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Karst Development in Northeastern Iowa

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Karst landforms of northeastern Iowa have developed on Silurian and Ordovician carbonate rocks through processes of dissolution and collapse. The karst areas are characterized by rapid infiltration, direct runoff into sinkholes, underground drainage through solution-enlarged fractures, bedding planes and caves, and groundwater discharge at springs. Mechanically induced karst is found along the Silurian Escarpment and in close proximity to major valleys, but the majority of northeastern Iowa's karst features are solutional in origin.

Collapse of rock and surficial deposits into solutional openings in underlying rock pose safety and engineering problems in the area. The direct connection of surfacewaters with shallow bedrock aquifers through sinkholes, swallows in streams, and rapid infiltration has resulted in degradation of the groundwater quality, posing possible health hazards to inhabitants of this region. These environmental problems can be reduced through recognition of the hazards posed by the presence of karst and through reasoned approaches to land management.

INDEX DESCRIPTORS: Karst, Iowa geology, northeast Iowa, caves, sinkholes, landuse hazards

Portions of northeastern Iowa, including the so-called "Driftless Area," contain abundant karst landforms. Although not recognized by many as a major karst area (Sweeting, 1973, figure 2), this region contains typical examples of karst features including caves, blind valleys, sinkholes, and springs. In the discussion that follows, we will outline the factors contributing to karstification, the major types of karst in northeastern Iowa, a brief history of Pleistocene karstification, and the known distribution of karst landforms in northeastern Iowa.

Regional Geology

The Paleozoic Plateau is unique in Iowa because of the domination of the landscape's morphology by bedrock. Erosion during the late Pleistocene removed vast quantities of the unconsolidated Quaternary deposits which mask the bedrock surface in other portions of the state (Hallberg, Bettis, and Prior, this volume). Downcutting by the Mississippi River and its tributaries has exposed Cambrian, Ordovician, Silurian, and Devonian-age sedimentary rocks which were deposited in marine and near-shore environments between about 600 and 350 million years ago.

Bedrock in northeast Iowa dips slightly to the southwest. The oldest rocks in this area, Cambrian strata, crop out along the Mississippi River and its tributaries in the northern and eastern portions of Allamakee County, and in the northeastern extremity of Clayton County (figure 1). These rocks are dominantly sandstones but also contain some dolomite and dolomitic siltstone (Anderson, *et al.*, 1979). Ordovician rocks, dominated by dolomite, limestone, and shales, overlie the Cambrian strata and crop out along most valleys in Clayton, Winneshiek, northeastern Fayette, and the southwestern half of Allamakee County. Silurian strata, primarily dolomite with some limestone, crop out along and southwest of the Silurian (or "Niagaran") Escarpment, a prominent ridge extending through northeastern Dubuque, southwestern Clayton, and northeastern Fayette Counties. This escarpment marks the northeastern limit of Silurian strata in Iowa. A few outliers of Silurian rocks are found north and east of the escarpment, but these are relatively small, isolated occurrences. The youngest widespread consolidated rocks in northeastern Iowa, Devonian-age strata, crop out along east- and southeast-flowing streams in western Winneshiek and central Fayette Counties. These rocks are dolomite and limestone.

Two major types of rocks, clastics and carbonates, make up the bulk of the consolidated rocks in the Paleozoic Plateau. Clastics are rocks composed of small pieces of older rocks which have been weathered prior to and during transport to another location. Sandstone is the most common type of clastic rock found in this area. Carbonates originated from the growth and accumulation of organisms in shallow portions of seas. These rocks derive their name from the calcium and magnesium salts (carbonate) which dominate their mineralogy. Dolomite and limestone are the most abundant type of carbonate rocks in northeastern Iowa.

Clastics in northeast Iowa are mostly sandstones composed primarily of quartz grains. These rocks are not soluble, but often contain large amounts of groundwater which moves through intergranular spaces in the rock. Because of this intergranular space, sandstones are said to have high primary porosity. Carbonates, on the other hand, generally have low primary porosity. During the formation of these rocks, carbonate crystals grow, filling most spaces originally present in the sediment. The calcium and magnesium salts making up these rocks are soluble, however, and water slowly percolating through the rocks along horizontal bedding planes or vertical fractures dissolves some of the rock forming secondary porosity. The porosity of carbonates can thus increase through time.

