Last interglacial sea-level proxies in the glaciated Northern Hemisphere

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Abstract. Because global sea level during the last interglacial (LIG; 130-115 ka) was higher than today, the LIG is a useful approximate analogue for improving predictions of future sea-level rise. Here, we synthesize sea-level proxies for the LIG in the glaciated Northern Hemisphere for inclusion in the World Atlas of Last Interglacial Shorelines (WALIS) database. We describe 82 sites from Russia, northern Europe, Greenland and North America from a variety of settings, including boreholes, riverbank exposures and along coastal cliffs. Marine sediments at these sites were constrained to the LIG using a variety of radiometric methods (radiocarbon, uranium-thorium, potassium-argon), non-radiometric methods (amino acid dating, luminescence methods, electron spin resonance, tephrochronology) as well as various stratigraphic and palaeoenvironmental approaches. In general, the sites reported in this paper do not offer constraint on the global LIG highstand, but rather evidence of glacial isostatic adjustment (GIA)-influenced sea-level positions following the Marine Isotope Stage 6 glaciation (MIS 6; 191–130 ka). Most of the proxies suggest that sea level was much higher during the LIG than at the present time. Moreover, many of the sites show evidence of regression due to sea-level fall (owing to glacial isostatic uplift), and some also show fluctuations that may reflect regrowth of continental ice or increased influence of the global sea-level signal. In addition to documenting LIG sea level sites in a large swath of the Northern Hemisphere, this compilation is highly relevant for reconstructing the size of MIS 6 ice sheets through GIA modelling. The database is available at https://doi.org/10.5281/zenodo.5602212 (Dalton et al., 2021).

1 INTRODUCTION

During the last interglacial (LIG), between 130 and 115 ka (peak interglacial at 123 ka; Lisiecki and Raymo, 2005), temperatures were warmer than today by up to 5°C in some regions of the northern Hemisphere (Dahl-Jensen et al., 2013), and global sea levels were up to 5-m higher (Dutton and Lambeck, 2012; Dyer et al., 2021). Like today, Greenland and Antarctica were the predominant global ice stores, as large continental ice sheets that grew repeatedly during the Quaternary over North America and Eurasia were absent at that time (see Batchelor et al., 2019). The LIG therefore represents a useful analogue for understanding the behavior of large continental ice sheets in a warming world, which is key for improving predictions of future melting of the Greenland and Antarctic ice sheets and concomitant sea-level rise (Slater et al., 2021).

The World Atlas of Last Interglacial Shorelines (WALIS) is a standardized database that has been created to archive global sea level sites constrained to the LIG. Here, we contribute 82 sites from the formerly glaciated Northern Hemisphere to WALIS. We focus on sites that were covered by ice during the Marine Isotope Stage 6 (MIS 6) glaciation (191–130 ka; Lisiecki and Raymo, 2005; Fig. 1), including Russia, Finland, Estonia, Poland, Sweden, Norway, Svalbard, Iceland, Greenland, Canada, and the United States. Sea-level proxies in the glaciated regions of the southern North Sea, Jutland Peninsula and Great Britain are the subject of separate studies in this issue (Cohen et al., 2021). To standardize the presentation of LIG proxy sites, we use marine isotope stages (MIS), as presented in Lisiecki and Raymo (2005) and consider that LIG corresponds with MIS 5e (130–115 ka) and the penultimate glaciation to be MIS 6. Most of the sediments described herein were deposited in isostatically depressed land immediately following the retreat of major continental ice sheets from the MIS 6 glaciation (Figs. 1–2). Isostatic recovery is sometimes preserved as a sequence of deep water, followed by shallowing, shoreline, deltaic, and estuarine depositional settings. Such LIG sites were subject to considerable erosion from subsequent glaciations, notably during MIS 5d (peaked at 109 ka), MIS 4 (71–57 ka) and MIS 2 (29–14 ka; see Batchelor et al., 2019 and Fig. 2) and are therefore only sporadically preserved. There are also many more sites preserved in Russia and Europe than in North America, likely a consequence of the smaller extent of the MIS 4 and MIS 2 glaciations relative to MIS 6 (Fig. 1). In general, areas near the center of large ice sheets underwent more isostatic depression than more peripheral sites. Our database of LIG sites in the Northern Hemisphere is open access and available at https://doi.org/10.5281/zenodo.5602212 (Dalton et al., 2021). A detailed description of database fields in the WALIS database is available at https://doi.org/10.5281/zenodo.3961544 (Rovere et al., 2020).

In the first part of this paper (Sections 2-5), we define the types of sea-level proxies, elevation measurements, dating techniques and quality assessment, all of which are technical aspects of entering the LIG data into the WALIS database. In Section 6, we describe each LIG site in detail, paying particular attention to the elevation of marine sediments and any geochronological constraints. In Section 7, we present sites containing LIG marine sediments that are not *in situ* and have been transported and/or glaciotectonised following deposition. These sites are unsuitable as precise indicators of relative sea level (RSL) and are therefore excluded from the WALIS database. However, they contribute to the general picture of LIG sea level and are therefore included here. In the Discussion (Section 8) we provide an overview of the LIG sites compiled for this paper, as well as examples of marine deposits of other ages in the glaciated region, notably MIS 7 (243 ka to 191 ka), MIS 5c (peak 96 ka), MIS 5a (peak 82 ka) MIS 3 (57–29 ka) and Holocene (11.5 ka to present-day; Fig. 2). We conclude with suggestions for future research. As shown in Figure 2, the LIG is known regionally as the Kazantsevo interglacial (Siberia; here however redefined as Karginsky, per Astakhov 2013), the Mikulino interglacial (Russia), the Eemian (western, central and northern Europe), the Ipswichian (United Kingdom), the Langelandselv interglaciation (Greenland) and the Sangamonian (North America).

2 SEA-LEVEL PROXIES

Our approach to describe sea-level proxies differs from the standard approach used in most of the studies in WALIS. Since most of the LIG sites are located in places that were undergoing rapid sea-level changes dominantly due to glacial isostatic adjustment (GIA) rather than global sea-level change, it is essentially impossible to pinpoint when sea level was at a particular elevation (especially given the large uncertainty in the dating methods). In many locations, there are indications of regression from an often indeterminate highstand position at deglaciation, to a position below the elevation of the outcrop. For many sites, there is clear evidence of coarse grained, wave influenced deposits that show that sea level was near the elevation of the investigated deposit. The indicative meaning of these deposits, as defined by Rovere et al. (2016), is not sufficiently clear to deduce a precise sea-level position.

We regard it as more useful to describe the sea-level proxies in terms of changes in sea level at each site during the LIG. Accordingly, this compilation is mainly intended for researchers who are interested in inferring the size of the MIS 6 ice sheets through GIA modelling (e.g. Lambeck et al., 2006). In the database descriptions (Dalton et al., 2021), we have indicated the relative water depth based on the geological descriptions at the sites (i.e. deep water, shallow water, near sea level, above sea level). From this information, it should be possible to test the reliability of MIS 6 ice sheet reconstructions.

In our database (Dalton et al., 2021), the vast majority of the sea-level proxies are denoted as "marine limiting". The entered elevation marks the highest elevation of marine sediments at a site. This usually marks an unconformity between the marine sediments and overlying younger sediments that date to between MIS 5d and MIS 1 (started at 14 ka; see Fig. 2). In a few cases, the contact is a conformable transition from marine to terrestrial (often fluvial or lacustrine) sedimentation. At sites where there is reasonably high confidence of the indicative meaning (generally where there is confidence of the sea-level highstand), we have defined them as sea-level indicators using the standard approach of WALIS (i.e. Rovere et al., 2016), and note that sea level likely never exceeded that elevation. At sites where there is evidence of a regression and transgression within the LIG, we have created two entries in the database. Based on the amount of information on sea-level position and variations at a site, we have assigned a quality score, which will be elaborated on in Section 5.

3 ELEVATION MEASUREMENTS

A summary of elevation measurement techniques and datums, as used in cited research, are found in Tables 1 and 2. However, techniques used to measure the elevation(s) were often not stated in the studies covered in our database and were instead extracted from stated elevations and section diagrams in the original publications. In these cases, we applied a nominal uncertainty of 20% of the stated elevation, as recommended by Rovere et al. (2016), or 10 m, whichever was smaller. It is unlikely the elevation uncertainty will be worse than the contour intervals of typical topographic maps (10–20 m), provided the authors were precise in pinpointing the location of their site. For studies that involved the authors of this paper, we were able to provide the details of the elevation measurements and provide narrower uncertainties. The datum used was not stated in most of the studies presented here and is assumed to be referenced to present day mean sea level. The tidal range in most locations covered in our database is presently relatively small (*i.e.* < 1-2 m), so this is unlikely to add significant uncertainty.

4 OVERVIEW OF DATING TECHNIQUES

A large number of dating techniques have been applied to LIG marine deposits covered in our database. These dating techniques include absolute (luminescence, electron spin resonance), minimum limiting (radiocarbon), and relative approaches (amino acid racemization, stratigraphy, environmental conditions). Generally, the absolute dating techniques have relatively large uncertainties and cannot be used to give a precise timing of deposition within the LIG. When combined with paleo-environmental conditions, it can usually be concluded that the deposit has a LIG age, rather than being part of another period of high sea level (*e.g.* Holocene, MIS 3, MIS 5a/c, MIS 7; see Fig. 2). Consideration of quality of the age control in the database is elaborated in Section 5.

4.1.1 Amino acid racemization dating

Amino acid geochronology measures the racemisation of amino acids. For the LIG, the epimerization of D-alloisoleucine to L-isoleucine is most used (known as the D/L ratio; Oldale et al., 1982; Miller and Mangerud, 1985). Older shells have a higher isoleucine epimerization ratio than younger shells. However, this is a relative dating technique, with the epimerization controlled by regional diagenetic temperature, among other factors (Andrews et al., 1983). Therefore, this technique can only be used for correlation between sites or to differentiate between different marine incursions in each region, rather than give precise ages.

4.1.2 Radiocarbon dating

Radiocarbon dating measures the amount of radioactive carbon (^{14}C) remaining in organic material after death of the dated animal/plant. The time since death can be approximated by consideration of the mean half-life (5.73 ka) of ^{14}C (Stuiver and Polach, 1977) and then converted to calendar year via calibration (Reimer et al., 2020). However, this chronological method is only useful for samples less than ~45,000 years old because the remaining ^{14}C in old samples is too scarce to be reliably measured beyond that point, and the sample becomes increasingly susceptible to modern-day carbon contamination (Douka et al., 2010). Thus, for the purposes of identifying LIG marine sites, radiocarbon ages offer only minimum constraint.

4.1.3 Stratigraphic inferences

In many cases, the stratigraphic position of a particular marine unit provides evidence for its age. When the marine unit is overlain by tills that are independently assigned to MIS 5d/b (peak MIS 5d conditions were at 87 ka), MIS 4 or MIS 2 glaciation, stratigraphic context is used as evidence to support a LIG age assignment (e.g., at Põhja-Uhtju and Peski; Miettinen et al., 2002; Sections 6.22-6.23). As another example, sometimes the presence of a till directly underneath the marine sediments suggests significant isostatic depression (often related to the MIS 6 glaciation), which. along with evidence of rapid marine inundation into the isostatically depressed landscape and shallowing of marine waters, is used as evidence of an LIG age assignment (e.g., Ile aux Coudres; Occhietti et al., 1995; Section 6.45).

4.1.4 Palaeoenvironmental inferences

Climate during the LIG was several degrees warmer than present-day temperatures in the Northern Hemisphere (Rasmussen et al., 2003; Sánchez Goñi et al., 2012). As a result, palaeo-indicators of warmer-than-present-day conditions are often used as support for a LIG age assignment. Marine-based palaeoecological indicators commonly preserved in the stratigraphic record include dinoflagellate cysts, foraminifera, Coelenterata, Bryozoa and Mollusca, diatoms, and marine gastropods (Bergsten et al., 1998; Mangerud et al., 1981). In the terrestrial sediments that often overlie the LIG marine unit, pollen assemblage zones (PAZ) and Coleoptera are some of the most used markers for determining palaeo-temperature (Dredge et al., 1992; Miettinen et al., 2002). Some caution is needed when considering these as correlating to the LIG in the absence of other numerical dating methods, as it is possible that these deposits could be from an older interglacial period. In our database, we refer to any site with environmental conditions supporting LIG assignment as an "Eemian interglacial deposit", as defined by Mangerud et al. (1979).

4.1.5 Thermoluminescence dating

A common dating method for LIG marine sediments is thermoluminescence (TL), although in recent years it has been largely replaced by optically stimulated luminescence (OSL; described in Section 4.1.7). The TL technique measures the last exposure of a sediment to sunlight via the resetting of electrons (Huntley et al., 1985; Lamothe and Huntley, 1988). In a laboratory setting, these changes are measured by heat stimulation. Either quartz or feldspar can be used, although feldspar is susceptible to anomalous fading, which can lead to large uncertainties in the age estimation because the electrons trapped in the crystal lattice ‘leak’ over time (Godfrey-Smith et al., 1988; Huntley et al., 1985).

4.1.6 Infrared stimulated luminescence dating

The infrared stimulated luminescence dating (IRSL) method uses wavelengths in the infrared range to induce luminescence in feldspar, which in some cases has been shown to reduce uncertainties in age estimates compared with TL (Godfrey-Smith et al., 1988).

4.1.7 Optically stimulated luminescence dating

Similar to TL dating, OSL measures the refilling of shallow electron traps in sediment grains that occur during burial following exposure of the sediment grain to sunlight; therefore, the time since burial can be obtained (Duller, 2008; Huntley et al., 1985). In a laboratory setting, the release of these electrons is induced by light stimulation and the escaping dose is measured. A key consideration in OSL dating is the former depositional context (largely shallow marine settings in our dataset) and its impact on bleaching (zeroing) of the sediments by sunlight, as well as the burial history of the sediment. Generally, OSL is considered to be more reliable than TL and IRSL.

4.1.8 Electron spin resonance dating

Electron spin resonance (ESR) dating estimates the time since deposition of certain materials (largely molluscs in our database) by measuring the trapping of electrons within the material’s crystal lattice. A key factor is the radiation occurring from the enclosing sediment, as well as the radioactivity of the sample (Grün, 1989). The precision of the age from ESR dates on mollusc shells is complicated, since the shells have an open system to uranium (Schellmann and Radkte, 1999). As a result, care must be taken in interpreting ESR ages, and the uncertainty can be larger than the stated analytical uncertainty. The analytical techniques used to determine ESR ages for many of the sites in our database are described in detail in Molodkov (1988) and Molodkov et al. (1998).

4.1.9 Uranium-thorium dating

As with ESR dating, uranium-thorium (U/Th) dates from mollusc shells are complicated to interpret since the shells have an open system to uranium and rely on assumptions on the exchange of the element with the surrounding environment (Radke et al., 1985). As a result, this technique is not commonly applied to LIG deposits. This method was used to constrain the age of deposits at two sites in our database (Miller et al., 1977, Israelson et al., 1994). For the later, the U/Th age provided only minimum constraint.

4.1.10 Tephrochronology

At one site in our database (Galtalækur site in Iceland; Vliet-Lanoë et al., 2018; Section 6.40), tephrochronology is used to support the LIG age assignment. Contained within the marine sediments is a tephra layer that was linked via geochemical analyses to a specific eruption (Grimsvötn volcano) which was, in turn, constrained to the LIG based on the position of the Grimsvötn tephra in North Atlantic marine sediment cores (Davies et al., 2014).

4.1.11 Potassium–argon dating

At one site in our database (Galtalækur site in Iceland; Vliet-Lanoë et al., 2018) potassium-argon (K/Ar) dating is used to constrain the age of a glacio-volcanic unit that underlies the LIG marine unit. This method measures the rate of decay from K to Ar and was possible at this specific site owing to the presence of volcanic rocks. It is otherwise not a common dating method in Quaternary research.

