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SUBGLACIAL MELTWATER CHANNELS (NYE CHANNELS OR N-CHANNELS) IN SANDSTONE AT HINDOSTAN FALLS, MARTIN COUNTY, INDIANA

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ABSTRACT. A flat-topped slab of sandstone bedrock about the size of a football field is exposed at low water just downstream from Hindostan Falls, Martin County, Indiana. The surface of this rock exhibits numerous subparallel linear grooves, many of which are 5–10 cm deep and 8–20 cm across. Most of the grooves span the entire exposed downvalley length of the rock. These are interpreted as Nye channels, commonly called N-channels, that were cut into the sandstone by the movement of meltwater beneath a confining layer of glacial ice. N-channels are the product of discrete or consolidated flow; such channels can transport large volumes of sediment-carrying meltwater, commonly as a slurry that can be a potent agency of erosion.

As compared to N-channels elsewhere described, those at Hindostan Falls are small and simple. Many features shown by the channels indicate that they were formed by confined water erosion, probably beneath ice, and not by ice movement or freely flowing water. These features include a subparallel pattern having little downvalley branching and rejoining, smoothly rounded cross sections, small meanders, undercut walls, channels that rise and fall slightly, channels that climb downvalley, and offsets or deviations around obstacles.

The tongue of ice beneath which the N-channels were formed lay about 5 km outside the presently mapped extent of pre-Wisconsinan glacial deposits. That boundary is imprecisely defined, however, mainly by scattered patches of till, and the proposed extension of the glacier is therefore plausible.

Keywords: Nye channels, subglacial meltwater flow, glacial boundary, southern Indiana

Setting.—Hindostan Falls is on the East Fork of White River about 15 km downstream from Shoals, Martin County, Indiana (Fig. 1). The falls is one of several places along the East Fork where a rock ledge extends entirely across the channel. Most such features were formed by one of the several processes by which a meander may be cut off and abandoned. In this case the process included: 1) deep incision of a valley meander into bedrock, 2) partial alluvial backfilling of that valley, mostly by outwash of one of the pre-Wisconsinan glaciers, 3) opportunistic relocation of the channel across the bedrock neck of the meander at a low spot, and 4) downcutting of the new channel as base level was lowered (Bajza 1944). A tongue of one of the pre-Wisconsinan glaciers may also have been involved in the cutting-off process.

Just downstream from the falls is a large flat rock slab known locally as Flat Rock, which is exposed only when the river is relatively low (Fig. 2). Formed of cross-stratified sandstone in the lower part of the Mansfield Formation (Pennsylvanian), the rock is about 100 m in each horizontal dimension. Except for a few deep potholes, several rows of square holes that were cut for the placement of a timber-framed dam, some other obviously man-made cuttings, and the grooves described below, the rock surface is smooth and exhibits vertical relief of less than 0.5 m.

Flat Rock has been there for a long time, but the grooves have stirred little comment. Bajza (1944) noted only that the rock has a "fluted surface" and did not remark further. The rock and the grooves were beautifully illustrated by Robinson (1990) in a short note on the history of the village that once was nearby, but he did not mention the grooves. And although I have visited the falls several times, I never saw the rock until I discovered the grooves by chance on a family tour in October 1998, when the river level was very low.

Description of features.—Flat Rock is crossed by dozens of long subparallel grooves, singly and in groups of a few dozens. Many of the grooves are about 5–10 cm deep and 8–20 cm across (Fig. 3). The bottoms of the grooves are rounded as are the shoulders.