Karst

Karst is a general term for landforms developed by the solutional and/or mechanical action of groundwater in carbonate rocks. These landforms are expressed at the surface in northeast Iowa as sinkholes, springs, and blind valleys (figure 2). Because of the solution of rock and the resulting increase in permeability, some of the surface runoff in karst areas is intercepted by vertical conduits and routed into a subsurface drainage network. This water reappears at springs located at lower stratigraphic and topographic levels, often several kilometers away. In areas with extensive karst development, organized surface-drainage networks are replaced by a series of disconnected and enclosed hollows, giving the landscape a pitted character. Underground, karst occurs as solutional conduits linking areas of sinkholes and blind valleys to springs. The carbonates (limestone and dolomite) in which these conduits develop are strong enough that the solutional openings do not readily collapse. Often these conduits enlarge and occasionally combine to produce extensive cavern systems.

Solutional Karst

Rainwater becomes slightly acidic as it interacts with carbon dioxide in the atmosphere and soil. As it percolates downward through limestone or dolomite, this slightly acidic water reacts with the carbonates [$CaCO_3$ or (CaMg) CO_3] disassociating and dissolving the rock.

In most carbonate rocks, there is relatively little intergranular porosity compared to sandstones. For this reason, most water movement in carbonates is along vertical fractures, or joints, and horizontal bedding planes. As water moves through these openings, it dissolves some of the confining rock, thus enlarging the openings and allowing greater flow. This diverts flow from smaller adjacent openings and concentrates flow in the larger conduits causing them to increase in diameter.

The overall direction of groundwater flow in carbonate rocks is down head in response to hydrostatic pressure as it is in a hydrologically more isotropic rock such as sandstone. In carbonates, however, flow is concentrated along fractures and bedding planes, zones of high hydraulic conductivity, or water movement. Thus, solutional conduit and cavern development in Iowa occur along those fracture trends which best facilitate downhead movement (Bounk, 1983a, 1983b).

The presently active and easily discernible karst landforms are not the first to develop in what is now northeast Iowa. Prior to the Pleistocene, other episodes of karstification occurred in carbonate rocks in this area. Most of this older karst was destroyed by erosion prior to and during the advance of Pleistocene glaciers into this area. The present northeast Iowa karst system began to develop after retreat of Pre-Illinoian glaciers from the area approximately 500,000 years ago (Hallberg, 1980). At that time, glacial deposits covered much of the landscape, and relief was subtle compared to that in the area today. Groundwater levels would have been fairly high and water flow was down head along horizontal bedding planes and vertical fractures (figure 3a). As time progressed, groundwater dissolved portions of the rock along these zones of high hydraulic conductivity and elliptical-shaped conduits began to develop (figure 3b). These first conduits developed while completely water filled, under *phreatic* conditions. Sometime before 30,000 years ago, entrenchment of the Mississippi River and its major tributary valleys lowered the level of groundwater far below the land surface in upland areas (figure 3c). As the level of the groundwater dropped, conduits closer to the land surface became partially air-filled and cavern formation continued under *vadose* conditions. Under these conditions, water in a conduit is analogous to a surface stream, and it dissolves and mechanically erodes the floor of the conduit, forming a canyon-like vadose trench below the elliptical phreatic tube. Many spectacular cave formations, such as stalactites and stalagmites form under vadose conditions as dripstone and flowstone accumulate because of the high carbonate content of water. Where a vertical conduit enlarged near the surface and the mantle of glacial or alluvial deposits collapsed, sinkholes developed. Occasionally, a surface drainageway was intercepted by a large sinkhole and a blind valley developed. When valleys intercepted conduits at the groundwater level, springs formed. As vadose processes operated in the aerated zone, conduit enlargement continued in the phreatic zone. These processes continue to operate today, increasing the secondary porosity of the carbonate rocks and allowing for faster groundwater flow through these aquifers.