5 QUALITY ASSESSMENT

At each LIG marine site documented in the WALIS database there is a quality assessment rating for the RSL proxies. In the WALIS documentation, the standard RSL rating is designed for far-field sea-level indicators, in which a precise assignment of sea-level position can often be determined. For glaciated areas where sea level was rapidly changing due to glacial isostatic rebound after the end of the MIS 6 glaciation, this type of quality assessment is not as useful, especially since the dating techniques are not precise enough to pinpoint when the marine sediments were deposited. As one of the primary uses of this database will be GIA modelling, we have devised a rating scheme to assess the usefulness for this purpose (Table 3). The best quality RSL proxies are sedimentary sequences that have well documented elevation measurements, and in which there is a clear transition from deep marine to shallow marine, beach, and terrestrial environments. A high rating is also assigned if it can be proved that sea-level position remained above a threshold for a long period of time, *i.e.* for most or all of the LIG. The rating decreases when there is less geological evidence of sea-level position changes and proximity to sea level.

The chronological rating for each LIG site follows the WALIS standard (Table 4) and is determined by how precise the age of the marine deposit can be constrained. In the standard WALIS documentation, higher chronological scores are generally only assigned for U/Th dated corals that can have precision of less than a few thousand years, which is not the case in the techniques applied to glaciated region sea-level proxies. Despite this, based on stratigraphy and environmental proxies, there is reasonable confidence that most of the proxies documented in our database fall either within the LIG, during the latest part of MIS 6 when the ice sheets were retreating, or during the early parts of MIS 5d when ice sheets began to grow again. Without environmental indicators, it can be difficult to distinguish deposits that might instead date to the sea-level highstand that happened after the MIS 5d glaciation (e.g. Mangerud et al., 1998). For North American sites, a high rating assignment from environmental conditions alone is not applied, as the LIG stratigraphy is not as well understood as in Europe (Otvos, 2015). Sites that have multiple age determinations increase the confidence in our LIG age assignment. However, the precision of the techniques is never high enough to elevate any site rating to the highest level.

The primary challenge of assessing past sea level in formerly glaciated areas is that the sea-level position likely did not remain fixed for any length of time. Moreover, the dating techniques that can be applied to LIG deposits lack the precision to determine when sea level was at a specific elevation (with the possible exception of the correlation with European pollen records, if such long-distance correlations are valid). Therefore, we chose to describe the proxies in terms of how much information they give to show sea-level variations in the LIG. Most of the studies we looked at lack information on how elevation was determined. However, we were able to include this information in the database for sites that involved the authors of this study. Since a large portion of sites described here were overridden by ice sheets during the last glacial period (MIS 2; see Fig. 1), most of the sections are incomplete due to erosion.

6 RELATIVE SEA-LEVEL PROXIES

Here, we describe sites from the formerly glaciated Northern Hemisphere that contain *in situ* LIG marine sediments, ordered roughly from east to west, and sorted by country. Geochronological results are reported for all the sites where data are available. Sediments overlying or underlying the marine strata are generalized unless they provide additional context for the LIG marine event. We offer no interpretation of tectonics, GIA or eustacy. Elevation measurements are in meters above sea level (MASL) or meters below sea level (MBSL). Owing to the global scale of this database, it is not possible to map all features/locations described in the text (especially rivers) and the reader is referred to the original publications for specific local site information. Additional details (including site coordinates, elevation of marine sediments, quality scores for both RSL and age determinations) are summarized in Table 5 and detailed in the database of Dalton et al. (2021).

6.1 Novorybnoye 2, Taimyr Peninsula, Russia

On the southernmost Taimyr Peninsula, ~30 m-high river bluffs close to the small settlement of Novorybnoye, on the south shore of the Khatanga River, expose a complex Mid- to Late Pleistocene stratigraphy (Fig. 3B). As described in Kind and Leonov (1982), this record encompasses three glacial till units on top of Cretaceous sandstone; the till beds are described as interbedded with two marine sediment successions, the lowermost to be, in their terminology, LIG in age and the upper one sandwiched between two Early Zyryanka tills (MIS 5d–5a). This chronostratigraphy was, however, not substantiated by any numerical ages. The Novorybnoye bluffs were reinvestigated by Möller et al. (2019a; 2019b), resulting in two more observed marine units and a very different chronology, in which the lowermost marine unit probably dates to MIS 9–11 (424–337 ka). Relevant to the present study, the LIG marine sediments span 14.8 –24 MASL and are divided into two units: F1 and F2. Marine unit F1 (spanning 14.8–21.5 MASL) is at the base a glaciomarine clayey silt with numerous occurrences of ice-rafted debris. Above these marine sediments are stratified and normally graded sandy shoreface sediment (F2) with an abundance of *Hiatella arctica* and *Astarte sp*. shells from 21.5–24 MASL. An OSL age of 124 ka is supported by a mollusc ESR date at 131 ka; Möller et al. (2019a) thus concluded that this entire marine unit (F1–F2) represents marine inundation following deglaciation and sediment deposition during isostasy-driven shore regression at the transition from MIS 6 into the LIG. The absolute height of unit F sediments is ≥25 MASL, which is a minimum deglacial sea-level altitude.

6.2 Bol'shaya Balakhnya River (BBR 17), Taimyr Peninsula, Russia

In the lower reaches of the Bol'shaya Balakhnya River (Fig. 3B), a sediment succession shows marine silty clay with dispersed ice-rafted debris situated between 6.2–7 MASL (site BBR 17B) and 7–13 MASL (site BBR 17A). At BBR 17B, there is an upper erosional contact to fluvial sediment at 7 MASL (Möller et al., 2019a, 2019b; Der Sarkissian et al., 2020). The mollusc fauna in the marine sediments is dominated by arctic *Portlandia arctica*, but there is also an abundant occurrence of subartic taxa: *Buccinum undatum*, *Mytilus edulis* and *Macoma baltica*, suggesting higher than present influx of Atlantic water. Electron spin resonance ages on *P. arctica* are 101–105 ka (n = 3) and indicate an MIS 5c age (known locally as Early Zyryanka). However, two molluscs in the above-lying fluvial sediments (OSL-dated to a MIS 3 age; the molluscs redeposited from erosion of the underlying marine sediment), yield ESR ages of 122 and 123 ka. Theses dates, together with the interglacial-type mollusc fauna composition, clearly set the marine sediments into the LIG, however with poor indication of sea level at deposition.

6.3 Kamennaya River, Taimyr Peninsula, Russia

Around the Kamennaya River (Fig. 3B), which is a tributary to the Leningradskaya River, Gudina et al. (1983) described several sites exposing marine and nearshore marine sediments forming regressive terraces from 133–40 MASL (site no. 373 located at the highest altitude of 133 MASL). The sediment successions are divided into a lower coarsening upwards member, from silts and clays to cross-bedded sand, and an upper member of sand and gravel. All sediments are rich in molluscs, predominantly *Astarte borealis, A. crenata, A. montuagi*, *Macoma calcarea*, *Hiatella arctica* and *Mya truncata*, (i.e. species that are Arctic to non-conclusive in their biogeography). As opposed to the molluscs, the foraminifera association (48 species detected) has a dominance of subarctic species, thus suggesting warmer than present sea temperatures. Based on the latter, Gudina et al. (1983) suggested that the marine sediments in the Leningradskaya basin were deposited at shore regression during the LIG.

6.4 Kratnaya River sections, Taimyr Peninsula, Russia

Three river-cut sections along the Kratnaya River (denoted KR1, KR2 and KR3; Fig. 3B), expose a thick basal till on top of which are marine sediments with a slight upwards-coarsening trend with off-shore silt and sand grading into shoreface-deposited sand with gravel stringers (Möller et al., 2008, 2015). The base of these marine sediments is situated at 37 MASL and the uppermost logged sediments reach ~43 MASL, but the marine sediment succession can locally be followed upslope to at least 50 MASL. The sediments host a variable abundance of molluscs with *Hiatella arctica, Mya truncata* and *Astarte borealis* as dominating taxa (all Arctic to non-conclusive in their biogeography). Six ESR ages on molluscs from the marine sediment form an age cluster between 111 ka and 142 ka, while two OSL dates gave younger ages of 84 ka and 100 ka (Möller et al., 2008, 2015). The ESR ages firmly suggest a transition from the MIS 6 glaciation (known locally as the Late Taz) into the LIG for the emplacement of this regressive marine sediment succession.

6.5 Anjeliko River sections, Taimyr Peninsula, Russia

Based on the composite stratigraphy of five river-cut sections (three of which have LIG sediments and are included in the database) along and in the vicinity of the Anjeliko River (Fig. 3B), Möller et al. (2008, 2015) report three marine units intercalated with glacial tills and suggested that two of these marine events, together with underlying tills, represent two full glacial cycles coupled with marine inundation and regression following deglaciations. Relevant to the present study, the intermediate marine unit consists of glaciomarine debris flow sediments followed by an upwards coarsening sediment succession of off-shore clay and silt into shore-face/fore-shore sand. These marine sediments are situated between 55 and 58 MASL. Outside of logged sediment successions, the marine sediments could be followed to ~80 MASL and, if observations from investigations by Mirošnikov (1959) and Šnejder (1989) from other nearby locations (notably on Cape Chelyuskin) refer to the same sediments, they might have a highest altitude of up to 140 MASL. The sediments host a variable abundance of the molluscs *Hiatella arctica, Mya truncata* and *Astarte borealis* as dominating taxa, all Arctic to non-conclusive in their biogeography. Three ESR ages on molluscs from the marine sediment yielded ages of 143, 145 and 156 ka, while two OSL ages suggested 79 and 135 ka (see Möller et al., 2015). The age envelope (disregarding the 79 ka OSL age) suggests a transition from the MIS 6 glaciation (known locally as the Late Taz) into the LIG for this marine sediment succession. The uppermost glacial/marine sediment succession in the Anjeliko River area dates from a glaciation followed by marine inundation during MIS 5d–5c (known locally as the Early Zyryanka; see Möller et al., 2008).

6.6 Ozernaya River, October Revolution Island, Russia

October Revolution Island is located offshore of the Taimyr Peninsula, in the Severnaya Zemlya archipelago, Arctic Russia (Fig. 3B). On this island, along the north to south-flowing Ozernaya River, are occasional exposures of up to 50-m thick paleo-valley fill sediment successions, ordered in a pancake-like stratigraphy. First briefly described by Bolshiyanov and Makeyev (1995), a more in-depth description was made in Möller et al. (2007), showing four till beds (Till I–IV) interbedded with three marine units (Marine I–III). Relevant to the present study, Marine unit III is situated between 75.5 and 80.5 MASL (sites Oz1b and 1d). These marine sediments can laterally be followed to higher ground with no covering till (sites Oz2 and 3; see Fig. 5A in Möller et al., 2015), eventually terminating in sets of beach ridges, the highest at ~140 MASL. In the database (Dalton et al., 2021), we have treated the highest elevation beach ridge as a sea-level indicator. The marine sediments show a general coarsening upward trend with off-shore to shore-face deposited silt and clay with varying frequency of ice-dropped clasts, continuing into massive or vaguely stratified sand (site Oz1) and finally beach-face gravels (sites Oz 2–3). Besides Arctic molluscs as *Hiatella arctica, Mya truncata* and *Astarte borealis*, the marine sediments also host biogeographically subarctic species such, as *Chlamys islandica* and *Buccinum undatum*. The foraminifera fauna is also mainly Arctic, but a warmer-water indicator is *Trifarina* cf. *angulosa* and the also occurring *Elphidium ustulatum* and *Islandiella inflata* that are rarely found in deposits younger than the LIG in Europe (Möller et al., 2007).

The age of the Marine unit III is not straightforward, as discussed in Möller et al. (2007, 2015). Electron spin resonance ages on the mollusc fauna have and age envelope of 77–105 ka (n = 8), while ESR ages on nearby found *Chlamys islandica* is 105 and 120 ka (Bolshiyanov and Makeyev, 1995). Optically stimulated luminescence ages on the sediment show an age envelope of 143–176 ka (n = 11). Based on the stratigraphic position in a regional context, the interglacial fauna elements in the marine sediments and an evaluation of the numerical ages from dating attempts, Möller et al. (2007) favoured an interpretation that the Marine unit III sediments in the Ozernaya River valley were deposited at the transition between the MIS 6 glaciation (known locally as the Late Taz) and the LIG, and that the deglacial sea had a highstand of at least 140 MASL.

6.7 Lower Agapa River, Taimyr Peninsula, Russia

In the lower reaches of the Agapa River (Fig. 3B), several river sections display three marine units (Gudina et al., 1968; later reinvestigated by Sukhorukova, 1998). The lowermost unit is interbedded fine sand and silt with the boreal bivalve *Cyprina islandica* (now *Arctica islandica*) followed by silt and clay (Unit 2), 30–35 m thick, spanning 30 to ≥63 MASL. Unit 2 hosts a rich mollusc fauna (16 subarctic (arcto-boreal) and 20 arctic species), however with no species list given. The foraminifera fauna also suggests a component of Atlantic water inflow. Marine Unit 2 with interglacial-type marine fauna reaches ≥63 MASL, which is a minimum sea-level altitude for these deeper marine sediments. The presented biostratigraphy strongly suggests that Unit 2, with a warmer-water fauna, represents interglacial conditions, most likely the LIG.

6.8 Karginsky Cape, West Siberian Plain, Russia

At Karginsky Cape (Fig. 3B), Western Siberian Plain, Kind (1974) described a ~16-m thick sequence of marine sands and silts situated between 5 and 21 MASL, sandwiched between two tills. This site is the LIG marine stratotype for this region (Karginsky Formation; see stratigraphy in Fig. 4). These marine sediments contain shells of the biogeographically Arctic-to-non-conclusive molluscs *Astarte borealis*, *Macoma calcarea*, *Mya truncata* and *Ciliatocardium ciliatum*, as well as the subarctic *Mytilus edulis*. Shells of a typical boreal mollusc, *Arctica islandica,* were found only on the beach. The sequence also contains remains of plants presently growing some 3–5° (approx. 300–500 km) to the south, suggesting it was deposited during a warmer interval. Conventional radiocarbon dates obtained in this section were 42, 42, 46 and ≥52 ka. However, the first ESR date on an *Arctica islandica* shell yielded an age of 121.9 ka (Katzenberger and Grün, 1985; Arkhipov, 1989). The LIG age of this marine formation was later confirmed by 6 OSL dates in the range of 117–97 ka (Astakhov and Nazarov, 2010b; Nazarov, 2011; Nazarov et al., 2018, 2020).

6.9 Tanama River, Western Siberian Plain, Russia (2 sites)

Along the Tanama River (Fig. 3B), Nazarov et al., (2021) describe marine sediments overlying till from the Taz (MIS 6) glaciation, below which are marine sediments from an earlier interglacial (interpreted as MIS 7 based on OSL dates). The upper unit of marine sediments (known locally as the Payuta marine formation) consist of sands and silts, with numerous shells of *Arctica islandica*, which indicate warmer water conditions. The unit is associated with terraces that reach an elevation of 60–70 MASL. The change in slope at 70 m took on the appearance of strandlines. Overlying the marine sediments are lacustrine and alluvial sediments that yielded ages in the range of MIS 4–3.

6.9.1 Tanama site 1

The unit is associated with terraces that reach an elevation of between 60 and 70 MASL.

6.9.2 Tanama site 2

The unit is associated with terraces that reach an elevation of between 60 and 70 MASL.

6.10 Bol’shaya Kheta, West Siberian Plain, Russia (4 sites)

In the Western Siberia Plain, there are LIG outcrops along the Bol’shaya Kheta River (Nazarov et al., 2020, 2021; Astakhov and Semionova, 2021). First described by Volkova (1958), these sites contain a similar stratigraphic record that can be traced along the river sections, with LIG marine sediments generally ranging from 5–40 MASL (stratigraphy and ages summarized in Fig. 4). The upper marine formation was assigned to the LIG by Sachs (1953). This marine unit contains only the extant species *Cyrtodaria siliqua* and *C. kurriana* and a rare occurrence of the boreal *Arctica islandica.* These sites are mapped in Fig. 3B.

