Quaternary Science Reviews 126 (2015) 26–40

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Near-field sea-level variability in northwest Europe and ice sheet stability during the last interglacial

A.J. Long [a,*], N.L.M. Barlow [a], F.S. Busschers [b], K.M. Cohen [c], W.R. Gehrels [d], L.M. Wake [e]

[a] Department of Geography, Durham University, Lower Mountjoy, Durham DH1 3LE UK
[b] TNO, Geological Survey of the Netherlands, Princetonlaan 6, P.O. Box 80015, 3508 TA Utrecht, The Netherlands
[c] Department of Physical Geography, Faculty of Geosciences, Utrecht University, POBOX 800.115, 3508 TC Utrecht, The Netherlands
[d] Environment Department, University of York, Heslington, York YO10 5DD, UK
[e] Department of Geography, University of Northumbria, Ellison Place, Newcastle upon Tyne NE1 8ST UK

ARTICLE INFO

Article history:
Received 13 May 2015
Received in revised form
13 August 2015
Accepted 19 August 2015
Available online 2 September 2015

Keywords:
Sea level
Interglacial
Ice-sheet collapse
Eemian
MIS 5e
Glacio-isostatic adjustment

ABSTRACT

Global sea level during the Last Interglacial (LIG, Marine Isotope Sub-stage 5e) peaked between c. 5.5 and 9 m above present, implying significant melt from Greenland and Antarctica. Relative sea level (RSL) observations from several far- and intermediate-field sites suggest abrupt fluctuations or jumps in RSL during the LIG highstand that require one or more episodes of ice-sheet collapse and regrowth. Such events should be manifest as unique sea-level fingerprints, recorded in far-, intermediate- and near-field sites depending on the source(s) of ice-mass change involved. To date, though, no coherent evidence of such fluctuations has been reported from near-field RSL studies in northwest Europe. This is an important problem because RSL fluctuations during the LIG are portrayed as warning signs for how polar ice sheets may behave in a future, warmer than present, world. Here we review the evidence for RSL change during the LIG using stratigraphic data from the best resolved highstand records that exist in the near-field of northwest Europe, from a range of settings that include lagoonal, shallow marine, tidal flat, salt marsh and brackish-water fluviatile environments. Consideration of previously published stratigraphic records from two sites in the Eemian coastal-marine embayment that existed in the central Netherlands, yields no clear indications for abrupt RSL change during the attainment of the near-field highstand. Nor do we find any such indications common to other records from countries bordering the North Sea, the Baltic Sea and the White Sea. Two modelling experiments that explore the global signal of hypothetical sea-level oscillations caused by partial collapse and regrowth of either the Greenland or Antarctic LIG ice-sheet, show that the North Sea region is relatively insensitive to mass changes sourced from Greenland but should clearly register events with an Antarctic origin, especially those that occur late in the LIG. The lack of evidence for abrupt sea-level fluctuations at this time in northwest Europe concurs with a lack of clear near-field evidence for ice sheet collapse.

1. Introduction

Several studies, mainly from low latitude sites suggest that polar ice-sheet collapse late in the Last Interglacial caused an already high sea level to jump abruptly by a further 2–6 m (e.g. Chappell, 1974; Bloom et al., 1974; Stein et al., 1993; Stirling et al., 1998; Thompson and Goldstein, 2005; Hearty et al., 2007; Rohling et al., 2008; Blanchon et al., 2009; O'Leary et al., 2013; Dabrio et al., 2013). Although not all studies document such variability (e.g. Muhs et al., 2002, 2011), reports of multi-meter scale sea-level jumps raise concern regarding the potential instability of polar ice sheets in what remains of the current interglacial. Such a collapse would have generated a distinctive geometry, or fingerprint, of global sea-level rise that palaeo sea-level studies can aim to detect (e.g. Mitrovica et al., 2001; Hay et al., 2014). However, no conclusive evidence for such a jump has been reported in relative sea-level (RSL) or ice-sheet records from higher latitude settings (e.g. Zagwijn, 1983; Funder et al., 2002; Lambeck et al., 2006) and,

