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Geologic Overview of the Paleozoic Plateau Region of Northeastern Iowa

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Steep slopes, varied slope aspects, and entrenched stream valleys carved into Paleozoic-age rocks provide the geologic framework for the unique and diverse ecology of northeastern Iowa. Differential weathering and erosion of these variable rock types resulted in irregular surface slopes in a multi-stepped, high-relief landscape. Additionally, solution of carbonate bedrock produced karst topography, cavern systems, ice caves, cold-air drainage, and perennial groundwater springs. The so-called "Driftless Area" in Iowa was glaciated repeatedly in Pre-Illinoian time, and should not be called "Driftless." The name Paleozoic Plateau for this physiographic region more accurately describes some of its special aspects and also incorporates the much larger region of distinctive physiography and ecology referred to by biologists. Although the bedrock geology provides the framework for this unique region, the high relief is a product of more recent geologic history. Evidence from studies of the upland Quaternary stratigraphy and erosional history, the development of the karst system, and the fluvial deposits in the stream valleys reveal a complex Pleistocene history. Stream erosion since the last episode of glaciation (ca. 500,000 years before present) produced the deeply dissected landscape. Current research suggests that the major episode of deep-valley incision occurred during the Wisconsinan. Numerous late-Wisconsinan terraces stand 12-25 m above the present streams. A large portion of northeastern Iowa's rugged terrain is remarkably young.
INDEX DESCRIPTORS: Quaternary geology, Pleistocene, "Driftless Area," Landscape development.

INTRODUCTION AND GEOLOGIC OVERVIEW

The scenic landscapes and rugged high-relief terrain of northeastern Iowa make a vivid impression on traveller and resident alike, and long have been the subject of scientific interest. This area is unlike any other portion of the state, because this is the only extensive region where bedrock so completely dominates the surface form of the land. Steep slopes, varied slope aspects, bluffs, abundant rock outcrops, waterfalls and rapids, sinkholes and springs, and entrenched stream valleys provide a geologic framework which, in turn, supports unique microclimates and habitats rich in diverse plant and animal communities.

This framework reflects deep dissection by streams through gently inclined Paleozoic rock units with varying resistance to erosion. Because of their regional inclination (or dip) to the southwest, progressively older Paleozoic rock units are exposed as the extreme northeastern corner of the state is approached. These rocks date from Devonian, Silurian, Ordovician, and Cambrian time, approximately 350 to 600 million years ago (Fig. 1). The more durable, resistant, carbonate and sandstone formations form numerous cliffs and escarpments high in the landscape, with waterfalls and rapids developed along stream channels. Less resistant rocks, such as shale, yield more gentle slopes. The differential erosion of these variable strata results in terrain which reflects its bedrock core so closely that it is often possible to trace distinct geologic formations across the landscape. Balltown Ridge in Dubuque County and Chicken Ridge in Clayton County are good examples of prominent ridges upheld by Silurian carbonates. Below these ridges, more gentle slopes are developed on the Brainard Shale of the Maquoketa Formation. These slopes grade downward onto younger erosion surfaces, held up by yet older carbonate rocks. Similar escarpments occur farther to the northeast along the outcrop belt of the older Ordovician-age Galena and Prairie du Chien Group dolomites (Fig. 1). The scenic ridge-crest roads, which radiate to the north and east from the Allamakee County highlands in the vicinity of Waukon, overlook landscapes that step down as the Decorah-Platteville limestones and shales, St. Peter Sandstone, and Prairie du Chien dolomites are encountered.

In addition, the Paleozoic carbonates (limestones and dolomites) exhibit extensive karst development resulting from solution of the rocks by groundwater moving along fracture traces within the formations (see Bounk and Bettis, this volume). Karst development yields characteristic topographic forms such as sinkholes and springs at the land surface and development of cavern systems beneath the surface. Dunning's Spring near Decorah and Cold Water Cave in Winneshiek County are examples. Karst features in northeastern Iowa are concentrated in the outcrop areas of the Devonian, Silurian, and Ordovician-age Galena Group carbonates (Fig. 1). Associated with some of these karst features are unique microclimates and specialized habitats termed "algific" or cold-air slopes. The right combination of steep north- and east-facing talus slopes, backed by creviced carbonates are favorable sites for cold-air drainage and the development of ice caves. The slopes remain permanently cool and moist and harbor populations of plants and animals which are relicts of the Pleistocene. These refugia for glacial biota are possible analogues of past glacial climates and environments in Iowa.

In addition to the distinctive landscapes that result from erosion and karst development on the Paleozoic bedrock are features more directly associated with the region's rivers. The Mississippi and its tributary valleys, such as Clear Creek west of Lansing, contain well preserved terraces, remnants of older floodplain deposits which partially document the region's complex alluvial history and response to changing base levels associated with glacial melting and drainage diversions. Impressive entrenched meanders occur along the larger valleys. The cutoff and abandonment of some of these has left "hanging meanders" well above the level of the present floodplain. Sand Cove, along the Upper Iowa Valley in Allamakee County, stands 35 m above the modern valley floor. These horseshoe-shaped segments of earlier valleys often surround a bedrock core, a detached mound of rock isolated from nearby valley walls by later shifts in the river's position. "The Elephant" and Mount Hope, also along the Upper Iowa, are excellent examples of these features.

The Paleozoic Plateau vs. the So-Called "Driftless Area"

The distinctive terrain in northeastern Iowa and adjacent parts of Minnesota, Wisconsin, and Illinois has been referred to for many years as the "Driftless Area." The term had its origins in the early geologic interpretation of the region. The earliest geological reconnaissance was in 1847 by David Dale Owen. After Owen, McGee (1891), Calvin (1894, 1906), Williams (1923), and Trowbridge (1921) made more detailed observations on this part of the state. The lack of recognition of glacial-drift deposits, and the high relief and extensive bedrock exposures in this area suggested that it had not been glaciated. The term "Driftless Area," however, should be discarded. It is incorrectly applied in Iowa to an area much larger than its original, geologically defined limits (Fig. 2). And within those original boundaries, patchy remnants of glacial drift are well documented (Williams, 1923; Trowbridge, 1966).