6.10.1 Site 7251, Bol’shaya Kheta River

At this site, the upper marine sand and clay beds are situated between 20 and 30 MASL. Two OSL ages on these marine sediments yielded ages of 124 ± 3 and 121 ± 11 ka (Nazarov et al., 2020, 2021; Astakhov and Semionova, 2021). These marine sediments directly overlie a till of MIS 6 age.

6.10.2 Site 7248, Bol’shaya Kheta River

Located 55 km south from site 7251, marine sand and clay beds are located between 5 and 30 MASL . Three OSL attempts on these marine sediments yielded ages of 110 ± 16, 127 ± 20 and 114 ± 12 ka (Nazarov et al., 2020, 2021; Astakhov and Semionova, 2021).

6.10.3 Site 7249, Bol’shaya Kheta River

Marine sand and clay are located between 5 and 30 MASL (Nazarov et al., 2021). No chronological constraints are available for this site, but the marine unit can be traced along the riverbank to the other sites dated to the LIG.

6.10.4 Site 7246, Bol’shaya Kheta River

Marine sand and clay beds are located between 5 to 30 MASL (Fig. 3; Nazarov et al., 2021). A single OSL age of 132 ± 11 ka suggests deposition during the LIG (Nazarov et al., 2021).

6.11 Observations Cape, West Siberian Plain, Russia

On the tip of the Taz Peninsula, Western Siberian Plain, the Observations Cape site (Fig. 3B) contains parallel laminated sand, silt and clay with an abundance of boreal molluscs as *Modiolus* sp and *Zirfaea crispata* and subarctic species as *Buccinum undatum*, *Macoma balthica* and *Mytilus.* Described and dated by Astakhov and Nazarov (2010b), these marine sediments are situated between 3 and 35 MASL and yielded 6 OSL dates with a mean age of 135 ka (stratigraphy and ages summarized in Fig. 4), leading to a LIG age assignment. These marine sediments are underlain by Middle Pleistocene glacial till and overlain by fluvial sand with OSL ages of 77 and 74 ka.

6.12 Sula, Pechora Lowland, Russia

In the Pechora Lowland (Fig. 5B), the best dated LIG site is the succession of shoreline sands along the Sula River, a left tributary to the Pechora River (denoted sites 21/22). The sand formation was originally described as lying on top of marine clay with a cool-indicating mollusc fauna (Lavrova, 1949), the latter, however, was not confirmed by later descriptions. The well-exposed marine sand spans the interval 31–41 MASL, starting with thin foreshore gravel in tabular foresets, containing paired shells of subarctic *Mytilus edulis* (stratigraphy and ages summarized in Fig. 4). The fining upwards and bioturbated sand contains abundant shells of boreal molluscs *Arctica islandica* and rare shells of *Cerastoderma edule* and *Zirphaea crispata* – all species not presently living east of the Kola Peninsula. This mollusc fauna is typical for a shallow sea with positive bottom temperatures and occurs through the sand formation, topped by a cross-bedded beach gravel. The marine unit, attributed to the LIG, is overlain by fluvial sand and cryoturbated black silty clay of glaciolacustrine origin, topped by aeolian silt (Mangerud et al., 1999). An approximate LIG age was later confirmed by numerous OSL dates; altogether 16 ages in the range of 90–128 ka with a mean age of 112 ± 2 ka (see Fig. 3, and Murray et al., 2007).

6.13 River Yangarei, Pechora Lowland, Russia

Marine sediments of a LIG age are also found at much higher elevations within the Pechora Lowland (Fig. 5B). As an example, marine sand with mollusc shells occur along the Yangarei River at 70 MASL, the sediments yielding OSL ages of 121.6 ± 9.2 and 114.8 ± 8.9 ka (Astakhov and Semionova, 2021).

6.14 Vorga-Yol Section, Pechora Lowland, Russia

Also in the Pechora Lowland, OSL ages of 126 ± 8, 131 ± 8 and 149 ± 10 ka were obtained from sand with shell fragments at 90 MASL, directly underlying the terminal glaciofluvial delta at Vorga-Yol section (Astakhov and Semionova, 2021; Fig. 5B).

6.15 Pyoza River, Arkhangelsk district, Russia (11 sites)

Marine sediments assigned to the LIG (known locally as the Mikulinian) were first noted in stratigraphic records along the Pyoza River, in the Arkhangelsk district, in the early-mid 20th century and examined more recently by Houmark-Nielsen et al., (2001) and Grøsfjeld et al., (2006). We describe 11 sites below, which are all mapped in Figs. 5B-C.

6.15.1 Zaton

First discovered by Ramsay (1904), the Zaton site (Site 0 of Houmark-Nielsen et al., 2001) was examined by Devyatova and Loseva (1964) and Devyatova (1982). As described most recently by Grøsfjeld et al. (2006), the entire LIG marine sequence spans 2–11 MASL. At the base of the section, from 2–7.5 MASL are marine clays with a gradual transition into silty sands, interpreted as an offshore to shoreface sediment succession (>45 m to <12 m water depth). At the top of the section, from 7.5–10 MASL are laminated sand and silt, separated by gravel horizons. These sediments are interpreted as deposited in a higher-energy coastal/tidal environment with channel erosion and infilling (foreshore environment; <12 m depth). Capping this sediment succession, from 10–11 MASL, are cross-bedded fluvial sands. Marine molluscs, dinoflagellate cysts and benthic foraminifera are present throughout (Grøsfjeld et al., 2006). The stratigraphy observed at this site is laterally continuous for ~800 m.

Several geochronological attempts have been made at the Zaton site. Early TL dating on sediments overlying the marine unit yielded an age of 93 ka, which supports a LIG-age for the underlying marine sediments (Hütt et al., 1985). Amino acid dating on shells from the marine unit yielded mean a D/L ratio of 0.051±0.006, which is 'slightly higher than expected' but 'probably Eemian' according to Miller and Mangerud (1985). Subsequent ESR dating confirmed a LIG age for this marine deposit (120–82 ka; Molodkov and Raukas, 1988; Molodkov and Bolikhovskaya, 2002). A LIG-age is also suggested by pollen analyses (Devyatova, 1982); according to the established pollen-based LIG climate for western Europe (Zagwijn, 1996), marine sediments at this site span the entire interval from ~133 to ~119.5 ka (Grøsfjeld et al., 2006). Moreover, molluscs from this site suggest warmer-than-present day conditions (notably, *Corbula gibba* and *Balanus improvises*), which also supports a LIG age (Grøsfjeld et al., 2006).

6.15.2 Bychye

The Bychye site (sometimes spelled 'Bychie'; Site 1 of Houmark-Nielsen et al., 2001 and Grøsfjeld et al., 2006) was first described by Devyatova and Loseva (1964) and again by Devyatova (1982). As described most recently by Grøsfjeld et al. (2006), the stratigraphy at this site is similar to the Zaton site. The entire marine sequence spans from 12.5–23 MASL. At the modern-day river level (~12 MASL) is a till unit, which is overlain by marine clays that gradually coarsen into clayey silt (12.5–19 MASL; >45 m water depth). These sediments are terminated by an erosional horizon (at 19 MASL), indicating falling sea level (Grøsfjeld et al., 2006), followed by laminated sand and silt separated by gravel horizons with channel incisions (from 19–23 MASL), interpreted as a regression sequence (shoreface/tidal environment; <12 m water depth). Marine molluscs, dinoflagellate cysts and benthic foraminifera (Grøsfjeld et al., 2006) are present throughout. The stratigraphy at this site is laterally continuous for ~500 m.

The marine sediments at the Bychye site are assigned to the LIG based on palaeoenvironmental and stratigraphic inferences. Pollen data (examined by Devyatova, 1982) suggest correlation to the ~133 to ~124-ka interval (Grøsfjeld et al., 2006) LIG climate for western Europe (Zagwijn, 1996). Various marine molluscs, dinoflagellate cysts and benthic foraminifera suggest a transition from cooler-than-present to warmer-than-present temperatures, which supports the capturing of the MIS 6 deglaciation, followed by establishment of LIG warmer marine conditions (Grøsfjeld et al., 2006).

6.15.3 Viryuga W

Located on the northern side of the Pyoza River, the Viryuga W site (Site 4 of Houmark-Nielsen et al., 2001 and Grøsfjeld et al., 2006) was first described by Devyatova and Loseva (1964). Our descriptions are derived from the more recent examination by Houmark-Nielsen et al. (2001) and Grøsfjeld et al. (2006). At the base is a marine unit (spanning 21–39 MASL) containing stratified sands with shells. A till is present between 39 and 45 MASL. Capping the stratigraphic section is an upper marine unit (spanning 46–49 MASL), consisting of a clayey diamict containing abundant *Mya truncata* and *Macoma calcarea* shells, often paired and thus suggesting *in-situ* preservation. Dinoflagellate cysts and benthic foraminifera are present throughout (Grøsfjeld et al., 2006).

The lower marine unit yielded OSL ages ranging between 237–194 ka, suggesting an ice-free interval during MIS 7 (Houmark-Nielsen et al., 2001). Accordingly, Grøsfjeld et al. (2006) interpreted the upper marine sediments as the earliest part of the LIG. Correlation of pollen data from this site with the climate for western Europe (Zagwijn, 1996) place the upper marine sediment unit between ~133 and ~130 ka (Grøsfjeld et al., 2006). Marine molluscs and benthic foraminifera suggest cooler-than-present conditions during this time, which suggests deposition began during the MIS 6 deglaciation at the beginning of the LIG (Grøsfjeld et al., 2006). However, because the upper marine sediments themselves remain undated and the stratigraphic context is unclear, earlier workers (Devyatova and Loseva, 1964; Houmark-Nielsen et al., 2001) interpreted this upper unit as Weichselian-aged (e.g. late MIS 5).

6.15.4 Viryuga E

The Viryuga E site (Site 6 of Houmark-Nielsen et al., 2001 and Grøsfjeld et al., 2006) was first described by Devyatova and Loseva (1964) and again by Grøsfjeld et al. (2006). Following Grøsfjeld et al. (2006), the basal interval at this site is a clayey till between 56–58 MASL, inferred to have been laid down during the MIS 6 glaciation. The till is, with a sharp boundary, overlain by clayey glaciomarine sediment between 58 and 60 MASL, interpreted as deposited during LIG marine inundation and sea-level highstand following collapse of the MIS 6 ice sheet. Capping the stratigraphy is marine, mollusc-bearing cross-bedded sand with gravel (60–63 MASL), interpreted as shoreface deposits. Marine molluscs, dinoflagellate cysts and benthic foraminifera are present throughout (Grøsfjeld et al., 2006). Marine molluscs and benthic foraminifera suggest cooler-than-present conditions during deposition, followed by warmer-than present molluscs; together, these data suggest deposition during the deglacial phase at the end of MIS 6 and into the early LIG (Grøsfjeld et al., 2006). Water depths were likely >45 m at time of deposition. Correlation of pollen data from this site with climate for western Europe (Zagwijn, 1996), along with the stratigraphic context, place the marine sediments between ~133 and ~130 ka (Grøsfjeld et al., 2006).

6.15.5 Kalinov

At the base of the Kalinov site (Site 8 of Houmark-Nielsen et al., 2001 and Grøsfjeld et al., 2006) marine clays are interbedded with sands (situated from 28–37 MASL). The sediment succession was interpreted as deposited in a lower shoreface environment (Grøsfjeld et al., 2006). The marine sediments are capped by fluvial sands from 38–40 MASL. The marine clay interval contains marine molluscs, dinoflagellate cysts and benthic foraminifera (Grøsfjeld et al., 2006). The correlation of pollen data from this site with climate for western Europe (Zagwijn, 1996) places the marine sediment succession between ~133 and ~130 ka (Grøsfjeld et al., 2006). Marine molluscs and benthic foraminifera suggest cooler-than-present conditions during this time, which suggest deposition during the deglacial phase at the end of MIS 6 and into the early LIG (Grøsfjeld et al., 2006).

6.15.6 Yatsevets

At the base of the Yatsevets site (Site 10 of Houmark-Nielsen et al., 2001 and Grøsfjeld et al., 2006) is a till situated between 32 and 34 MASL. Overlying this till is a sequence of marine clay between 33 and 38 MASL, containing marine molluscs, dinoflagellate cysts and benthic foraminifera (Grøsfjeld et al., 2006). Molluscs and benthic foraminifera suggest cooler-than-present conditions during sediment deposition and with an increasing water depth (>45 m depth), which support deposition during the deglacial phase at the beginning of the LIG (Grøsfjeld et al., 2006). Correlation of pollen data (Devyatova and Loseva, 1964) from this site with the climate for western Europe (Zagwijn, 1996) place the marine sediment deposition between ~133 and ~130 ka (Grøsfjeld et al., 2006).

6.15.7 Site 11 Orlovets

The Orlovets site contains almost entirely laminated marine silts that coarsen upward (from 38–43.5 MASL), the sediment succession interpreted as deposited in a lower shoreface environment (Grøsfjeld et al., 2006). The laminated silts are capped by sand and gravel, interpreted as deposited in a foreshore environment. Numerous marine molluscs, dinoflagellate cysts and benthic foraminifera are present throughout , all suggesting slightly warmer marine conditions than present-day (Grøsfjeld et al., 2006). According to the established LIG climate for western Europe (Zagwijn, 1996), marine sediments at this site potentially span from ~128 to ~124 ka (Grøsfjeld et al., 2006).

6.15.8 Site 12 Orlovets

The stratigraphic record at Site 12 Orlovets is identical to that of Site 11 Orlovets. Laminated marine silts that coarsen upward (from 38–43.5 MASL) were interpreted as deposited in a lower shoreface environment (Grøsfjeld et al., 2006). At this site, however, the marine interval is capped by sand, interpreted to be deposited in a fluvial environment (Grøsfjeld et al., 2006).

6.15.9 Site 13 Yolkino

Site 13 Yolkino was first described by Devyatova and Loseva (1964) and later by Houmark-Nielsen et al. (2001) and Grøsfjeld et al. (2006). At the base of the section is marine sand containing molluscs, dinoflagellate cysts and benthic foraminifera, between 48 and 51 MASL. Correlation of pollen data from this site with the climate for western Europe (Zagwijn, 1996) place marine sediment deposition between ~130 and ~128 ka, and the marine molluscs suggest warmer than present-day conditions (Grøsfjeld et al., 2006). The marine sediments are overlain by a series of organic-bearing lacustrine sediments, dated by OSL to 89 ka (Houmark-Nielsen et al., 2001), as well as tills and fluvial sediments.

6.15.10 Site 14 Yolkino

The stratigraphic record at Site 14 Yolkino is identical to that of Site 13 Yolkino. Importantly, marine sand containing molluscs, dinoflagellate cysts and benthic foraminifera are situated at the base of this stratigraphic section between 48 and 51 MASL. An OSL age on these marine sediments suggests deposition at 124 ka (Houmark-Nielsen et al., 2001).

6.15.11 Burdui

Marine sand at the Burdui site (Site 24 of Houmark-Nielsen et al., 2001 and Grøsfjeld et al., 2006) is situated between 59 and 60 MASL. These sediments are overlain by a 1-m interval of proglacial sand, dated by OSL to 97 ka (Houmark-Nielsen et al., 2001). Marine molluscs, dinoflagellate cysts and benthic foraminifera are present throughout (Grøsfjeld et al., 2006). Analysis of the marine molluscs suggest warmer conditions than present-day (Grøsfjeld et al., 2006). According to the established LIG climate for western Europe (Zagwijn, 1996), the marine sediments at this site seemingly span an age interval from ~131 to ~130 ka (Grøsfjeld et al., 2006).

