Sedimentary Geology 338 (2016) 51–71

Contents lists available at ScienceDirect

Sedimentary Geology

journal homepage: www.elsevier.com/locate/sedgeo

Glacially-streamlined hard and soft beds of the paleo- Ontario ice stream in Southern Ontario and New York state

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ARTICLE INFO

Article history:
Received 3 September 2015
Received in revised form 23 January 2016
Accepted 25 January 2016
Available online 3 February 2016

Keywords:
Rock
Drift drumlins
Hard and soft beds
Ontario Ice Stream

ABSTRACT

An extensive tract of glacially-streamlined terrain across a large part of Southern Ontario, Canada, is recognized as the footprint of the paleo-Ontario Ice Stream (OIS) within the easternmost Great Lakes sector of the last Laurentide Ice Sheet. The upstream part is a drumlinized and megagrooved 'hard bed' underlain by Cambro-Ordovician carbonates and sandstones. Subglacial plucking of jointed limestone on the lateral margins of drumlinized escarpment interfluves and rock drumlins generated a large flux of coarse debris within the ice base, recorded by sporadic spreads of hummocky rubble moraine. Downstream, the hard bed passes underneath a streamlined 'soft' bed of till-cored ('drift') drumlins and megaridges of the classic Peterborough and New York State drumlin fields. The boundary between the two bed types is a ~ 10 km wide 'mixed bed' of isolated drift drumlins resting on drumlinized rock suggesting a common erosional origin. Spatial variation in the geomorphology of ~2500 drift drumlins, indicates that megaridges are clones resulting from the erosion and dissection of larger parent drumlins. A large moraine system may mark the final collapse and melt of the ice stream, accompanying abrupt flow switching of its margin.

1. Introduction and purpose

Much work continues to be focused on developing geomorphological criteria to identify the presence of paleo-ice streams in ancient ice sheets (e.g., Dyke and Morris, 1988; Dyke et al., 1992; Hart, 1999; Knight et al., 1999; Stokes and Clark, 1999; Jansson et al., 2003; Roberts and Long, 2005; Evans et al., 2006a, 2006b; 2012, 2014; Mosola and Anderson, 2006; Dowdeswell et al., 2006; Kleman et al., 2006; Winsborrow et al., 2008; De Angelis and Kleman, 2008; Ross et al., 2009, 2010; Graham et al., 2009; Livingstone et al., 2012; Stokes et al., 2013; Eyles, 2012; Eyles and Putkinen, 2014; Margold et al., 2015; Krabbendam et al., 2016). This paper significantly advances understanding of the geomorphic record of ancient ice streams by describing the well-exposed bed of a former ice stream that flowed southwestward across much of Southern Ontario, Canada, into the USA where it left thousands of sediment-cored drumlins ('drift drumlins') and associated elongate megaridges of the Peterborough and New York State drumlin fields (Fig. 1). In addition, an extensive glacially-streamlined 'hard bed' can now be identified north of the main belt of drift drumlins and consists of drumlinized and megagrooved limestone escarpments and dip slope plains. An irregular zone between the two (a 'mixed bed') shows isolated drift drumlins resting on drumlinized rock.

The bed of the former ice stream is very well exposed across Southern Ontario and upper New York State and offers an excellent opportunity to describe its geomorphology in some detail and to distill a paleo-ice stream landsystem model. This paper provides insights as to the subglacial processes that formed the hard and soft beds and how these two bed types may have co-evolved below the ice stream. These observations may help inform work elsewhere in similar paleo glaciological settings and moreover, may provide a comparative guide for explorations of the beds of modern ice streams.

