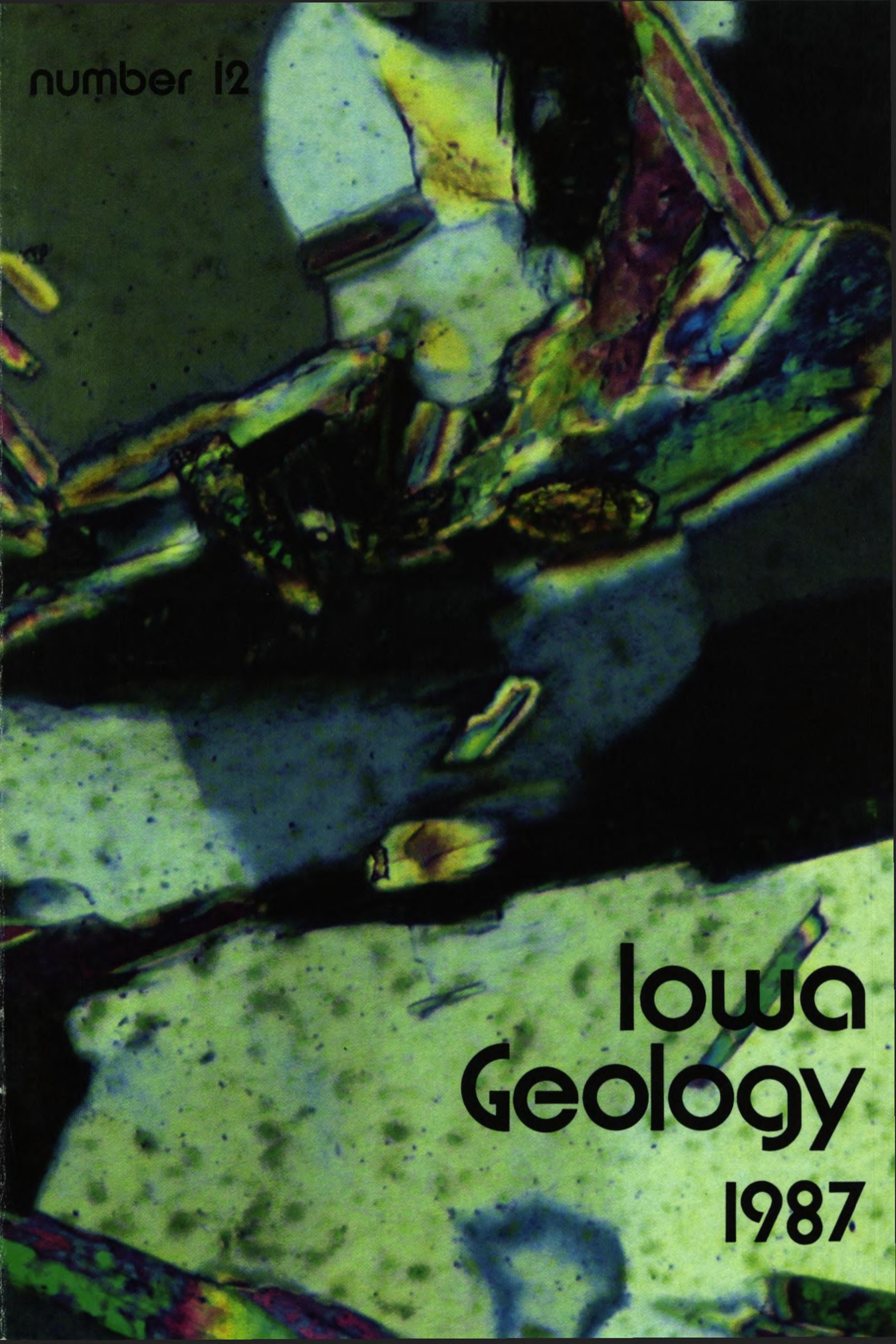

Iowa Geology

1987

Iowa Geology 1987

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Cover:

This thin-section view of a metamorphic rock (gneiss), as seen through a petrographic microscope, shows interlocking mineral crystals of white, gray, and black quartz with varicolored muscovite mica. The rock is from a cored sequence of uplifted Precambrian-age rocks near Manson in northern Calhoun County. Thin-section studies provide important information about the composition, origin, and history of Iowa's rock materials. Cross-polarized light, magnified 235x.

Cover photo by Greg A. Ludvigson
Cover design by Patricia Lohmann

Jean C. Prior . . . . Editor
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Editor's Note: Appreciation is expressed to Mary Pat Heitman for her secretarial assistance and to the individual authors for their cooperation.

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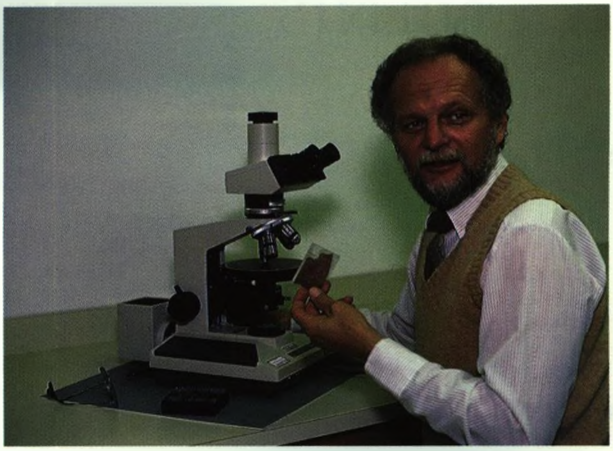


With each issue of *Iowa Geology* we hope to broaden our readers' acquaintance with different aspects of the state's geology and hydrology. Past issues have included articles on coal exploration; irrigation of croplands; mineral resources; caves; water resource investigations; topographic mapping; hazardous-waste disposal; fossils; oil exploration; and groundwater contamination. And yet we have hardly scratched the surface of interesting topics and significant matters that could be brought to your attention.

As you read this issue, you will develop a new sense of our state's geologic setting, from the megascopic to the microscopic. There are high-altitude images of the Mississippi Valley and the western Loess Hills; magnified details of crystal configurations; maps to estimate flood characteristics; monitoring results from sand and gravel aquifers; and underground limestone mines. Thus, you will become further exposed to the wide range of our geological investigations — geographically across the state, vertically through the subsurface — at both large and small scales.

Just as geology itself is dynamic, so are the tools which geologists utilize to conduct investigations. New techniques permit further study and understanding of our finite natural resources, and new geologic concepts demand reexamination of long-held ideas and theories. What areas of investigation remain to be addressed? What work remains to be done?

The current detail of geologic mapping is inadequate for much of the state. More accurate information is required for land-use planning, environmental protection, and hazards control. Our groundwater resources need further evaluation relative to available supplies, the extent and type(s) of contamination, and, yes, the impacts of a predictable drought. We need to further assess our supplies of industrial minerals (limestone, clay, gravel, etc.), particularly where urbanization continues to limit extraction of these commodities.

And of course there is more to learn about our state's potential for commercial oil and gas. Additional exploration likely will occur in "shallow" sedimentary rocks of southeast and southwestern Iowa, largely through the efforts of individual operators and small companies. AMOCO Production Company started to drill their M.G. Eischeid #1 test in Carroll

STATE GEOLOGIST'S VIEWPOINT

County on March 16, 1987. This is perhaps the most significant "geologic event" in Iowa's history. The information from this intended 15,000-foot test (nearly three times as deep as the current depth record in Iowa) may confirm, deny, or alter geologic interpretations about the Midcontinent Rift that presently are based upon geophysical data (gravity, magnetic, seismic). Whether or not oil or gas is discovered, the drill-hole data will add immensely to our knowledge about the geologic framework of Iowa.

With all that geologic work to be done, how do we prioritize and fund new projects, especially in light of a limited staff and budget, and be responsive to the information needs of taxpayers? Most new projects, once implemented, should be two years or less in duration so that timely results are available to the user community. All expenses for a project must be fully considered so that no significant cost overruns occur. Federal funds should be sought for certain projects that provide immediate, direct benefits to the state or that otherwise mesh well with the goals and responsibilities of the Geological Survey Bureau (GSB). Certainly the longer term projects and ongoing programs of basic data acquisition should be supported by state appropriations — these projects and programs represent an investment by the state in the acquisition of information that is critical to wise development, management, and conservation of our natural resources. Many projects require coordination (and often participation) with other state/federal agencies to assure that all interests are considered, that duplication of effort is avoided, and that maximum use is made of each bit of information derived from the project.