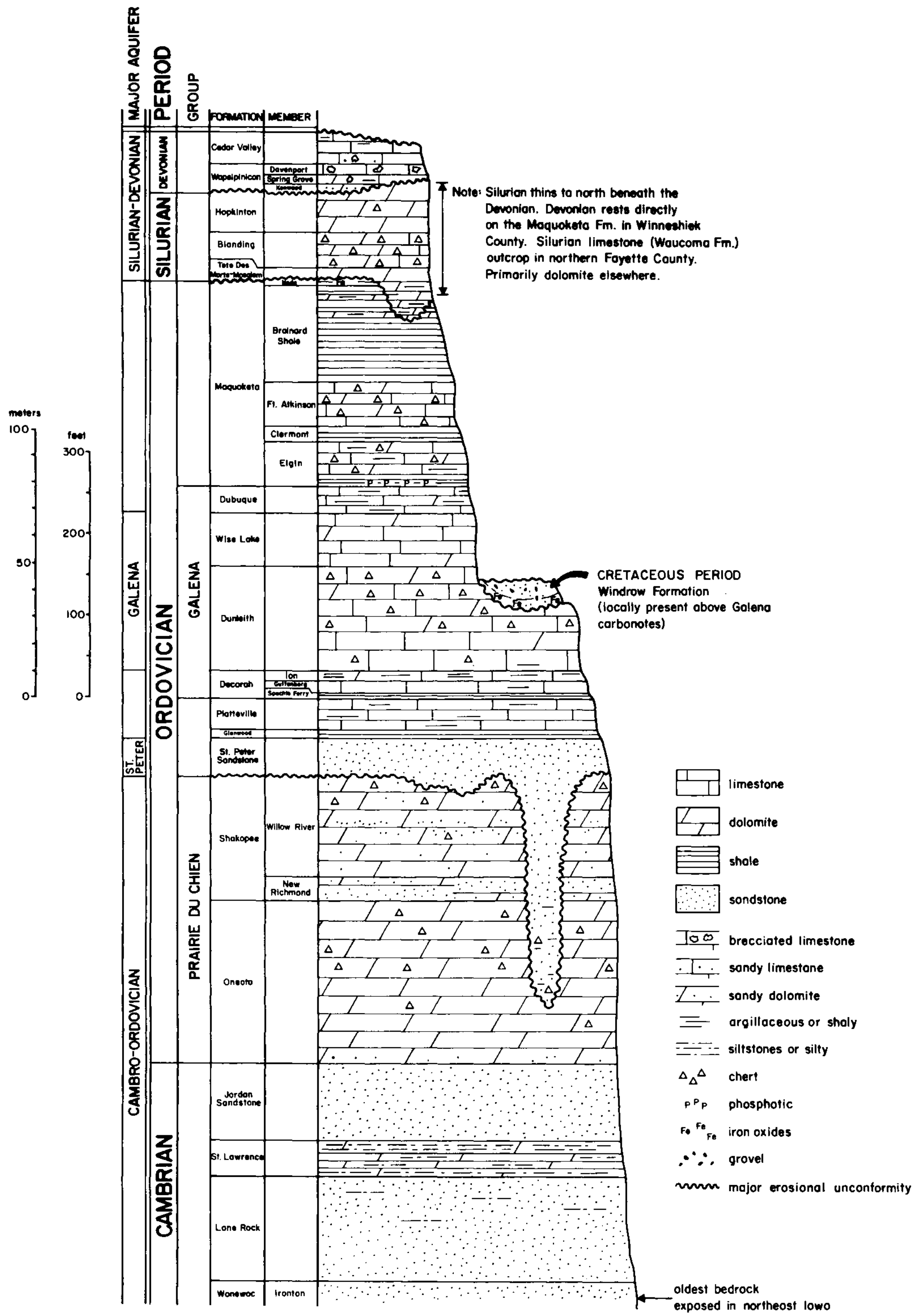

Fig. 1: Paleozoic rocks are one of the key ingredients responsible for the unusually scenic landscapes of northeastern Iowa. In this part of the state, Paleozoic rocks range from Cambrian to Devonian age (oldest to youngest), and the sequence of included bedrock formations is shown here in a generalized stratigraphic column (prepared by Brian Witzke, IGS).

This larger region, recognized by biologists and ecologists as having many of the same characteristics as the original, more geographically restricted "Driftless Area," is better referred to as the Paleozoic Plateau (Prior, 1976). It stands in marked contrast to the remainder of the state where the terrain is more subdued, and dominated by thick deposits of glacial drift which mantle and mask the underlying bedrock. Samuel Calvin, writing in 1906 on the geology of Winneshiek County, noted that in portions of the county where drift had occasionally been observed, "The topography in general is that of the Driftless Area. It is not deemed advisable to attempt to set off the driftless from the drift covered parts of the county by a definite line."

The boundaries of this larger area of topographic and ecologic similarities is easily observed along its western and southern margins. Here the terrain changes abruptly from a rugged, dissected, rock-controlled landscape to the more gently rolling, lower relief landscapes of the Iowan Erosion Surface and the Southern Iowa Drift Plain (Fig. 2). This change is in large part defined by the bluffs and cliffs developed along the northeast-facing outcrop belt of the resistant Silurian dolomites. This prominent physiographic feature, known as the Silurian or "Niagaran" Escarpment, cuts diagonally across Jackson, Dubuque, Clayton, and Fayette Counties. Further north, through central Winneshiek County, this escarpment is less pronounced and is upheld by Devonian-age carbonate rocks.

