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Lacustrine sediments in Porter Cave, Central Indiana, USA and possible relation to Laurentide ice sheet marginal positions in the middle and late Wisconsinan

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ABSTRACT

Proglacial lakes formed in the late Quaternary with the advance of the Laurentide ice sheet into Mill Creek Valley of central Indiana. These lakes backfilled into the mouth of Porter Cave deposited organic matter and thinly bedded silty sediment that conforms to the underlying cave floor and shelves. Optical and radiocarbon ages indicate that deposition of fine-grained sediments into Porter Cave occurred in two proglacial lake phases during marine oxygen isotope stage (MIS) 3 (ca. 40 to 30 cal. ka) and MIS 2 (ca. 27 to 18 cal. ka), the latter phase is consistent with other proxy evidence for ice sheet extent and timing. We contend that the ice sheet lobe that dammed a proglacial lake during MIS 3 in central Indiana was ~7 km behind the Last Glacial Maximum limit based on current topography. This conclusion is in opposition to previous assessments which infer ice free conditions in central Illinois and central Indiana ca. 130 to 25 ka. The paucity of MIS 3 deposits may be due to erosion by the more extensive MIS 2 ice sheet, with glacial-lacustrine sediments preserved in the protective confines of Porter Cave. This outlet lobe in central Indiana may be short lived and reflects a variable response of lobes of the Laurentide ice sheet during MIS 3, with expansion possibly associated with cooling during Heinrich event 4.

1. Introduction

The Laurentide ice sheet (LIS) is a major driver of late Quaternary sea level (e.g. Dyke et al., 2002; Marshall et al., 2002). Geophysical modeling indicates that the expansion of LIS in North America accounts for 60 to 50% (Dyke et al., 2002; Peltier, 2004; Winograd, 2001) of the approximately 130 m sea level depression during the Last Glacial Maximum (Lambeck, 2004; Peltier and Fairbanks, 2006). Marine geologic evidence, particularly Heinrich events (Jullien et al., 2006; Kirby and Andrews, 1999), indicate the presence of the LIS over parts of North America during marine oxygen isotope stage (MIS) 3 (ca. 59 to 30 ka), with global sea level at −60 to −90 m (Siddall et al., 2008). An unknown number of outlets of the LIS are inferred to have advanced just beyond the Great Lakes catchment in MIS 3, because of the occurrence of the eolian-derived Roxana Silt in mid-continental North America, sourced from glaciofluvial surfaces within the Mississippi and Missouri River valleys ca. 55 to 30 ka (Bettis et al., 2003; Follmer, 1996; Forman and Pierson, 2002; Leigh, 1994; Rittenour et al., 2007; Winters et al., 1988). The presence of the LIS in the Mississippi River catchment is also indicated by a succession of meltwater spikes in the Gulf of Mexico ca. 55 to 30 ka (Tripsanas et al., 2007). The extent of the Laurentide ice sheet associated with MIS 3 meltwater input is largely unknown.

A "Younger Dryas" like configuration for the LIS (40 to 50 m sea level equivalent; Peltier, 2004) during MIS 3 is inferred because this configuration represents the minimum extent that would route meltwater into the Gulf of Mexico (Clark et al., 1993; Dyke et al., 2002; Mickelson and Colgan, 2003). This ice sheet would be confined mostly to the Great Lakes Basin. Large areas of the upper Midwest, like the lower peninsula of Michigan are inferred to be ice free and to be covered by a boreal forest ca. 46 to 35 cal. ka, based on radiocarbon dating of organic matter beneath Late Wisconsinan tills (e.g. Rieck et al., 1991; Schaetzl and Forman, 2008; Winters et al., 1988). Uncertainty remains if this organic matter yielded truly finite estimates particularly for ^{14}C ages >40 ka providing an equivocal assessment of the timing of ice free conditions in MIS 3. Ice free conditions are also inferred for northern Illinois ca. 155 to 25 ka, with a contracted Lake Michigan lobe deduced from pedogenic morphologies and ^{10}Be inventory ages of a contiguous stratigraphic succession including the Sangamon Geosol, the Farmdale Geosol and late Wisconsinan deposits (Curry and Pavich, 1996; Jacobs et al., 2009). Ice free conditions are also inferred for the middle and early Wisconsinan in southeast Indiana and southwest Ohio based on amino acid epimerizaton ratios on gastropods from organic silts intercalated with tills (Miller et al., 1992). In contrast, the LIS margin was grounded along Lake Ontario's northern shore during MIS 3 inferred from a glacial-lacustrine sedimentary sequence and

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associated ^{14}C and thermoluminescence ages (Berger and Eyles, 1994; Eyles et al., 2005). However, this outlet of the LIS may have advanced >30 km south of the Lake Ontario basin ca. 37 cal. ka, possibly coincident with Heinrich event 4 indicated by radiocarbon ages on in situ and reworked organic matter from glacial-lacustrine sediments and diamictons (Young and Burr, 2006). This variable record of ice position around the Lake Ontario basin may indicate a dynamic glaciological response of outlet lobes of the LIS to internal mechanical (Hooyer and Iverson, 2002) and external climate forcing (Lowell et al., 1999). This study presents evidence for the expansion of the LIS beyond the Great Lakes basin during MIS 2 and 3 into central Indiana forming a proglacial lake. This MIS 3 ice sheet is hypothesized to have advanced and retreated with variations in solar insolation and North Atlantic climate oscillations and to have a configuration at times closer to the MIS 2 extent than previously inferred (Clark et al., 1993; Dyke et al., 2002).