Whether a project is large or small, or whether the necessary tools and equipment require high-altitude imagery or a microscope, the expertise of the GSB staff will assure a quality product.

Donald L. Koch

State Geologist and Bureau Chief

GROUNDWATER POLICY AND GEOLOGY

Bernard E. Hoyer

Groundwater has always been important to Iowans, but it has never been regarded as a prominent, front-page issue. About 80 percent of the state's population utilizes this resource for their drinking water supply, yet most are unaware of the geological conditions which supply water to their wells. Although the occurrence, availability, and quality of groundwater vary from one region of the state to another, its quantity and quality have been accepted as inalterable products of the earth, and its purity has been taken for granted. The only hazards to wells were thought to be associated with poor construction or improper placement, implying risks from local sources such as septic systems or barnyards.

Findings of the past few years, however, have revealed another side to the story. Gasoline has leaked into wells and basements. Leachate from landfills has moved off-site. Chemicals have been documented in wells near farm-supply businesses. Hazardous substances from spills or waste-disposal sites have locally contaminated groundwater and threatened public water supplies. Nitrate, long a problem of shallow aquifers, has invaded deeper strata and increased in concentration, a reflection of two decades of intense agricultural expansion. Minute residues of pesticides, especially commonly used herbicides, have leached through the soil and been found in about 40 percent of wells thus far sampled in Iowa. Many of these findings have been chronicled in the press over the past five years.

Today, the public is concerned. A Department of Natural Resources (DNR) sponsored public-opinion survey of 400 citizens, taken in the fall of 1986, revealed that 86 percent of Iowans considered groundwater contamination as a serious problem, and 83 percent believed more needed to be done to protect the resource. Sixty-three percent of those who believed there was a problem volunteered ag-chemicals as the most significant source of that contamination. Documentation of water-quality problems, combined with widespread media coverage and the educational efforts of agricultural and other professional groups are responsible for developing the public's awareness and concern for Iowa's groundwater supplies. The General Assembly perceived this concern and mandated that the Environmental Protection Commission develop a groundwater protection plan for Iowa.

This plan, the *Iowa Groundwater Protection Strategy 1987*, is the state's first comprehensive attempt to design policy related to the protection of groundwater resources. The strategy was developed by DNR staff, along with advisory committees drawn from government and interested public groups. After approval by the Environmental Protection Commission in January 1987, the plan was sent to the General Assembly. Legislation to implement the plan will be controversial, but there is general agreement that

Groundwater contamination occurs when surface drainage, carrying society's by-products, infiltrates the soil and percolates downward to recharge aquifers in deeper geologic materials. Examples of conditions which are addressed in the Iowa Groundwater Protection Strategy 1987 include (from top to bottom) landfills where waste is buried, watersheds which drain to sinkholes, streams into which petroleum products have leaked, application of farm chemicals to the land, and migration of leachate away from waste-disposal sites.


Cindy Turkle


George Hallberg


Lary Kolczak


Cindy Turkle

some form of groundwater legislation will be enacted.

The plan establishes a goal of "non-degradation," a concept which emphasizes no further deterioration of present groundwater quality and, where possible, improving water supplies to previous quality levels. Prevention of contamination is the key to groundwater protection. In addition, the public must be confident that decision makers and administrators have the best available information for establishing sound policies and programs. This information and the need for its acquisition, in turn, must be understood and supported by the public. Reliable information on groundwater quality and the geological characteristics of the aquifers in which it occurs is a vital part of the strategy.

To a geologist, there is a certain "sameness" to all contaminant sources and the threats they pose to groundwater. Each potential contaminant has chemical properties which enable it to react with soil, water, air, micro-organisms, and sunlight. Each potential contaminant also varies in how it is used, the percentage lost to groundwater, the accompanying health risk, and the recommended control mechanisms. But the same sources of groundwater are vulnerable to them all.

Contaminants move into our aquifers along with the infiltrating waters which recharge them. Products in the air, on the land, in the soil or buried beneath the soil are all potential contaminants. Groundwater starts as rainwater and soaks the topsoil. Continued rainfall allows percolating water to fill voids around soil particles. Clay-rich soil slows movement and tends to direct the flow laterally; sand-rich soil speeds movement downward. Burrows and cracks in the soil conduct water downward at even faster rates. Such openings provide avenues for groundwater recharge through clay-rich glacial deposits as well as through bedrock. Contaminants from the land surface are found only in aquifers where historic recharge has occurred. And even though only trace amounts of a particular contaminant are found, their detection serves as an early warning system that the aquifer is vulnerable. While water generally tends to infiltrate rather slowly, the threat to aquifers is greatest where recharge is the most direct.

Research at the Geological Survey Bureau is aimed at understanding the various geological settings which provide groundwater throughout the state, and includes the collection of water-quality data. This information about thickness, characteristics, and geographic distribution of geological materials is combined with conceptual models which predict changes in water quality with time and location. This geologic and hydrologic information is utilized to understand the movement of contaminants in the subsurface. Aquifers identified as most susceptible to contamination are the shallow sand and gravel deposits along stream valleys, sand and gravel lenses within the glacial drift which mantles most of Iowa, and shallow bedrock where the drift covering is less than 50 feet thick. Areas of the state containing sinkholes, abandoned wells, or agricultural drainage wells run even higher risks because of the direct routing of water from the land surface into the groundwater supply.

The *Strategy* is a starting point. It represents a first progress report on an evolving groundwater policy. It tries to identify what is known and what is unknown; it tries to respond to public and professional opinions, and to Iowa's traditions and laws; and it tries to define what information is needed to guide future policy decisions. Groundwater policy needs to reflect politics, economics, hazard assessments, monitoring results, and physical realities. Geological considerations are a basic part of the mechanism which should influence policy development and guide forthcoming recommendations.

Prevention, public education, and reliable information punctuate all

Strategy recommendations. There is emphasis on acquiring information about contaminants and their behavior in surface and subsurface environments. This must include a strong monitoring program for a wide variety of contaminants in aquifers which supply municipalities and private wells throughout the state. The adoption of best-management practices by farmers is recommended for minimizing the threat to groundwater posed by agricultural fertilizers and pesticides. Uncontrolled, potentially hazardous waste sites need to be evaluated and possible clean-up procedures initiated. Construction standards designed to prevent and detect leakage are needed for underground storage tanks and for commercial chemical-storage and handling facilities. Site assessments are needed for landfills, and alternative waste-management techniques need to be developed. Ag-drainage wells and abandoned wells can be made illegal. Financial assistance may be used to promote both proper plugging of these wells and adoption of conservation measures in watersheds that drain to sinkholes. Easement programs can encourage minimal-use areas for grazing, wildlife, and recreation. An assessment of the health impacts of drinking-water sources is needed, along with interagency cooperation, local involvement, and an increase in public awareness about causes of contamination and practices that can be adopted to protect their water supplies.

Groundwater protection is a new issue. The *Protection Strategy 1987* sets the direction for a policy to deal with this issue. The *Strategy* recognizes that both the issue's origins and solutions lie with society and its use and management of the land. Geologic and hydrologic conditions which exist between the land surface and the point from which water is pumped from the ground are a vital link to understanding the present situation and to guiding future policy development. Careful land management based on reliable information and on the support of a well-informed public will assure that Iowa's land supports those uses for which it is best suited and protects those groundwater resources which lie below its surface. ☐

George Hallberg

Understanding Iowa's geologic settings can provide valuable guidelines for selecting land management practices that effectively protect the land and underlying groundwater resources.

GEODES:

A LOOK AT IOWA'S STATE ROCK

Brian J. Witzke

Iowa geodes have long been objects of curiosity, their sparkling interiors containing some of the most beautiful crystals to be found anywhere in the Midwest. Although geodes are known from many localities around the world, one of the most productive and famous collecting regions is encompassed within a 35-mile radius of Keokuk, Iowa. Rock collectors commonly refer to geodes from this region as "Keokuk geodes." In keeping with the world-renowned status of the Iowa geodes, the Iowa General Assembly declared the geode as the official "State Rock" in 1967.