* Corresponding author.
E-mail addresses: a.j.long@durham.ac.uk (A.J. Long), n.l.m.barlow@durham.ac.uk (N.L.M. Barlow), freek.busschers@tno.nl (F.S. Busschers), K.M.Cohen@uu.nl (K.M. Cohen), roland.gehrels@york.ac.uk (W.R. Gehrels), leanne.wake@northumbria.ac.uk (L.M. Wake).

http://dx.doi.org/10.1016/j.quascirev.2015.08.021
0277-3791/

as a result, the global fingerprint of this event is not known. This has led to uncertainty as to whether the jump is indeed global in nature – i.e. triggered by polar ice-sheet collapse - or simply the product of regional (e.g. climate) or local (e.g. tectonic) processes.

The aim of this paper is to review the European near-field evidence for abrupt relative sea-level (RSL) change during the LIG highstand (as defined and dated in the far-field) by scrutinising previously published records from northwest Europe, where the LIG is known as the 'Eemian'. We start by reviewing RSL evidence from sites located distant to the MIS 6 ice sheets, to identify key features that characterise many of these studies. Next, we consider how such abrupt oscillations might be preserved in the near-field stratigraphic record, drawing in part on sedimentary principles that have been established from working on equivalent Holocene sequences (e.g. Vis et al., 2015). We focus on evidence from the coastal deposits preserved in the Amsterdam and Amersfoort glacial basins (central Netherlands), which have a superbly preserved depositional record of the LIG transgression and RSL highstand. The region is the bio- and chronostratigraphical type region of the 'Eemian' (Harting, 1874, 1875; Zagwijn, 1961; Turner, 2002) and data from here, as well as from other sites in the Netherlands, are critical for constraining the LIG RSL highstand in northwest Europe (e.g. Zagwijn, 1983, 1996; Streif, 1990).

We find no compelling signs of abrupt RSL oscillations during the near-field highstand in the coastal deposits of the Netherlands, or from elsewhere in northwest Europe. We note, however, that due to solid earth deformation and equatorial syphoning, the attainment of this highstand may be several thousand years later to that observed in far- and intermediate-field sites, meaning that if fluctuations occurred early in the interglacial, these could have happened before the near-field highstand was attained. The lack of evidence for abrupt sea-level fluctuations during the latter part of the LIG in northwest Europe concurs with a lack of clear near-field evidence for ice-sheet collapse at this time.

2. Sea-level changes during the last interglacial

Evidence for higher-than-present sea level during the LIG is recorded in emergent landforms and sediments that include coral reef tracts, bioerosional notches as well as nearshore deposits (e.g. Szabo et al., 1994; Stirling et al., 1998; Muhs et al., 2002; Bruggermann et al., 2004; Hearty et al., 2007; Rohling et al., 2008; Thompson et al., 2011; O'Leary et al., 2013; Dutton et al., 2015). Consideration of RSL records selected from different parts of the world exemplify elements of LIG sea-level behaviour that are common to many far- and intermediate-field RSL records that record sea-level oscillations within the LIG highstand (Fig. 1).

From the Seychelles, Dutton et al. (2015) report evidence from raised coral deposits of an early "rapid collapse" of a polar ice sheet, likely part of Antarctica, by 128.6 ± 0.8 k yr ago that pushed sea level to at least +5.9 ± 1.7 m above present (Fig. 1A). This was followed by a slower rise of a further c. 2 m, at a rate of c. 0.22 ± 0.04 m/k yr that is attributed to partial melt of the Greenland Ice Sheet, thermal expansion and the loss of mountain glaciers. Peak eustatic sea level of c. 7.6 ± 1.7 m was reached at c. 125 k yr ago, after which sea level fell and the Seychelles RSL record ends.