Water in a sinking stream or entering a sinkhole also carries

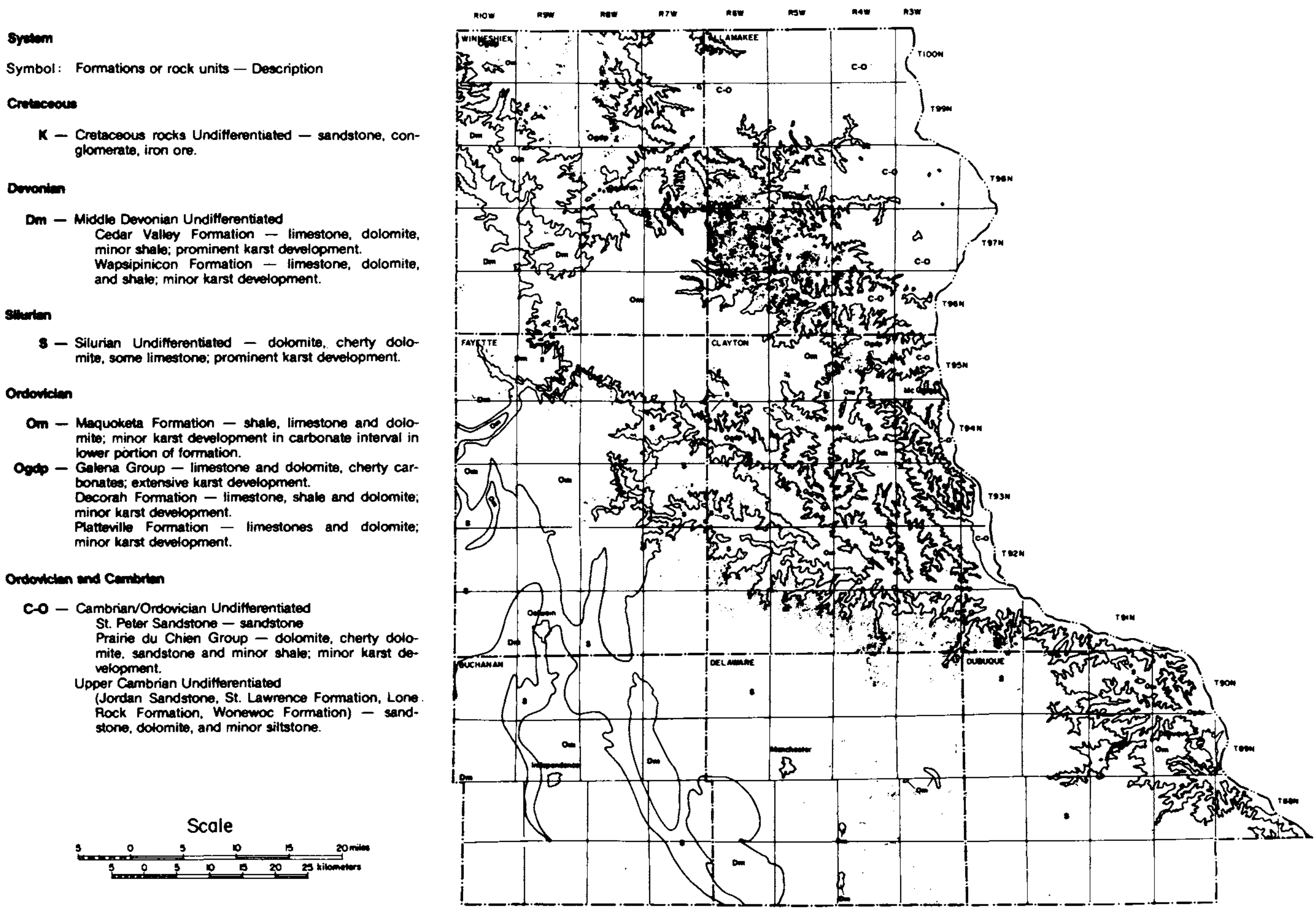

Fig. 1. Distribution of major bedrock units and karst features in northeastern Iowa. Gray dots are sinkhole locations. Adapted from Hallberg and Hoyer, 1982, Plate 2.

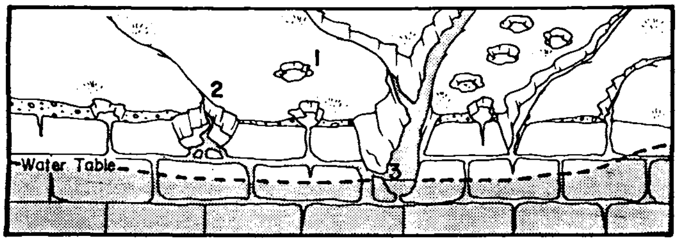

Fig. 2. Common karst landforms in northeastern Iowa, 1 — sinkhole; 2 — blind valley; 3 — spring.

sediment into the conduit system. As conduits are abandoned, they may become partially or entirely filled with sediment. Many of these plugged passages, remnants of earlier cavern systems, are known from explored sections of northeast Iowa caves. In addition, large blocks of rock occasionally will fall from the roof and sides of caverns, forming "breakdown." Some passages become blocked with breakdown and are abandoned. In some instances breakdown plus the downcutting of a surface stream into a cavern will result in destruction of the cavern and the formation of a deep, steep-sided valley at the surface. Large blocks of breakdown on the valley floor and natural bridges, formed from small, uncollapsed sections of the original cavern, are good indicators of such an occurrence. Spectacular examples of large caverns partially destroyed by this method are found in Maquoketa Caves State Park in southwestern Jackson County and in the Dutton's Cave area in northeastern Fayette County.

