Glaciated Karst Terrain in the Door Peninsula of Wisconsin

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Abstract. *Glaciated karst terrain, which is poorly documented in the United States, is well developed in the Door Peninsula of northeastern Wisconsin. The peninsula is a southeastward-dipping cuesta developed on the Silurian Niagaran dolomite. Wisconsinan glacial plucking east of the escarpment produced glaciokarst features including alternating steps and risers* (schichttreppenkarst) *and extensive dolomite pavements. Pre- and post-glacial karst landforms include enlarged crevices (grikes), sinkholes, and caves. Staircases and pavements are predominantly south- and east-facing and are particularly well developed on the Brussels Hill outlier. Their distribution is as predicted by the general model of northwest-southeast ice movement. Many of the smaller karst landforms are postglacial, although shallow features may have an important inherited component, and the larger sinkholes and the caves may antedate Wisconsinan glaciation. Much of the postglacial karst development is in the Burnt Bluff Formation on the western side of the peninsula where the hydraulic gradient is steepest, joints are dilated, and the drift is thinnest. Regional joint sets at 25, 70, and 155 degrees have strongly influenced cave and sinkhole development.*

Although large areas of carbonate bedrock in the United States experienced the effects of Pleistocene glaciation, glaciokarst—characteristic terrain developed through glaciation of karst landscape—is poorly documented. In many areas glaciokarst is limited because the limestones or dolomites are mantled by thick, often carbonate-rich glacial deposits. These mask any preglacial karst, as well as the effects of glacial erosion, and hinder postglacial karst development. Nevertheless, glaciokarst is present in some areas, particularly where drift deposits are thin. In this paper we call attention to one major area of glaciated karst terrain developed on dolomites in northeastern Wisconsin and present some initial results of studies of the karst landforms.

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The Regional Setting

The Door Peninsula, which extends some 100 km into Lake Michigan and ranges from 5 to 30 km wide (Fig. 1), is a cuesta developed on the Silurian-aged Niagaran dolomite (Sherrill 1978). The Niagaran Series is approximately 107-m thick and consists dominantly of light gray, medium to coarse-grained, thin-bedded, fossiliferous dolomites. Bioherms are common and are expressed topographically in outliers such as Brussels Hill, the highest point on the peninsula at 260 m (Thwaites and Bertrand 1957).