As inferred above, major portions of the region are not "driftless" either. As early as 1923, geologists (Williams, 1923) recognized deposits of till and glacial erratics *throughout* the "Driftless Area" in Iowa. Trowbridge (1966) reviewed investigations in this region, documenting glacial deposits throughout the uplands in Iowa east to the Mississippi River, and north to the Minnesota border. Willman and Frye (1969) documented two tills in Iowa and glacial outwash on upland surfaces in the "Driftless Area" of Illinois. Most recently, Knox (1982) showed that Pre-Illinoian till is present in the Wisconsin portion of the area, just east of the Mississippi River. While other portions of the "Driftless Area" in Wisconsin are apparently driftless (Knox, 1982), there is no driftless area in Iowa, and substantial portions of the region in Illinois and Minnesota contain glacial deposits as well. Hence, the term Paleozoic Plateau seems a more fitting name for this physiographic province, particularly in Iowa.

Although the Paleozoic rocks provide the key ingredients of this unique landscape, its high relief is a product of more recent geologic history — events during glacial (Pleistocene) and post-glacial (Holocene) time. Perhaps the most fascinating insight gained from current geologic research in the region is that much of the relief is remarkably young.

Present research in Iowa and adjacent states is aimed primarily at understanding the geology and groundwater resources of this region. This work is, however, also providing new insights into the landscape evolution of the Paleozoic Plateau as well as defining clear needs for additional research. The remainder of this paper presents a brief introduction to ongoing work and current thinking, and points out some of the fundamental directions that research efforts and results are taking.

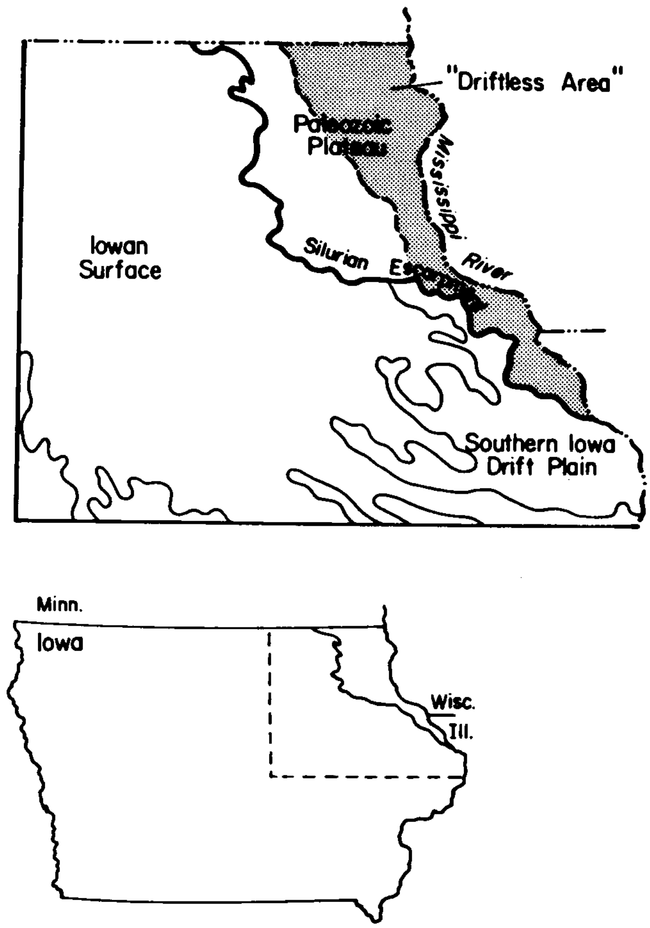

Fig. 2: The term "Driftless Area" was applied to a restricted geographic area based on specific geologic interpretations. Its extent as originally mapped is shown here. The concept of the "Driftless Area" is no longer valid in Iowa, and this area is more logically included within the larger, clearly defined Paleozoic Plateau, which exhibits similar topographic and ecological characteristics.

QUATERNARY HISTORY OF THE PALEOZOIC PLATEAU

Current research on the Quaternary history of the northeastern Iowa Paleozoic Plateau region is focued on: 1) the upland stratigraphy and erosional history; 2) the age and development of karst features which connect the uplands to the valleys; and 3) the stratigraphy and age of the fluvial deposits and stream valleys of the region.

Upland Quaternary Stratigraphy and Erosional History

Patchy glacial deposits occur on all major stream divides in northeastern Iowa. In the past these deposits have been assigned to either Kansan or Nebraskan age (see Trowbridge, 1966). Recent work has rendered these glacial-stage terms obsolete, and the age of these deposits is now considered Pre-Illinoian (Hallberg, 1980a). This area was glaciated repeatedly in the Pre-Illinoian; tills of two major Pre-Illinoian formations (the Wolf Creek and older Alburnett Formation) occur in the Paleozoic Plateau area (e.g., Hallberg, 1980a, p. 101-102). The youngest of these Pre-Illinoian tills (Wolf Creek Formation) cannot be directly dated in northeastern Iowa, but in southwestern Iowa it is younger than 600 ka (kilo-annum, thousands of years before present), and its age may be *estimated* at about 500 ka (Hallberg and Boellstorff, 1978; Lineback, 1979; Hallberg, 1980b). This provides an estimate for the age of the last glacial advance that covered northeastern Iowa.

Stream erosion and hillslope development since the last glacial event has produced the deeply dissected landscape, and in the process also has removed the glacial deposits in most areas from all but the highest upland divides. In addition, the upland surfaces are mantled with 3 to 6 m of late-Wisconsinan-age loess. Organic carbon from the base of the loess, near Garnavillo in Clayton County, was radiocarbon dated at 25.3 ± 0.65 ka (ISGS-512; Hallberg et al., 1978). The end of loess deposition in Iowa is generally considered to be about 14 ka (Ruhe, 1969). The loess cover often obscures the recognition of the older glacial deposits.