The word "geode" is derived from the Latin meaning "earthlike," a reference to their rounded shape. Most Iowa geodes are roughly spherical, often lumpy or cauliflower-like in external form, with diameters typically ranging between about two and six inches. However, specimens up to 30 inches are known. The most prized geodes have hollow interiors, although many geodes are solid objects in which crystal growth has filled most or all of the interior volume. Although the distinction may seem subtle, it is important to contrast geodes with other crystal-lined cavities, or "vugs." Geodes differ from vugs in possessing an outer mineral layer which is more resistant to weathering than the host rock. As such, complete geodes commonly weather out of rock exposures and accumulate in stream bottoms. Crystal-lined vugs would not weather in such a manner.

Geodes from the Keokuk area contain a variety of minerals, but quartz is dominant in most. Quartz is silicon dioxide, the primary mineral in ordinary sand. Beautiful transparent to white quartz crystals cover the walls of many geode cavities. These crystals become larger and fewer in number towards the center of the geode, and terminate in characteristic pointed hexagonal pyramid shapes. Micro-crystalline quartz, or chalcedony, whose component crystals are too small to be seen with the naked eye, forms the outer shell in all "Keokuk geodes." Chalcedony layers also encrust the interior walls of many geode cavities, covering the surfaces of the earlier-generation quartz crystals in a variety of colors, including white, gray, blue, yellow, and orange. Calcite is a common and attractive calcium carbonate mineral in many geodes, which occurs in a variety of crystal habits and colors. An additional 17 minerals have been identified in "Keokuk geodes." Some of the more noteworthy include: kaolinite, a white clay mineral; dolomite in saddle-shaped crystals; pyrite or fool's gold, an iron sulfide; and sphalerite, a blackish zinc sulfide.

Iowa's renowned "Keokuk geodes" can be found in specific stream drainages and excavations in parts of southeastern Iowa (especially Lee, Henry, and Van Buren Counties), including the area near Geode State Park. Most geodes are derived from strata of the lower Warsaw Formation, a widespread rock unit of Mississippian age. Muds deposited in a shallow sea about 340 million years ago were primarily calcium carbonate and clay, and were subsequently lithified to form the shales, shaley dolomites, and limestones that we see today. Fresh geodes can be dug out of exposures of the lower Warsaw Formation, where they are concentrated in certain layers. Where water and streamflow have eroded these strata, concentrations of geodes may accumulate in stream channels. Although the bulk of Iowa's geodes

Tim Kemmis

Crystals of quartz reflect from the partially hollow interior of this 8-inch diameter geode from the Warsaw Shale of southeastern Iowa.

are derived from the Warsaw Formation, geodes also are known from other formations of Devonian and Mississippian age at scattered localities in eastern and central Iowa.

The origins of geodes have vexed geologists for a considerable time, and many hypotheses have been put forward. The most recent geologic research, however, agrees on three general points: 1) Geode precursors were concretions (nodules formed by outward growth around some nucleus) which grew within soft, unlithified sediment. 2) The outer shells of these concretions were replaced subsequently by chalcedony. 3) The interiors of the concretions were dissolved, leaving a hollow space into which quartz crystals could grow. The composition of the original concretions is unclear, though geologists propose they were either limestone or anhydrite, a fairly soluble calcium sulfate mineral related to gypsum.

The minerals now seen inside geodes were transported in groundwater solutions and then precipitated as replacements of the geode walls or as crystalline growths within their hollow interiors. The ultimate source of the mineralizing waters remains speculative. Many common geode minerals, especially quartz, are only weakly soluble. Therefore, substantial volumes of water had to migrate through the lower Warsaw strata to precipitate the observed minerals.

Collecting geodes can be both fun and educational. Once you've located exposures of lower Warsaw strata or a geode-bearing stream course, all that's required is a little patience and a good bricklayer's or rock hammer. A sharp blow with a hammer is usually sufficient to crack open individual geodes, exposing their crystalline interiors to daylight for the first time. Remember that most geode-collecting localities are on private land, and permission must be secured before entering. □

Additional information is found in Horick, P.J., 1974, The Minerals of Iowa: Iowa Geol. Survey, Educ. Series 2, 88 p.; and Sinotte, S.R., 1969, The Fabulous Keokuk Geodes: Wallace-Homestead Co., Des Moines, 292 p.

MICROSCOPIC STUDIES OF ROCK THIN-SECTIONS

Greg A. Ludvigson

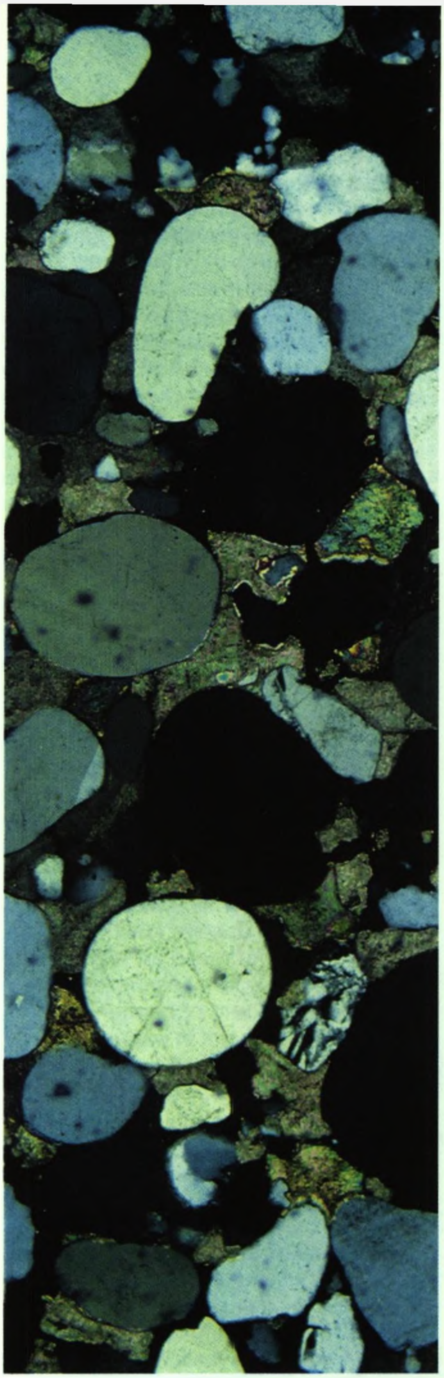
Geologists are often required to provide detailed information about the physical properties of Iowa's rock materials. Petrology is a subdiscipline of geology that is concerned with the composition, origin, and history of rocks. As might be expected, there are even further subdisciplines, as some geologists consider themselves to be sedimentary, igneous, or metamorphic petrologists, depending upon the principal rock groups they study. All are allied, however, by a reliance on the microscopic examination of thinly sliced sections of rock in order to study and interpret these earth materials. This article describes the practice of thin-section petrography, one of the most widely used procedures in the geological sciences.

Petrography was developed as a useful geologic technique in the early 1850's. As practiced today, optical petrography is performed using thin sections that are sawed from hand-sized rock samples, mounted on glass slides, and ground down to a thickness of 30 microns (about one-thousandth of an inch). The polarizing microscope is the standard instrument for petrographic studies. It is specially designed to aid in the identification of translucent minerals by utilizing their unique crystallographic properties.

The crystalline structure of many minerals distorts, or refracts, the rays of light that pass through them. When viewed through the petrographic microscope, these refracted light rays pass through two opposing polarizing filters, and appear as a characteristic interference color against an opaque background of unrefracted light. The colorful mosaics seen in petrographic images of thin sections *(see cover)* have a wonderful aesthetic appeal, but also are a powerful tool for evaluating rocks in all their aspects. The optical properties of most rock-forming minerals are well known, and experienced petrographers usually are able to quickly identify the mineral constituents of rocks in thin-section view.

While the mineralogical composition of a rock is of obvious importance, textural relationships between separate mineral grains and their arrangement within the fabric of the rock are of equal importance to the geologist. These relationships record evidence as to how the rock was formed and what has happened to it since. Petrologic research has shown that different components of a rock's fabric may form at different times, and that major physical and chemical transformations may occur in rocks long after their initial deposition.