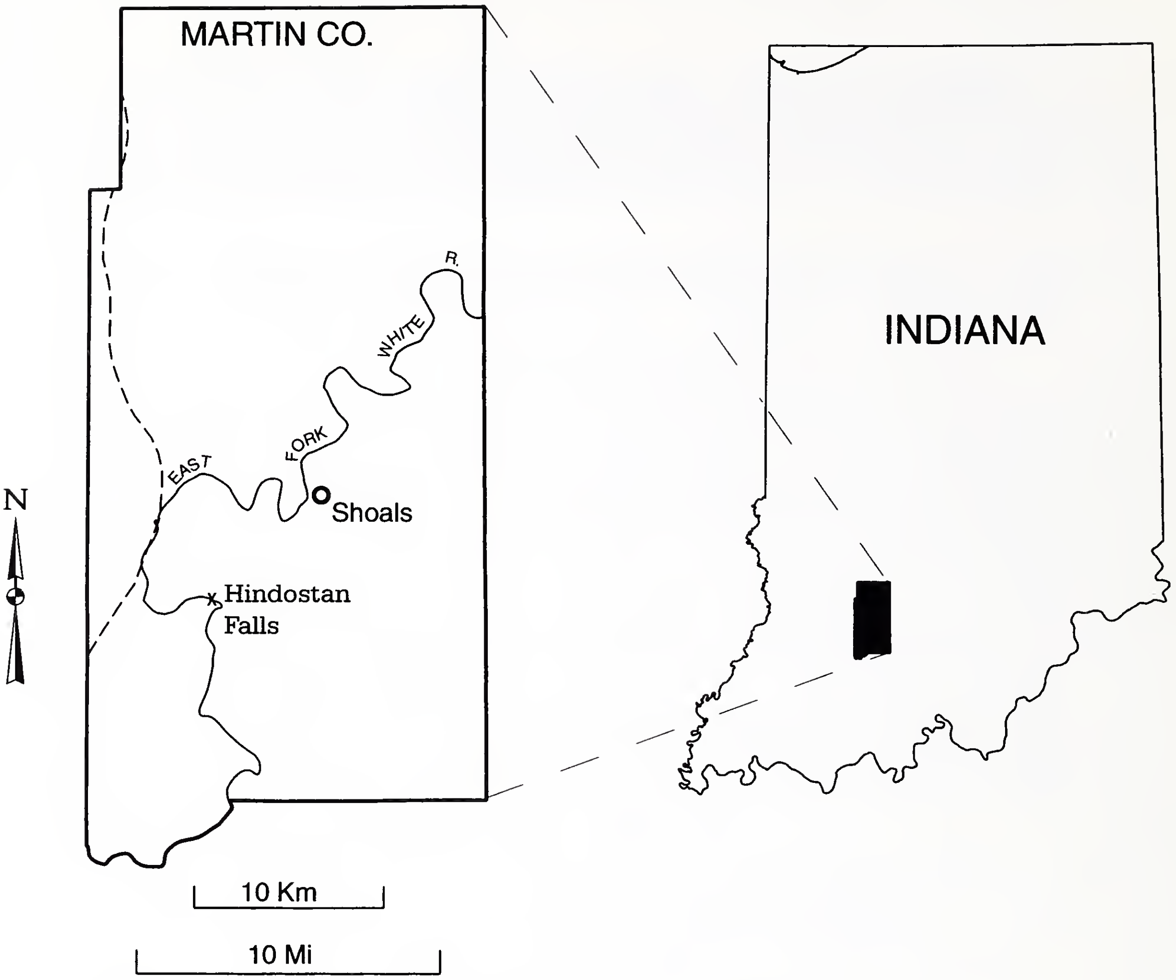

Figure 1.—Maps showing location of Hindostan Falls (×), Martin County. Dashed line indicates approximate limit of deposits of pre-Wisconsinan glaciers (modified from Gray 1989).

Most of the grooves deviate only slightly from a down-valley azimuth of about 118°, but small low-amplitude meanders are common and a few grooves show down-valley branching or rejoining at acute angles. In places, the walls of the grooves are undercut (Fig. 4). At the up-valley and down-valley edges of the rock the grooves are more deeply and elaborately cut and those at the up-valley edge of the rock rise down valley (Fig. 5), but for most of the way across the nearly level surface of the rock the grooves are relatively uniform in depth and are nearly straight.

In a few places the grooves deviate around an obstruction, such as a possible concretion now gone (Fig. 6). Some grooves terminate or are offset at major joints that cross the groove trend at an obtuse angle; but many cross the entire down-valley length of the rock, about 100 m. On one part of the rock are a few grooves so indistinct and shallow that they almost escape attention. The grooves are not precisely horizontal, but rise and fall with the subtle relief of the rock surface without change in cross section. This can most readily be observed when there are broad shallow puddles of rainwater on the surface of the rock.