2. Proglacial lakes in central Indiana

The Laurentide ice sheet frequently pooled meltwater and diverted drainages forming proglacial lakes along the margin (cf. Teller, 1995). The focus of this study is the Mill Creek Valley of central Indiana (Fig. 1), which sits astride the mapped Late Wisconsinan margin and hosted proglacial lakes multiple times during the late Quaternary (Autio, 1990; Thornbury, 1940; Wood et al., 2010). These proglacial lakes formed when the ice margin dammed the east flowing Mill Creek to impound water against Devore Ridge to the south (Fig. 1). This east–west trending ridge is a prominent karst upland with associated caves, and is incised by numerous former proglacial lake outlets, now in the form of steep-walled valleys and underfit streams with mid-valley waterfalls (Addington, 1926; Thornbury, 1950; Wood et al., 2010). These outlets drained proglacial lakes that formed at least in the past ca. 135 ka (Wood et al., 2010). Steep down valley

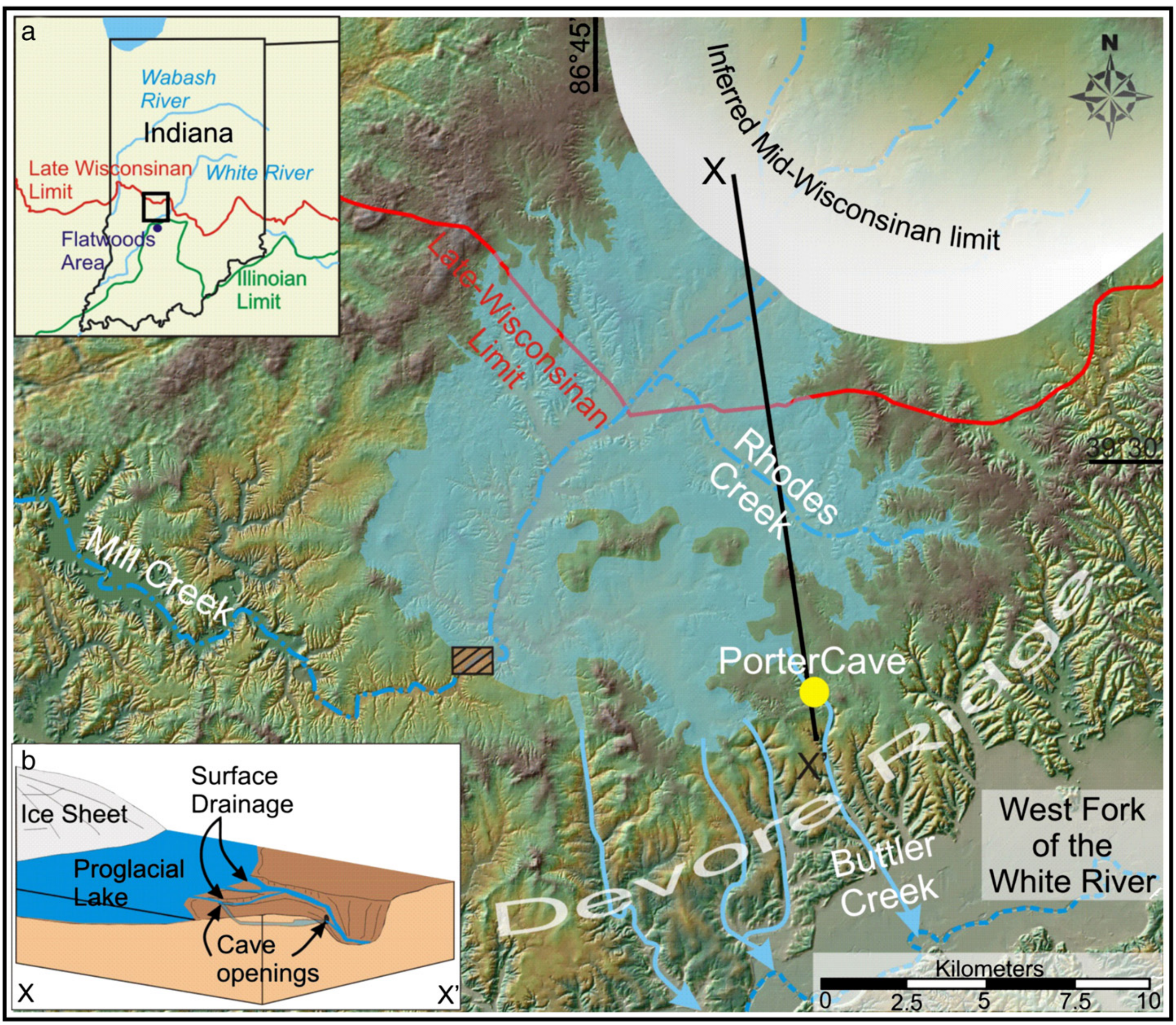

Fig. 1. A middle Wisconsinan proglacial lake, ca. 40 to 30 ka and associated ice sheet advance into the Mill Creek Valley. Shown is the minimum ice margin configuration to impound meltwater between the ice sheet and inferred pre-Wisconsinan glaciogenic valley fill based on current topography (brown hashed area). The Late Wisconsinan proglacial Lake Alaska may have had a similar configuration to the middle Wisconsinan proglacial lake, but is associated with the Last Glacial Maximum ice margin position near Rhodes Creek (Autio, 1990). a: Location of study area in the Midwest (black box). b: Diagrammatic cross-section (X–X′) showing relation between Porter Cave openings, proglacial lake, and ice sheet margin.