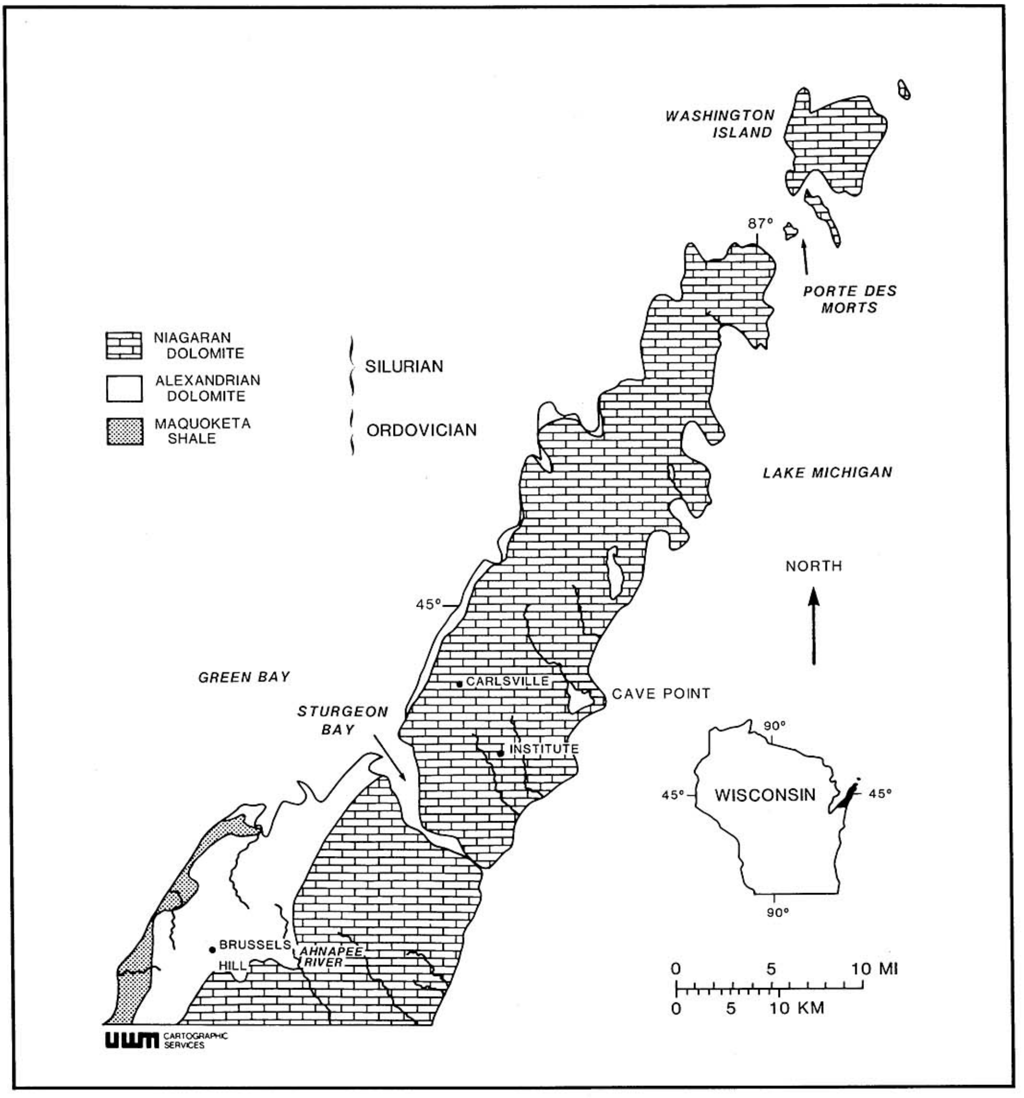

Fig. 1. Map of Door County (adapted from Sherrill 1978).

On the western, Green Bay side of the peninsula the Niagara Escarpment rises up to 79 m above present lake level; the cuesta backslope, sloping to the southeast at generally less than one degree, forms the main body of the peninsula. Headlands, talus-strewn bluffs, and island outliers characterize the west coast; the eastern coast is gently sloping and has sandy beaches and dunes.

The peninsula is traversed by a series of five northwest-southeast-trending lowlands, the most conspicuous being Sturgeon Bay, the Porte des Morts channel, and the Ahnapee River Valley (Fig. 1). These probably represent preglacial river valleys modified by glacial and meltwater erosion (Deller and Stoelting 1986; Johnson 1987).

The Door Peninsula was glaciated extensively during the Pleistocene, latterly by two major advances of the Green Bay Lobe during the Wisconsinan Stage: the Port Huron advance during the Woodfordian Substage (22–13ka) and, following the Twocreekan Interstade, a subsequent advance during the