Analysis.—Because the grooves are less than perfectly parallel, are rounded in cross-section, do not stop abruptly, and are not accompanied by chatter marks or signs of ice plucking, they almost certainly were not made by the sharp cutting action of rock fragments embedded in moving ice. This may, however, have been the manner in which they were initiated. Because they rise and fall across the rock surface and do not form any kind of branching network, they almost certainly were not formed by a free-flowing stream. And although this site was historically the launching point of many flatboats and keelboats, man-made grooves, such as may be seen on the walls of historic locks where the tow-ropes have over the years worn long tapering and very straight grooves, must also be ruled out.

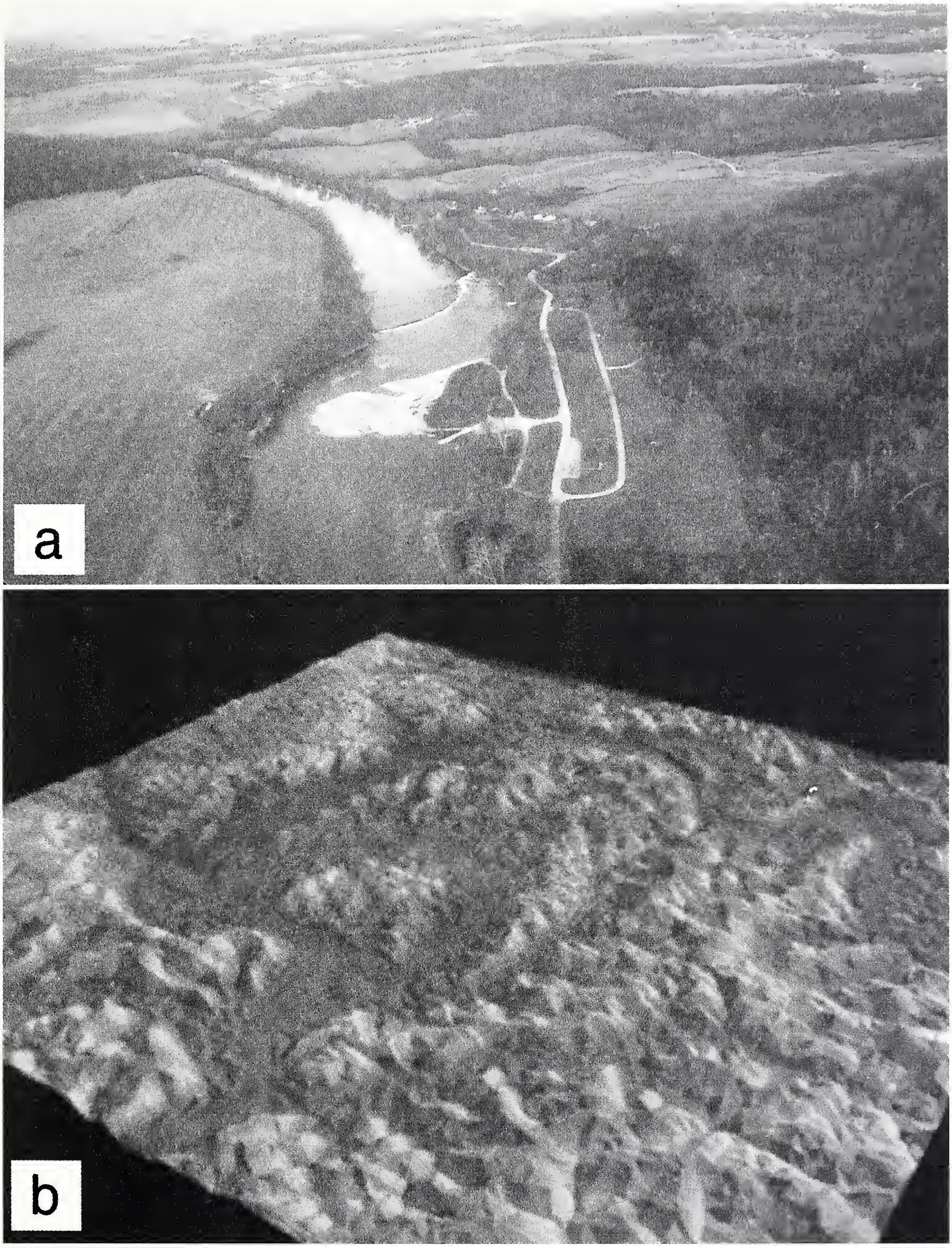

Figure 2.—(a). Low-angle oblique aerial photograph (21 December 1999) looking northwestward across Hindostan Falls. The East Fork of White River flows toward the camera. An abandoned former meander of the East Fork is in the distance; rock on which the N-channels may be seen is in the foreground. River stage is about 42 m^3/s (1500 cfs). (b). Digital elevation model looking northwest at a higher angle, showing setting of Hindostan Falls in a broader context than in Figure 2a. Width of block scanned is about six miles. (Digital data from parts of Loogootee, Shoals, Alfordsville, and Rusk 7½-minute U.S. Geological Survey topographic quadrangle maps; DEM created by Denver Harper).

Figure 3.—View downstream showing numerous subparallel N-channels. In the distance, a major joint crosses the N-channels almost at right angles. Broad grooves that cross channels at acute angles in the foreground probably mark the former location of fossil tree-trunks. Square hole is one of many that were excavated long ago for anchoring a timber dam.