Our second example is based on the calibration to sea level of a stable oxygen isotope record of sea surface temperatures obtained from planktonic foraminifera extracted from core KL11, located in the central part of the Red Sea (Rohling et al., 2008) (Fig. 1B). The record contains two main and one subsidiary sea-level fluctuation of 4–10 m. Sedimentological observations from adjacent Red Sea coastlines are cited by Rohling et al. (2008) as supporting evidence of a fluctuating RSL during the LIG highstand (e.g. Orszag-Sperber et al., 2001; Bruggermann et al., 2004).

The next two examples document sea-level changes from the middle and towards the end of the LIG. From the Yucatán Peninsula (Mexico), an intermediate-field location relative to the former Laurentide Ice Sheet, Blanchon et al. (2009) identify a 2–3 m RSL jump that they attribute to a short-lived (c. 1500 yr) interval of ice-sheet instability that is 'tentatively' dated to c. 121 k yr ago (Fig. 1C). The evidence for this sea-level jump is the sudden demise of an outer lower reef (developed to a sea-level at +3 m) that coincided with backstepping and accretion of an inner patch-reef (to a c. 3 m elevation; see also Blanchon, 2010). Finally, in far-field western Australia, O'Leary et al. (2013; see also O'Leary et al., 2008) use stratigraphic and geomorphic mapping with U-series dating of fossil coral reefs to identify two architecturally distinct LIG highstand units that are separated by an unconformity contact and a palaeosol. These coral reef units are interpreted as indicating two phases to the LIG highstand; the former developing over the period 127 to 119 k yr ago under slow 3 m RSL fall from an initial highstand, and the second unit deposited late in the interglacial, dated to 118.1 ± 1.4 k yr ago. The two units are observed at c. 2.5 m and c. 5–6 m above present MSL. O'Leary et al. (2013) include a glacial isostatic adjustment (GIA) modelling analysis as part of their study and propose a broadly stable "eustatic" sea level (i.e. ice-volume equivalent) of c. +3–4 m between 127 and 119 k yr ago and one at +9 m for c. 118 k yr ago, implying a c. 5 m sea-level jump late in MIS 5e (Fig. 1E). Although the tectonic stability of the region has been challenged (Whitney and Hengesh, 2015), the sea-level jump component has not.

From these studies we identify the following as important elements of sea-level change during the LIG highstand:

1. LIG sea-level oscillations are recorded at the start, during the middle and towards the end of the LIG highstand, and are often interpreted as evidence for polar ice-sheet collapse. The North American (Laurentide) and European ice masses are typically assumed to have only contributed to RSL rise early in MIS 5e (up to 127 k yr ago: Rohling et al., 2008; O'Leary et al., 2013). Chronological differences reflect, in part, the duration of the different records and the interval of time when sea level was higher than present, which is when sedimentary records are preserved. Several far-field sites record unconformities and palaeosols within double-reef architectures, from which meter-scale RSL oscillations are reconstructed. In the intermediate-field, younger reef elements bury older elements and a marked sea-level jump is inferred against a broadly stable background RSL trend.
2. It is claimed by some studies that there was at least one interval during the main LIG highstand when RSL fell and then rose, possibly abruptly, to re-attain a LIG highstand, several meters higher than before. In the coral reef examples discussed above, the RSL fluctuation during the MIS 5e highstand was c. 3–5 m in amplitude. The fluctuation seems best characterised as a multi-millennia period of relatively stable sea level that terminated with a short-lived period of relatively rapid rise, the midpoint of which is dated to between c. 121 and 118 k yr ago.
3. Rates of sea-level change calculated from one of the Red Sea isotope records (core KL11), suggest RSL fluctuations with magnitudes of up to 10 m in 1–2 k yr or less, with peak rates of rise of 2.1 cm yr and fall of −1.8 cm yr during the LIG highstand (Rohling et al., 2008). The size of the Red Sea RSL fluctuations are approximately twice as large as those inferred from most reef records.

These different elements of the LIG sea level records form a basis for considering how near-field, low energy depositional environments might have responded to such changes.