Marine Geology 383 (2017) 1–13

Contents lists available at ScienceDirect

Marine Geology

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

Deposition rates and ^{14}C apparent ages of Holocene sediments in the Bothnian Bay of the Gulf of Bothnia using paleomagnetic dating as a reference

Thongchai Suteerasak [a,b], Sten-Åke Elming [a,*], Göran Possnert [c], Johan Ingri [d], Anders Widerlund [d]

[a] Division of Applied Geophysics, Luleå University of Technology, S-97187 Luleå, Sweden
[b] Faculty of Technology and Environment, Prince of Songkla University, 83120 Kathoo, Phuket,Thailand
[c] Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden
[d] Division of Applied Geology, Luleå University of Technology, S-97187 Luleå, Sweden

ARTICLE INFO

Article history:
Received 25 November 2015
Received in revised form 18 October 2016
Accepted 19 October 2016
Available online 12 November 2016

Keywords:
Bothnian Bay
Holocene sediments
Paleomagnetism
^{14}C dating
Deposition rate
Radiocarbon age offset

ABSTRACT

Three 6-m-long cores of sediments were collected in the northern, middle and southern part of the Bothnian Bay. The sediments were dated by paleomagnetic dating techniques, constrained by magnetic properties and geochemical data. The results indicate the ages of the sediments in the bottom part of the cores in the northern, middle and southern parts of the Bothnian Bay to be approximately 5300 years BP, 5350 years BP and 3500 years BP, respectively. The deposition rate calculated from the estimated ages at various depths show that the deposition rate was generally in the range 0.5–1.5 mm/year but it was higher in the southern part than in the middle and northern parts of the bay. There was a significant increase in the deposition rate at ca 2200 years BP, recorded in all three cores, a rate varying between 2.47 and 3.07 mm/year and lasting until ca 1840 years BP. A proposed constant uplift rate of the crust during the period ca 5500 years BP to present is thus not reflected by a constant deposition rate. The peaks in deposition rates at ca 2200–1840 years BP were followed by a decrease in salinity. This phenomenon is suggested to be caused by crustal uplift, with a threshold being formed in the southern part of the bay, thereby increasing the reactivation of bottom sediments and reducing the inflow of brackish water from the Bothnian Sea. The ^{14}C ages of the sediments reveal differences in age compared with the paleomagnetic ages. In the southern core, the ^{14}C ages are ca 1350 years older, and in the north, the age offset is mixed. The reactivation and re-deposition of sediments is argued to be the reason for the apparent ^{14}C age differences. This finding demonstrates that ^{14}C cannot be used for the dating of Bothnian Bay sediments unless the radiocarbon age offset has been determined.

1. Introduction

The Gulf of Bothnia, located north of the Baltic Proper, consists of two basins, the Bothnian Sea and the Bothnian Bay, divided by a sill at the North Kvark (Fig. 1). The area of the Bothnian Bay is 36,300 km^2 with a volume of water of ca 36,800 km^3. The catchment area is approximately 280,100 km^2, and there are eleven large rivers running through it. Altogether, the rivers bring approximately 115 km^3 per year into the shallow sea, and the salinity in the Bothnian Bay varies between 4‰ (in the south) to 2‰ (in the north) (Laine and Kronholm, 2005). The catchment area is dominated by metasediments, granite, granodiorite, gabbro and greenstone of Early-Middle Proterozoic age, covered by glacial deposits from the latest glaciation.

During the last glacial period, which ended ca 11,500 years ago, large ice sheets covered the northern hemisphere. This additional load depressed the Earth's surface by several hundreds of meters, and the formerly glaciated land areas are therefore now uplifted.

The isostatic rebound in Fennoscandia has its center located in the Bothnian Bay with an uplift rate of approximately 8 mm per year during the last ca 5000 years (Lidberg et al., 2007).