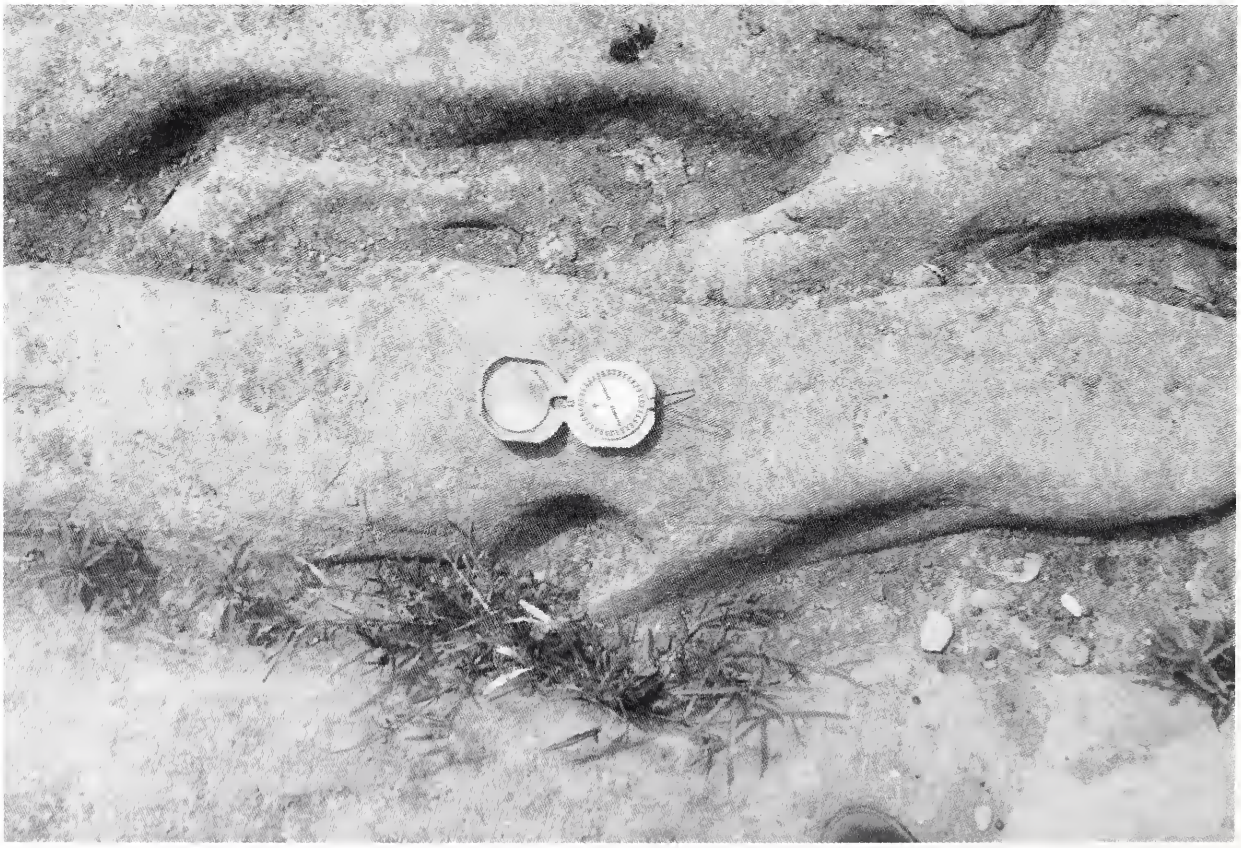

Figure 4.—N-channels showing undercut walls. Downstream is to the left.

Features such as these could have been formed only by water flowing under a confining layer, such as ice.

Subglacial meltwater flow has been studied by glaciologists and glacial hydrologists for the past 30 years (for example, Weertman 1972; Walder & Hallet 1979; Whillans 1979; Sharpe & Shaw 1989). These hydrologic studies get deeply into mathematics, but textbooks such as Bennett & Glasser (1996) and Benn & Evans (1998, esp. pp. 109–117) offer more easily understood summaries. Two types of such subglacial flow are recognized. In distributed flow the meltwater flow is diffuse, as, for example, Darcian flow through a permeable substrate. In discrete flow, meltwater, typically well-laden with sediment, flows as a thin sheet or in discrete closed channels.

Two principal types of discrete subglacial channels have come to be recognized, each named after a person who was early and influential in their definition and understanding. These are Nye channels, usually called N-channels, which are cut into the bedrock substrate, and Rothlisberger channels, or R-channels, which are cut into the base of the glacial ice. In both types of channel, the channel is completely water-filled and flow is by hydraulic pressure, not by simple gravity. Researchers commonly point out that these channels have never been seen in the process of formation, and that subglacial flow in confined channels has only been postulated. And some argue that the major meltwater movement takes place along a film a few millimeters thick at the ice-bedrock interface rather than in channels of any kind.