Loess-mantled, Pre-Illinoian glacial deposits dominate the surficial materials outside of the Paleozoic Plateau in northeastern and east-central Iowa (see Ruhe, 1969; Prior, 1976; Hallberg, 1980a). The landscape developed on these deposits is dominated by multi-leveled, stepped, erosion surfaces cut prior to and during loess deposition (Ruhe 1969; Hallberg et al., 1978). These loess-mantled surfaces (where all are preserved), descending from oldest to youngest, from divides toward the valleys, are the Yarmouth-Sangamon, the Late-Sangamon, and several Wisconsinan-age, "Iowan" erosion surfaces. In different areas of the state, different surfaces dominate the landscape (Ruhe, 1969; Hallberg et al., 1978, 1980). The different surfaces are marked by geomorphic, topographic, and pedologic discontinuities. Of particular interest are the paleosols which define these surfaces beneath the loess. The Yarmouth-Sangamon and Late-Sangamon Paleosols are both developed in Pre-Illinoian deposits, but they can be distinguished by their geomorphic relations; the Late-Sangamon Paleosols also tend to be less weathered, thinner, and have more consistent soil morphology than Yarmouth-Sangamon Paleosols (Ruhe, et al., 1967; Hallberg et al., 1978, 1980). By contrast, on the lower, younger Wisconsinan-age erosion surfaces, no paleosol intervenes between the loess and the till, and radiocarbon dates show that these surfaces stabilized and were buried by loess in the late-Wisconsinan, between 20 and 17 ka (Ruhe, 1969; Hallberg et al., 1978). These patterns are repeated throughout southern and eastern Iowa and form a predictive model of landscape and soil development (Ruhe 1969; Hallberg et al., 1978; Hallberg, 1980c; Hallberg et al., 1980). Indeed, this same model and sequence of erosion surfaces and paleosols can be discerned in the Paleozoic Plateau region, although the greater topographic relief and steep slopes complicate the picture.

These relationships between the loess, buried soils, and erosion surfaces in the region provide insights into the evolution of this landscape. Historically, the area has been described as the dissected relict of various peneplains (Trowbridge, 1921) because of the nearly accordant elevations of divides. A discussion of these historic concepts is beyond the scope of this paper. From a modern perspective, the region is better described in terms of stepped erosion surfaces, pediments, episodic erosion, and dynamic equilibrium (Ruhe, 1975; Hack, 1960).

Ongoing work in the Paleozoic Plateau provides some general insights into its landscape evolution. On the primary stream divides, 4 to 6 m of loess overlies well-drained paleosols developed on Pre-Illinoian tills. The paleosols are generally 1 to 2 m thick, but locally may be thicker (2-5 m). These paleosola thicknesses, as well as other features, are typical of Late-Sangamon Paleosols, not the Yarmouth-Sangamon, and these characteristics suggest that the Late-Sangamon erosion surface has cut across the entire landscape. Only in local areas are remnants of the older Yarmouth-Sangamon paleosols preserved on the divides. These Late-Sangamon erosion surfaces form pediments which grade toward the present valleys, and show that the present drainage was established by "Late-Sangamon time." The Late-Sangamon Paleosol and surface may truncate the Pre-Illinoian till and descend onto the Paleozoic bedrock. On the carbonate rocks, the reddish, clay-rich B-horizon of the paleosol has often been called residuum or "terra rossa," supposedly derived from weathering of the underlying rock over long periods of time. In most areas, however, this "residuum" contains erratic pebbles derived from the glacial deposits. The mineralogy and chemistry of these "red clays" generally bear little resemblance to the bedrock, but are similar to the eroded Pleistocene deposits. The origin of the "red clays" associated with carbonate rocks is complex, but work in other areas of the Midwest has reached similar conclusions — that few of these "clays" are truly residuum (Ballagh and Runge, 1970; Olson, 1979; Olson et al., 1980; Frolking, 1982).

Where the "red clays" descend onto karst terrain, their distribution may be complex; the clays sometimes fill in sinkholes and solutionally enlarged fractures in the bedrock. In some instances they clearly have been "recycled" many times and washed in. Some "red clay" karst-fills are associated with Holocene radiometric dates. In other instances, "red clays" within karst cavities may be associated with weathering of bedrock, in part (Frolking, 1982). In still other areas, the "red clays" have been reworked in slope-wash deposits, and on some slopes, thin interbeds of sediment derived from loess and the red clays occur.

Inset below these Late-Sangamon surfaces are younger "Iowan" erosion surfaces which vary in number. These surfaces typically show a thinner increment of loess lying directly on bedrock with no intervening paleosol. These "Iowan" surfaces stabilized and were buried by loess between 20 and 17 ka. Yet, these young surfaces often stand 35 to 55 m above the major streams (e.g., Turkey River) and 10 to 30 m above smaller streams. Where an individual erosion surface is bordered by steep slopes and high relief (15 to 20 m or greater), the loess and rock grade laterally off the shoulder of the slope into a steep colluvial slope-deposit composed of a mixture of loess and large angular boulders of the local bedrock. These deposits comprise the slopes and grade into, or are truncated by fluvial deposits in the valley below. (See discussion of valley history.)

Other facets of the upland Quaternary deposits are related to the valley or erosional history. For example, in many regions of Iowa the bedrock surface is deeply buried by Quaternary deposits. This buried bedrock surface exhibits ridges and valleys reflecting a complex fluvial history. The bedrock valleys may range widely in age, but generally are thought to be Pleistocene (see Willman and Frye, 1970; Frye, 1963). In many areas of Iowa these bedrock valleys are buried by 75 to 100 m or more of Quaternary deposits. However, in the Paleozoic Plateau area of Iowa, these valleys have been exhumed. These exhumed valleys also are filled with till and glaciofluvial deposits but are now exposed by erosion in the modern valley walls. The few that have been observed cut across the modern drainage.

The general thought has been that the modern drainage system and deep entrenchment occurred in the Pleistocene, and the Upper Mississippi River valley originated as an ice-marginal stream during "Nebraskan" glaciation (Willman and Frye, 1970; Trowbridge, 1921; Trowbridge, 1966). Although we cannot now date this drainage derangement as "Nebraskan," evidence (Willman and Frye, 1969, 1970; Frye, 1963; Trowbridge, 1966) still supports the Pleistocene age for establishment of the Upper Mississippi River because: 1) the valley is out of adjustment with the bedrock stratigraphy and structure; 2) topographically high outwash in Illinois has been related to till on the uplands in Iowa, clearly suggesting that no intervening valley was present; and 3) other related deep valleys which are also out of adjustment with the bedcrock are either ice-marginal or were deranged by Pleistocene ice sheets.