6.16 Ponoi River, Kola Peninsula, Russia

The Ponoi site is in the Ponoi River valley on the eastern part of the Kola Peninsula (Fig. 6B). The most complete section in the area is about 20-m thick and was studied by Lavrova (1960), Nikonov (1966), Gudina and Yevzerov (1973), Ikonen and Ekman (2001) and Korsakova et al. (2016). According to the latter two studies, a till at the base of the section (interpreted as desposited during MIS 6) is overlain by a marine clay unit (denoted unit 2) with sand and gravel interbeds. This clay unit is situated between 7 and 11 MASL and contains sporadic unbroken mollusc shells and shell fragments. The mollusc, foraminifera, and diatoms, together with palynological and lithostratigraphical evidence, suggest that the marine clay can be correlated with the LIG. Overlying this marine unit are stratified sands and gravels with shell detritus and unbroken shells. This upper unit is 8-m thick and has a sharp lower contact with the underlying marine clays (Korsakova et al., 2016). Mollusc shells and sand in this upper unit have been dated via ESR and OSL to between 96 ± 8 and 71.9 ± 8.2 ka indicating that this upper sand was deposited during MIS 5 a–c (Early Weichselian substage; see Korsakova et al., 2016). This age assignment for the uppermost sediments supports a LIG age for the underlying marine clays. Capping the entire stratigraphic section is a glacial unit consisting of glaciolacustrine silt with clast and a till unit (Korsakova et al. 2016).

6.17 Svyatoi Nos, Kola Peninsula, Russia

The Svyatoi Nos site is located on the northeastern coast of the Kola Peninsula (Fig. 6B). As described by Korsakova (2019, 2021), the MIS 6 (known locally as the Moscovian glaciation) glaciomarine sediments are overlain by marine mollusc-bearing silty sands that are present between 11 and 16 MASL. The mollusc species indicate sublittoral faunal assemblage (e.g. Ikonen and Ekman, 2001) and temperate saline water conditions (e.g. Korsakova, 2019). Based mainly on mollusc, foraminifera, and pollen results, the silty sands are thought to have been deposited during the LIG (Gudina and Yevzerov, 1973; Ikonen and Ekman, 2001; Korsakova, 2009, 2019) despite the slightly younger IRSL age of 109.9 ± 10.9 ka obtained from these sands.

6.18 Chapoma, Kola Peninsula, Russia

In the southeastern part of the Kola Peninsula (Fig. 6B), exposures at the Chapoma site occur in the river terraces on the bank of the River Chapoma, about 3.4 km from the river mouth (Gudina and Yevzerov, 1973). The exposure is approximately 25-m high. A till bed at the base is suggested to have been deposited during MIS 6 (known locally as the Moscovian glaciation; see Gudina and Yevzerov, 1973; Korsakova et al., 2004; Korsakova, 2019). Relevant to the present study, the till bed is overlain by clay, silt and sandy silt beds that span 6.5–10 MASL, and with abundant mollusc shells (Korsakova, 2019). The foraminifera fauna identified from these marine sediments include a rich and relatively warmwater-indicating fauna with species such as *Bulimina aculeata, Bolivina pseudoplicata and Hyalina baltica* (e.g. Gudina and

Yevzerov, 1973; Ikonen and Ekman, 2001). Pollen data from the marine sediments indicate a succession from a closed to open *Betula–Pinus* forests. Electron spin resonance dating obtained from molluscs at 9 MASL yielded ages of 128 ± 7.5 and 138.5 ± 9.6 ka, which supports deposition during the LIG. An additional marine bed at this section post-dates the LIG and was likely deposited during MIS 5a (see Discussion).

6.19 Strelna River, Kola Peninsula, Russia

Located just south of the Kola Peninsula, the Strelna site is situated approximately 7 km upstream from the mouth of the River Strelna (Fig. 6B). Many researchers, for example Grave et al. (1969) have studied the litho- and biostratigraphy for this >16-m thick sediment succession. The most recent summary of previous work is given in Korsakova (2019). At the base of this site is a 2.5-m-thick unit of mollusc-bearing fine sand and silt situated between 33 and 35.5 MASL. The ESR-dated molluscs from this unit yielded an age of 111.5 ± 11.2 ka. Taken together, the mollusc and diatom assemblages suggest that the basal marine sediments were deposited in a coastal environment, possibly indicating a sea level above 36 MASL (Korsakova et al., 2016). Pollen evidence suggest that a *Betula/Pinus* forest existed in the area (Grave et al., 1969). Accordingly, this unit is most likely correlative with the LIG (e.g. Korsakova et al., 2004; Korsakova, 2019).

6.20 Varzuga, Kola Peninsula, Russia

Exposures along the banks of the Varzuga River between the Koytolov and Kletnoy rapids (south of Varzuga village) have been studied by Lavrova (1960), Gudina and Yevzerov (1973), Apukthin (1978) and Lunkka et al. (2018). An exposure located on the right bank of the Kletnoy rapid (Fig. 6B) consists of a marine mollusc-bearing clayey silt at the base of the section (situated between 10 and 14 MASL), conformably overlain by glaciolacustrine silt and sand-rich silt (Site 'S1' of Lunkka et al., 2018). Pollen, diatom and foraminifera indicate that the marine silt was deposited in a sublittoral zone at water depths of 40–50 m during an interglacial stage, correlated with the LIG (Ikonen and Ekman, 2001, and references therein; Lunkka et al., 2018). Although the sedimentary sequence along the banks of the Varzuga River is glaciotectonized in places (Apukthin, 1978), the marine clay/silt situated between 10 and 14 MASL is *in situ*, where it is conformably overlain by glaciolacustrine silt at around 14 MASL. These overlying glaciolacustrine silts are thought to have been deposited during a later stage of MIS 5, prior to 88 ka (Lunkka et al., 2018). Capping the stratigraphic sections are two till units interbedded with sand and silt (Lunkka et al., 2018).

6.21 Petrozavodsk, Western Russia

Marine sediments assigned to the LIG were first noted in a borehole record from Petrozavodsk, western Russia (Fig. 6B), by Wollosovich (1908). These sediments are located at 40 MASL and conformably overlie glaciolacustrine clays (Wollosovich, 1908; Lukashov, 1982). A marine origin for these sediments is confirmed by saline diatom taxa (Ikonen and Ekman, 2001) and several mollusc species, suggesting saline conditions on the order of 10 to 15 ‰ (Funder et al., 2002). The LIG-age is based on correlation to the local pollen record (Lukashov, 1982; Ikonen and Ekman, 2001). Based on the pollen taxa and its correlation to the saline diatom taxa, Ikonen and Ekman (2001) showed that the marine phase prevailed in the area for a long time during the LIG, i.e. from the *Pinus-Betula* PAZ to the *Picea-Alnus-Carpinus* PAZ (possibly between 130–124 ka).

6.22 Peski, Western Russia

Miettinen et al. (2002) described a 32-m borehole record from Peski, western Russia (Fig. 6B). Sediments between 9 and 13.5 MASL were correlated to the LIG. The base of the borehole is a till (interpreted as deposited during the MIS 6 glaciation), followed by a dark bluish, organic-bearing clay and silt deposit containing *Portlandia arctica* molluscs between 10.5 and 11.5 MASL, interpreted as deposited during relatively deep-water marine conditions. The marine deposit is assigned to the LIG based on palaeoecological and stratigraphic context. Pollen data from this interval suggest warm conditions, especially the occurrence of *Corylus* and *Carpinus,* which are associated with the climatic optimum of the LIG (Miettinen et al., 2002). Diatoms contained in the marine unit suggest relatively deep-water, planktonic conditions, possibly representing the maximum of the marine transgression (Miettinen et al., 2002). Marine conditions were confirmed by the subsequent identification of dinoflagellate cysts and foraminifera in these sediments (Miettinen et al., 2014). The LIG unit gradually transitions to later-stage MIS 5 deposition, which is distinguished by a change to grey colour and cooler conditions deduced from pollen and diatoms. This transition likely indicates that sea level remained above 13.5 m throughout the entire LIG. Stratigraphically, the marine unit is overlain by a 16-m thick till associated with the advance of MIS 5d/b ice sheets (Miettinen et al., 2002).

6.23 Põhja-Uhtju, Estonia

Miettinen et al. (2002) described a Quaternary sediment sequence in a 70-m deep borehole from the Põhja-Uhtju island in Estonia (Fig. 6B). The base of the recorded stratigraphy is composed of sands and silty clay, interpreted as deposited during the MIS 6 deglaciation. Overlying these sediments, between 51–49 MBSL, is clay and silt, interpreted as marine in origin and suggesting a sea level above the present at that time. Above these are ~35 m of silty clays and tills, associated with later ice advances. The 51–49 MBSL interval is assigned to a LIG marine incursion, an interpretation based on their palaeoecological and stratigraphic context. Pollen data, especially the occurrence of *Corylus* and *Carpinus*, suggest warm conditions at the climatic optimum of the LIG (Miettinen et al., 2002). The diatom assemblage in these sediments suggest shallow marine to brackish water conditions.

6.24 Suur-Prangli, Estonia

Similar to the nearby island of Põhja-Uhtju, a borehole at Suur-Prangli, Estonia (Fig. 6B) records marine sediments assigned to the LIG. Liivrand (1987) reported a silt/clay sediment succession between 61 and 75 MBSL that is both overlain and underlain by tills. The diatom record suggests brackish-water conditions, followed by a shallow marine environment (Liivrand, 1991). This assignment to the LIG was based on stratigraphic position (bracketed by tills assigned to MIS 6 and MIS 4) and paleoclimate succession recorded in pollen composition, notably a maximum *Picea* and *Carpinus* interval

(Liivrand, 1991). As further justification for the LIG age assignment, the pollen assemblage observed at Suur-Prangli show a similar succession to nearby pollen successions (Forsström and Punkari, 1997) and a well-dated LIG pollen record from Germany (Field et al., 1994).

6.25 Lower Vistula Region, Poland (2 sites)

Extensive late Pleistocene stratigraphic records in the Lower Vistula region of Poland were first described by Roemer (1864). We describe two representative sites that later have been subject to extensive stratigraphic, sedimentological and palaeoecological analyses. However, we note that additional occurrences of LIG marine records from this areas are presented in Makowska (1986).

6.25.1 Obrzynowo

A 212-m borehole record from Obrzynowo, Poland (Fig. 6B), was first described in an unpublished report from the Polish Geological Institute at Warsaw University (Janczyk-Kopikowa and Marks, 2002), and was subsequently published in Knudsen et al. (2012). This borehole record (ground surface at 104.5 MASL) contains a sequence of glacial and interglacial deposits and intersects marine sediments between 108 and 115 m depth, which situates the entire marine sequence between 10.5 and 3.5 MBSL (Janczyk-Kopikowa and Marks, 2002; Knudsen et al., 2012). This record captures a beach/shoreline environment from 10.5–6.5 MBSL (fine-grained sand and silt with mollusc shells) that gradually transitions into deeper-water marine deposit from 6.5–3.5 MBSL (clays, silts and very fine sands). Dinoflagellate cysts and diatoms confirm saline conditions (Knudsen et al., 2012). These marine sediments are both overlain and underlain by tills, fluvial sediments, varved clays and organic-rich sediments and this site likely documents several glacial-interglacial transitions over the late Quaternary. The marine sequence at Obrzynowo has been assigned to the LIG based on its stratigraphic position and a comparison with the Licze core (discussed next; Head et al., 2005), as well as comparison to other regional pollen successions that have been assigned to the LIG (an interpretation especially based on the presence of *Picea* and *Carpinus*; Mamakowa, 1989, 1988).

6.25.2 Licze

A borehole record at the Licze site (ground surface at 87 MASL; Fig. 6B) records a transition from freshwater to marine conditions between 8–14.5 MBSL (Makowska et al., 2001; Zawidzka, 1997) in which there is freshwater molluscs that are gradually replaced by a marine assemblage. The first marine molluscs are present at 13.5 MBSL and they remain common until 8 MBSL (Mamakowa, 1989). Dinoflagellate cysts and diatoms confirm marine conditions through this stratigraphic interval and suggest warmer waters than present-day conditions (Head et al., 2005; Knudsen et al., 2012). Throughout this interval with sediment transition from silty sand to silt and clay suggests an environmental change (transgression) from a beach environment to deeper marine conditions (Makowska et al., 2001). These marine sediments are both overlain and underlain by extensive Quaternary deposits (tills, fluvial deposits, varved clays and organic-rich sediments). These marine sediments are assigned to the LIG owing to their stratigraphic position, along with a comparison to the pollen record at the Obrzynowo site (Head et al., 2005) and to other regional pollen successions, assigned to the LIG (especially due to the presence of *Picea* and *Carpinus*; Mamakowa, 1989, 1988)

6.26 Rewal coastline, Poland (3 sites)

Marine sediments bracketed by tills were described in several borehole records along the Rewal coastline, Poland, by Krzyszkowski et al. (1999) as well as by Krzyszkowski (2010). The marine sediments consist of fine-grained sand (known as the Rewal Sand) containing a rich assemblage or plant detritus and marine shells (largely boreal *Cardium* sp. (now *Cerastoderma),* but also *Astarte borealis*, and the boreal *Thracia popyracea;* Krzymińska, 1996). Krzyszkowski et al. (1999) suggested that these sediments represent deposition either a lagoon or a beach setting. They were assigned to the LIG based on their stratigraphic position. Both sites are overlain by the Ninikowo Till (assigned to the last glacial cycle) and underlain by the Pustkowo Till (assigned to MIS 6 glaciation; Krzyszkowski et al., 1999). Here, we describe the position of LIG marine sediments in three representative boreholes from this region (sites mapped in Fig. 6B).

6.26.1 Rewal borehole

The Rewal borehole (WH5) encountered a marine sand unit at an elevation between 5.5 and 13 MBSL (Krzyszkowski et al., 1999).

6.26.2 Ciećmierz borehole

The Ciećmierz borehole intersected a thin lens of the Rewal Sands situated between 6.5 and 8 MBSL. Additional pollen work suggests boreal conditions at the time of deposition of this marine unit (Krzyszkowski, 2010).

6.26.3 Sliwin borehole

The Sliwin borehole (WH4) encountered the marine unit between 6.3 and 9 MBSL (Krzyszkowski et al., 1999).

6.27 Ollala, Finland

Forsström et al. (1988) described a sediment exposure and four boreholes at Ollala in central Finland (Fig. 6B) on their lithology, pollen, plant macrofossil and diatom content. At borehole F, there is a till (>4 m thick) at the base above the Proterozoic crystalline bedrock. Overlying this till are < 1 m of glaciofluvial sands, which then change into silt (situated between 116.25 and 116.5 MASL) and then thick greenish gyttja (situated from 116.5–117.5 MASL). The silt and gyttja intervals contain diatom taxa indicating a shallow marine (saline and brackish water) basin passing upwards into fresh-water diatom taxa, typical for a lake basin. This change from saline to fresh-water taxa takes place in the lower part of the gyttja layer at 117 MASL, indicating that the fresh-water lake was isolated from the marine basin during the latter part of the LIG, likely the result of GIA uplift. Pollen data from this interval also clearly suggest that these sediments were deposited during interglacial conditions (Grönlund, 1991a, 1991b; Nenonen, 1995). The gyttja unit is overlain by 0.5-m of glacially sheared and compressed organic-rich material that is, in turn, overlain by up to 5-m thick Weichselian till (Forsström et al., 1987; Grönlund, 1991a). This marine gyttja unit is also present between 116.6 and 116.8 MASL at nearby borehole B (Forsström et al., 1987; Grönlund, 1991a).

6.28 Ukonkangas, Finland

The Ukonkangas site is a till-covered esker, located 8 km southeast of Kärsämäki, central Finland (Fig. 6B). According to Grönlund (1991b) the Ukonkangas pit exposes gravel at its base, overlain by ~0.5-m-thick bluish, organic-bearing silt (situated between 105.4 and 105.95 MASL). This silt bed is laterally continuous for 15 m in the exposure, suggesting it is *in situ*. Grönlund (1991b) interpreted the silt bed as deposited in a littoral zone of the LIG White Sea (Fig. 1), with time becoming more shallow and less saline. Pollen content indicates that the regional vegetation was forested and composed of broad-leaved trees and other pollen (e.g. *Osmunda*) indicating temperate climatic conditions (Eriksson, 1993). The diatom taxa are typical to the LIG White/Baltic Sea taxa, which also occur at the LIG sites in adjacent areas (Grönlund 1991a, b). The silt unit is overlain by parallel bedded sand, interpreted as beach sand (situated between 105.95 and 108 MASL; Grönlund 1991b). The top 2 metres of the section is composed of till (MIS 2?).

