Geomorphology 220 (2014) 50–57

Contents lists available at ScienceDirect

Geomorphology

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

Morphometric analysis of ice-walled lake plains in Northern Illinois: Implications of lake elongation by wind-induced dual-cycle currents

Kory Allred [a,*], Wei Luo [a], Mike Konen [a], B. Brandon Curry [b]

[a] Department of Geography, Northern Illinois University, DeKalb, IL 60115, USA
[b] Illinois State Geological Survey, Institute of Natural Resource Sustainability, University of Illinois at Urbana-Champaign, 615 E. Peabody Dr., Champaign, IL 61820, USA

ARTICLE INFO

Article history:
Received 31 August 2013
Received in revised form 19 May 2014
Accepted 26 May 2014
Available online 3 June 2014

Keywords:
Ice-walled lake plain
Morphometry
Orientation
Illinois
Glacier
Quaternary

ABSTRACT

Ice-walled lake plains (IWLPs) are rounded, flat-topped mounds that formed in stagnant ice environments along the margins of the Laurentide Ice Sheet. We conducted detailed morphometric and statistical analyses of the shape, size, and orientation of more than 400 IWLPs identified from aerial photos aided with LiDAR data in DeKalb County, Illinois, USA. Lake elongation theories include extraterrestrial impact (e.g. the Carolina Bays), ice flow dynamics and crevasses, and wind induced currents that preferentially erode the shorelines perpendicular to the dominant wind direction. The results indicate that elliptical IWLPs with a perimeter greater than 3050 m have preferred orientations roughly normal to the paleo-wind direction as indicated by contemporaneous parabolic dunes located 50 km to the west. The orientations of the IWLPs with a perimeter less than 1220 m are scattered and show no apparent trend. The IWLP orientation is not related to ice flow dynamics or glacial crevasses because no statistically significant relationship exists with regard to the ice flow as proxied by the moraine direction. The orientation of large IWLPs in DeKalb County are consistent with wind-induced lake elongation observed in modern permafrost thaw lakes, suggesting that the prevailing wind also played an important role in controlling the orientation of IWLPs during the last glacial period and led to the preferred orientation we see today.

1. Introduction

Ice-walled lake plains (IWLPs) are rounded (in map view), flat-topped mounds (some with mildly depressed centers) that formed in stagnating, supraglacial environments along the margins of the Laurentide Ice Sheet during the last glaciation (Clayton and Cherry, 1967; Eyles et al., 1999; Clayton et. al. 2008; Young and Joseph, 2009). The lakes, when they were active, were surrounded by dead-ice permafrost. IWLPs formed as the bounding, dead ice melted, leaving the sediment previously at the bottom of an ice-walled lake higher than the surroundings (i.e., creating an inverse topography), often within or near hummocky terrain (Clayton et al., 2008; Fig. 1). In Illinois for example, the IWLPs are located within the same morainic system as hummocky terrain. The IWLPs vary in size (typically from 10 m to 10 km across) and relief (typically between 2 and 25 m) and occur in areas adjacent to the Great Lakes and Alberta, including the Dakotas, Minnesota, Wisconsin, and Illinois. IWLPs are most abundant atop wide recessional moraines and morainal reentrant, but also on the glacier side of the recessional moraines and near the edge of terminal moraines (Fig. 1).

Supraglacial development of the IWLPs is evidenced by the positive-relief mounds along with the rhythmically bedded lake sediment composition. In Illinois, low-relief IWLPs are composed of the following sedimentary facies, from bottom to top, including; 1) poorly sorted sand and gravel or sand, 2) rhythmically bedded silt and very-fine sand (often containing fossils of pill clams, ostracods, tundra plants, and wood fragments reworked from paleosols), 3) sand and gravel or loose, sandy diamicton, and 4) a mantle of loess (Clayton et al., 2008; Curry et al., 2011). The successions rest on diamicton which, in places, diapirically intrudes the successions (Curry and Petras, 2011) and in some extraordinary cases completely punches through the entire sedimentary section (Eyles et al., 1999; Curry, unpublished data).