Mechanical Karst

Another type of karst, mechanical karst, develops in massive carbonate units which overlie shale. In this instance, the carbonate/shale contact is lubricated by groundwater, and blocks of the overlying carbonates slide downslope on the underlying shale. Often, the base of the moving rock rotates outward, forming a roofed cave. Slumping of overlying unconsolidated material results in the development of sinkholes which tend to develop in parallel alignment to the nearby bluffline. This type of sinkhole usually occurs within a few hundred feet of the bluffline (Hansel, 1976).

Distribution of Karst in Northeastern Iowa

Karst development includes several types of landforms which result from solution and mechanical movement of carbonate rocks and from collapse of overlying, unconsolidated deposits into solutional and mechanically induced openings. These landforms are not uniformly distributed across northeastern Iowa. Instead, they are concentrated where lithologic, hydrologic, and geomorphic conditions have promoted their development and preservation.

Figure 1 shows the general distribution of karst features in northeastern Iowa. Two major areas of concentration are readily apparent: the outcrop area of the Ordovician-age Galena Formation, and a zone extending roughly northwest to southeast along the leading edge of Silurian-age strata in northern Dubuque, southwestern Clayton, and northeastern Fayette Counties.

Solutional karst dominates the Galena outcrop area. Sinkholes are abundant in portions of this area, with more than 1800 recorded in a single township in southwestern Allamakee County (Hallberg and Hoyer, 1982). Sinkholes in northeast Iowa range from about two meters in diameter and one half meter deep to large depressions one hundred meters in diameter and in excess of ten meters deep. Blind valleys also are common in this area where high sinkhole concentrations are found. Several caves are known in the Galena outcrop area. These range from a minimum of a few meters to a maximum known length of over 13 kilometers. Generally, the larger caves contain streams and are said to be hydrologically active. Cold Water Cave in northern Winneshiek County and Spook Cave in eastern Clayton County are examples of hydrologically active caves developed in the Galena Formation. The streams in both these caves, as well as those in many other unexplored or partially explored caves in the area, emerge at the surface as springs. Springs issuing from the Galena vary in average discharge from less than three liters per minute to over 75,000 liters per minute, although the majority occur at the low end of the spectrum. A single spring also can show wide fluctuations in discharge throughout the year. At the spring issuing from Dutton's Cave, for instance, an estimated 100 fold increase in flow can occur following a heavy rain or spring snowmelt.

Occasional examples of mechanical karst also are found in the Galena outcrop area. These usually are restricted to escarpments along major valleys draining the area. Some of these mechanical karst features are shaped so as to trap cold winter air and hold it far into the warmer spring and summer months. Water descending into these areas during the spring freezes and forms ice, from which the term, "ice cave," is derived. Prior to widespread use of refrigeration, several ice caves, such as the Decorah Ice Cave, were used by local inhabitants for cold storage.