The grooves described above are here interpreted as N-channels, and if illustrations in the literature are representative, they are among the smaller and simpler examples of that type. They also may be more easily understandable. The parallel pattern in which downstream branching and rejoining is uncommon, the undercut walls, the meanders, and deviation around obstacles are critical evidence. Equally important are the climbing channels (Fig. 5) on the upvalley edge of the rock (falling channels on the downvalley edge are less definitive) and the gentle rise and fall of the channels as they cross the slightly irregular rock surface. Most of these features could have been formed only by flow beneath a confining layer that is no longer present and under hydraulic head sufficient to prevent invasion of the grooves by the overlying material. For the now-missing confining layer, glacial ice well fits. Further explanation of the criteria of N-channels may be found in Benn & Evans (1998, pp. 328–332).

How do these features compare with related features elsewhere? Some of the best-known, though perhaps controversial, examples are on Kelleys Island in Lake Erie. The dimensions of these megagrooves, which are cut into limestone bedrock, are measured in meters. Their prominent characteristics, which include meanders, finely grooved and polished surfaces, undercut walls, and streamlined crag-and-tail features, prompted Whittlesey (1879) and Chamberlin (1888, notably on pp. 212–213) to suggest that the megagrooves were cut by sediment-laden water flowing under hydraulic pressure beneath glacial ice. Immediately after the initial cutting, the advancing ice molded itself into the channels so as to create the final finely striated and polished surface. (That surface, unfortunately, quickly disappears when exposed.)