6.29 Viitala, Finland

At the Viitala site, located in western Finland (Fig. 6B), three borehole records documented a clay beneath the MIS 2 till (Nenonen et al., 1991). The clay unit is ~5 m thick. Diatom taxa indicate that the lower ~2 m of the clay was deposited in a large cool and freshwater basin during the early part of the LIG, and that the upper ~3 m was deposited in a brackish/saline littoral zone of the LIG White/Baltic Sea (e.g. Grönlund, 1991a; see Fig 1). These marine sediments are situated between 81.5 and 84.5 MASL. Pollen data from the entire clay unit suggest a lower birch-dominated zone (~2 m; freshwater sediments) and an upper birch–pin–-oak–hazel-dominated zone (~3m; marine sediments). The interglacial-type pollen taxa and the stratigraphical position of the clay suggest that the clay unit was deposited during the LIG (Nenonen et al., 1991; Eriksson, 1993).

6.30 Mertuanoja, Finland

The Mertuanoja region is in the outskirts of Ylivieska, Finland (Fig. 6B), and is the stratotype area for the LIG of southern Finland (Nenonen, 1995; Eriksson et al., 1999). We present a composite of several sediment exposures studied in the Mertuanoja area. At the base of the stratigraphy is a till, deposited during the Saalian glaciation (MIS 6) (e.g. Nenonen, 1995; Lunkka et al., 2016). Overlying this till is the Mertuanoja Clay (average thickness ~1.6 m), consisting of laminated silt and organic-bearing silty clay in its basal part overlain by a sand layer (2–20-cm thick), which is, in turn, overlain by laminated silt. Diatom data suggest deposition in a fresh-water environment in the basal part of the Mertuanoja Clay, changing to marine/brackish water, and then back to fresh-water conditions at deposition of the laminated silt and clay above the sand layer (Nenonen, 1995; Eriksson et al., 1999). Relevant to the present study is the transition from the fresh-water diatom taxa at the basal part of the Mertuanoja Clay into the marine taxa that takes place at around 59 MASL. Coastal marine conditions are recorded in this stratigraphic record until the sand layer at 60–61 MASL, interpreted as littoral sand. The pollen spectra from the Mertuanoja Clay suggests that it was deposited during interglacial conditions correlated to the LIG (e.g. Grönlund, 1991a; Nenonen, 1995). A sand and gravel unit overlying the Mertuanoja Clay was OSL dated to 110 ± 7 ka (Lunkka et al., 2019), followed by tills and an upper-most sand and gravel unit dated by radiocarbon methods to between 70 and 35 ka (Lunkka et al., 2016).

6.31 Norra Sannäs, Sweden

Sub-till marine sediments were intersected in boreholes in the vicinity of Lake Dellen, central Sweden (Fig. 6B), during field work carried out in the late 1980s and early 1990s. Robertsson et al. (1997) described a representative borehole record from Norra Sannäs (surface at 45 MASL) that shows a marine (littoral) sequence at 17.35-m depth in the core, which translates to 27.65 MASL. The diatom assemblage in clay sediments suggests deposition during marine to brackish conditions, which abruptly change to fresh-water diatoms at 17.1-m depth, suggesting the end of marine conditions (Robertsson et al., 1997). Stratigraphically, the marine sediments are overlain and underlain by tills that have been assigned to MIS 4 and MIS 6, respectively, thus suggesting a LIG age for the marine sediments. This age assignment is also supported by pollen data (Robertsson et al., 1997), which bear a similar succession to other LIG records from the region. The sole geochronological attempt at this site was a radiocarbon dating of the marine sediments that gave an age of 25.48 ka (Ua-1666); Robertsson et al. (1997) considered this age unreliable owing to a very low organic content at the sampled interval.

6.32 Fjøsanger, Norway

The Fjøsanger site, located in the outskirts of Bergen City (Fig. 6B), is situated along a small fjord, well inside the extent of the Scandinavian Ice Sheet during large Quaternary glaciations, including MIS 6 and MIS 2. The marine limit was 55 MASL during the last deglaciation, dated to 11.5 ka (Mangerud et al., 2019). Relevant to the present study, at Fjøsanger there is a continuous sequence of shallow marine sediments, presently situated between 0 and 15 MASL, where molluscs, foraminifera, and pollen show that the climate changed from cold to warmer-than-present conditions and back to cold (Mangerud et al., 1981). The sequence is covered by a till. The fauna, especially the boreal *Littorina littorea*, and the coarse-grained sediments (gravel) suggest very shallow-water sediments, but beach sediments were not found; thus, sea level was slightly higher. Correlation of the pollen stratigraphy with sites in the Netherlands, Denmark and Germany shows clearly that the warm period represents the LIG, a conclusion supported by the occurrence of the marine gastropod *Bittium reticulatum*, which is known only from the LIG sediments in Europe (Mangerud et al., 1981), and by TL ages (Hütt et al., 1983). Amino-acid stratigraphical correlation with classical European LIG sites yielded slightly high D/L values for Fjøsanger, but within uncertainty (Miller and Mangerud, 1985). A surprising, and indeed important, conclusion is that the

RSL at Fjøsanger was above 15 MASL from late MIS 6 through the entire LIG and into MIS 5d (Fig. 7) (Mangerud et al., 1981). We consider this as a secure conclusion because the Fjøsanger sequence shows a complete LIG succession and 15 MASL is the elevation of the top of the *in situ* marine beds. Fjøsanger was one of the first sites where it was demonstrated that the LIG (Eemian) should be correlated with MIS 5e, and not with the entire MIS 5 (Mangerud et al., 1979).

6.33 Bø, Norway

The Bø site is located on the eastern side of the large island Karmøy, on the extreme south-west coast of Norway (Fig. 6B). Like the Fjøsanger site, Bø is situated well inside the extent of the Scandinavian Ice Sheet during large Quaternary glaciations, including MIS 6 and MIS 2. The marine limit was about 16 MASL during the last deglaciation, dated to 17.5 ka (Vasskog et al., 2019). Relevant to the present study, interglacial sediments were found between 1 and 6 MBSL in an excavation, but only the upper 3 m could be sampled (Andersen et al., 1983). The interglacial sequence was covered by till and other sediments. The pollen stratigraphy (Andersen et al., 1983; Høeg, 1999) and amino-acid stratigraphy (Miller and Mangerud 1985; Sejrup, 1987) clearly shows that this site is LIG in age. The very early part of the interglacial is missing in the samples, but molluscs, foraminifera (Sejrup, 1987) and pollen show that the warmest part is present. Andersen et al. (1983) concluded that LIG RSL was more than 15–20 MASL because they postulate an open sea-connection across the island. Sejrup (1987) described paired shells of the boreal molluscs (*Lucinoma borealis* and *Pecten maximus*); these presently live-in water depths of 20–50 m and he postulated that sea level was this high during the LIG, however at lowest at the end of the interglacial. While we cannot determine a precise RSL at Bø, the results support the conclusion from Fjøsanger, namely that sea level in western Norway during the entire LIG was at least 15 m higher than the current sea level.

6.34 Hidalen, Svalbard, Norway

The Hidalen site is in eastern Svalbard, on the island of Kongsøya (Fig. 8B). The marine limit from the last deglaciation is about 100 MASL (Salvigsen, 1981). The stratigraphy at Hidalen contains three coarsening-upward sequences from marine silt to littoral gravel, separated by till beds (Ingólfsson et al., 1995). The youngest coarsening-upward sequence (Unit F) is of Holocene age, whereas the two older have non-finite radiocarbon ages. The oldest (Unit B) obtained a TL age of 148 ka and combined with the amino acid D/L ratio, Ingólfsson et al. (1995) considered Unit B to be of pre-LIG age. Based on the amino acid D/L values they argued that the younger Unit D is of LIG age. Mangerud et al. (1998) presented two alternative interpretations, the first being the one by Ingólfsson et al. (1995). However, they argued that it was more probable that the oldest Unit B is of LIG age. Kongsøya is a national park with strong regulations, and no Quaternary geologist has later been allowed to go ashore to solve this problem. For the present interest, we state that LIG marine sediments are present on Kongsøya and they span ~50 to >60 MASL. If Unit D is indeed of LIG age, then sea level was up to ~80 MASL. In our database, we have added both units, and note the controversy in age.

6.35 Kapp Ekholm, Svalbard, Norway

The Kapp Ekholm site (mapped in Fig. 8B; field photographs in Fig. 9) is in central Svalbard, ~14 km outside the large Nordenskiöldbreen glacier, which occupies the head of Isfjorden-Billefjorden. This implies that if Kapp Ekholm was ice free, glaciers on Svalbard were not much larger than at present. The marine limit during the last deglaciation was 90 MASL (Salvigsen, 1984) and the stratigraphy at Kapp Ekholm suggests that this site was repeatedly covered by ice during the Quaternary. The site was first described by Lavrushin (1967, 1969) who found the subarctic mollusc *Mytilus edulis* within one of the marine formations (Fig. 10). *Mytilus* requires warmer climate on Svalbard than during the 20th century (Mangerud and Svendsen, 2018). Kapp Ekholm is the only pre-LGM site on Svalbard where *Mytilus* or other "warm-water" molluscs are found.

Several marine and glacial units are found in superposition at Kapp Ekholm (stratigraphy shown in Fig. 9). The entire exposure is described in detail by Mangerud and Svendsen (1992); here we will only describe the formation containing *Mytilus* ('Formation B'), which is situated between 5 and 22 MASL. The lower ~5 m of Formation B contains thick marine mud with numerous floating stones (called 'marine diamicton'). The stones have probably rolled down the steep slope from the shore. Molluscs, including thick *Mya truncata*, in living position, are common and paired shells of subarctic *Mytilus edulis* are also found in this unit (Fig. 6). The mud is overlain by thin and almost horizontal sand beds, capped by 12 m thick, steeply dipping gravel foresets. The latter are interpreted as formed by long-shore drift, and the top (22 MASL) therefore reflects sea level during the formation. The entire Formation B suggests a shallowing during deposition and thus sea level was considerably higher than 22 MASL when the mud and sand were deposited. Chronologically, Formation B is dated with five OSL dates that yielded an average of 118 ka (Mangerud et al., 1998), suggesting a LIG age, subsequently supported by several IRSL dates (Eccleshall et al., 2016). Moreover, the frequent occurrence of the "warm-water" demanding *Mytilus edulis*, suggests that Formation B should be correlated with an interglacial in northern Europe when sea water was warmer than at present. Amino acid D/L values also strongly suggest that Formation B cannot stem from an older interglacial.

6.36 Skilvika, Svalbard, Norway

In southwestern Svalbard, Skilvika is located on western Spitsbergen (Fig. 8B). The site was first described by Semevskij (1967), and later studied by several scientists. A detailed description was provided by Landvik et al. (1992). The entire Quaternary exposure is 1-km long and stretches up to 35 MASL. Most of the exposure consists of Formations 3 and 4, which are the candidates for the LIG age and together span 15 to 30 MASL (stratigraphy summarize in Fig. 11). Formation 3 is a coarsening upward sequence from glaciomarine silt, through sand (shoreface) to cross-bedded gravel (foreshore). The overlying Formation 4 consists of a strange sediment, namely foresets of boulders and containing marine fossils in sand lenses between the up to 2-m large boulders. The foresets of Formation 4 interfinger with the beds in Formation 3 (Figs 11 and 12). The interpretation is that Formations 3 and 4 together represent a prograding beach showing a sea level about 30 m above the present (Landvik et al., 1992). Formation 4 was formed by an advance of the local glacier. There were found neither foraminifera (Lycke et al., 1992) nor molluscs (Landvik et al., 1992) that require as warm water as at present and based on TL ages and amino acid D/L values Landvik et al. (1992) concluded a MIS 5c age, which was also accepted by Mangerud et al. (1998), although with the comment that "an Eemian age cannot be ruled out". Alexanderson and Landvik (2018) then performed an extensive dating program, obtaining 20 OSL ages from Formation 3. The result was large spread in ages from 66–263 ka, although when excluding two outliers the range was 99 ± 7 to 149 ± 17 ka, with a mean of 119 ± 5 ka (n=18). After another quality screening, they obtained a mean age of 118 ± 7 ka (n=10). The conclusion is that Formations 3 and 4 probably are of LIG age, although warm-water species are missing, and a MIS 5c age cannot be excluded. The RSL was about 30 MASL.

6.37 Kongsfjordhallet, Svalbard, Norway

The site Kongsfjordhallet is located on the north shore of Kongsfjorden, northwestern Spitsbergen (Fig. 8B). Marine limit during the last glaciation was about 40 MASL. (Lehman and Forman, 1992). These exposures have been studied by several scientists, apparently first by Boulton (1979). The oldest Quaternary marine units are probably about 1 million years old (Houmark-Nielsen and Funder, 1999). In this review we mainly rely on results reported by Alexanderson et al. (2018). Relevant to the present study, units 4 and 5 are considered to be of LIG age. The altitude of these units varies along the ~700 m studied section of the coastline, but they are largely present from 27–34 MASL. The base of these sediments is ~1.5 m thick glacimarine mud. This is overlain by up to 3-m-thick littoral sand and gravel, suggesting a shallowing due to glacial isostatic uplift. The assumed LIG age is based on two OSL dates with an average of 132 ± 7 ka, supported by a diverse foraminifera fauna (Alexanderson et al., 2018). This age is also consistent with the chronology of the entire sequence. We find it probable that these units are of LIG age, although based on two OSL ages only. The RSL was about 34 MASL when the littoral sands and gravels were deposited. However, the units are parts of an emergence cycle; thus, sea level was initially higher than indicated by the littoral sediments.

6.38 Poolepynten, Svalbard, Norway

The Poolepynten site is located on the island Prins Karls Forland on the west coast of Spitsbergen (Fig. 8B). The marine limit from the last deglaciation is about 40 MASL (Forman, 1990). The site was first described by Miller (1982) and later in more detail by Bergsten et al. (1998), Andersson et al. (1999) and Alexanderson et al. (2013). The site has attracted much interest because the oldest known bones of polar bear (*Ursus maritimus*) were discovered here (Ingólfsson and Wiig, 2009; Lindqvist et al., 2010). In the present review, we mainly rely on results reported by Alexanderson et al. (2013). The exposure shows a sequence of several marine and glacial units with ages between 10–130 ka as dated with different geochronological methods. The lowermost unit (named A1 in Alexanderson et al., 2013) is considered to be of LIG age, and is the only unit discussed here. It is exposed between 2 and 4 MASL and consists of thin sand beds with scattered pebbles, shell fragments and kelp, and it is interpreted as shallow marine or sublittoral deposits. The polar bear jaw was found in this unit.

The LIG age of unit A1 is based on several lines of evidence: the stratigraphical position, amino acid D/L values (Miller, 1982), slightly warm foraminifera fauna (Bergsten et al., 1998), the phylogenic position of the polar bear mandible (Lindqvist et al., 2010), and two robust OSL ages of 118 ± 13 and 105 ± 10 ka (Alexanderson et al., 2013). We consider it very probable that Unit A1 is of LIG age and that it indicates a RSL of 2–4 MASL. However, as with all other sites on Svalbard, the unit is interpreted as part of an emergence cycle caused by GIA uplift. Thus, the mentioned sea level does not show the LIG highstand and possibly neither the lowstand.

6.39 Leinstranda, Svalbard, Norway

The Leinstranda site is located on the northwest coast of Spitsbergen (Fig. 8B). The site was discovered by Troitsky et al. (1979) and later studied by several scientists, in most detail by Miller et al. (1989) and Alexanderson et al. (2011b). A synthesis and critical review was provided by Alexanderson et al. (2011a). The marine limit from the last deglaciation is 46 MASL (Forman, 1990). The sequence consists of several formations of marine, beach and glacial sediments dated to 200–10 ka with different geochronological methods. The units considered to be of LIG age are found between 16 and 19 MASL. The lower part consists of 2-m-thick glaciomarine silt considered to reflect a sea level about 80-m higher than at present. The sediments are coarsening upwards to shore-face sand reflecting a sea level of 20 MASL at its formation. Almost all dated samples are collected from the shore-face sand. Marine mollusc shells, some being paired, are found in all units. All species are common on Svalbard today.