Precambrian-age igneous, metamorphic, and sedimentary rocks beneath Iowa's land surface date from 2.5 to 1.1 billion years old, and record episodes of deposition and mountain-building deformation during the assembly of the North American continent. Over the last 550 million years, Iowa's rock record has originated exclusively from sedimentary processes operating in terrestrial, coastal, or marine environments. These sedimentary rocks contain abundant evidence of the biological activity of ancient organisms, and petrographic studies have shown that some rocks are composed totally of fossil remains. Sedimentary rock strata in the midwest also have been offset along faults, fractured by regional stresses, and bent by broad, gentle warping of the earth's crust. Additional characteristics and minerals have been imparted to these rocks by their subsequent interaction



Greg Ludvigson

Well-rounded quartz grains are cemented with calcite crystals in this sandstone cored from a depth of 652 feet in western Sioux County. Cross-polarized light, magnified 29x.

with migrating groundwater. Probably the most peculiar of these ancient fluids were the hot mineralizing brines that emplaced the veins of zinc and lead ores that were once mined in northeast Iowa, and now are believed to have migrated from a distant area of mountain building in Arkansas about 260 million years ago.

Petrologic studies of many of the major rock units in Iowa have been completed, and others are currently under study. Correct geologic interpretations, aided by petrographic analysis, of how these interacting physical and chemical processes have shaped the geology of Iowa are of fundamental importance to the Geological Survey's ability to provide reliable information on the characteristics of Iowa's rock materials and their associated groundwater and mineral resources. The porosity and permeability of many sandstones, for example, makes them especially suitable for development as sources of groundwater supplies. Shales, on the other hand, with their tightly spaced grains, are not suitable aquifer materials because of their low permeability. In addition, the solubility of carbonate rocks, particularly where fractured or along certain porous zones, makes them desirable, high-yield groundwater aquifers.

As more drillhole, petrographic thin-section, and other geologic data are accumulated, the accuracy of our picture of the state's subsurface geology is steadily refined. The results of long-term collective efforts on the part of geoscientists have contributed to a more complete understanding of the physical, chemical, and biological processes that have shaped our state through time. And from a practical standpoint, these research efforts have improved the ability of Survey geologists to anticipate and respond to today's resource issues through better information on Iowa's earth materials. □

HISTORY OF THE UPPER MISSISSIPPI VALLEY

E. Arthur Bettis III

Since its "discovery" by Marquette and Joliet in 1673, the Upper Mississippi River valley has fascinated geologists interested in the landscape history of the Upper Midwest. The first detailed description of the geology and physiography of the lands drained by the Upper Mississippi system was made by David Dale Owen in 1839 and 1852 following U.S. government-sponsored expeditions to the area. Owen's reports touched off a series of investigations aimed at documenting the region's geologic deposits, inventorying their economic minerals, and correlating the Upper Mississippi Valley strata with the better known rocks to the east. Some of these investigations focused on materials deposited during the Pleistocene, or Ice Age. By the turn of the century, it was generally accepted that the Mississippi Valley between Iowa and Illinois had been directly affected during at least three major periods of Pleistocene continental glaciation.

Studies of the buried bedrock surface reveal the network of connecting valleys shown on the accompanying map. Recent investigations have concluded that these valleys, including the Mississippi, developed during the Pleistocene and are not pre-glacial in age. The distribution of overlying glacial deposits provides clues concerning their age relationships and also gives us an inkling of the impact that glaciers had on development of the ancestral Mississippi.

Three distinct groups of old glacial deposits (tills) have been documented in eastern Iowa and western Illinois. Two of these groups are Pre-Illinoian age (more than 500,000 years old); the other is Illinoian. Deposits of the oldest group have not been found east of the present Mississippi Valley north of the Princeton Channel. This suggests that the ancestral Mississippi, along what is now the border of Iowa, Illinois, and Wisconsin, came into being as a stream flowing along the eastern margin of the early glaciers that deposited these tills. Deposits of the second group of tills are found on both sides of the present Mississippi Valley; the glaciers which deposited them also flowed in a southeasterly direction across Iowa and into western and southwestern Illinois. At their maximum extent, a river draining the ice margin flowed in a southeasterly direction through the Cordova and Princeton Channels *(see map)*, joined the bedrock valley which straddles the central and lower reaches of the modern Illinois River, then flowed southwesterly to join the ancestral Mississippi Valley in the St. Louis area. This drainage network persisted in eastern Iowa and west-central Illinois after these early glacial episodes. The modern Mississippi Valley between the Princeton Channel and the St. Louis area was not in existence during Pre-Illinoian time.

The Illinoian glaciers, in contrast to earlier events, advanced from the northeast out of the Lake Michigan region. As they pushed southwestward and crossed the Princeton Channel, ice blocked the ancestral Mississippi Valley and caused a series of lakes to form upstream of the ice dam. As lake levels rose, water spilled over divides between the blocked valleys and cut new channels along the advancing glacier's margin. At its maximum extent, the Illinoian glaciation extended west of the present Mississippi Valley into southeastern Iowa. Two diversion channels which carried the ancestral Mississippi's flow, the Goose Lake Channel and Cleona Channel, are evident in eastern Iowa today; they appear as broad, shallow swales crossing the uplands. One of the unsolved mysteries of this period is the location of the diversion channel south of the Iowa and Cedar Rivers. Possibly, the Mississippi River flowed under or even on top of the glacier south of the ice front which blocked the Iowa-Cedar Valley. At the close of Illinoian glaciation, ice no longer blocked the Princeton Channel and the drainage network reoccupied essentially the same valleys it had previously.

During the Sangamon Interglacial period which followed, climatic conditions similar to today's prevailed, and the drainage network continued to develop. The ancestral Mississippi and its tributaries north of the Princeton Channel area were in essentially their modern positions, but not as deeply entrenched into the bedrock as their modern counterparts. Downstream of Clinton, the ancestral Mississippi still flowed through the Princeton Channel and into the Illinois system.

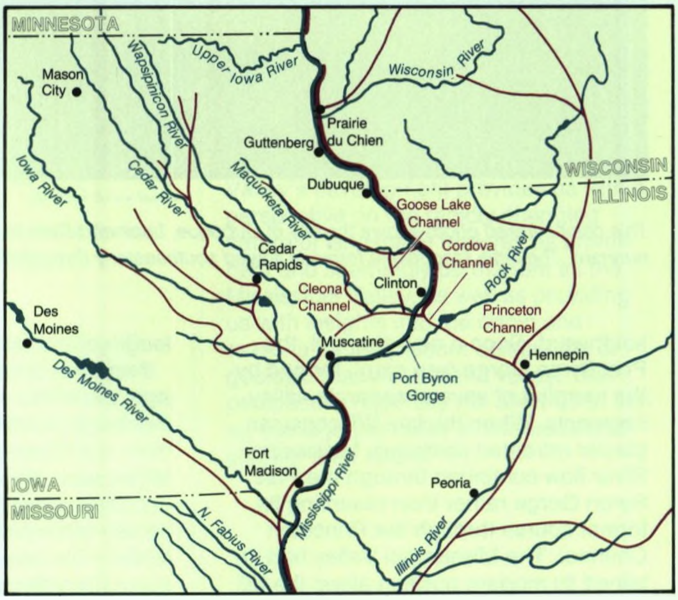
Major valley entrenchment, on the order of 100 feet or more in depth, took place between about 100,000 and 60,000 years ago. During that interval, valleys were cut down to the level of their present bedrock floors. Most of the pre-Wisconsinan valley landscapes were altered as rivers adjusted to their new, lowered gradients. By about 35,000 years ago, a major period of valley filling was underway. Great thicknesses of alluvial sand and gravel accumulated in tributary valleys, and probably in the Mississippi Valley though they are not preserved because of later erosion. This period coincided with the discharge of glacial meltwater and outwash into the headwaters of the Mississippi during the onset of the last or Wisconsinan glaciation of the Upper Midwest.

