

# Genesis of streamlined landforms and flow history of the Green Bay Lobe, Wisconsin, USA

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## Abstract

The distribution of streamlined landforms in southeastern Wisconsin suggests that drumlins and flutes formed during several phases of the Green Bay Lobe between 18 and 14,000 BP. The largest group of drumlins formed during a still-stand of the ice margin during the Johnstown phase, presumably about 18–16,000 BP. Flutes and smaller drumlins are superimposed on larger forms, and larger drumlins are remolded. This indicates that drumlin modification continued during retreat. Three fields containing smaller drumlins formed after ice re-advanced a short distance or stabilized during the Green Lake, Rush Lake, and St. Anna phases about 16–14,000 BP.

The drumlin-forming process included erosion and deformation of pre-existing ice-marginal and proglacial sediments. Drumlins associated with the Johnstown phase show an increase in length up glacier. This is probably the result of variations in flow velocity, length of time of drumlin formation, and sediment availability. Flutes and small drumlins are associated with retreat moraines and formed near a thin, retreating ice margin.

Ice surface profile reconstructions suggest that margins were relatively steep during the Johnstown, Milton, Green Lake, and early Rush Lake phases. During the Lake Mills and late Rush Lake phases, when flutes were forming, the ice surface slopes were lower and margins were retreating. During retreat minor sublobes developed, some perhaps resulting from surges into small proglacial lake basins. Thus, steep ice margins and driving stresses on the order of 15–25 kPa were typical during drumlin formation. The formation of flutes, and the remolding of larger drumlins into smaller forms, took place beneath gently sloping ice of retreating margins associated with lower driving stresses (<10 kPa).

## 1. Introduction

Drumlins and flutes are the dominant landforms in many parts of the glaciated region of Wisconsin, especially in the area covered by the Green Bay Lobe (Fig. 1). These landforms provide a detailed record of ice flow direction, allowing interpretations of glacier bed conditions and flow regime. Streamlined landforms of the Green Bay Lobe developed during

at least four phases and were subsequently modified by thinning ice during retreat. By estimating the glaciological conditions associated with streamlined landforms, we can better understand their genesis.

While the morphology, distribution, and structure of streamlined landforms have been studied intensively, their origin remains a matter of debate (Menzies, 1979; Smalley, 1981; Rose, 1987; Patterson and Hooke, 1995). At present, explanations of drumlin genesis include: (1) erosion, deformation, and deposition by a subglacial deforming layer (Smalley and Unwin, 1968; Boulton, 1987); (2) erosion, de-

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