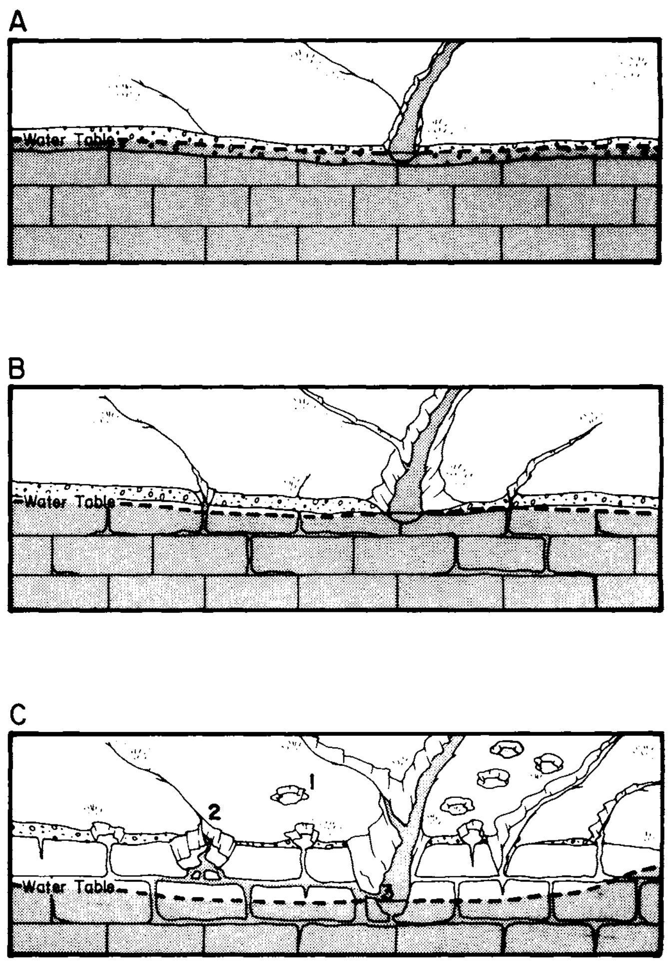

Fig. 3. Idealized evolution of northeastern Iowa's karst landscape. A — shortly after 500,000 years ago; B — 300,000 to 200,000 years ago; C — 30,000 years ago to today. (1 — sinkhole; 2 — blind valley; 3 — spring).

Karst along the Silurian Escarpment is dominantly mechanical in origin (Hansel, 1976). Here, Silurian strata are underlain by the Ordovician-age Maquoketa Shale. Water percolating through the Silurian carbonates is perched at the contact with the underlying shale. This lubricating action coupled with high relief along the escarpment induces downslope movement of the Silurian rocks and development of mechancial karst. Some solutional karst is also developed in this area, but the caves and other solution features are smaller than those formed in the Galena outcrop area. In northern Fayette County, solutional karst has developed through the Devonian-age Wapsipinicon Formation downward into the Silurian strata.

DISCUSSION

Karst is both a blessing and a curse for modern man. The resource adds to the unique scenic appearance of the Paleozoic Plateau. Blind valleys, tree-lined sinkholes, and picturesque springs are present in unequalled numbers in this portion of the state. These features, which are of little agricultural or urban value, provide mini-refuges for some of the unique fauna and flora of the area. Caves are probably the most spectacular of northeast Iowa's karst landforms. They provide recreation for speleological groups who explore and map the myriad passages and formations. A few commercial enterprises that add to the tourist economy have developed around caves in this region.

Karst features have been forming in northeast Iowa since glaciers left the area approximately 500,000 years ago. Speleothems (dripstone and flowstone) found today in caves preserve a record of the early stages of downcutting by the Mississippi River and its tributaries, since the speleothems began to develop only after the caverns in which they occur became partially air-filled. U-series dating and oxygen-isotope studies of the speleothems reveal a partial record of the post-glacial fluvial and environmental history of northeast Iowa (Harmon et al., 1979; Lively, 1983).

An abundance of springs and cold water streams has permitted the establishment of trout fisheries in northeast Iowa. The Iowa Conservation Commission operates trout hatcheries at sites where large springs issue from Ordovician-age carbonate rocks near Elkader in Clayton County and Decorah in Winneshiek County. Fish reared at these hatcheries are released in designated spring-fed cold water streams where water temperatures are low enough to permit the fish to live.

Along with these scenic and recreational benefits, karst conditions result in two major environmental problems in northeastern Iowa. Sinkholes, sinking streams, and the shallow fractured bedrock associated with the karst provide direct routes through which surfacewater can enter shallow bedrock aquifers. Surfacewater in this highly agricultural region often contains excessive amounts of nitrates, pesticides, bacteria, and sediment which degrade the quality of the bedrock aquifers used by local residents for water supplies. Studies currently in progress indicate that this is a severe problem in northeastern Iowa, and several state, federal, and local agencies are cooperating to determine the extent of groundwater degradation and to suggest remedies for the problem (Hallberg and Hoyer, 1982; Hallberg et al., 1983).

Sinkholes and collapse of bedrock also present unique landuse hazards in northeast Iowa. Numerous instances of sinkholes opening in cropland have been recorded. These present obvious hazards to farmers and grazing livestock and result in the loss of valuable cropland. Sinkholes also present problems for road builders throughout the area. These problems are twofold, including hazards to both the road and its bed from rock collapse and interruption of drainage in roadside ditches by sinkholes opening in or near the ditches. These hazards can be minimized, however, through proper foundation studies and road placement.

Karst is an integral part of the northeastern Iowa landscape and one of the reasons for this area's unique appearance. It has been developing in the region for hundreds of thousands of years and will continue to do so in the future. We must accept its presence and, through more reasoned approaches to land use, adjust our activities on the land surface in order to avoid potential hazards. In this way, we, and future generations, can reap the benefits karst brings and enjoy this unique aspect of the northeastern Iowa landscape.

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