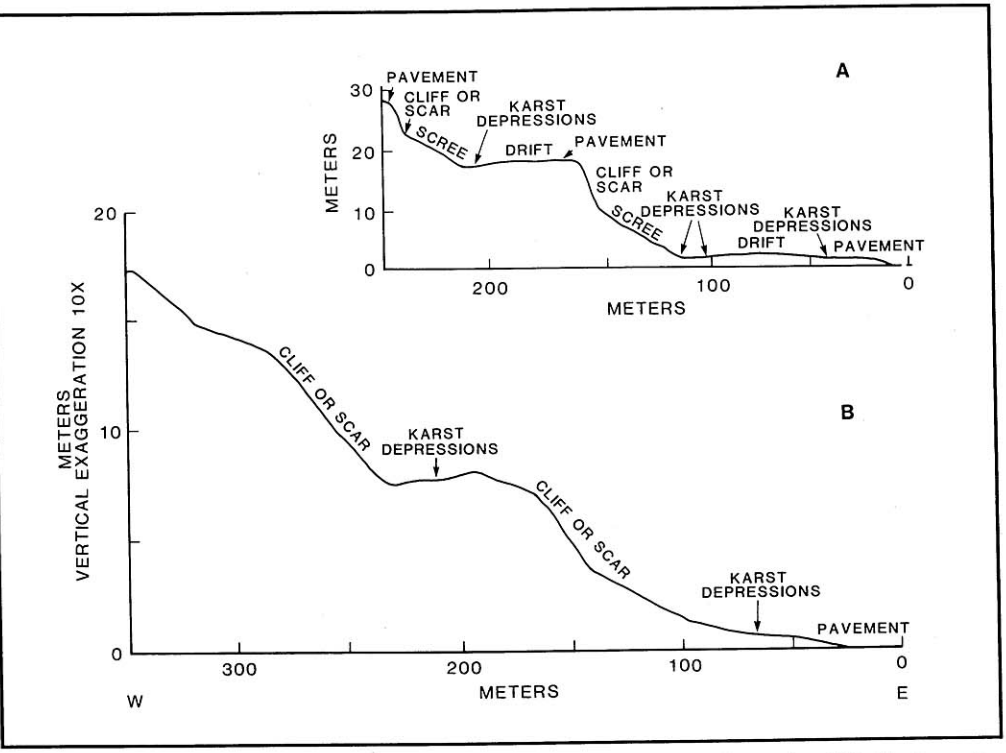

Fig. 2. Stepped glaciokarst profiles. A in Yorkshire, England, after Sweeting (1972), B on the east side of Brussels Hill.

Greatlakean Substage (11.5–10ka) (Schneider 1981, 1986, 1989). Ice movement was predominantly north-south or northwest-southeast (Thwaites and Bertrand 1957; McCartney and Mickelson 1982; Schneider 1981, 1986, 1989; Need 1985). The peninsula is covered by a thin veneer, mostly less than 1 m thick, of unstratified sandy till, much of which contains more than 25% calcium carbonate (Thwaites and Bertrand 1957). The drift thickens towards the southeast, where there is a cover of red clayey till and where there are moraines and some drumlins. Locally there are lacustrine and fluvial deposits, plus some outwash, beach, and dune sands (Deller and Stoelting 1986).

Mean annual precipitation is 690 mm, and mean annual daily maximum and minimum temperatures are respectively 11.6 and 1.3 degrees Celsius (Link et al. 1978). Surface water infiltrates into the dolomite aquifer very rapidly, giving rise to serious groundwater contamination (Sherrill 1975, 1978; Wiersma et al. 1984; Johnson 1987). Groundwater is calcium-magnesium-bicarbonate dominated, with a mean total hardness (as $CaCO_3$) of 299mg/l ($s=66.1$, $n=23$) (Sherrill 1978).

The Glaciated Karst Terrain

The Door Peninsula glaciokarst is similar to that developed on the Niagaran dolomite in the Bruce Peninsula of Ontario (Cowell 1976; Cowell and Ford, 1980, 1983) and has many of the characteristics of the "classic" glaciokarst of western Europe (Williams 1966; Sweeting 1972). The principal diagnostic features are the numerous nearly horizontal ledges and benches alternating with steep steps, or risers (Fig. 2). The ledges are developed on bedding planes that have been accentuated by intense glacial scouring and plucking on the down-ice side of the cuesta. East of the escarpment, the main body of the peninsula decreases in elevation via a series of large benches that attain widths of over 1 km and cover areas up to 10 km^2. The benches are drift mantled, and bedrock is exposed usually only where drift has collapsed into widened joints, locally giving rise to sinkholes. Between the benches, the steps, although generally obscured by drift, are as much as 10 m high.

Superimposed upon the large benches, and most evident on steeper east-facing slopes, are smaller ledges and steps that together make up distinct staircases—the *schichttreppenkarst* of Bögli (1964). These ledges range typically from 5 to 20 m in width, and steps range from 0.5 to 10 m high. On ledges where the drift cover is thin, there are exposed bedrock pavements, some with striations, others bearing well-defined, dissolutionally-molded clints and grikes (Rosen 1984; Johnson 1987). The ledges also carry a variety of karstic depressions, which have been documented by Rosen et al. (1987) and by Johnson (1987), and in overall morphology the staircase assemblages bear a striking resemblance to European examples (Fig. 2).

The staircases are predominantly south- and east-facing and are best developed on the south- and east-facing sides of hills and valleys. This distribution provides independent evidence that supports the theory that ice movement was predominantly from northwest to southeast. Particularly well-developed staircases occur on the eastern flanks of the Brussels Hill outlier, along the western margin of Sturgeon Bay, and on the eastern coast of the peninsula, for example at Cave Point (See Fig. 1 for locations). At Brussels Hill well-defined pavements occupy areas up to 0.75 km^2 and achieve widths over 50 m (Rosen 1984). Risers, in part near-vertical but mostly veneered by talus, are 5 to 10 m in height (Fig. 2B). Pavements on the western side of Sturgeon Bay are up to 20 m wide, with risers 1 to 5 m high.