The salinity of the water in the Bothnia Bay is suggested to have increased by the intrusion of brackish water from the northern Baltic Proper, with the highest salinity being observed during ca 6000 to 5000 years BP (e.g., Gustafsson and Westman, 2002). This peak in salinity is related to the higher relative sea level at the start of the Littorina phase (e.g. Björk, 1995) with various sills at deeper depth allowing water from the North Sea to enter further north in the Baltic Sea. This was followed by a decrease in salinity (from ca 8 to 3 psu, 1 psu = 1 g/kg, Unesco, 1985) from ca 3000 years BP to the present (Widerlund and Andersson, 2011). The increasing global temperature will increase the freshwater input to marginal marine basins. This suggests that the sedimentary record of the Bothnian Bay may be useful to predict future salinity-related environmental changes in other parts

* Corresponding author.
E-mail address: sten-ake.elming@ltu.se (S.-Å. Elming).

http://dx.doi.org/10.1016/j.margeo.2016.10.009
0025-3227/

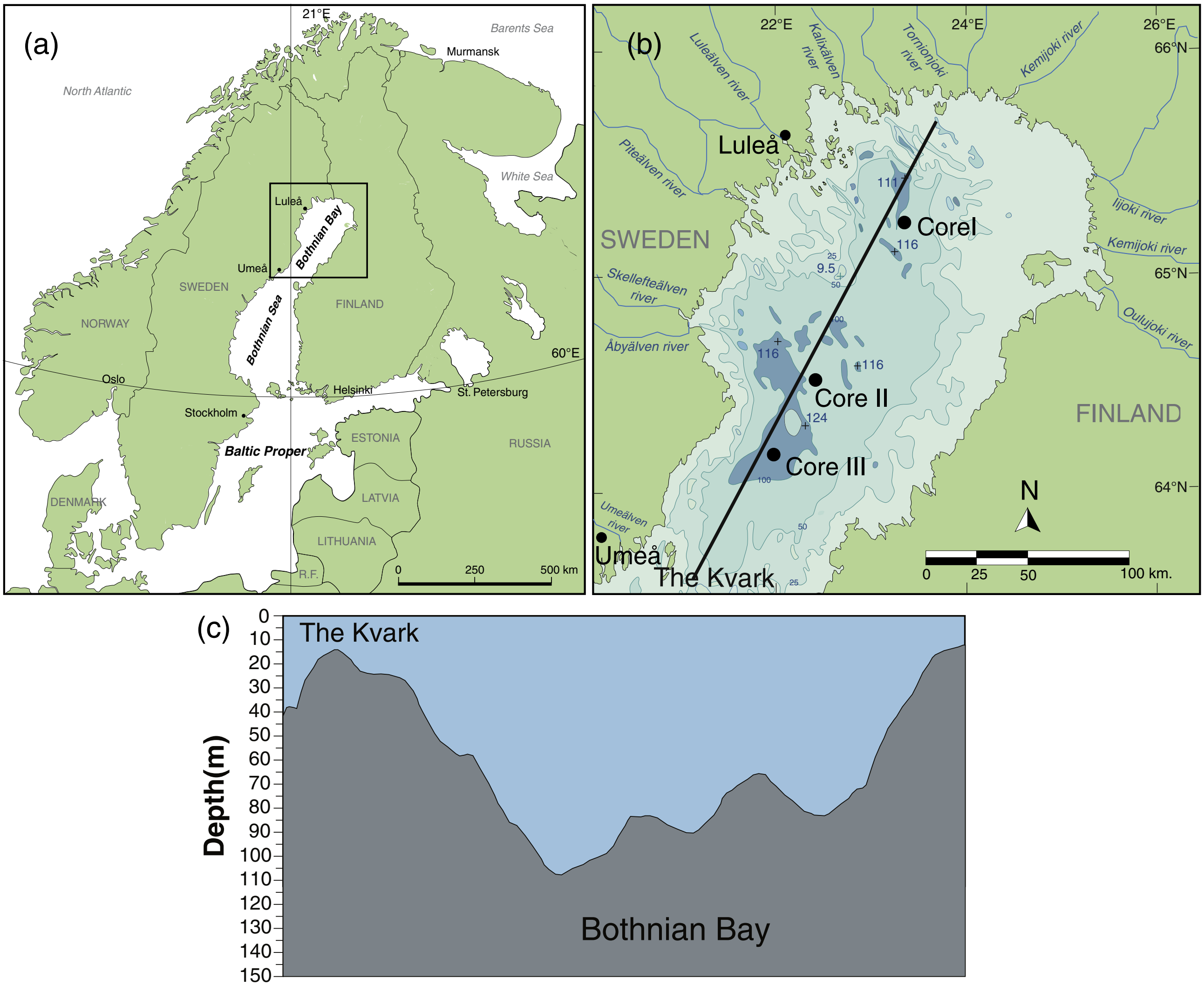

Fig. 1. (A) Location of the study area and (B) the locations of the three cores of sediment collected in the Bothnian Bay. The sill at the Kvark (B), separating the Bothnian Sea from the Bothnian Bay, is shown in the bottom topography along the profile (C).

of the Baltic Sea (and other coastal areas). To read this environmental record, accurate time-depth relationships for the sediments and thus also the deposition rates are necessary to be determined.

The potential of using the paleosecular variation record for the dating of lake and sea sediments has been demonstrated in a number of studies from other parts of the world (e.g., St-Onge et al., 2003; Lund et al., 2006; Yang et al., 2009; Gogorza et al., 2012). The secular variation (SV) of the Earth's non-dipole field originates in the outer core of the Earth, and the time scale of changes ranges from several years to 10,000 years. Using paleomagnetic analyses, the directions of the Earth magnetic field at the time of deposition of sediments can be determined. By comparing the reconstructed record of the paleosecular variation (PSV) in the cores with master curves, the sediments can be dated. The PSV master curves are based on radiometric ^{14}C age determinations (e.g., Thompson and Turner, 1979) or varve chronological analyses (e.g., Ojala and Tiljander, 2003). However, the accuracy of the ages obtained from ^{14}C dating may be hampered by low organic carbon content and contamination by re-suspended older organic carbon (Kotilainen et al., 2000; Ojala and Tiljander, 2003; Snowball et al., 2007; Zillén et al., 2008). For northern Europe, Saarinen (1999) and Snowball and Sandgren (2002) constructed varve and paleomagnetic chronologies from five lakes in Finland and two lakes in northern Sweden, respectively. The work on PSV master curves in northern Europe was extended by, e.g., Ojala and Tiljander (2003), who used paleomagnetic records and varve chronology to construct an independent and continuous 10,000-year long chronological timescale and PSV record for Finland. Following that, Snowball et al. (2007) presented a PSV master curve, FENNOSTACK, based on varve chronologies from seven lake sediment sequences in Sweden and Finland, supported by radiocarbon dating and tephrochronology. This master curve shows smoothed inclination and declination patterns of paleomagnetic data back to ca. 10,200 years BP.

Radiocarbon (^{14}C) dating is the most common method for the determination of ages of sediments <50.000 years old. The dating technique has been greatly improved by dendrochronology-based calibration curves (e.g., Reimer et al., 2004, 2009, 2013), by which the ^{14}C ages may be converted to calibrated ages. ^{14}C is produced in the upper atmosphere. It rapidly oxidizes to $^{14}CO_2$ and mixes in the atmosphere (Damon et al., 1978), which means that terrestrial macrofossils can be accurately dated. In the oceans, $^{14}CO_2$ is absorbed and dissolves to form $H_2^{14}CO_3$. The long residence time of carbon in the oceans may result in marine macrofossils with apparently older ages. The ^{14}C-marine age-difference, when compared with the calibration curves for a specific calendar age, is known as the reservoir age. The knowledge of local reservoir ages is important when constructing ^{14}C geochronologies. Reservoir ages have been estimated for the Baltic Sea (e.g., Lougheed et al., 2013), for which effects from limestone stable radiocarbon isotope dilution of the ^{14}C signal, ^{14}C-marine and ^{14}C-runoff have been analysed.