Between 25,000 and 21,000 years ago, glacial ice advancing westward out of the Lake Michigan Basin once again blocked the Princeton Channel and dammed the ancestral Mississippi. As lakes formed in the flooded valley, their waters topped low divides and flowed

ANCESTRAL AND MODERN MISSISSIPPI DRAINAGE SYSTEM

Ancestral valleys

Modern valleys



This color-infrared photo shows the city of Dubuque, Lock and Dam 11, and the Little Maquoketa entering the Up remnant. The Little Maquoketa formerly flowed southeasterly through Dubuque. Its abandoned channel, known a

southward. Soon a new channel, the Port Byron Gorge *(see map)*, formed by the merging of several separate valley segments. When the late Wisconsinan glacier retreated eastward, Mississippi River flow continued through the Port Byron Gorge rather than resuming its former course through the Princeton Channel. The Mississippi Valley had attained its modern position along the full length of the Iowa-Illinois border.

From that point until about 9,500 years ago, the valley acted as a conduit for the discharge of meltwater and outwash from late Wisconsinan glaciers in Iowa, Minnesota, Wisconsin, and Illinois. On occasion, large floods, produced by the catastrophic drainage of large glacial lakes in the headwater areas, rushed down the valley and eroded the glacial

Geological Survey Bureau

per Mississippi River at Peru Bottoms, a Savanna Terrace
s Couler Valley, may be traced in the photo.

deposits present in the main valley. During these floods, fine-grained sediment was deposited in quiet backwaters ponded in the lower parts of tributary valleys. Today these backflooded deposits underlie the Savanna Terrace, a prominent landform found in the lower few miles of most Mississippi Valley tributaries. This terrace rises up to 60 feet above the modern floodplain in northeast Iowa tributary valleys, while south of the Muscatine area its surface is about 10 feet above the Mississippi floodplain. A younger, prominent sandy terrace is found throughout the extent of the Mississippi in Iowa. Prairie du Chien, Guttenberg, and portions of Dubuque and Muscatine are built on this outwash terrace, which accumulated after the Savanna Terrace during the waning stages of glacial meltwater input into the Mississippi system.

During the last 9,500 years (Holocene), the Mississippi Valley has continued to evolve, but at a slower pace than during the late Wisconsinan. Minor downcutting, lateral channel migration, and construction of large, low-angle fluvial fans, or deltas, at the junction of large tributaries have been the main processes.

The most significant event in the late Holocene history of the Mississippi Valley was the authorization by Congress in 1930 of the construction and maintenance of a 9-foot navigation channel to the St. Paul area. The lock and dam system built by the U.S. Army Corps of Engineers produced the series of pools and flooded bottomlands characteristic of the Upper Mississippi today. These areas provide unequalled habitat for migratory waterfowl and freshwater fisheries, in addition to a dependable avenue of commerce for the region.

The long history of the Mississippi Valley's development provides us with a perspective on the rapidly changing nature of landscape features as prominent and seemingly permanent as the Mississippi Valley, as well as providing us with insights into the origin and reasons for the present distribution of geologic resources in the valley. This perspective hopefully will allow us to better manage the valley's resources and plan for their future. □

LOESS HILLS:

A NATIONAL NATURAL LANDMARK

Jean C. Prior

Loess is one of the most common geologic materials found on the land surface in the Midwest. This can also be said for the lower Mississippi Valley, the Palouse district of eastern Washington, central and eastern Europe, the Ukraine of southwestern Russia, and eastern China. The word itself is German in origin, and as late as the 1860s was regarded as a "provincial" name for deposits along the Rhine Valley. Loess, glacial history, native grasslands, and productive agricultural regions are linked together across the mid-latitudes of the northern hemisphere.

In Iowa, this wind-deposited sediment of silt-sized quartz grains was deposited over ice-free landscapes as continental glaciers melted to the north. The valley of the Missouri River, which carried this glacial outwash, was the source of the sediment. Its floodplain was wide, and its braided river channel was clogged during low-flow seasons with exposed bars of flood-spilled sediment. The winnowed silts were blown from the valley and deposited downwind. The thickest and coarsest deposits accumulated in western Iowa, immediately adjacent to the great valley. The loess reached thicknesses of 100 feet or more as it buried the pre-existing land surface and became the dominant element of the terrain in this region.

The loess was anchored first by coniferous then deciduous forests, and eventually, as the post-glacial climate continued to warm, by the prairie. Kneaded by the deep root systems of prairie plants and associated organisms, watered and baked, frozen and thawed by seasonal climatic patterns during the last few thousand years, the upper several feet of these deposits were transformed into some of the world's most fertile soils.

Today in western Iowa, extending north-south along the bluffs which border the Missouri Valley, is a narrow band of rough, corrugated terrain covered with a ragged cloak of unkempt plants that seems out of place in the state's otherwise meticulously manicured landscape. Last summer, nearly 10,000 acres of this land were selected by the U.S. Department of Interior, National Park Service as a nationally significant example of landscapes dominated by loess. Visitors to the Loess Hills of western Iowa have an opportunity to see, on a scale rarely seen among the world's landforms, deposits of wind-blown silt that accumulated in sufficient thicknesses to have obscured the older relief and contributed their own distinctive signature to the landscape. The Loess Hills region is a place to appreciate the geologic process responsible for the parent material which accounts for nearly 40 percent of our state's soil types. It is a place to see the steep faces of this deep, fine-textured geologic deposit whose form elsewhere is usually lost against the more bulky underpinnings of earlier ice-deposited materials or even older bedrock foundations. It is a place to ex-

LeRoy Pratt

The spine-leafed yucca blooming along this steep sideslope is one of the unusual prairie plants that thrives in the dry habitat among the peaks and saddles of the Loess Hills Nature Preserve in Monona County. This classic association of topography and ecology is part of the recently designated National Natural Landmark.

amine the special topographic forms that subsequent erosion carved from the uniform, porous silt. It is the first place where today's west-bound, cross-country travellers can see a hint of the extensive native grassland habitats that once dominated the heartland east to the Ohio border. Only scattered, stamp-sized remnants remain east of Iowa's Loess Hills.

In a state dominated by agriculture, it is important to retain some reminders of the geological and biological systems which made this land so productive. The Loess Hills have protected themselves in the sense that their ruggedness and steeply pitched slopes have kept them relatively isolated from the cropland which surrounds them on all sides. Their protection has been assisted by the establishment of three state parks — Stone, Preparation Canyon, and Waubonsie — and several smaller county conservation areas. A concerted effort during the past 10 to 12 years by private conservation organizations, college and university research projects, and the state preserves and natural resources programs has made valuable progress toward the inventory, protection, and interpretation of this unusual natural area.

The designation of portions of the Loess Hills as a National Natural Landmark adds important federal recognition to these significant landscapes and habitats. The Landmarks Program includes select portions of America's land

Geological Survey Bureau

The rough-textured Loess Hills in southern Monona County contrast sharply with the cultivated Missouri Valley and the channelized Little Sioux River. Thick, wind-deposited loess was carved by erosion into intricate landscapes of alternating ridges and troughs.

and waters — an array of landforms, geological features, habitats, and plant and animal communities that constitute the best examples of the nation's natural history. The objectives of this program are four-fold: 1) to encourage preservation of sites which illustrate the geological and ecological character of the United States; 2) to enhance the educational and scientific value of sites preserved; 3) to strengthen the cultural appreciation of natural history; and 4) to foster greater concern in the conservation of the nation's natural heritage. The designation does not affect land ownership, nor does it restrict the use of the land. Landowners are encouraged, however, to adopt sound conservation practices in the use, management, and protection of the property in order to preserve its significant qualities.

National Natural Landmark designation of the Loess Hills includes two separate tracts in the heart of the deep-loess country. The Turin site occupies a wedge-shaped parcel of 7,440 acres in central Monona County between the Missouri/Little Sioux Valley on the west and the Maple River valley on the east and south. Approximately 30 percent of the area consists of large, interconnected prairies, much of it included in the state-owned Loess Hills Wildlife Area and Loess Hills Nature Preserve. The second tract is the Little Sioux-Smith Lake site, a 2,980-acre parcel in northern Harrison County between the Soldier River valley and the Missouri/Little Sioux floodplain. This site is associated with a long history of scientific investigation of the loess and associated Quaternary deposits, and also has considerable support among local landowners interested in protecting the hills.

