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Accumulation rates, focusing factors, and chronologies from depth profiles of ^{210}Pb and ^{137}Cs in sediments of the Laurentian Great Lakes

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ABSTRACT

Sediment cores from 41 sites were collected from the Laurentian Great Lakes during 2010–2014, sectioned into 0.5–2.0 cm intervals, and the activities of ^{210}Pb, ^{137}Cs, and ^{226}Ra were measured in the upper 25 to 40 cm of the sediment column by gamma spectrometry. Sediment mass accumulation rates (dry mass) calculated from ^{210}Pb profiles range from 0.006 ± 0.001 to 0.59 ± 0.06 g cm^{-2} yr^{-1} and are similar to those reported in previous Great Lakes sediment studies. Sediment mass accumulation rates decreased with increasing water depth. ^{210}Pb-based models in cores exhibiting favorable characteristics (i.e., those having the highest unsupported-^{210}Pb activity at the sediment-water interface, exponential decrease of unsupported-^{210}Pb with increasing depth in sediment cores, and a clear peak in ^{137}Cs activity at some depth below the sediment-water interface) give calendar date profiles that are largely concordant with the maximum ^{137}Cs peak activity at 1963. Sediment focusing factors derived from unsupported-^{210}Pb inventories range from 0.09 to >5.34, and are well correlated with those derived from ^{137}Cs inventories that range from 0.07 to 4.04, demonstrating the ubiquitous occurrence of horizontal sediment transport processes within the lakes. This more recent survey provides a Great Lakes-wide chronological framework for comparing the depositional histories and inventories of a wide variety of persistent, bioaccumulative and toxic pollutants that have been measured in the same sediment cores. This information will be useful for resolving scientific and practical issues pertaining to the environmental quality and management of contaminated sediments in the Laurentian Great Lakes ecosystem.

Introduction

Sediments in large lakes are repositories of environmental change and can provide chronological records of loadings for various substances that enter the lakes from atmospheric deposition and riverine input (Astle et al., 1987; Carroll et al., 1999; Colman et al., 2002; Johnson, 1984; Tylmann et al., 2016). For the Laurentian Great Lakes of North America, such records are of particular interest when studying pollutant loadings over the past ~150 years, as this period includes the maximum human population growth and industrial activity in the region. Population and industrial activity are heterogeneously distributed in the region, with major population centers in southwestern Lake Michigan (Chicago-Milwaukee), western Lake Erie (Detroit-Toledo), and western Lake Ontario (Toronto-Hamilton).

Watersheds of the Laurentian Great Lakes were sculpted by repeated glaciations of bedrock and sediment, which deposited glacial moraines at the limits of the oscillating ice sheet, along with other glacial landforms in the southern portions of the lakes and surrounding landscapes (Soller and Garrity, 2018). The lake shores consist of a mixture of bedrock cliffs, bluffs cut into glacial sediments, lacustrine plains and beach ridges, and sandy beaches with large dunes (Chrzastowski and Thompson, 1994; Johnston et al., 2012; Johnston et al., 2014; Karrow and Calkin, 1985; Kincare and Larson, 2009; Larson and Schaetzl, 2001; Loope and Arbogast, 2000). Sources of sediment to the lakes include aerosol input, riverine input, bluff erosion and lake bottom erosion, as well as biogenic particulates including silica, carbonates, and organic matter formed within the lakes (Eadie et al., 2008). Variations in bathymetry, water currents, and sediment supplies generally result in inhomogeneous sedimentation patterns within the Great Lakes (Bell and Eadie, 1983; Cahill, 1981; Eadie et al., 1990; Eadie et al.,

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2008; Edgington and Robbins, 1990; Plattner et al., 2006; Waples et al., 2005). Some locations within the lakes might have nearly continuous deposition, whereas others are almost completely non-depositional. Post-depositional events that can alter the chronological record include sediment disturbances caused by large storms, sediment slumps, wind- and thermally-driven currents, bioturbation, and anthropogenic activity such as dredging (Hermanson and Christensen, 1991; Robbins, 1978; Robbins, 1982; Robbins et al., 1978; White and Miller, 2008).

For determining rates of sediment mass accumulation in lakes, previous studies have employed methods based on measurements of ^{210}Pb, a radioactive decay product in the ^{238}U decay chain having a half-life ($t_{½}$) of 22.2 years (Goldberg, 1963; Krishnaswami et al., 1971; Robbins, 1978; Appleby and Oldfield, 1978). Determination of recent (<150 y) sediment mass accumulation rates commonly involves simple models that are based on either of two fundamental assumptions about accumulation of ^{210}Pb in sediments: (1) the constant initial concentration (CIC) model, which assumes that the initial ^{210}Pb concentration in the deposited sediment is a constant, regardless of changes in the sediment accumulation rate; and (2) the constant rate of supply (CRS) model, which assumes that the flux of ^{210}Pb to the accumulating sediment is constant when averaged over a timescale of 100–200 years (Robbins and Edgington, 1975). Assumptions and limitations of ^{210}Pb-based sedimentation models are discussed elsewhere (Robbins and Herche, 1993; Smith, 2001; Kirchner, 2011; Mackenzie et al., 2011). The sediment focusing factor (FF) measures sediment redistribution caused by horizontal movement of sediment particles on the lake bottom due to wind- and thermally-induced water currents, downslope creep, and other causes (Edgington and Robbins, 1990). It is an important parameter for calculating the fluxes of direct deposition of pollutants from the water column to sediment at specified locations. It is generally assumed that the pollutants of interest are sorbed to sediment particles in a way that is analogous to the sorption of ^{210}Pb and ^{137}Cs.