2. Study area and glacial history

At its maximum extent, the Laurentide Ice Sheet (LIS) was dominated by more than 100 fast-flowing ice streams, now identified by distinct corridors (flow sets) of megascale glacially-lineated (MSGL) terrain principally composed of megaridges and drumlins (Margold et al., 2015). Fast ice flow is recorded in the Ontario Basin of the eastern Great Lakes sector of the LIS by the Peterborough Drumlin Field (PDF) north of Lake Ontario, and by the coterminous New York State Drumlin Field (NYSDF) south of Lake Ontario (e.g., Fairchild, 1907, 1929; Slater, 1929; Boyce and Eyles, 1991; Briner, 2007; Kerr and Eyles, 2007; Hess and Briner, 2009; Maclachlan and Eyles, 2013; Englert et al., 2015) (Fig. 1). Collectively, these areas comprise the geomorphic footprint of a large, recently identified ice stream (#49 of Margold et al., 2015) which is named here for convenience the 'Ontario Ice Stream' (OIS) in reference to its principal flow path through the Ontario Basin as a result of topographic funneling of ice from Quebec and the Adirondack Mountains into the St. Lawrence River valley (Carl, 1978; Ross et al., 2006). As it flowed west and left the confines of the valley it was

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http://dx.doi.org/10.1016/j.sedgeo.2016.01.019
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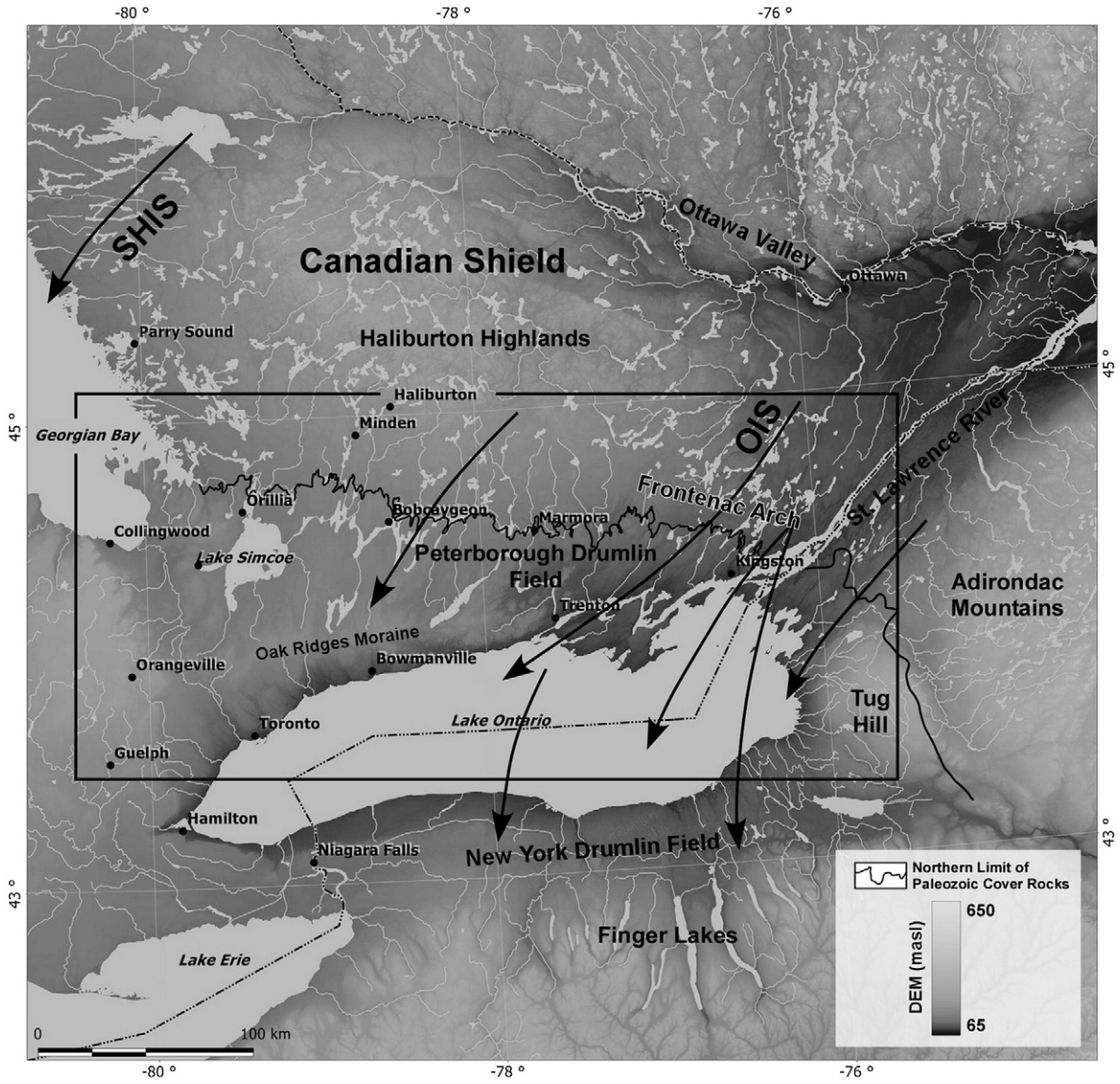