The Iowa Department of Natural Resources has recently launched a major land-acquisition project to establish the Loess Hills Pioneer State Forest in Harrison and Monona Counties. Pioneer is the right word. Prairie was the prevailing vegetative cover on the Loess Hills 100 years ago. As settlement took place in western Iowa, prairie fires, which are an important element in the maintenance of this ecosystem, were suppressed. Trees from the more moist and protected backslopes and ravines have spread quickly into the grasslands, to the extent that these "pioneering" woodlands have been proposed as a state forest.

The Loess Hills are foremost a topographic form developed in thick deposits of coarse silt. While they originated as a wind-blown deposit between 30,000 and 14,000 years ago, they are equally a product of fluvial erosion. The modern landscape is a product of several episodes of gully cutting and filling during the last 25,000 years. The steep hillslopes and intricately dissected terrain are related to both the extreme erodibility of the loess and yet its great apparent cohesiveness when dry, as well as the inherent cleavage planes that extend vertically through the deposits. The steepness of the topography, the permeability of the loess, and high density of deeply incised drainageways contribute to strong contrasts in soil moisture and temperature. These conditions produce specialized habitats for an interesting variety of plant and animal communities.

This association of exceptionally thick loess, unique topography, and specialized habitats is a classic example of the geologic-ecologic themes that the National Natural Landmarks Program strives to recognize. No better example of these associated features exists within the tens of thousands of square miles of loess-covered landscapes in the midwestern United States than in western Iowa's Loess Hills. □

ALLUVIAL AQUIFERS:

NORTHWEST IOWA SUMMARY

Carol A. Thompson

In Iowa, as well as other agricultural regions of the country, concern about the quality of drinking water is increasing. Several Iowa studies have documented the existence of increased concentrations of nitrate and other agricultural chemicals in private and public water supplies. Wells at depths of less than 50 feet are particularly susceptible to contamination from land-surface activities. In northwest Iowa, most of the municipalities, irrigators, and rural water-supply systems rely on shallow alluvial (river valley) groundwater sources. Many of these shallow sand and gravel aquifers are covered by sandy soils which present little impediment to the downward percolation of water and associated chemicals. The potential for increased water-quality problems in the region is directly tied to cropland management practices. In most northwest Iowa counties, from 60 to more than 80 percent of the land is in corn and soybeans, row crops which receive seasonal chemical applications. Alluvial valleys in particular, with their level terrain and fertile soils, are intensively cropped.

Regional increases in nitrate levels in groundwater have occurred in direct relation to the increased use of nitrogen fertilizers since the mid-1950s. Nitrate concentrations in public water supplies in northwest Iowa have risen steadily over the past thirty years. Data from the University of Iowa Hygienic Laboratory on samples from private water wells less than 100 feet deep indicate that 40 to 70 percent have exceeded the recommended maximum contaminant level (MCL) of 45 mg/l for nitrate (10 mg/l NO_3-N). These high concentrations can cause methemoglobinemia (blue baby).

In order to fully evaluate water quality in northwest Iowa, 66 monitoring wells were installed at 35 different locations along the West Fork Des Moines, Ocheyedan, Little Sioux, and Rock Rivers. In addition, thirteen surfacewater sites are included. Samples are collected monthly or bi-monthly for nitrate and bacteria. A subset of the wells have been analyzed for pesticides during the spring and summer months.

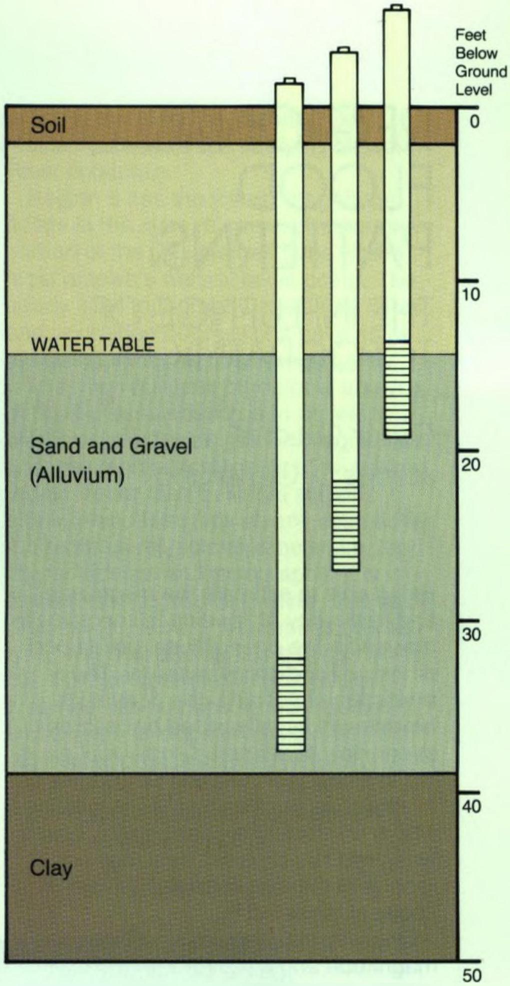
Results of this nitrate monitoring have shown that although nitrate concentrations generally are not excessively high, widespread contamination has occurred. Nitrate has been detected at 31 of the 35 well sites and at all surfacewater sites. No single well or river, however, has consistently exceeded the MCL.

Interestingly, the distribution of nitrate within the aquifers is not uniform. Variations in concentration occur from well to well in addition to varying over time. Even with this variability some consistent trends have been noted. Nitrate concentrations rise in response to precipitation and snowmelt events and fall as infiltration decreases. Thus, nitrate levels in wells from the same alluvial system show corresponding trends, although they may differ in magnitude. Nitrate also has been found to decrease with depth in all of the alluvial systems studied. This has important ramifications for the depths to which wells are drilled. Whether or not the contamination documented in the upper part of the aquifer will migrate over time to lower parts of the aquifer is not yet known.

Studies by several agencies in Iowa over the past six years have shown that many commonly used pesticides also are being found in groundwater. Forty-five percent (20/41) of alluvial wells sampled on a statewide basis showed some pesticide contamination. Seven out of 16 of the alluvial monitoring wells in northwest Iowa have tested positive. Pesticides are currently found in low concentrations, well below toxic levels. However, some evidence suggests that pesticide concentrations are increasing, analogous to the rise in nitrate concentrations that followed increased use of nitrogen fertilizers.

Stratification, or layering, of the pesticide occurrence within the aquifer is evident, as it is with nitrate; positive occurrences are confined to the shallower wells. All surface-water samples contain a variety of pesticides, although no multiple residues are present in any of the monitoring wells. In contrast, work done on municipal systems utilizing the alluvium along the Little Sioux River showed that 88 percent had measurable pesticide residues present regardless of depth. Perhaps the heavier pumping of larger capacity wells destroys the stratification and induces flow from nearby rivers. Pesticides have been found in groundwater throughout the year, with some types being more persistent than others. There is evidence that many herbicides are persisting in the subsoil and then moving into the groundwater during recharge events.

The occurrence of chemicals in Iowa's groundwater today, even in low concentrations, is of concern because of the potential hazard to health through long-term exposure. Some initial studies suggest that elevated nitrate concentrations may be associated with higher incidences of cardiovascular disease, birth defects, and several forms of cancer. The persistence of low concentrations of pesticides also raises legitimate concerns about chronic toxicity and related carcinogenic effects. With certain herbicides, the possibility also exists for combination with nitrogen compounds to form other carcinogenic compounds. Since pesticides are just beginning to occur in groundwater, several decades of data will be needed before the impact on human health is known. The long-term health impacts of these chemicals are difficult to assess; epidemiological studies require an extended time frame for cause and effect to be shown. □



Nested wells placed to different depths within an aquifer enable vertical sampling of a site's water quality characteristics.

Additional information is found in Thompson, C.A., 1985, Alluvial Aquifers: Iowa Geology, v. 10, p. 8-11; and Hallberg, G.R., 1986, Ag-Chemicals and Groundwater Quality: Iowa Geology, v. 11, p. 4-7.