Glacier basal bulldozing, plucking, and abrasion erases shallow karst features (Ford 1987) and, since the staircases and pavements themselves are of glacial origin, the crevices and sinkholes developed on them are essentially postglacial in age. Most grikes terminate at the level of the first or second bedding plane beneath the surface, but perhaps 25% are deeper, suggesting that in part they may have been initiated prior to Wisconsinan glaciation. A certain proportion of grikes, at least in the master joint set, may survive glacial scouring (Ford 1987), and thus the postglacial pavements may have an important inherited component.

Larger karst landforms may also have survived glacial action, although the majority of sinkholes are small enough to have developed entirely during the Holocene. Some larger sinkholes may antedate the last glaciation, and some may have originated as glacial scour holes, although there is no firm evidence of this. Caves too probably antedate recent glaciations, although it seems unlikely that they are strictly preglacial, i.e. developed prior to all episodes of Quaternary glaciation. As yet there has not been sufficient analysis of cave deposits to provide a chronological framework.

Postglacial karst development on the stepped surfaces is influenced strongly by three major regional joint sets oriented at 25, 70, and 155 degrees (Sherrill 1978; Rosen 1984). Consistent joint sets throughout the Michigan Basin are attributed by Holst (1982) to Paleozoic folding and more recent tectonic stresses. The 25-degree joint set is expressed only rarely on the eastern side of the peninsula. At Brussels Hill 71% of all sinkholes ($n=61$) follow a joint trace. Fifty-eight percent of sinkholes occur at three-way joint intersections, 21% at two-way intercepts, and 21% are on a single joint (Rosen et al. 1987). Caves also show this structural control, especially by the 70- and 155-degree joint sets. Paradise Pit Cave, at 554 m long, and Horseshoe Bay Cave, at 945 m long, are among the longest in Wisconsin (Hennings et al. 1972; Barden 1980). Brussels Hill Pit Cave, the deepest in the state at −28 m, is currently yielding a rich suite of Holocene faunal remains (Kox 1988).

Karst depressions on the stepped surfaces range from 0.6 to 12.0 m wide and from 0.15 to 3.0 m deep. At Brussels Hill, mean depression depth is 0.28 m (s=0.07, n=61). Large scattered depressions are evident in farm fields, where many have been filled in. In less-altered woodland areas most depressions are grouped in high-density lattice networks that reflect the closely spaced joint sets. At Brussels Hill densities are up to 8.7/100 m^2, and at Ledge Woods, west of Carlsville (Fig. 1), depressions occupy 95% of the surface of a 170 m^2 area.

Other karst features developed throughout the peninsula include swallets, which take runoff primarily from farm fields, and various types of karren (grooves, runnels, and solutional basins) (Rosen 1984; Johnson 1987). Enlarged joints, which are common where surficial deposits are less than 0.6 m thick, range up to more than 10 m in length and 0.8 m wide. Near Institute (Fig. 1) dissolution-widened crevices occupy about 0.4 km^2. Mean spacing of joints on the 70-degree azimuth is 3.1 m and that on the 155 azimuth is 5.1 m.

Many of the sinkholes, swallets, caves, and other karst landforms of the Door Peninsula are developed on the western side of the peninsula. This distribution reflects several factors (Rosen 1984):

1. Some karst features are developed preferentially in the Burnt Bluff Formation (Barden 1980), which outcrops at an elevation of about 190 to 215 m.
2. The hydraulic gradient is steepest close to the escarpment (see Cowell and Ford 1983).
3. Close to the escarpment, joints are dilated as a result of glacial unloading or ice-wedging (e.g., see Stieglitz et al. 1980).
4. The drift cover is thinnest on the western side of the peninsula. 96% of exposed karst features are in areas with less than 1.2 m-thick drift and 73% are developed where drift is less than 0.6 m thick (Rosen 1984).

Conclusion

The Door Peninsula is possibly the most impressive glaciated karst landscape in the United States. It contains a characteristic suite of glaciokarst landforms, including staircases and pavements, together with postglacial crevices and sinkholes, and probably preglacial caves. Development of the karst merits further study particularly because its environmental implications are now being fully realized. Distribution of the glaciokarst agrees with predictions based upon previous models of Wisconsinan ice movement. Most of the surface landforms are postglacial in age, although some may have characteristics inherited from karstification antedating the Wisconsinan glaciation. Caves and larger karst landforms may have been initiated prior to the last glaciation, but like the smaller features they too are oriented preferentially along the regionally dominant joints.

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