Fig. 1. The Ontario Ice Stream (OIS) at c. 20,000 ybp with the Saginaw-Huron Ice Stream; SHIS) in the Huron Basin to the west. Heavy line marks the boundary between the Canadian Shield (to the north) and Paleozoic cover rocks (southwards). Ice flow directions changed dramatically during deglaciation (e.g., Fig. 2). Inset box shows location of Figs. 3 and 4.

deflected south and southwestwards toward the Appalachian Plateau in New York State by the high standing Niagara Escarpment (where it abutted another ice stream flowing south through the Huron Basin; the Saginaw-Huron Ice Stream; Eyles, 2012).

The study reported here describes that part of the bed of OIS exposed from the Niagara Escarpment in the west to the Adirondack Mountains in the east (~ 350 km), and southwards from the southern limit of Precambrian crystalline rocks of the Canadian Shield to Lake Ontario (~ 50 km) (Fig. 1). Most of this extensive area lies entirely within Southern Ontario, Canada with the easternmost part lying on the east side of Lake Ontario and the St. Lawrence River, in coterminous Upper New York State, USA. The regional glacial stratigraphic record of LIS expansion and decay in the region broadly agrees with reconstructions of global sea level after 110,000 ybp (years before present) which is a proxy for LIS volume. Early Wisconsin growth was followed by a lengthy phase of mid-Wisconsin stasis when the LIS margin is thought to have followed the southern boundary of the Shield, ponding large proglacial lakes in the Great Lakes Basin (Eyles and Westgate, 1987; Dyke et al., 2002; Dyke, 2004; Kleman et al., 2013). These lakes left extensive and thick (up to 100 m) spreads of relatively fine-grained glaciolacustrine and glaciofluvial sediments that now sub-crop below younger late Wisconsin tills, and which are widely exposed in cliffs along the Lake Ontario shoreline (Brookfield et al., 1982; Martini and Brookfield, 1995; Eyles et al., 2005). Large volumes of these sediments were incorporated into late Wisconsin tills such as the Northern Till which reaches a maximum thickness of 60 m and is the principal till below the Peterborough Drumlin Field and surrounding areas (Boyce et al., 1995; Boyce and Eyles, 2000; Gerber and Howard, 2000; Meriano and Eyles, 2009). Access to large volumes of fine-grained wet sediment may have facilitated ice streaming. Maximum LIS expansion took place at about 20,000 ybp or shortly thereafter. The maximum southward extent of OIS lay along the northern edge of the Appalachian Plateau in southern New York State and the position of the ice margin between c. 15,600 to 14,100 ybp is defined by the Valley Heads Moraine at the southern end of the Finger Lakes (Ridge et al., 1991; Wellner et al., 1996; Dyke, 2004). OIS had pulled back from the Niagara Escarpment by ~13,300 ybp in agreement with stratigraphic records from other Great Lake basins (e.g., Dyke et al., 2002, p. 16). However, at c. 13,000