REGIONAL FLOOD PATTERNS:

THE INFLUENCE OF TOPOGRAPHY

Oscar G. Lara*
James D. Giglierano

Being able to estimate the magnitude and frequency of flooding is important to those who live on, cultivate, build upon, or insure flood-prone property. The prediction of flooding characteristics, however, is usually based on records of streamflow at scattered, individual gauging stations. New culverts or bridges, for example, must often be built at locations where no streamflow data exists. Even when records do exist, they may not represent the long-term distribution of floods at those sites.

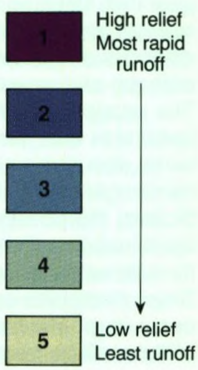
One way to better estimate flood magnitude and frequency is to study the contributing factors over a broad geographic area. Regional analysis takes into account the records for all stations in a hydrologically homogeneous area. This tends to reduce the errors associated with incomplete or non-representative data, and thus may improve the estimates of flood characteristics at gauged as well as ungauged sites.

Records show that typically a one square-mile basin in the uplands along the Mississippi River has a potential for producing a 100-year flood equal to 1,300 cubic feet per second (cfs), while a 100-year flood from a one square-mile basin on the Des Moines Lobe of north-central Iowa is about 180 cfs. The climatic differences between these two areas are not great enough to account for this difference in flood magnitude. The physiographic differences, however, are pronounced. The bluffs along the Mississippi are steeply dissected with well developed drainage, while the area within the Des Moines Lobe is quite level and not well drained. What separates these areas as hydrologic regions is the drainage efficiency of their river basins.

Five hydrologic regions can be delineated in Iowa, which take into account the physiographic characteristics of the land and available hydrologic data. On the map *(lower right)* these hydrologic regions are shown as they relate to the topographic relief of the state. The shaded-relief map was generated by computer, using image processing methods. Computations were performed on topographic data to add the effects of an artificial "sun" near the horizon. Illumination and shadowing from the low sun angle give a three-dimensional appearance to the valleys and ridges, and enhance the differences between regions.

Region 1 extends north and south

REGIONAL VARIATIONS IN DRAINAGE EFFICIENCY



along the bluffs that border the Missouri Valley; it covers approximately the area defined as the Loess Hills of western Iowa. The rough, corrugated terrain of alternating, steep-sided waves and troughs is highly conducive to rapid surface runoff.

Region 2 varies from rough to rolling topography and exhibits a well-integrated drainage network. Runoff may be rapid and flash flooding is common. The bluffs along the Mississippi Valley are typical of this landscape. It also includes part of the Missouri-Mississippi drainage divide, portions of the Iowa and Cedar river basins, the eastern border area of the Loess Hills, and the upper basins of south-central Iowa streams.

Region 3 is described as gently rolling terrain with fairly well-established drainage systems. It covers most of the landform region known as the Iowan Erosion Surface, as well as large portions of the Southern Iowa Drift Plain and Northwest Iowa Plains.

Region 4 is characterized by level terrain and poorly developed drainage. It occupies approximately the southern two-thirds of the recently glaciated Des Moines Lobe, and the flat-lying Missouri River floodplain.

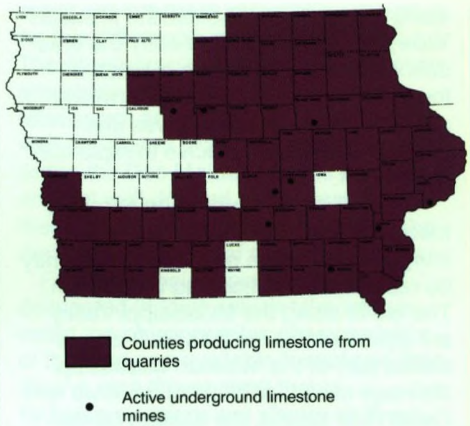
Region 5 has the lowest magnitude floods in the state. It covers the northern portion of the Des Moines Lobe where most of Iowa's natural lakes occur. The nearly level topography, scattered lakes, and undrained depressions have an attenuating effect on flood magnitude.

The main purpose of regional analysis of flood characteristics is to develop methods of estimating flood magnitudes and frequencies applicable to an entire region rather than to single stations alone. Also, this study clearly establishes the regional relationships between flood characteristics and topography. It is important to recognize, however, that each region represents a predominant terrain type, and that anomalous settings do occur. Further quantitative analysis of drainage basin shape, stream density, and degree of slope will help refine this regional approach to flood prediction. □

**Oscar Lara is recently retired from the U.S. Geological Survey in Iowa City.*

UNDERGROUND LIMESTONE MINING

Robert M. McKay
Michael J. Bounk



Each year aggregate companies in Iowa produce about 35 million tons of raw material from over 500 locations to supply a myriad of construction projects across the state. The bulk of this supply is extracted from the familiar pits and quarries where gravel deposits and limestone bedrock are close to the land surface. But at ten locations across the state *(see map)*, where geologic and market conditions permit, limestone for aggregate is extracted from underground mines.

Though more costly than quarrying, the underground mining of limestone can be both economical and necessary in some areas of the state. Shallow rock units, which were once acceptable, may no longer meet newer engineering standards for construction aggregate. In other instances, it is not economical to strip both the overlying glacial deposits and the poorer quality, shallow bedrock in order to quarry. An operator must decide whether to cease production and move to an alternate location, if one exists, or to shift operations underground. Numerous factors are weighed to determine the feasibility of such a production change. Is the needed quality rock present in sufficient thickness and at suitable depth? Are the market conditions satisfactory to warrant the added expense of underground start-up and production? In the last decade several Iowa stone producers have opted to shift production underground.

Most underground mines in Iowa are opened from the floors of existing quarries. An entrance road or haulway is driven into the quarry wall or floor depending on whether the layers to be mined are at the same level as the floor or deeper. The depth of the mining level below the land surface may vary from 75 to 400 feet. Once the entrance road or ramp has reached the proper level, the mine is ready to go into production.

A major element of the mining process is breaking up the rock. This fragmentation is accomplished by detonating explosives set in blastholes. The heading, or rock face to be blasted, is typically 40-feet wide by 20- to 25-feet high. A designed pattern of 40 to 50 horizontal drill holes two inches wide by 12- to 14-feet deep, are bored into the rock face by large portable drills. This configuration of holes is called a "round." In a typical round, the holes are drilled at an angle with the free face. Five hundred or more pounds of explosives may be loaded in one round depending on the size of the face. The detonation devices, or blasting caps, have set delay times so that charges in the center of the face detonate first and the surrounding charges detonate two to several milliseconds later. Using this method, the explosives in the central angle-cut holes blast the rock into the open area in

Bob McKay and Mike Bounk

The production of limestone aggregate from underground workings requires machinery to illuminate the rock face and to hoist miners into position to clean drill holes and load explosives for blasting the rock. River Products Company, Columbus Junction Mine.

front of the face, allowing the delayed charges to thrust material into and past the initial blast opening. A typical operation can drill and blast up to five rounds per day, loosening tons of rock in several different headings. The time-delayed explosions not only increase blast efficiency, but greatly reduce ground vibration.

Front-end loaders then lift the rock into haul trucks which transport it to a rock crusher, usually outside the mine. In deep mines, such as the Kaser Corporation's Durham Mine in Marion County, the primary crusher is inside the mine, and crushed rock is moved via conveyor belt through an inclined tunnel to the surface where it is processed further.

As the mine becomes larger, the primary means of ceiling support are the pillars of rock left in place between the rooms of mined out rock. This "room and pillar" mining plan is often mapped out in advance with the help of engineering firms specializing in underground developments. Secondary roof stabilization, if necessary, usually involves mechanical scaling of loose slabs of rock from the ceiling, and less frequently, mechanical bolting of potentially loose ceiling rock to more sound rock above.

An occasional problem related to local geologic conditions occurs when a room intersects a shale or sediment-filled cavity in the limestone. The material in these paleo-karst features usually extends above the ceiling, has little supporting strength, and can collapse into the mine. A combination of roof bolts and supporting wire mesh is sometimes used to stabilize this condition. At worst, that portion of the mine may have to be closed off from further activity. Safety decisions are usually determined by federal inspectors from the Mine Safety and Health Administration, in consultation with the operator.