This work is part of the Great Lakes Sediment Surveillance Program (GLSSP), which examined depositional histories and inventories of persistent, bioaccumulative and toxic pollutants in sediments. The radionuclide profiles measured in this work provided sediment mass accumulation rates and focusing factors to allow reconstruction of the temporal trends of pollutants deposited and sequestered in the Laurentian Great Lakes sediments. Companion papers in this issue (Bonina et al., 2018, this issue; Li et al., 2018, this issue) and a number of papers published elsewhere (e.g., Codling et al., 2014, 2018a, 2018b; Guo et al., 2017; Peng et al., 2016) have used the data from this study to establish depositional histories of anthropogenic pollutants, and to distinguish natural from anthropogenic sources of halogenated organics. The principal objectives of this paper are to report the data of measured activities for radionuclides, to examine the spatial patterns of sediment mass accumulation rates and focusing factors, and to explore synoptic relationships of the key measured and derived variables. The data set presented here provides a new baseline for future studies of sedimentation in the Laurentian Great Lakes.

Methods

Sample collection and preparation

A total of 41 sediment cores were collected in 2010–2014 from the five Laurentian Great Lakes aboard the EPA research vessel *R.V. Lake Guardian*. Coring locations (Fig. 1) were selected from open-lake stations used for regular EPA water-quality monitoring surveys, at sites considered likely to have experienced continuous sediment accumulation based on available information from previous studies. A box-corer and an Ekman-corer were used initially during sampling on Lake Michigan in 2010. The collecting area of the box-corer was 30 cm × 30 cm, with a maximum depth of 90 cm. Four polycarbonate core tubes (10 cm o.d., 9.5 cm i.d. and 59.6 cm long) were carefully inserted into the sediment collected in the box. The tubes were capped on top, and a polyethylene puck with two o-ring seals was inserted into the bottom opening of each tube. The tubes were pulled upwards from the bottom with a custom-made L-shaped metal puller. During sampling of Lakes Michigan, Superior, Huron, Erie, and Ontario in 2011–2014, a multi-corer MC400 (Ocean Instrument, San Diego, CA) was used to collect four subcores in each deployment. The individual core tubes were

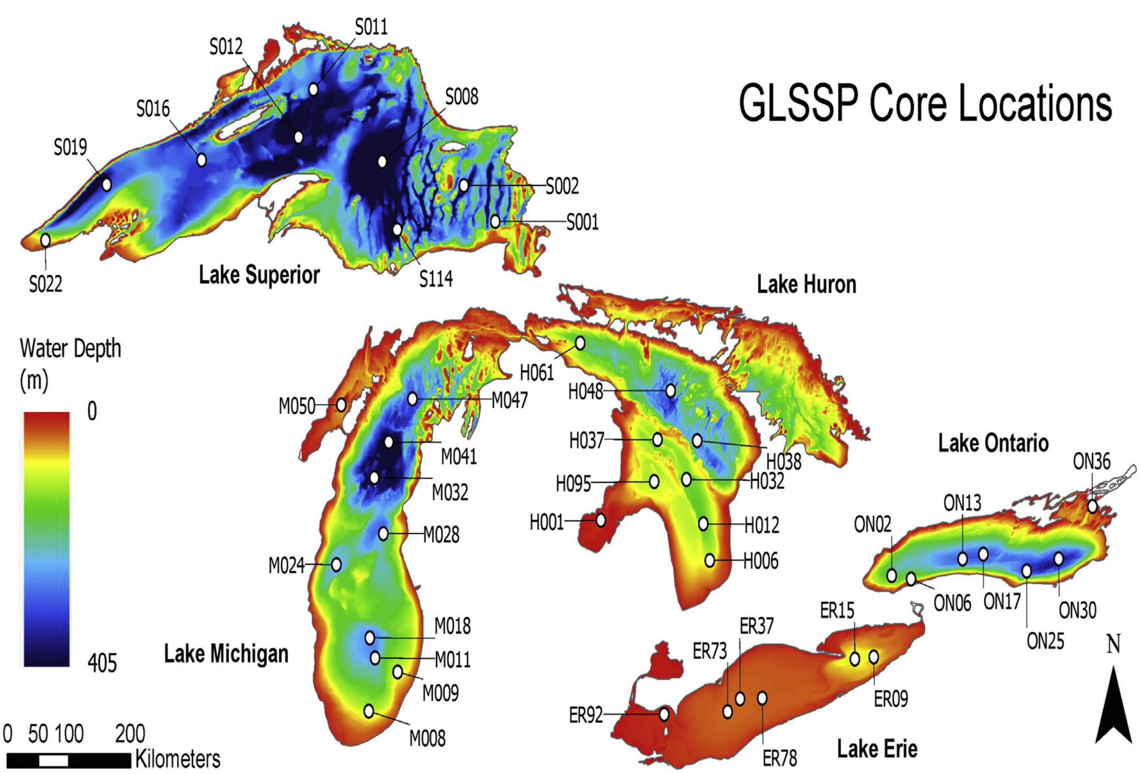

Fig. 1. Core locations and bathymetry of the Great Lakes (NOAA, 2018).