In Illinois, the oldest dated IWLPs began forming on the Ransom Moraine about 22,000 cal. yr BP (calibrated years before present); the youngest IWLPs, located on the Deerfield Moraine (a Lake Border Moraine near Wadsworth, IL) began forming about 17,000 cal. yr BP, implying a period of over 5000 years to complete the IWLP formation (Fig. 2; Curry and Petras, 2011). Outside of Illinois, the youngest documented IWLPs began forming on the Algona Moraine just southwest of Minneapolis at about 14,500 cal. yr BP (Jennings et al., 2011). Younger dates are associated with IWLPs in North Dakota, but the ages are from analyses of fossils from the upper parts of the rhythmic lacustrine layers, whereas the ages from Illinois and Minnesota IWLPs are from basal stratigraphic positions, and thus provide a minimum age of

* Corresponding author. Tel.: +1 815 753 063; fax: +1 815 753 6872.
E-mail address: kallred@niu.edu (K. Allred).

http://dx.doi.org/10.1016/j.geomorph.2014.05.022
0169-555X/

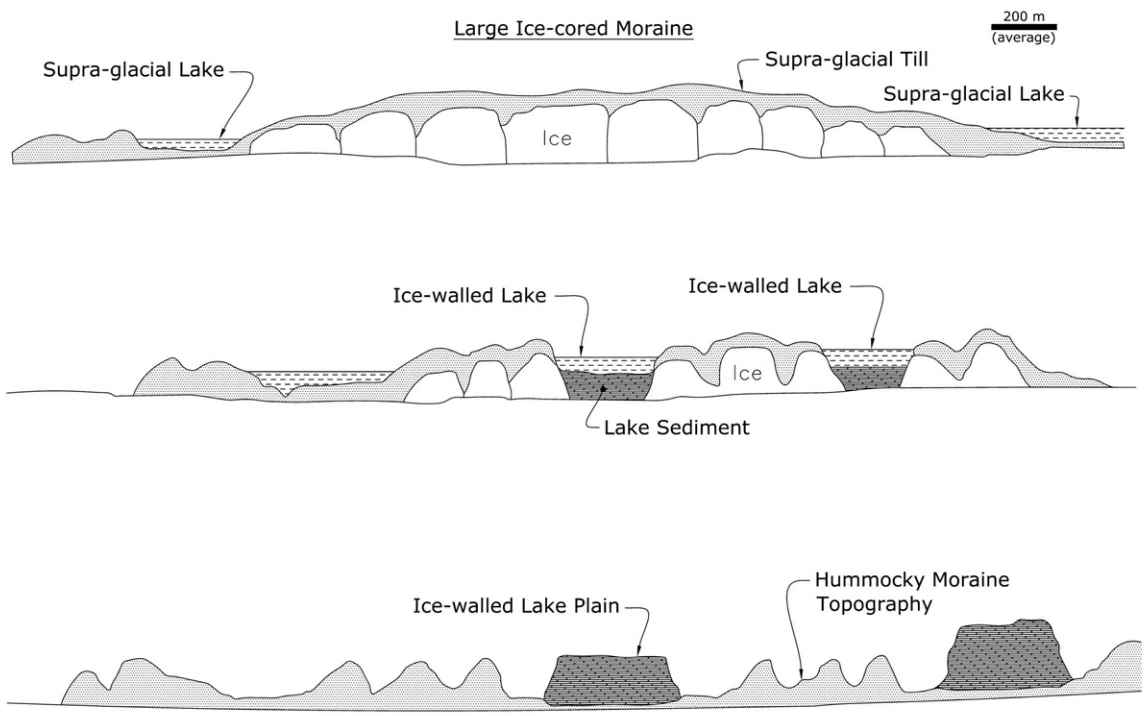

Fig. 1. IWLP formation from an ice cored moraine covered with till (top), to the formation of ice-walled lakes filled with lake sediment (middle), and IWLPs that rise above the surrounding area which are an example of inverse topography (bottom).
After Below (2006).

when the ice became stagnant. Dates obtained from artifacts at both the top and bottom of the IWLP give a range of dates for the presence of the ice, giving temporal data to glaciers in the area.