Thus, the nature of the upland stratigraphy and the upland erosion surfaces suggest: 1) the master stream, the Mississippi, evolved within the Pleistocene; 2) the widespread occurrence of till across the uplands indicates that the drainage network (in Iowa at least) could not have begun to develop until after the last glacial event in the region (ca. 500 ka); 3) the present major drainage lines were established by the time of development of the Late-Sangamon erosion surface and paleosol; 4) a substantial amount of deep dissection of the region has taken place recently, in a geologic sense, specifically during the Wisconsinan as indicated by the high-level Wisconsinan-age erosion surfaces; and 5) this landscape has evolved from episodic periods of erosion and downcutting.

Karst Features

The history of karst development can provide additional insights into the landscape evolution of the Paleozoic Plateau region through careful observation of the relationship between the karst and the Pre-Illinoian glacial deposits and the present surface-drainage features. Additional information on the age of the karst can be obtained by radiometric dating of speleothems. Subsurface karst conduits are linked to the history of dissection in the region because karst solutional activity generally takes place at, or just above, the piezometric surface in a carbonate aquifer (Thrailkill, 1968; LeGrand and Stringfield, 1973; White, 1977). The volume of solution channels tends to decline "almost exponentially with depth below the water table" (LeGrand and Stringfield, 1973, p. 358). The karst-carbonate aquifers discharge to the major stream valleys, such as the Mississippi, Turkey, Yellow, and Upper Iowa Rivers. Thus, the depth of dissection of these valleys acts as a base level for the piezometric surface in these aquifers, and controls the depth of solutional conduit development. As the piezometric surface lowers, karst development can proceed to greater depth, and higher (older) conduits or caves pass into a vadose or partially air-filled (unsaturated) state. In a vadose condition, secondary carbonate deposits, or speleothems, (stalactites, stalagmites, and flowstone), can begin to form. Various aspects of the karst system are thus related to the landscape evolution of the region.

Paleokarst, as old as Cretaceous, may exist in the area. Cretaceous-age Windrow Formation deposits rest on Paleozoic carbonates (Fig. 1) that exhibit karst-solution features (Andrews, 1958). However, the Windrow Formation deposits are fluvial and they are preserved on upland divides. Thus, they represent only "roots" of the landscape in which they were deposited. Most of the karst that would have developed on this landscape has long since been removed by erosion. Though it seems likely that some of the known karst features in the Paleozoic Plateau may be paleokarst or pre-Pleistocene, there is little evidence to substantiate it.

Bounk (1983) concluded that most of the karst caves in northeast Iowa have formed since the last glaciation of the region. The caves examined are related to the present topographic-hydraulic gradient, and thus formed after the present drainage network became established. Only a few of the highest level (oldest) caves were not in adjustment with the configuration of the modern landscape. Bounk (1983) interpreted these to have formed immediately after the last glaciation, before (and during) the establishment of the drainage network.

Speleothem deposits can be radiometrically dated by uranium-series methods. Dates on the speleothems provide minimum ages on major valley downcutting, which lowered the piezometric surface and allowed speleothem growth in the vadose caves. Growth of speleothems is episodic and, in part, climatically controlled (Lively et al., 1981). Lively (1980, 1983; Lively et al., 1981) of the Minnesota Geological Survey has compiled over 50 dates from various caves in Minnesota and Iowa. A few samples have dated between 250 and > 350 ka; some of these dates were from samples of vein calcite which may relate to much older diagenesis and mineralization (Ludvigson et al., 1983). The remaining dates fall into three age groups: 163 to 100 ka; 60 to 35 ka; and from 15 ka to present.

Other aspects of cave development along the Silurian Escarpment adjacent to the Turkey River and its tributaries reveal features directly related to the history of the valleys. These caves generally underlie subtle, minor, surface valleys. The caves and valleys emerge from the Silurian Escarpment into small, narrow gorges which are filled with large, angular, blocky talus. These gorges mark the collapsed sections of former cavern systems (Hedges, 1967). The talus grades into the colluvial mixture of loess and bedrock blocks that mantle the steep slopes of the region, which in turn, are related to the late-Wisconsinan erosion surfaces on the upland. At Dutton's Cave, Fayette County (Hedges, 1967), and at other localities observed by the authors, the talus descends to, and interfingers with, high-level terrace deposits.

In summary, karst features contribute evidence on the geologic history of the region: 1) the majority of the karst apparently has evolved since the last (Pre-Illinoian) glacial event in the region, and is related to the modern drainage network; 2) major valley downcutting lowered the piezometric surface and caused vadose conditions to develop in karst conduits, permitting the initiation of speleothem development by ca. 160 ka; and 3) collapse of prominent, exhumed, karst conduits can be stratigraphically related to talus slopes, erosion surfaces, and terrace deposits of late-Wisconsinan age.

Evidence from Stream Valleys

The geologic evidence from stream valleys, like that from uplands and karst features, must be analyzed to understand the landscape evolution in the Paleozoic Plateau region. The various terraces and fluvial deposits can be dated by relative and absolute methods to help establish a chronologic framework.

The oldest known valley feature preserved in the Paleozoic Plateau area is the Bridgeport Terrace, located in the lower reaches of the Wisconsin River valley. This terrace surface is about 45 to 50 m above the adjacent Wisconsin River floodplain, and approximately 30 m higher than the (presumed) late-Wisconsinan terrace on which the town of Prairie du Chien is built (Knox, 1982). The Bridgeport Terrace is actually an intra-Pleistocene bedrock strath cut into dolomite and sandstone of the Prairie du Chien Group (Knox et al., 1982). Till, correlated with the Wolf Creek Formation tills present on uplands on the Iowa side of the Mississippi, occurs on the strath at the mouth of the Wisconsin River. Fluvial deposits, interpreted as outwash associated with this till, extend up the present Wisconsin valley thinning and fining to the east (Knox et al., 1982). The reversed gradient on the outwash and the fact that it fines in an easterly direction suggest that the ancestral Wisconsin River flowed eastward when this Pre-Illinoian glacier advanced into the area. High-level benches cut into rock, just slightly lower than upland landscape positions, are present in upper portions of the Kickapoo River valley, a major south-flowing tributary to the Wisconsin River. These benches are capped by alluvium in which a paleosol has developed. The alluvium and paleosol are, in turn, buried by Wisconsinan colluvium and loess (Knox et al., 1982). These benches grade to and therefore appear to be roughly equivalent in age to the Bridgeport Terrace (Knox, 1982). Equivalent deposits have not been recognized in northeastern Iowa, and no surfaces as prominent as the Bridgeport are known from anywhere else along the Upper Mississippi Valley.