Miller et al. (1989) found a foraminifera fauna that suggested slightly warmer conditions than at present and named the unit for the Leinstranda interglacial. Their amino-acid results suggested a LIG age, which subsequently was supported by IRSL dating (Forman, 1999). We consider four recent OSL dates, with an average of 129 ± 10 ka, to provide the most reliable age (Alexanderson et al., 2011a; Alexanderson et al., 2011b). The conclusion is that Leinstranda represents a LIG site. The sea level was above 20 MASL when the dated bed was deposited and sea level was thus considerably higher before. Whether sea level later in the LIG dropped even lower due to glacial isostatic uplift is unknown.

6.40 Galtalækur site in Jökulhlaup valley, Iceland

Van Vliet-Lanoë et al. (2018) describe, in central southern Iceland, marine sediments exposed in deeply incised valleys (Rangá, Þjórsá and Hvítá rivers) that formed because of late glacial jökulhlaups (flooding events) from nearby glaciers (Fig. 13B). The Rangá Formation is around 30-m thick and records two separate marine transgressions following the MIS 6 deglaciation of the region. The marine unit (represented by the regional stratigraphic unit R-C2) consists largely of sands draped by thin silt sediment, representing a coastal fluvial setting, where a tidal delta formed in an estuary (Van Vliet-Lanoë et al., 2018). It is best preserved at the Galtalækur site, where it is located at approximated 120 MASL (extracted from a stratigraphic plot; exact measurements at that site were not provided). The Rangá Formation sediments are assigned to the

LIG based on stratigraphic context, absolute dating and tephrachronology. From a stratigraphic standpoint, the Rangá Formation is overlain by extensive deglaciation deposits (tills, glaciofluvial and glacial marine sediments) that are dated to the Holocene via tephrachronology (presence of Vedde ash; Van Vliet-Lanoë et al., 2018). Contained in these marine sediments is a tephra layer from the Grimsvötn volcano which is dated to the LIG based on its position in North Atlantic marine cores (Davies et al., 2014). Both underlying and overlying units that bracket the Rangá Formation have absolute ages. Van Vliet-Lanoë et al. (2018) presented three K-Ar ages on the glacio-volcanic unit that underlies the Rangá Formation between 155 and 129 ka. Two other ages from this unit (using the $^{39}Ar/^{40}Ar$ method) also yielded ages in this range (Clay et al., 2015; Flude et al., 2008).

6.41 Region of Scoresby Sund, East Greenland (8 sites)

Last Interglacial sites in the region of Scoresby Sund, eastern Greenland, were the subjects of intensive research in the early 1990s as part of the Polar North Atlantic Margins; Late Cenozoic Evolution (PONAM) project, which resulted in several papers published in the mid-1990s. A common indicator of LIG age is the presence of warmer-water than today fauna, e.g. *Balanus crenatus.* Present are also members of the Astarte genus, some arctic and some subarctic to their biogeography (Funder et al., 2002). The presence of *Astarte borealis*, generally regarded as an Arctic species, is, however, thought only possible in this region under conditions of increased advection of Atlantic water, which occurred only during the LIG and the Holocene (Vosgreau et al., 1994). Some sites are also constrained to the LIG based on >20 luminescence ages (Mejdahl and Funder, 1994). Below, we present 8 locations where these LIG sediments were documented in the vicinity of Scoresby Sund. The coordinates for these sites are estimated from maps in the original publications.

6.41.1 Kikiakajik section

At Kikiakajik (Fig. 13C) there is a 700-m long and 10–15-m high coastal cliff, but it is partly covered by perennial snowbanks. Mangerud and Funder (1994) cleaned and described two exposures. The first exposure has a coarsening-upwards sequence from horizontally bedded marine silts at 3.5 MASL through sand to gravel foresets, which are cut by a till at 7.5 MASL. The second exposure consists only of the gravel foresets at 9–13 MASL, covered by till. The silt and sand contain a molluscs fauna similar to the one described at Kap Hope, including *Balanus crenatus* and the warmer than today-indicating *Astarte borealis*. A single shell was radiocarbon dated to >44 ka, and the sand was dated with TL to 132 ± 10 ka. The distinct fauna strongly suggests a correlation between Kap Hope and Kikiakajik, and the warm water requirements of the fauna together with the dates from both sites indicate a LIG age.

6.41.2 Kap Hope

At Kap Hope there is a 20-m high coastal section where Mangerud and Funder (1994) described a marine silt between 2 and 3 MASL, directly overlying bedrock (Fig. 13C). The silt contains a rich *Astarte* fauna including the warmer-water species *Balanus crenatus* and *Astarte borealis,* which are not living in East Greenland today. The fauna suggests an offshore environment warmer than at present. From the silt there is a coarsening upward sequence through sand (well-sorted, ripple laminations with gravel lenses) to gravel (includes well-rounded boulders), representing a regression from off-shore through shoreface to beach environment at 10 MASL. The beach sediments are covered by a 5-m thick sandy gravel interpreted to suggest a rising RSL, eventually capped by a till. Two radiocarbon dates from individual shells gave non-finite ages (>42 ka) and two TL/OSL dates from the shoreface sand yielded 97 ± 10 and 75 ± 8 ka, respectively. Mangerud and Funder (1994) assigned the entire clay-sand-gravel sequence to the LIG based on the fauna and supported by the TL/OSL dates, although the latter yielded too young ages. In the database, we have added separate entries for both the regressive and transgressive units.

6.41.3 Kap Stewart composite

Marine sediments assigned to the LIG are present from 0.5–40 MASL around Kap Stewart (Tveranger et al., 1994; Fig. 13C). In their study, the authors examined several sites to better understand the sedimentology and to find as many fossils as possible. However, ultimately, all sedimentary structures, dates and fossils were assumed to represent one single site, which we follow here. To provide additional context on the LIG marine event, we provide a brief overview of each individual site below.

At Loc. 471 marine sediments interpreted as deposited in a tidal, shallow marine delta environment were found between 9 and 12 MASL and at Loc. 473 similar sediments were found at 0.5–8 MASL (Tveranger et al., 1994). These sediments contain marine molluscs suggesting warmer-than-present water. Based on these molluscs and the stratigraphic position below diamicton and more recent sediments, these deposits were assigned a LIG age. From Loc. 473 the interglacial unit could be mapped on the surface some 500-m inland (towards the north) to Loc. 468 where the unit consists of tidally influenced channels and estuarine/lagunal deposits up to about 40 MASL. The unit was mapped through Loc. 470 where it consists of trough cross-bedded sand and gravel located between 30 and 38 MASL and interpreted as fluvial deposits with paleocurrents towards the fjord. The interpretation is that the transition from marine to a coarsening upwards fluvial sequence reflects a progradation of the paleo-Ostraelv river delta. The vertical stacking of tidal channels and the thickness of fluvial deposits indicate that progradation took place during a RSL rise up to about 40 MASL.

6.41.4 Hesteelv composite

Similar to the Kap Stewart site, in the Hesteelv area (Fig. 13C), workers examined several sites to better understand the stratigraphic record (Tveranger et al., 1994). Ultimately, all sediment successions, dates and fossils from studied sections were assumed to represent the same marine unit, situated between 5–35 MASL, and tied to the LIG. For additional context on the LIG marine sediment, we provide below a brief overview of some individual sites.

At Hesteelv 13 outcrops, located in an area stretching 5 km along the fjord and 1 km inland, were cleaned and sedimentological logged in detail (Tveranger et al., 1994). Sediment units could (at several places) be traced on the surface between the outcrops and the correlations between the outcrops mentioned here are considered reliable. At Loc. 153 a continuous outcrop was cleaned from 5–71 MASL and this is a key exposure for the full stratigraphy of the area but here we will only describe the LIG sequence (Unit A in Tveranger et al., 1994), which is found 5–35 m MASL. The lower 15 m consist of 2–50-cm thick sandy turbidites interbedded with massive or weakly laminated mud layers containing molluscs, dropstones and synsedimentary slumps. The turbidites are overlain by low-angle, cross-stratified sand, with layers of gravel, and sand with climbing ripples and planar cross-bedding. Depositional direction was towards the fjord (i.e. south) throughout the unit. The unit is interpreted as a prograding delta sequence with transition from offshore turbidites to shoreface deposits with migrating bars. The altitude and facies indicate a sea-level between 35 and 40 MASL. The interglacial sediments are overlain by a till, interstadial marine sediments and another till and deglacial sediments, not described here. The LIG unit can be followed from Loc. 153 to Loc. 152 (18–30 MASL) and Loc. 154 (9–33 MASL) by surface mapping. Both localities have a coarsening upward sequence like that at Loc. 153 and thus support the interpretation there. Last interglacial sediments were described also from some of the other outcrops and fossils collected. At some places erosional, regressive facies are mapped and interpreted to stem from the subsequent falling RSL. Several terrestrial plant macrofossils (e.g. *Betula pubescens*), beetles and marine molluscs (e.g. *Mytilus edulis*) collected from the LIG unit in different outcrops show warmer-than-at-present climate, and mean July temperature was estimated to have been about 5 °C (Tveranger et al., 1994). Thus, an interglacial origin is clear. The average of 9 OSL ages is 115 ± 29 ka and suggests a LIG age, which is consistent with the full stratigraphy at the site and indeed by correlation with other sites along Scoresby Sund (Vosgerau et al., 1994).

6.41.5 Site 443d, Fynselv area

At Site 443d (Fig. 13C), marine sediments were identified between 12 and 21.5 MASL, dated by TL/OSL to 120 ± 10 ka, 121 ± 10 ka, and 122 ± 10 ka (Hansen et al., 1994). The marine sediment succession was interpreted as deposited in a deltaic to shallow marine environment (units Ib, Ic, Id). These marine sediments are overlain by a till followed by marine sediments, representing a later incursion.

6.41.6 Langelandselv composite

Like the Kap Stewart and Hesteelv sites, workers in the Langelandselv region (Fig. 13C) examined several sites to better understand the stratigraphic record (Landvik et al., 1994). The LIG marine unit (amalgamated from several sites) spans 0–70 MASL. For additional context on the LIG marine sediment, we provide below a brief overview of some individual sites.

At sites 77A and 77D, a layer of marine silts and sands is situated between 0 and 5 MASL (Landvik et al.,1994). OSL/TL dating of the uppermost silt sediments yielded 122 and 121 ka (Mejdahl and Funder, 1994). Nearby, at sites 74 and 76A, marine silts and sands were documented between 4 and 11 MASL. These marine sediments are overlain by ~10m of sand, interpreted to be of fluvial origin. These were OSL/TL dated to 100 ka, 106 ka, 117 ka and 129 ka, the whole sediment succession suggesting an environmental change from marine conditions into a fluvial setting (Landvik et al.,1994).

At four sites in the Langelandselv region (sites 95, 96, 97 and 113), LIG marine sediments are situated at an anomalously high elevation. Landvik et al. (1994) suggested these marine sediments were deposited early during the LIG during isostatic recovery from the MIS 6 glaciation and were believed to represent an earlier interval than the other sites from the Scoresby Sund area, typically situated much closer to present-day sea level. At sites 95, 96 and 97, Landvik et al. (1994) described a sand unit containing ripple and herring-bone cross-beds, situated between 44 and 57 MASL. These sands were interpreted as a shallow marine environment and were OSL dated to 117 ka (Landvik et al., 1994). The mollusc assemblage in these sands suggests deposition during a warm-water interval, which is also indicative of the LIG (Vosgreau et al., 1994). Finally, at site 113, Landvik et al. (1994) described marine sand (Unit A_0) situated between 67 and 70 MASL.

6.41.7 Location 72, Aucellaelv River

On the north shore of Scoresby Sund, along the Aucellaelv River (Fig. 13C), are marine sediments at the base of the stratigraphic record which consist of mollusc-bearing (largely *Astarte borealis*) sand and silt, situated between 12 and 16 MASL, and interpreted as deposited in a sublittoral shallow marine environment (Unit 2; see Israelson et al., 1994). The sediments were dated via OSL and TL to 122 and 144 ± 15 ka (sample R9110004). A broad LIG age is also suggested by the presence of warm-water mollusc fauna. The marine sediment unit is both underlain and overlain by till and on top is sediment from a later marine event.

6.41.8 Lollandselv-Falsterselv region, Greenland

Ingólfsson et al. (1994) noted LIG marine sediments at 23 stratigraphic sites between the Lollandselv and Falsterselv rivers (Fig. 13C). A composite diagram of these sites shows shell-bearing marine silts situated between 0 and 8 MASL in this region (Ingólfsson et al., 1994). The maximum elevation of marine sediments in this location is 20 MASL. The authors interpreted these marine silts as deposited during the LIG, representing a transition from glaciomarine to tidal and eventually a littoral depositional setting. Macrofossils (plants, molluscs) suggest temperatures warmer than the Holocene. These LIG marine sediments are overlain by a series of cross-bedded sands (fluvial), till (ice advance), topped by sediments suggesting a later marine incursion.

6.42 Thule, Western Greenland (7 sites)

Kelly et al., (1999) described three separate marine events in sediment sequences from western Greenland (Fig. 13D). The middle marine sediment succession (known as the Qarmat Event) contains mollusc shells from *Mya truncata*, *Hiatella arctica* and *Chlamys islandica*. The age of these marine sediments is assigned to the LIG, based on TL ages between 91–154 ka (mean age at 127 ka). The Qarmat sediments coarsen upwards, and the uppermost sediments have wave influenced sedimentation. We outline 7 sites below (locations mapped in Fig. 13D), as described by Kelly et al. (1999). Some of the chronological data are from Sejrup (1990).

6.42.1 Iterlak K

Sands and muds are situated from 25–27.5 MASL. Marine shells are present, and two amino acid dates suggest deposition during the LIG, which is supported by a non-finite radiocarbon age.

6.42.2 Iterlak L

Sands and muds are situated from 11–14 MASL. No marine shells or foraminifera were noted, but a TL age suggests deposition at 118 ka.

6.42.3 Saunders Ø B

The Qarmat marine event is situated between 3–20 MASL. Glaciomarine muds are present from 3–6 MASL. Overlying the glaciomarine sediments is a ~1-m interval of sands, followed by clast-supported gravels with varying amounts of mud and sand, which was interpreted as a beach deposit. Marine shells are present. Three TL ages from the lower-most sediments yielded 154 ka, 153 ka and 119 ka.

6.42.4 Saunders Ø C

The marine interval spans 5–12 MASL. The lower part of the section consists largely of sands which gradually coarsens to sandy gravels at ~8 MASL, which was interpreted as a beach deposit. Marine shells are present and the uppermost sediments, at ~12 MASL, were dated with a TL to 91 ka.

6.42.5 Narsaarsuk D

Sand with occasional coarse gravel beds are situated from 0–6 MASL. The sediments have signs of being wave influenced. Marine shells and foraminifera are present, and amino acid dating of shells suggest deposition during the LIG.

6.42.6 Narsaarsuk E

Clay and silt, transitioning to sands are situated from 11–17 MASL. Marine shells and foraminifera are present. A TL age from the upper sediments suggests deposition at 119 ka, which is supported by amino acid dating suggesting a LIG timeframe, as do two non-finite radiocarbon ages.

6.42.7 Narsaarsuk F+G

At this site, sand with occasional coarse gravel beds is situated from 3–9 MASL. Marine shells, foraminifera and plant matter are present. Amino acid dating suggests deposition of these sediments broadly within the LIG, which is supported by a non-finite radiocarbon age as well as a TL age of 123 ka.

6.43 Iles de la Madeleine, Quebec, Canada (3 sites)

In eastern Canada, the Iles de la Madeleine contains sediment exposures bearing an extensive stratigraphic record that details the interplay between sea level and Pleistocene ice sheets. Marine sediments assigned to the LIG have been described at three sites, shortly described below.