Curry et al. (2010) and Curry and Petras (2011) addressed the sediment architecture, fossil content, and age of IWLPs through soil boring analysis and classified them into three basic geometries based on their aerial shape: circular, elliptical, and complex. However, we found no literature that considered the spatial distribution and orientation of IWLPs. Cursory observation of IWLPs in the DeKalb region suggested a preferred orientation roughly normal to wind-direction as indicated by sand dunes on the Green River Lowland within Whiteside, Lee, and Rock Island counties, Illinois (Miao et al., 2010; Fig. 2). Our investigation is a morphometric exploration (shape, size, ellipticity, and orientation) of the hypothesis that prevailing wind directions account for the orientations of the long-axes of IWLPs.

The Carolina Bays are a collection of thousands of commonly oriented circular or elliptical lakes along the Atlantic seaboard of North America (Kaczorowski, 1977; Grant et al., 1998; Firestone et al., 2007; Pinter and Ishman, 2008, Firestone, 2009). One hypothesis regarding their formation is a continental-scale extraterrestrial impact event occurring over North America from which either some ejecta reached the Earth surface or a massive shockwave was sent across the continent, and created the lakes. This event is termed the Younger Dryas impact hypothesis (YDIH) because it has been attributed as the cause of the Younger Dryas cooling approximately 12,900 cal yr. BP (Firestone et al., 2007; Pinter et al., 2011). This hypothesis is highly controversial and has been the cause of much debate. Evidence in favor of the impact includes a sediment layer composed of magnetic grains and spherules, megafaunal remains, carbon remnants, increased radioactivity and several elliptical lakes throughout North America that are all approximately oriented with the Great Lakes where the proposed impact was thought to occur (Firestone, 2009). However, little evidence exists that signifies that an impact was the cause of the Carolina Bays and other oriented lakes. Very little meteoric material has been gathered from the lake rims; there is a considerable variation in the lake orientations, both locally and regionally, and the Carolina Bays did not form instantaneously, but rather over multiple periods of erosion (Pinter et al., 2011).

Other previous studies have attributed the common orientation of some modern lakes in periglacial and permafrost environments (e.g., those found in parts of Alaska and Canada) to wave action and currents created by the prevailing wind (Cooke, 1954; Livingstone, 1954; Rex, 1961; Carson and Hussey, 1962; Cote and Burn, 2002; Hinkel et al., 2005). Instead of the wave energy creating surface and rip currents which would direct energy parallel to the prevailing winds, the wave energy is split as it approaches the far shore, establishing a two-cell circulation in the lake (Fig. 3). In this scenario, maximum littoral drift is approximately 50° away from the prevailing wind direction (Rex, 1961; Cote and Burn, 2002). This mechanism preferentially erodes the shorelines perpendicular with the wind, elongating the lake in the direction normal to the prevailing wind (Fig. 3). It has been demonstrated theoretically (Livingstone, 1954), reproduced in laboratory (Kaczorowski, 1977), and supported by empirical evidence in the field in Alaska and Canada (Livingstone, 1954; Carson and Hussey, 1962). More recently, Cote and Burn (2002) measured the location and morphology of 578 lakes and basins in Canada using digital base maps. They used GIS tools to find best fit ellipses of the lakes and basins and found that their orientation was almost exactly normal to the prevailing wind direction. Hinkel et al. (2005) used image processing techniques to automatically detect 13,214 thaw lakes and 6539 drained thaw lake basin in Alaska. They concluded that the close relationship between the orientations of the thaw lakes and drained thaw lake basins may be indicative of the current and paleowind direction, respectively, although they do no attempt to interpret or derive that direction. Therefore, a part of the intent of this research is to investigate this wind driven mechanism for IWLP formation since, to the best of our knowledge, it has not been established for IWLPs formed during the last glacial period.

Evidence exists to suggest that during the end of the Quaternary period, sand dunes were mobilized across the northern Midwest states and their formation was influenced by the prevailing winds of the period (Arbogast and Packman, 2004; Rawling III et al., 2008). Miao