High-level, bedrock-cored, cutoff meanders are inset below these high, loess-mantled benches and straths in southwest Wisconsin (Knox, 1982). Equivalent bedrock-cored meanders also are present in all major northeastern Iowa valleys, with the exception of the Mississippi. Drill-hole data from Wisconsin (Knox, 1982) and Iowa show that the rock-cored meanders are filled with a very thick sequence (25-35 m) of deposits, with sand and/or gravel at the base, extending to depths of 10 to 20 m below the present floodplain. The surface of the sediments filling these meanders usually stands 20 to 25 m above the present floodplain, and in some instances, such as at Sand Cove near the mouth of the Upper Iowa River, are as much as 35 m above the floodplain. The surfaces of these meanders increase in elevation above the floodplain in a down-valley direction, suggesting that the present valley gradient is steeper than when the river flowed through the rock-cored meanders. This relationship is complicated by deposition of local alluvium, colluvium, and eolian materials on the original surface of the fluvial deposits.

Earlier work has offered several different opinions on the age of these meanders and related high terraces. Calvin (1894, 1906) concluded that these "high gravelly terraces" were "Kansan" in age, "deposited by floods from the melting Kansan ice . . ." (Calvin, 1906, p. 124). In contrast, Leonard (1906) considered their age uncertain but suggested they might be Wisconsinan. More recently, Knox (1982, p. 12-14) inferred a post-"Kansan" to early-Illinoian age.

Recent investigations in Iowa have dated these terraces as Wisconsinan. The upland, loess-mantled, Late-Sangamon surfaces sit high above the present valleys and are graded to valley levels much higher than those of the bedrock-cored meanders, perhaps to positions similar to the high-level benches in Wisconsin. Moreover, the bedrock-cored meanders are inset *below* the late-Wisconsinan ("Iowan") erosion surfaces. As noted previously, these loess-mantled, late-Wisconsinan surfaces grade laterally, on the shoulders and backslopes, into steep slopes mantled with colluvium or talus in a silty matrix. The silty matrix was derived from late-Wisconsinan loess which accumulated during development of the colluvial aprons. These colluvial aprons grade into the rubble associated with the collapse of abandoned karst conduits. In a section near Elkader, in Clayton County, these colluvial deposits can be traced down the slope and *beneath* the fluvial deposits which fill a bedrock-cored meander related to the Turkey River. Spruce wood in the colluvium, about 15 m below the surface of the terrace and 2 to 5 m from the bedrock floor of the meander, was radiocarbon dated at 20.53 ± 0.13 ka (Beta-2748). The colluvium flanks the valley wall of the meander and passes under the fluvial deposits which fill the meander. The colluvium also grades laterally and interfingers with fluvial deposits, cross-bedded sands and gravels of the Turkey River.

In Grant County, Wisconsin, organic sediments, from near the base of similar colluvial and fluvial sediments along the side of a valley, were dated by Knox (1982, p. 3) at 20.27 ± 0.65 ka (ISGS-558). In Vernon County, Wisconsin, within a similar colluvial deposit, peat occurs about 4 to 5 m above the bedrock and 12 to 13 m below the land surface, and has been dated at about 29.6 ka (Knox, 1982, p. 37; pers. commun.). Furthermore, drill cores within Citron Valley, a large, correlative, bedrock-cored, cutoff meander, revealed organic-rich sediments at the top of the fluvial deposits which fill the base of the valley. The organic sediment was about 22 m below the surface of the terrace, and about 8 m above the bedrock floor. The sample was radiocarbon dated at 21.91 ± 0.35 ka (Beta-4808; Knox, pers. commun.).

The talus and colluvium which descend into the alluvial fills in these high-level, meander terraces are clearly late-Wisconsinan in age. Since the late-Wisconsinan colluvium lines the valley walls and partially fills the bedrock-cored meanders, entrenchment of the meanders predates them. Based on present information, the entrenchment can only be estimated at some time prior to about 30 ka. The dates already cited from deep within these valley fills, and the intimate association of the colluvial rubble and the bedrock walls, suggest that most of the entrenchment probably occurred in the late-to-middle (pre-30 ka) Wisconsinan.

Although slope processes and mass-movement on these colluvial slopes continue even today, the major period of development of this rubbly colluvium was associated with this period of valley entrenchment during the Wisconsinan. Most younger terrace deposits, inset below the rock-cored meanders, do not interfinger with the colluvium. The colluvial slopes were truncated by lateral migration and downcutting of the streams, and left as colluvial benches several meters above the younger terrace surfaces. It is generally thought that this colluvium resulted from a period of intense periglacial conditions (see Knox and Johnson, 1974; Whittecar, 1979; Knox, 1982; Mickelson et al., 1982). These conditions favored intense freeze-thaw activity and promoted mechanical weathering of the bedrock exposed on these steep slopes. In addition, the deep entrenchment of the adjacent stream valleys, described here, certainly contributed to the instability and provided added gradient to move this coarse material down the slopes.