6.43.1 Camping site

Rémillard et al. (2017) described marine sediments (Fig. 14B) along the cliffs of the Iles de la Madeleine that overlie local bedrock. These sediments consist of fine to medium red sand with gravel beds, moderately to poorly-sorted, and 10–30 cm in thickness. This unit was located at 14 MASL with a maximum thickness of 4 m. The sediments were interpreted as a barrier beach sediment displaying alternating low and high energy fluctuations and were assigned to the early part of MIS 5 (likely 5e), based on an IRSL age of 115 ± 8 ka (OSL51; Rémillard et al., 2017). The unit was originally interpreted as being marine limiting, which we have kept, despite a beach barrier being more strictly a terrestrial limiting deposit.

6.43.2 Portage du Cap

The Portage du Cap site (Fig. 14B) was first described by Prest et al. (1976) and subsequently by Dredge et al. (1992). At this site, a sequence of sub-till silts, pebbles and gravel are exposed within a gravel pit. The entire marine sequence spans 14–17 MASL (Dredge et al., 1992). Underlying the entire marine sequence is sandstone bedrock containing borings from *Zirfaea* sp., a species that lives in the modern intertidal zone in the region. The lowest unit, situated at 14 MASL, is a grey marine silt, rich in dinoflagellate cysts, containing a pollen, beetle and diatom assemblage suggesting conditions warmer than present-day in the region (Dredge et al., 1992; Prest et al., 1976). Within this unit there are clast-supported beach gravels with well-rounded pebbles. Overlying the gravel unit is a 1–2 m thick organic sand unit with a woody organic horizon. For this reason, the lowermost section of this stratigraphic sequence has been assigned to a LIG marine incursion that immediately followed the removal of MIS 6 ice from this area. On top of this unit is a gravel unit with a pollen assemblage similar to present-day, likely the result of relative climatic cooling following peak LIG conditions, paired with local sea-level rise and beach formation (Dredge et al., 1992). Three radiocarbon ages are available at this site. Plant detritus and wood have been dated to >38 ka and >35 ka (GSC-2313 and BGS-259; Prest et al., 1976) and a marine shell was dated to 42.9 ± 0.72 ka (GSC-4633 HP; McNeely and McCuaig, 1991). The finite age on the marine shell is possibly beyond the reliability limit for dating marine shells (Pigati, 2002), and all radiocarbon ages considered as minimum.

6.43.3 Le Bassin site

Dredge et al. (1992) described a stratigraphic section of sub-till peat overlain by clays, sands and gravels at the Bassin site, Iles de la Madeleine, Canada (Fig. 14B). At the base of the section overlying bedrock is a 0.5-m sand interval, followed by a 0.2-m peat layer. This was interpreted as formed in nearshore fluvial and lacustrine environments. Overlying the peat layer is a 0.9-m silt and clay unit, followed by 0.1 m of sand, both interpreted as marine in origin based on the presence of warm-water oyster shells (*Ostrea virginica*). The altitude of these marine sediments is unclear; we assume the base of the stratigraphic section is 0 MASL ('just below tide level' according to Dredge et al., 1992), which would situate the marine silt, clay and sands between 0.7 and 1.7 MASL. Pollen data from these sediments suggest conditions similar to present-day (Mott and Grant, 1985). The sub-till sediments suggest that, following deglaciation of this region, the local area became a peatland and, as sea levels rose, it transitioned to a lagoon environment, with beach ridge and coastal barrier formation (Dredge et al., 1992). Three U/Th ages on these sediments range from 89–106 ka (UQT-182, UQT-183, UQT-184) and were interpreted as minimum age constraints by the original authors. Two diamictons (interpreted as tills deposited during ice advances) truncate the sand unit. Based on pollen and stratigraphic position, Dredge et al. (1992) suggested a LIG age assignment.

6.44 Clyde Foreland, Baffin Island, Canada (3 sites)

First described by Løken (1966) and Feyling-Hanssen (1967), sub-till mollusc-bearing marine sands are present along cliffs of the Clyde Foreland, Baffin Island (Fig. 14C). These are known as the Cape Christian marine sediments. Several radiocarbon dating attempts on organic material from this unit yielded infinite ages or finite ages (e.g. QL-188) that can be considered as minimum ages. Feyling-Hanssen (1967) suggested that these sediments were deposited during the LIG owing to its content of relatively warm-water-indicating foraminifera (*Cassidulina teretis*). Warm conditions were confirmed via pollen analyses. Later, these sites were re-visited by Miller et al. (1977) who reported a ^{230}Th age of 130 ka. Below, we document 3 of these sites, as described by Miller et al. (1977). These sites are correlated to each other based on stratigraphic position and amino acid ratios.

6.44.1 Profile 6

Cape Christian marine sediments are situated between 27 and 28 MASL. They are underlain by a series of sands and tills and overlain by a thin layer of buried soil along with till from later Pleistocene ice advance.

6.44.2 Profile 9

Cape Christian marine sediments (coarse sand and cobbles) are found between 9 and 11 MASL. These marine sediments are overlain by two tills and younger marine sediments. This is the type section for the Cape Christine marine sediments.

6.44.3 Profile 10

Miller et al. (1977) documented coarse sands and gravels between 1.8 MASL and 2.5 MASL, which they correlate to the LIG Cape Christian marine sediments.

6.45 Ile aux Coudres, Quebec, Canada

Occhietti et al. (1995) described a core taken on Ile aux Coudres, located in the Saint Lawrence Estuary, Canada, that showing a succession of Pleistocene-aged deposits (Fig. 14B). A till was noted at the base of this record (known as the Baie-Saint-Paul glacial complex), followed by a series of clays, rhythmites and deltaic sediments, known as the "Guettard Sea" sediments, present from 125–2 MBSL. Occhietti et al. (1995) described, at the base of this stratigraphic unit, a very compact, finely stratified grey clay between 125 and 102 MBSL. A dinoflagellate cyst at 119 MBSL suggests a marine origin for these sediments, and the authors interpreted it as a transgressive prodeltaic (deep marine) deposit. Next, between 102 and 71 MBSL, are grey rhythmites, hypothesized to be a high-level prodeltaic deposit resulting from the gradual shallowing of marine waters. Lastly, the sediment core shows silts and sandy silts between 71 and 2 MBSL, interpreted as prodeltaic, transitioning to deltaic sediments. This uppermost unit contains benthic foraminifera common to brackish marine water. Based on stratigraphic context (i.e. heavily isostatic depression following large-scale glaciation), Occhietti et al. (1995) aligned this record with the transition period between MIS 6 and the LIG. They inferred a large-scale, long-lasting glaciation followed by ice recession, rapid marine inundation into the isostatically depressed landscape, and shallowing of marine waters owing to subsequent rebound. This accumulation of marine sediments may represent 3.5 kyrs of deposition (Occhietti et al., 1995). Since the age of the deposit is based on regional correlations and environmental conditions from pollen assemblage composition, rather than direct dating, we assign the lowest age quality score.

6.46 Bridgehampton, New York, United States

Marine sediments, typically sandy clay that is brown or grey/green in colour, were first encountered at depth on Long Island, New York in the early 1900s (Fuller, 1914; Fig. 14B). The so-called "Gardiners Clay" is present at depth in several borehole records between 20 and 45 MBSL in various well records in this region (Nemickas and Koszalka, 1982). Paleontological work revealed a variety of warm-water fauna, including foraminifera, coelenterata, bryozoa and mollusca (Gustavson, 1972), confirming a marine origin for these sediments. At the Bridgehampton site, the Gardiners Clay was encountered between 23 and 46 MBSL (Nemickas and Koszalka, 1982).

The Gardiners Clay is provisionally assigned to the LIG, based on stratigraphic context and amino acid dating. Stratigraphically, this marine unit is overlain by a series of Pleistocene deposits, notably the Montauk till, associated with the most recent (MIS 2) glaciation (Nemickas and Koszalka, 1982). Moreover, at some sites, the Gardiners Clay is underlain by a gravel deposit (Jameco Gravel; Fuller, 1914) that has been associated with fluvial or glaciofluvial deposition immediately following retreat of the MIS 6 ice sheet and prior to the marine incursion. The interpretation of the age is complicated by the fact that no amino acid racemization had been conducted on shells from the Bridgehampton site. However, shells contained in the Gardiners Clay from a nearby outcrop (40002; the stratigraphy of which was not described in detail) yielded an age assignment of early MIS 5 (Wehmiller et al., 1988; Wehmiller and Pellerito, 2015). The significant difference in elevation and depositional context (at-depth in a drill core vs. sub-aerial outcrop) implies the Gardiners Clay might represent two marine deposits of different ages.

6.47 Kwataboahegan River, Ontario, Canada

The Hudson Bay Lowlands contain a rich stratigraphic record consisting of tills interspaced by non-glacial sediments. Along the Kwataboahegan River (Fig. 14B), *in situ* marine sediments were first discovered underlying till by Bell (1904), and later described in detail by Skinner (1973). These so-called "Bell Sea" sediments were first reported to be at 75 MASL (Skinner, 1973), however subsequent geochronological work on samples originally obtained by Skinner (1973) report the elevation as 90 MASL (McNeely, 2002). The reason for this discrepancy is unknown. These marine sediments consist of 0.8 m compact bluish grey sand and silt that are deformed owing to subsequent Wisconsinan ice advance over the region. An 'undulating bed of marine mollusc shells' is present near the mid-point of the sediment package (Skinner, 1973).

The Bell Sea sediments are assigned to the LIG based on stratigraphic context, amino acid dating and minimum limiting radiocarbon ages. Stratigraphically, this marine deposit is overlain by tills that are assigned to the MIS 4 and MIS 2 glaciations. Amino acid dating also supports a LIG assignment for the Bell Sea sediments; Andrews et al. (1983) show that isoleucine epimerization ratios from shells in the Bell Sea sediments (average of ~0.2) are significantly older than ratios from assumed mid-Wisconsinan marine deposits (~MIS 5-3) in this region (average of ~0.14), which are even older than shells from the post-LGM marine incursion (average of ~0.03). In calculating the amino acid dates, the average regional diagenetic temperature (0.6°C) can only be reconciled with the isoleucine epimerization ratios if the smallest isoleucine epimerization ratio (Bell Sea sediments), is assigned to the LIG (Andrews et al., 1983). For that reason, the Bell Sea sediments were assigned to ~130 ka (Andrews et al., 1983). Finally, two radiocarbon ages on marine shells (*Hiatella arctica*) from the Bell Sea deposit yielded >37 ka (GSC-1475; Blake, 1988) and 47.85 ± 1.09 ka (TO-2503; McNeely, 2002). The finite age is unreliable because shells samples are susceptible to modern-day contamination, and the date is very close to the limit of radiocarbon dating (McNeely, 2002). Thus, both are considered as minimum limiting radiocarbon ages.

6.48 East of Nicholson Peninsula, Northwest Territories, Canada

Along the westernmost coastline of the Northwest Territories, Canada, sediments representing the Liverpool Bay Interglaciation are exposed as part of the Ikpisugyuk Formation (Fig. 14D). As described by Rampton (1988), a layer of organic-bearing marine sand and silt is present between 0 and 2 MASL (Locality VH-83-050), which was interpreted as an intertidal beach complex. Fossils from a nearby exposure of the Ikpisugyuk Formation (VH-83-040; does not contain a marine unit) suggest a climate warmer-than-present, which supports LIG deposition (Rampton, 1988). Radiocarbon age attempts on driftwood contained in this unit were non-finite (GSC-3722) and amino acid ratios 0.1–0.15, both supporting a LIG age assignment based on the amino acid framework for nearby Banks Island (Vincent, 1982, 1983).

7 OTHER LIG MARINE SITES

During our search for sites to include in this database, we located several LIG sites containing marine sediments that are not *in situ*, mostly due to post-depositional deformation and/or relocation. These sites are thus unsuitable as indicators of RSL but merit inclusion in this paper. We describe several such sites below, ordered east to west.

7.1 Lower Ob sites, West Siberian Plain, Russia

As shown in Fig. 4, the stratigraphic record present at the Lower Ob sites, West Siberian Plain, contains a well-dated LIG section consisting of alluvial sediment with OSL ages of 125–138 ka and thick peat with U/Th ages of 133 and 141 ka. These terrestrial sediments occur at the same altitudes or slightly higher than the corresponding marine sediments of the Arctic. However, marine sediments at the base of this stratigraphic sequence (separated from the overlying terrestrial beds by a till) yielded a youngest age of 153 ± 15 (sand with rich fauna of boreal foraminifers of the LIG assemblage in Hashgort borehole at lat/long 65.42, 65.67; Arkhipov et al., 1992). This marine unit possibly represents an earlier marine incursion and is therefore excluded from our database.

7.2 Pechora Lowland, Russia

At the More-Yu site, Pechora Lowland (lat/long 67.867, 60.183), OSL ages of 112 ka and 120 ka were obtained from large sand blocks with shells of boreal molluscs included into the glacially deformed diamict sequence (Fig. 3). The U/Th date of 130 ± 8 ka from this section on boreal *Arctica islandica* shell confirms a LIG age of the detached marine sand and a Weichselian age of the encompassing till with fossil glacial ice (Astakhov and Svendsen, 2002). We exclude this site from our database owing to the likely glacial translocation of the marine unit. Another site in the Pechora Lowland is Vastiansky Kon, which was first described in 1938 and revisited by Tveranger et al. (1998). The stratigraphic record, along with the presence of warmer-water marine shells, suggest a LIG age for marine sediments at this site. However, it has been glaciotectonized and is therefore inappropriate for inclusion in our database.

7.3 Malaya Kachkovka, Kola Peninsula, Russia

The Malaya Kachkovka site is in the tributary valley of the Malaya Kachkovka River on the eastern coast of the Kola Peninsula (lat/long 67.40, 40.90; 140 MASL). The entire sediment exposure is ~10 m thick (Gudina and Yevzerov, 1973). The mollusc and foraminifera fauna, as well as the pollen content of a marine sediment interval between 127.5–134 MASL were studied by Lavrova (1960) and Gudina and Yevzerov (1973). The marine part of the section comprises a 0.5-m thick clay unit at the base of the exposure, overlain by mollusc-bearing sands. Lavrova (1960) considered that the mollusc fauna contained in the sediments represents the upper sublittoral zone, and according to Gudina and Yevzerov (1973) the faunal assemblage represents the warmest fauna of interglacial marine sediment faunas discovered on the Kola Peninsula. Uranium/thorium ages on *Astarte borealis* shells from coarse and medium marine sands at around 132 MASL yielded ages of 102 ± 4 and 114 ± 4 ka (Arslanov et al., 1981), suggesting that the sediments were deposited during the LIG. However, Gudina and Yevzerov (1973) pointed out that the characteristics of the faunal assemblages and the high altitude of the marine sediments might suggest that they do not represent the LIG but rather an older interglacial. Even if this is not the case (i.e. from an earlier interglacial), the till on top of the marine sediments might indicate that the marine sequence is not in an *in situ* position and has been glacially thrust as a block to its present high-altitude position. The site is thus excluded from our LIG database.

7.4 Ludyanoi, Kola Peninsula, Russia

Grave et al. (1969) described a riverbank section of the Ludyanoi creek (lat/long 66.33, 39.92; 70 MASL), a small tributary to Pulonga River, southeastern costal area of the Kola Peninsula. They described a sediment exposure where the top 10.7 m of the section is glaciofluvial sands and gravels overlying a 1.5-m thick till. Below the till is a 3.7-m thick greenish grey marine clay with shells and shell fragments recognised as *Astarte borealis, A. elliptica, A. crenata and A. montaqui*, of which the latter two are considered subarctic to their biogeography. The top of the marine clay unit is at around 60 MASL, but it is not precisely known if this marine unit is *in situ*. It is therefore excluded from our database.