More recently, Goldthwait (1979) concluded that the megagrooves on Kelleys Island represent conventional small stream channels initially cut during an interglacial phase and later modified by glacial sculpture during a glacial maximum when the ice was more than a mile thick. Snow, Lowell & Rupp (1991), after an extensive discussion of the same features, seem to have left the question open; but other recent papers (for example, Walder & Hallet 1979; Whillans 1979; Sharpe & Shaw 1989) illustrate and describe features similar to those on Kelleys Island and assign them to subglacial meltwater erosion.

Most of the authors cited above believe that meltwater erosion and modification by ice were almost contemporaneous. They suggest that frequent but temporary and local detachment of the ice from its bed allowed for repeated episodes of erosion of the substrate by sediment-laden meltwater. This was followed almost immediately by the polishing and striating action of the ice as the ice excluded the meltwater, which then occupied other subglacial routes. Extensive and complex surfaces may be formed in this way. Walder & Hallet (1979, pp. 340–341) summarized the pertinent criteria as follows.

Figure 5.—Meanders and undercut walls in N-channels on upstream edge of rock. Channels ascend downstream, away from camera, and lead into smaller normal grooves.

Figure 6.—N-channels diverge around obstacle no longer present, possibly a concretion, and rejoin downstream (to the left).

> "Nye channels do not appear to form an arborescent network; neither the channel density nor the average channel cross-sectional area changes systematically down-glacier . . . Nye channels tend either to nearly parallel the former ice-flow direction or to follow local bed slope . . . the cavities and Nye channels form a practically continuous network of drainage conduits . . . Approximately 20% of the bed area mapped was not in close contact with the basal ice during much of the glaciation . . . our map [of the former bedrock floor of the glacier] does not represent an instantaneous picture of conditions at the glacier bed; rather, it represents basal conditions averaged over an uncertain length of time, probably several or several tens of years."

Many of the larger and more elaborate features that elsewhere have been attributed to subglacial meltwater flow are not present at Hindostan Falls. One possible reason for this is that much work on such flow has been done in carbonate terrain, where solution may have been as important an erosional process as abrasion. Also, many of these studies have been carried out in mountainous regions where the hydraulic head and thickness of the ice may have been much greater than it was here, at the very margin of a wasting continental glacier. And finally, it appears that the large-scale and complex features seen elsewhere connote repeated channel formation beneath very active glaciers, whereas it seems likely that the N-channels on Flat Rock were the result of a single short-lived episode of erosion at the distal margin of a waning ice sheet.

Commentary.—Flat Rock lies about 5 km outside the commonly recognized boundary of deposits of the pre-Wisconsinan glaciations (Fig. 1). The suggestion that it was ice-covered at the time of formation of the N-channels is not altogether surprising for two reasons. First, the glacial boundary in this area (Gray 1989) is uncertainly defined by scattered exposures of till and areas of soil in which the parent material is interpreted to be till or loess over till. Such a boundary is likely to be the subject of occasional revision as new data are developed. Second, it is entirely possible that the ice may have been only a tongue that briefly extended from the main body of one of the pre-Wisconsinan glaciers and flowed down the valley of the East Fork. Such a tongue might also have contributed to the breaking-through of the meander-core ridge to form the channel in which the East Fork now flows.

Although this is presently the only known instance of N-channels in Indiana, it seems likely that there are unrecognized examples elsewhere in the three-fifths of Indiana that has been glaciated. Stripped surfaces in quarries, which commonly display glacial striations, might in some places also show evidence of N-channels. Such channels in limestone may be difficult to distinguish from interstratal solution channels; for example, both might exhibit anastomosing patterns and other criteria that suggest formation under hydrostatic head.

One final note: the surface of Flat Rock is available for observation only when the flow in the East Fork at this point is below about 85 m^3/s (3000 cfs) and stable or declining rather than rising. Data from the gauge at Shoals, about 15 km upstream, may be taken as a guide. (Internet access to these data, which are reported in conventional units, may be had through www.usgs.gov.) Normally the rock is visible during much of the months of July through December, but in drought years it may be accessible in other parts of the year. When the flow is as low as about 11 m^3/s (400 cfs) it is possible to walk dry-shod around the entire perimeter of the rock and to observe all its interesting features.

ACKNOWLEDGMENTS

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