There is no precise date for the age of the cutoff and abandonment of the rock-cored meanders. Fluvial deposition was occurring actively in these meanders at ca. 20 ka, as already noted. Ten to twenty meters or more of sediment were deposited in the meanders after 20 ka. After valleys had aggraded to this level, the rivers began to downcut again, abandoned these bedrock-cored meanders, and formed the present valley configuration, which has a much straighter alignment. Dating the youngest deposits in these terraces, however, is difficult. Small side valleys are still depositing alluvium and colluvium locally. These terrace surfaces have also been modified by erosion, and on some, sand dunes have formed, further modifying the surfaces. On some of the terraces, however, loess-like silts occur, generally in protected areas around the periphery of the terrace. In related exposures, the "loess" obviously has been reworked and is a slope-wash deposit. The morphology of other deposits, however, has the appearance of primary loess. The best etimate at present suggests that these surfaces were stabilized and then abandoned near the end of the period of loess deposition, ca. 14.0 to 17.0 ka.

The history of the stream valleys in northeastern Iowa after this time is complex because there are numerous younger terrace levels inset below the bedrock-cored meanders. Away from the mouths of the valleys, the younger terrace deposits vary in composition from coarse sand and gravel in some terraces to finer sands and loamy sediments in others. Near the mouths, some terraces are composed of very fine-grained, silty clays. None are mantled with loess.

From about 14 to ca. 9.5 ka, meltwater from the retreating Wisconsinan Laurentide ice-sheet influenced fluvial activity in the Mississippi River system. Clayton (1982) suggested that when the Laurentide ice terminated south of the continental divide, outwash was transported down the Minnesota and St. Croix Rivers into the Mississippi causing aggradation. Whenever the ice front was north of the divide, lakes (Agassiz and Superior) formed behind the divide and eventually spilled into the Mississippi via the Minnesota and St. Croix Rivers (Teller and Clayton, 1983). Since lake water did not carry bed load from the glacier, the Mississippi tended to erode and degrade (Clayton, 1982). Although this model is simplistic, it outlines some of the complex processes which affected drainage in the Mississippi basin.

During this period, the terminus of the ice-sheet fluctuated back and forth across the continental divide. This resulted in multiple cut-and-fill episodes in the river valleys. Periods of degradation in the Mississippi system were interrupted at times by large floods, possibly the result of rapid draining of the glacial lakes. During these episodes, the Misssissippi back-flooded into the tributary valleys, and silts and clays suspended in the floodwaters accumulated on the submerged tributary valley floors. Floodwaters originating from the Superior basin deposited red, kaolinitic clay, while discharge from the Lake Agassiz basin was dominated by gray, montmorillonitic clay, similar to the mineralogy of their respective glacial lobes (Clayton, 1982; Kemmis et al., 1981).

These slack-water deposits are comprised of laminated silty clays and silts, and are preserved in terraces near the mouths of many of the moderate-sized tributaries of the Mississippi River. The most prominent of these terraces is capped by red — Superior provenance — clays. These are informally known in Iowa as Zwingle terraces, after the name of the soil series mapped on these deposits. Excellent examples of these Zwingle terraces can be seen along Clear Creek (Allamakee County) in the town of Lansing, and near the mouths of Sny Magil and Buck Creeks, north of Guttenberg in Clayton County. In these areas, Zwingle terraces are broad, flat surfaces standing 12 to 18 m above the present floodplain and cut into late-Wisconsinan colluvial slopes. The gradient of Zwingle terraces is nearly flat within a tributary valley. Internally, the Zwingle terraces consist of stratified sand and gravel in their lower part, grading upward into interbedded sand and clay, which then grades upward into laminated clays and silts with occasional sand lenses.

A few dates from these fluvial deposits are available and some chronologic relationships are emerging. For example, south of Dubuque, in the northern portion of the Mines-of-Spain tract, a dated terrace remnant along Catfish Creek provides some relative age relationships between the various terraces. North of the present Catfish Creek, an abandoned valley segment of the creek sits, as a terrace, about 10 to 18 m above the present stream (the height of the terrace varies because of an irregular mantle of eolian sand). This abandoned valley was called "Kansan" in age by Calvin and Bain (1900). A recent exposure in the terrace showed from the surface down: 0-3.7 m, sand and sandy loam; 3.7-9.8 m, laminated, gray, silty clays with silt-loam partings, and with common, thin, sand interbeds towards the base; 9.8-13.7 m, stratified coarse sand and gravel, with occasional thin, gray, silty clay beds. Wood from the fluvial deposits at 9.5 m dated 12.66 ± 0.18 ka (Beta-4979), and wood from 7.6 m dated 11.15 ± 0.11 ka (Beta-4978). The laminated gray, silty clays are typical of the montmorillonitic, slack-water deposits which resulted from back-flooding of the Mississippi River.

Other terraces occur in the complex of present and abandoned valleys. About 15 m above the present creek, the Zwingle terraces occur, and they are above the dated terrace with the gray, silty clays. Thus, the Zwingle terraces in this area must be older than ca. 11.2 ka. In addition, the Zwingle terraces are younger than the loess, and in many areas are clearly inset below the bedrock-cored, cutoff meanders. Thus, the Zwingle terraces are, at least in part, younger than ca. 14 to 17 ka.

With these relationships in hand, we can proceed to the north side of Dubuque and review the relative age of Couler Valley, a distinctive and unique abandoned valley of the Little Maquoketa River (Prior and Heathcote, 1978). Trowbridge (1954) referred to Couler Valley as "Kansan" in age, and correlated it with the Bridgeport strath. However, the Zwingle terraces occur within Couler Valley and near the mouth of the valley at Sageville; again, the terraces lie about 15 m above the Little Maquoketa. Most of Couler Valley is cut below these Zwingle terraces, and thus must be younger, probably Holocene in age. In fact, in historic times, Couler Valley has taken overflow from the Little Maquoketa (Calvin and Bain, 1900, p. 392). Ongoing investigations are disproving the great antiquity assigned to these features by earlier work, and point out how remarkably young much of this landscape is.

These relative age relationships can be pushed a little further. A few large, sandy terraces are present in the Mississippi Valley, inset below the Zwingle terraces, but 12 to 15 m above known Holocene terraces. The towns of Harpers Ferry and Prairie du Chien are built on these terraces. Since these terraces are at a lower elevation than Zwingle terraces, they must also be younger than the Zwingle terraces.