Controlling groundwater is another important aspect of mining operations. Water is usually present at some depth below the surface; and once encountered by mining, open crevices, fractures, and solutional voids in the limestone may produce variable flows of groundwater. This inflow must be routed along drainage slopes and ditches to collection places where it can be discharged from the mine. Most operators eventually need to collect water in a sump, or low spot, within the mine and pump it out from that point. On rare occasions, a heading may intersect a fracture or void which releases hundreds of gallons of water per minute. If the problem cannot be remedied, a portion or all of the mine may be closed.

Proper ventilation also must be maintained in any underground mine. Exhaust fumes from machinery must be vented and fresh air introduced. Natural ventilation of level headings is adequate when mine workings are not extensive. Warm air, either from outside or within the mine, will flow along the ceiling while cool air will move along the floor. As the workings are extended, however, forced ventilation becomes necessary. Fans move air from one or more exterior openings to the active part of the mine. As workings progress or become deeper, the producer may have to drill large-diameter vertical ventilation shafts from the surface to the mine level. Large volume ventilation fans are installed which move air down, usually in colder weather, and can be reversed to move air up during warmer humid weather.

Although operations of an underground limestone mine are more expensive and require some specialized techniques to overcome inherent difficulties, there are also significant advantages to underground stone extraction. Stripping unneeded overburden, a costly inconvenience in surface operations, is eliminated. The land above the mine can be utilized for other purposes simultaneously with stone removal. Reclamation of disturbed land and its associated costs are reduced. Noise and dust pollution is generally contained within the mine. Working conditions, while dark, are arguably more comfortable because mine air temperature hovers around 50° F throughout the hot summers and cold winters.

If geologic conditions are suitable and proper planning has been done, large portions of the mine workings may eventually be converted to usable underground space. This space can be utilized for warehouses, offices, industrial production, agricultural product storage, and even recreational facilities, such as tennis courts. In Missouri, part of one mine has been converted into a roller rink, and in Clayton County, Iowa, an abandoned underground sandstone mine is now used as a storage facility. Underground mining in urban areas can be an attractive future alternative when the stone producer must compete with other land uses and increasing land acquisition costs.

Throughout most of Iowa, production of limestone aggregate from surface quarries will undoubtedly remain the principal method of mining. Underground mining, however, is an important and an increasingly common method of limestone production in the state. □

Editor's Note: Additional information on economic mineral resource topics in past issues of Iowa Geology include: Lead and Zinc Mining in the Dubuque Area (No. 9, 1984); Gypsum Resources of Iowa (No. 10, 1985); and Mining Iowa's Coal Deposits (No. 11, 1986).

FOSSIL AMPHIBIAN SITE:

A SIGNIFICANT NORTH AMERICAN FIND

Robert M. McKay

In the spring of 1985, geologists working in Keokuk County discovered fossils of perhaps the oldest known four-footed animals to walk the North American continent (see *Iowa Geology*, 1986). These are fossils of primitive amphibians, the earliest terrestrial vertebrates or tetrapods. Dr. John Bolt, a specialist at the Field Museum of Natural History in Chicago, enthusiastically examined the preliminary collections, which contained abundant, well preserved amphibian and fish material. Paleontological finds of this type and geologic age (Mississippian: 340 million years old) are exceedingly rare worldwide. In the summer of 1986 preparations began for an excavation by the Geological Survey Bureau and the Field Museum, aided by a grant from the National Geographic Society.

During the first two weeks of excavation ten feet of rock overlying the main bone-bearing horizon was carefully removed by backhoe. A crew of four to six people spent the remainder of the summer in a painstaking effort to unearth and remove about 1,000 specimens from the 1- to 2-foot thick bone bed. Specimens include skeletal material from at least two extinct amphibian groups (colosteids and anthracosaurs), reptilian-like vertebrae, and fossil fish (sharks, acanthodians, palaeoniscoids, and rare lungfish [*see photo*] and crossopterygians).

Interpretation of the bone-bearing St. Louis Formation indicates the environment of deposition was a sub-equatorial lowland dotted with bodies of fresh or brackish water inhabited by a variety of fish, tetrapods, and invertebrates. As the Field Museum prepares and describes the individual fossils, a more complete picture of early land-dwelling vertebrates and their habitat on the North American continent will emerge. □

Brian Witzke

Skeletal remains of the rare lungfish include skull plates and scattered ribs.

SELECTED SURVEY PUBLICATIONS

PUBLICATIONS OF THE IOWA GEOLOGICAL SURVEY
A revised and updated listing of publications was prepared in 1986. This brochure contains a comprehensive register of the Geological Survey's various publication series, both current and discontinued, as well as map products. These publications include much that is known about the state's groundwater, bedrock, Quaternary materials, and mineral deposits, in addition to important historical references. The 56-page booklet is available without charge, and contains ordering information.

PRECAMBRIAN GEOLOGY OF IOWA
Iowa Geological Survey Open-File Map Series 86-1 by R.R. Anderson (1986). This black and white, 1:1,000,000 scale map is compiled from on-going studies and is available on a limited-edition basis. This interim map displays the geology of Iowa's oldest and deepest rocks as presently interpreted from drill-hole and geophysical data. Price: $1.00, plus $.75 post./hand.

STRUCTURAL CONFIGURATION OF THE PRECAMBRIAN SURFACE OF IOWA
Iowa Geological Survey Open-File Map Series 86-2 by R.R. Anderson (1986). This black and white, 1:1,000,000 scale map is compiled from on-going studies and is available on a limited-edition basis. This interim map displays the structural configuration of the Precambrian surface using a sea-level datum and a contour interval of 100 feet. Price: $1.00, plus $.75 post./hand.

LATE WISCONSINAN AND HOLOCENE LANDSCAPE EVOLUTION AND ALLUVIAL STRATIGRAPHY IN THE SAYLORVILLE LAKE AREA, CENTRAL DES MOINES RIVER VALLEY, IOWA
Iowa Geological Survey Open-File Report 86-1, 330 pages, by E.A. Bettis III and B.E. Hoyer (1986). This contract report, prepared for the U.S. Army Corps of Engineers, Rock Island District, presents the results of a detailed geomorphic investigation of the study area. Landforms and underlying deposits were identified, mapped, and dated in order to provide archaeologists and resource managers with a physical framework in which to evaluate cultural resources of the area. Available without charge.

UNDERGROUND COAL MINES OF CENTERVILLE IOWA AND VICINITY; MINE-RELATED PROBLEMS AND SUBSIDENCE POTENTIAL
Geological Survey Bureau Open-File Report 86-2, 93 pages, by M.R. Howes, M.A. Culp, H. Greenberg, and P.E. VanDorpe (1986). The location and extent of abandoned coal mines and known occurrences of mine-related problems are documented. The report also covers local geology, mining history, and factors affecting subsidence. A detailed map and extensive appendices of compiled historical and physical data provide information for landuse planning. Available without charge.

PALYNOSTRATIGRAPHY OF THE LOWER AND MIDDLE PENNSYLVANIAN COALS OF IOWA.
Iowa Geological Survey Technical Paper #7, 245 pages, by R.L. Ravn (1986). This monograph contains a thorough analysis of the stratigraphic distribution of plant microfossils (spores) preserved in the state's coal deposits, and includes formal descriptions of paleobotanical genera and species. Abundant plates. A primary reference for Pennsylvanian stratigraphic correlations in Iowa. Price: $10.00, plus $1.50 post./hand.

GROUNDWATER RESOURCES OF HAMILTON COUNTY
Iowa Geological Survey Open-File Report 86-40 WRD, 31 pages by C.A. Thompson (1986). This compilation of available data summarizes the distribution, accessibility, yield, and quality of surficial and rock aquifers in Hamilton County. Price: $1.00, plus $.50 post./hand.

GROUNDWATER RESOURCES OF IOWA COUNTY
Iowa Geological Survey Open-File Report 86-84 WRD, 40 pages by P.E. VanDorpe (1986). This compilation of available data summarizes the distribution, accessibility, yield, and quality of surficial and rock aquifers in Iowa County. Price: $1.00, plus $.50 post./hand.

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