Nearly all current work agrees that these complex late-Wisconsinan events ended with a minor period of stream degradation between about 10.8 and 9.5 ka. Subsequently, the fluvial history of northeastern Iowa has been one of alluviation, lateral stream migration, and minor downcutting. By approximately 9.2 ka, the Mississippi was probably within a few meters of its present level in the northeastern Iowa-Wisconsin area. Headward erosion had proceeded up most tributary valleys by this time in response to the late-Wisconsinan and early-Holocene downcutting in the Mississippi trench. Radiocarbon dates from fine-grained alluvium in smaller tributary valleys indicate that by shortly after 11 ka, alluviation was already rebuilding floodplains in higher portions of the drainage network (Knox et al., 1981; McDowell, 1983).

Valley alluviation appears to have continued throughout the Holocene in northeastern Iowa, punctuated by relatively short periods of downcutting. Several researchers have suggested that these fluvial episodes were controlled by climatic changes and related runoff patterns (Knox, 1975; Knox et al., 1981). The response of northeastern Iowa fluvial systems to intrinsic "geomorphic thresholds" has also played a role in producing some of the Holocene episodes (McDowell, 1983).

Regardless of the cause(s) of the alluviation and downcutting episodes, Holocene fluvial deposits in northeastern Iowa can be grouped into two major lithologic/age groups; 1) early through mid-Holocene deposits (11.0-3.0 ka); and 2) late Holocene (approximately 3.0 ka to present). Early through mid-Holocene deposits are usually silty or loamy, oxidized, and have soils with A/B/C profile sequences developed into their upper parts. These deposits often occupy low (1-3 m above the streams) terraces in small valleys, and somewhat higher (3-6 m) terraces in the middle and upper reaches of larger valleys. Late-Holocene deposits are usually silty or loamy, are less oxidized than early- to mid-Holocene deposits, and have soils with cambic B horizons or A/C profiles developed into them. Late-Holocene alluvium is inset below these older deposits in floodplains throughout the area.

Sediment deposited during the last 100-150 years often buries these earlier deposits. Logging, land clearing, and urban development have caused dramatic increases in upland erosion and the delivery of sediment to streams in this area. Artificial raising of water levels in the Mississippi River by construction of the lock and dam system for navigation has both promoted accumulation of sediment on floodplain areas and submerged many mid- and late-Holocene terraces along the Mississippi. Low terraces in the downstream portions of many tributary valleys, such as the Yellow and Upper Iowa Rivers, have also been buried by historic sediment from repeated back-flooding of the Mississippi.

Geologic evidence available from the fluvial deposits and terrace sequence shows: 1) in early- to middle-Pleistocene time, small valleys occupied positions which today are very high in the landscape (on the shoulders of the uplands); 2) main valleys (e.g., the Wisconsin River) were 45 to 50 m above present floodplains; 3) prominent, cutoff, bedrock-cored meanders which stand 20 to 25 m or more above the floodplains are Wisconsinan features; 4) between 14 and 10 ka the valleys had a very complex history, with numerous episodes of cutting and filling, leaving terraces as young as ca. 11.2 ka standing 12-15 m above the modern floodplains; and 5) the great antiquity earlier assigned to many landscape features and terraces is unjustified, and the major period of downcutting, aggradation, and terrace building is very young — Wisconsinan in age.

SUMMARY AND CONCLUSIONS

Northeastern Iowa presents a unique and varied cross-section of Iowa's geologic history, ranging from extensive exposures of Paleozoic rocks to varied evidence of its geologically young Quaternary history. The steep slopes, varied rock types, and diverse slope aspects combined with the entrenched stream valleys provide the geologic framework for diverse microclimates which support the unique ecology of the region. The so-called "Driftless Area" in Iowa was glaciated repeatedly in Pre-Illinoian time, and should not be called "Driftless." The name Paleozoic Plateau more accurately describes this physiographic region and also incorporates the much larger but similar area of special habitats referred to by biologists. This region encompasses contiguous portions of Iowa, Illinois, Minnesota, and Wisconsin.

Current research reveals that much of this deeply dissected landscape is quite young. Evidence from studies of the upland stratigraphy and erosional history, the development of the karst system, and the fluvial deposits in the stream valleys are beginning to reveal a coherent picture of the Pleistocene history of the region. A few key points to emphasize are: 1) the Mississippi River and its tributaries evolved within the middle Pleistocene, probably after the last glacial event in the region (ca. 500 ka); 2) the drainage network was established by "Late-Sangamon" time, but major stream incision probably began ca. 160 ka; 3) the major period of valley downcutting was in the Wisconsinan, and formed the prominent bedrock-cored, cutoff meanders; 4) as these deep valleys were aggrading ca. 20 ka, periglacial activity formed prominent colluvial slopes, and vadose karst conduits collapsed, leaving a mantle of bedrock-derived rubble with a loessial matrix on steep slopes and in related valleys; and 5) the stream valleys underwent a complex history of erosion and aggradation between 17 and 10 ka, in response to changes in glacial drainage in the Mississippi River basin. As further work is done on the complex evolution of this landscape, the valley history must be tied in with other studies of the Mississippi River to the south (e.g., Anderson, 1968), and with the continuing question of whether or not isostatic uplift has played any role in the deep incision of the streams into the bedrock (Trowbridge, 1921; Willman and Frye, 1970).

Early workers suggested that many of the landscape features in this region, such as the various high-level terraces, were very old. However, modern investigation of these fetaures show that they are geologically quite young, generally Wisconsinan or even Holocene in age. Terraces as young as 11.2 ka stand 10 to 15 m above the modern floodplains. This evidence also shows that the geologic framework that supports the microclimates and "glacial refugia" for disjunct (and otherwise extinct) plants and animals evolved during the Wisconsinan glacial period. Indeed, the talus deposits that form the unique algific slopes formed only about 20 ka. Though further research is needed, it is evident that a large portion of the Paleozoic Plateau's rugged terrain and unique ecology is remarkably young.

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