7.5 Lovozero, Kola Peninsula, Russia

There is a thick sediment sequence at the Lovozero site located in the inner part of the Kola Peninsula, Russia (lat/long 67.08, 38.970; 210 MASL). The lower part of the drill hole sections contains a 44-m thick sand and silt unit between 140 and 184 MASL. A proportion of the diatom flora in the lower part of the sediment core is marine and the pollen taxa is dominated with pine and birch (Ikonen and Ekman 2001). However, it is generally thought that diatoms and pollen are mostly reworked in this lower sand-rich sediment unit and therefore, the correlation of this unit to the LIG is not possible and the position of the sea level cannot be reconstructed (e. g. Ikonen and Ekman, 2001). We do not include the Lovozero site in our database.

7.6 Evijärvi, Finland

The Evijärvi site is situated in central Ostrobothnia, western Finland (lat/long 63.434, 23.322; 67 MASL). At this site, the LIG sediments occur on the proximal flank of a drumlin (Eriksson et al., 1980). In the top 6.4 m of the borehole record, several till and sand beds occur. The interglacial sediments consist of silt (9.0–9.5 m depth) and gyttja (6.4.–7.4 m depth) interbedded with till. Samples for pollen and diatoms were analysed from borehole sediments (Grönlund, 1991; Eriksson, 1993). The pollen spectra of the silt layer (9.0–9.5 m depth) and gyttja layer (6.4–7.4 m depth) indicate only one local pollen assemblage zone consisting of *Betula*, *Alnus*, *Picea* and *Corylus*, which is correlated to the LIG (Erikson, 1993). Diatoms in the silt bed (9.0–9.5 depth) above the till at the base of the core are exclusively marine while the diatom taxa in the gyttja is dominated with marine lagoonal types (Grönlund, 1991a). We do not include the Evijärvi site in our database because these LIG marine sediments are not at their original position of deposition but have been transported for an unknown distance and altitude by ice (e.g. Eriksson, 1993).

7.7 Norinkylä, Finland

The Norinkylä site is situated in southern Ostrobothnia, western Finland (lat/long 62.58, 22.020, 114 MASL). This site exposes till on top of the flanks of an esker, and in between are glacially deformed gyttja, organic-rich silt and sand, suggested to be LIG in age (Niemelä and Tynni, 1979; Donner, 1988). Boreholes made in the Rahkaneva mire next to the till-covered esker display silt, clay and gyttja in between two till beds with a maximum thickness of 4.5 m. The inter-till sediments have been studied for their lithology and pollen and diatom content (Grönlund, 1991b; Erikson, 1993). The pollen assemblage shows a succession typical for the LIG in western Finland (Eriksson, 1993). Fresh-water diatom taxa dominate the lowermost part of the inter-till sediments (biostratigraphically belonging to the early LIG *Betula* regional zone; Grönlund, 1991b) while there is a transition to marine diatom taxa that takes place at around 97 MASL. Saline diatom taxa dominate the interglacial sediment between 97 and 102 MASL (Grönlund, 1991 a, b). We do not include the Norinkylä LIG sediments in our database because these sediments are glaciotectonised and have been transported an unknown distance from their original place of deposition.

7.8 Svartenhuk Halvø, west-central Greenland

Kelly (1986) and Bennike et al. (1994) describe a raised marine deposit in west-central Greenland, which was correlated to the LIG based on amino acid dating. They found no evidence of a Holocene highstand in this location. However, more recent work at this site suggests it may not have been deposited during the LIG (Lane et al., 2015). We were unable to add this site to the database as there was limited information on the elevation, geology and conflicting age constraints.

7.9 Nantucket Island, Massachusetts, United States

Marine sediments, bracketed by two tills, on Nantucket Island, Massachusetts, United States, were first described in the 1800s (Desor and Cabot, 1849; Verrill, 1875). These marine sediments are located between 0–20 MASL (Oldale et al., 1982). These sediments consist of a gravel base, overlain by several meters of cross-bedded so-called ‘Sankaty Sands’ that contain stratified silt and clay along with abundant marine shells. Oldale et al. (1982) assigned the Sankaty Sands to the LIG based on stratigraphic context, palaeoenvironmental data, absolute chronology (U/Th, minimum radiocarbon ages) and relative age determinations (amino acid racemization). The lowermost till was assigned to MIS 6 and the upper till to MIS 2 ice advances, and the Sankaty Sands were stratigraphically constrained to the time interval immediately following retreat of the MIS 6 ice sheet. Palaeoenvironmentally, well-preserved warm-water oyster shells (*Crassostrea virginica*) and clam shells (*Mercenaria mercenaria*) are present at the base of this marine unit, and cooler-water clams (*Mercenaria campechiensis*) and mussels (*Mytilus edulis*) are present near the top (Verrill, 1875). These marine shells capture the transition from warm-water LIG conditions to more temperate MIS 5d conditions (Oldale et al., 1982). In terms of absolute chronology, corals located within the Sankaty Sands were dated via U/Th methods to 133±7 ka, which the authors believed to be a maximum age for this deposit (SHIO/80-9; Oldale et al., 1982). Moreover, seven radiocarbon ages were obtained from wood and shells located at this site. Four yielded non-finite ages and three were finite. However, the latter were suspected to be affected by modern carbon contamination (Oldale et al., 1982). Finally, amino acid racemization analyses (isoleucine epimerization ratios) of 10 shells from this marine unit suggest deposition between 140 ka and 120 ka (Oldale et al., 1982). In summary, the palaeoenvironmental data, stratigraphic context and available age assignments all suggest a LIG age for the Sankaty Sands. Despite the clear evidence of LIG age assignment, the section is glaciotectonized, and is therefore unreliable as an estimate of palaeo-sea level.

7.10 Western Banks Island, Canada

Lakeman and England (2014) describe a glaciotectonized marine deposit on Phillips Island, located off the west coast of Banks Island, which dated to the LIG based on OSL dates and non-finite radiocarbon dates. The exposure has interbedded sand, silt and clay with abundant mollusc fossils. The OSL samples were taken at 7 MASL. Several other raised in-situ marine deposits were sampled in western Banks Island but returned finite ages that would place the age of those deposits to MIS 3. They cautioned that the results from the Phillips Island OSL dates means that those radiocarbon dates may be minimumages. If regarded in this way, these sites may be from the LIG, but the ambiguity means we have not added these sites to the database.

8 DISCUSSION

This paper brings together 82 LIG sea-level proxies from the formerly glaciated Northern Hemisphere. In general, the sites reported in this paper do not offer constraint on the global LIG highstand, but rather evidence of GIA-influenced sea-level positions after the end of the MIS 6 glaciation. The motivation behind some of the research described herein was to constrain the extent of the Barents Sea, and the (possible) connection between the White Sea and the Baltic Sea caused by the glacio-isostatic depression of western Russia during the MIS 6 glaciation and into the LIG (Ikonen and Ekman, 1991; Funder et al., 2002; Miettinen et al., 2014). Last Interglacial sites in Svalbard, Iceland and Greenland are largely located along the modern-day coastline. Comparatively fewer LIG sites are present in North America, likely owing to more glacial erosion or their sub-surface position in borehole records. Overall, LIG marine sites in the Northern Hemisphere have ‘poor’, ‘average’ or ‘good’ chronological constraint (ranks of 2, 3 or 4; see Table 5 and Fig. 15), due to conflicting geochronological data, a dependence on chronostratigraphic inference, large dating uncertainties and a fragmented stratigraphic record. The quality of

RSL data is more varied, with some sites ranking very low (e.g. rank of 0 for the Kwataboahegan River site), and others very high (e.g. rank of 5 at the Fjøsanger and Bø sites; see Table 5 and Fig. 15).

8.1 Pre- and post-LIG sea-level oscillations

Northern Hemisphere ice sheets waxed and waned many times during the Quaternary (Batchelor et al., 2019), allowing for marine incursions prior to the LIG (e.g. during MIS 7) and during later intervals (e.g., during MIS 5c, MIS 5a, MIS 3 and the Holocene), with maximum highstands preferentially during the transitional stages between glacials and following interglacials/interstadials. However, given difficulties inherent to dating sediments beyond the range of radiocarbon dating, chronological constraints remain a key challenge for these deposits. Here, we highlight some locations where pre-LIG and post-LIG sea-level oscillations are recorded. This list is not exhaustive; rather, it is meant to provide examples of other sea-level oscillations that are preserved in the stratigraphic record, and to provide context for the difficulties in assigning ages to marine deposits in the glaciated Northern Hemisphere.

Several pre-LIG marine units have been described at Kongsfjordhallet, Svalbard (Houmark-Nielsen and Funder, 1999). The oldest marine unit is probably as much as 1 million years old. Marine sediments dating to MIS 7 have been documented at several sites in Russia. At the Bol'shaya Kheta River sections (lat/long 67.97, 83.10), in addition to LIG marine sediments (see Section 6.10), a lower marine bed contains shells of the extinct mollusk *Cyrtodaria jenisseae* Sachs (today generally considered as *Cyrtodaria angusta*, see e.g. Möller et al., 2019a) and OSL ages at 225 ± 16, 226 ± 21, 162 ± 23, 231 ± 17 ka indicate a MIS 7 age (Nazarov et al., 2020; Astakhov and Semionova, 2021). A pre-LIG age is also suggested for numerous sites on the Taimyr Peninsula. Kind and Leonov (1982) claimed that >60 outcrops on central Taimyr Peninsula, south of Lake Taimyr, expose LIG-aged marine sediments. In the Bol´shaya Balakhnya river valley such sediment should reach 30–40 MASL, while further to the NE, in the Bol´shaya Rassokha river valley, such sediment should reach 60–70 MASL. However, as demonstrated in Möller et al. (2019a) from a large number of sections along the Bol´shaya Balakhnya River, these sediments are of an older age as suggested from numerous ESR and OSL dates (Möller et al., 2019a, 2019b). The sediments that Kind and Leonov (1982) presumed were LIG in age are often overlain by a till; as the sediment sections are south of the Severokokora ice marginal zone, marking the southern maximum boundary of the MIS 5d (known locally as the Early Zyryanka) glaciation over Taimyr (Möller et al., 2019a), this till must predate the MIS 5d glaciation (MIS 6 or older) and the marine sediments are consequently of a pre-LIG age.

Post-LIG marine sediments are far more commonly preserved in the stratigraphic record. For example, at the Chapoma site on the Kola Peninsula, in addition to LIG marine sediments (see Section 6.18), an upper marine silt is present between 11 and 13 MASL (Korsakova, 2019). Two ESR dates on shells at around 12 MASL in this marine unit yielded ages of 85.5 ± 3.2 and 86.0 ± 3.9 ka (Arslanov 1981), placing it into MIS 5a. Multiple sea-level oscillations are also present at the Lower Agapa River sections (Gudina et al., 1968) as well as the Strelna River site (Section 6.19) where a sequence of upper marine sediments was dated via IRSL and ESR to between 102 and 84 ka (Korsakova et al., 2004; Korsakova, 2019). Möller et al. (2015, 2019a) describe several marine sequences in the central and southern parts of the Taimyr Peninsula, Russia. All these marine sediment successions were dated with ESR and OSL; with six outliers excluded the mean age is ~86 ka (n = 62) with an age scatter of ± 15 ka, which firmly puts these sediments into MIS 5c–b (known locally as the Early Zyryanka). Finally, marine sediments at the Anjeliko River site (Section 6.5) have been constrained to an ESR age cluster of 80–93 ka (mean age 86 ka), suggesting deposition at marine inundation during MIS 5a following a Kara Sea Ice Sheet glaciation during MIS 5d–5c.

Marine sediments dating to MIS 3 have been described in the glaciated region of Russia and Europe. For example, at the Ozernaya River on October Revolution Island, offshore of Taimyr Peninsula (section 6.6), Marine unit IV sediments were exposed in two sections on opposite sides of the river valley, ~2.5 km apart (Oz 4 and Oz 5; Möller et al., 2007). These sediments contained a rhythmical sedimentation pattern, several *in situ*-positioned paired mollusc shells and almost complete skeletons of at least 9 narwhals (*Monodon Monoceros*) that were in the process of eroding out at the top of the sediment succession. The Marine IV sediments were interpreted as formed in a marine setting at a water level >65 MASL within a deeply embayed estuary behind a valley-mouth bar/barrier system in the Ozernaya valley (Möller et al., 2007). Radiocarbon dating of a narwhal tusk and molluscs yielded ages of ~50, 45.4 and 46.8 ka (all at the upper limit of radiocarbon dating), ages supported by a single mollusc shell ESR dated to 59 ka. The dating of Marine IV sediments thus suggests that they are of a MIS 3 age, formed at a marine inundation of the island that probably was glaciated during the whole timespan of MIS 5d–4. Marine sediments dated to between the LIG and MIS 2 are widespread in Svalbard (Mangerud et al., 1998; Alexanderson et al., 2018). For example, at Kapp Ekholm (described in Section 6.35) there are two pre-Holocene marine units situated stratigraphically above the LIG beds, one considered to be of a MIS 5c age and the younger of MIS 3 age. Beds of basal till are found between these marine units.

Marine sediments dating to MIS 3 are uncommon in North America and are often less reliably constrained than similar sites in Russia and Europe. Nevertheless, shallow marine and beach sediments in Eastern Canada constrained to MIS 3, using OSL and radiocarbon dating, are situated at 30, 37 and ~15 MASL (Rémillard et al., 2016, 2017). Also, in the Saint Lawrence Lowlands, marine sediments dated by radiocarbon to MIS 3 are situated at 30 MASL (Dionne and Occhietti, 1996). Finally, there is evidence for a marine incursion between the LIG and the Holocene in the Hudson Bay Lowlands, Canada (Severn River marine unit; 55 MASL). These marine sediments have been dated via amino acid techniques (Andrew et al., 1983), TL age attempts (Forman et al., 1987) and OSL attempts (Dalton et al., 2016). However, there is no clear consensus on the age of this marine incursion as most attempts spanned MIS 5a–3 and were of relatively low precision (e.g. ± 10 ka).

8.2 Holocene sea-level databases

Holocene marine sediments are widely preserved in the glaciated Northern Hemisphere and are documented in several databases, including the Russian Arctic (Baranskaya et al., 2018), the Baltic Sea (Rosentau et al., 2021), European west coast (García-Artola et al., 2018), Greenland (Long et al., 2011) and eastern Canada (Vacchi et al., 2018).

9 CONCLUSIONS AND FUTURE RESEARCH

Reconstructing sea-level change through the LIG is critical for understanding the sensitivity of the Earth System to future change. Here, we contribute 82 LIG sea-level proxies from the formerly glaciated Northern Hemisphere to the WALIS database. Given their position in the envelope of Northern Hemisphere ice sheets, these data are useful for testing the reliability of MIS 6 ice sheet reconstructions, and deducing LIG sea level. Obtaining an accurate chronology remains one of the most significant challenges for LIG deposits in the glaciated region. When geochronological data are lacking, often the only way to distinguish between interglacial deposits is via palaeoecological inferences, which have their own set of uncertainties. Therefore, key areas of future research should focus on revisiting these sites to vet the stratigraphic record and testing new geochronological methods (especially U/Th, OSL, and the potential for cosmogenic nuclide methods to constrain the age of buried sediments, e.g. Balco and Rovey, 2008). Future work to locate new LIG sites (particularly in North America, which has a relative scarcity of LIG sites) should be focussed on coastal regions that are known to contain extensive stratigraphic records (e.g. the Saint Lawrence valley).

DATA AVAILABILITY

The database on LIG sites in the glaciated Northern Hemisphere is available here: https://doi.org/10.5281/zenodo.5602212 (Dalton et al., 2021). A detailed description of database fields in the WALIS database is available here: https://doi.org/10.5281/zenodo.3961544 (Rovere et al., 2020).

AUTHOR CONTRIBUTIONS

ASD and EJG conceptualised this paper. ASD wrote the first draft with substantial input from JM, PM, JPL and VA. EJG managed data entry into the WALIS database and developed the methodological framework. All authors reviewed/edited subsequent drafts of the manuscript.

COMPETING INTERESTS

The authors declare no competing interests.

DISCLAIMER

The information contained in this database was the result of studies from many scientists over the course of several decades. Please cite the original sources of the data in addition to this database.

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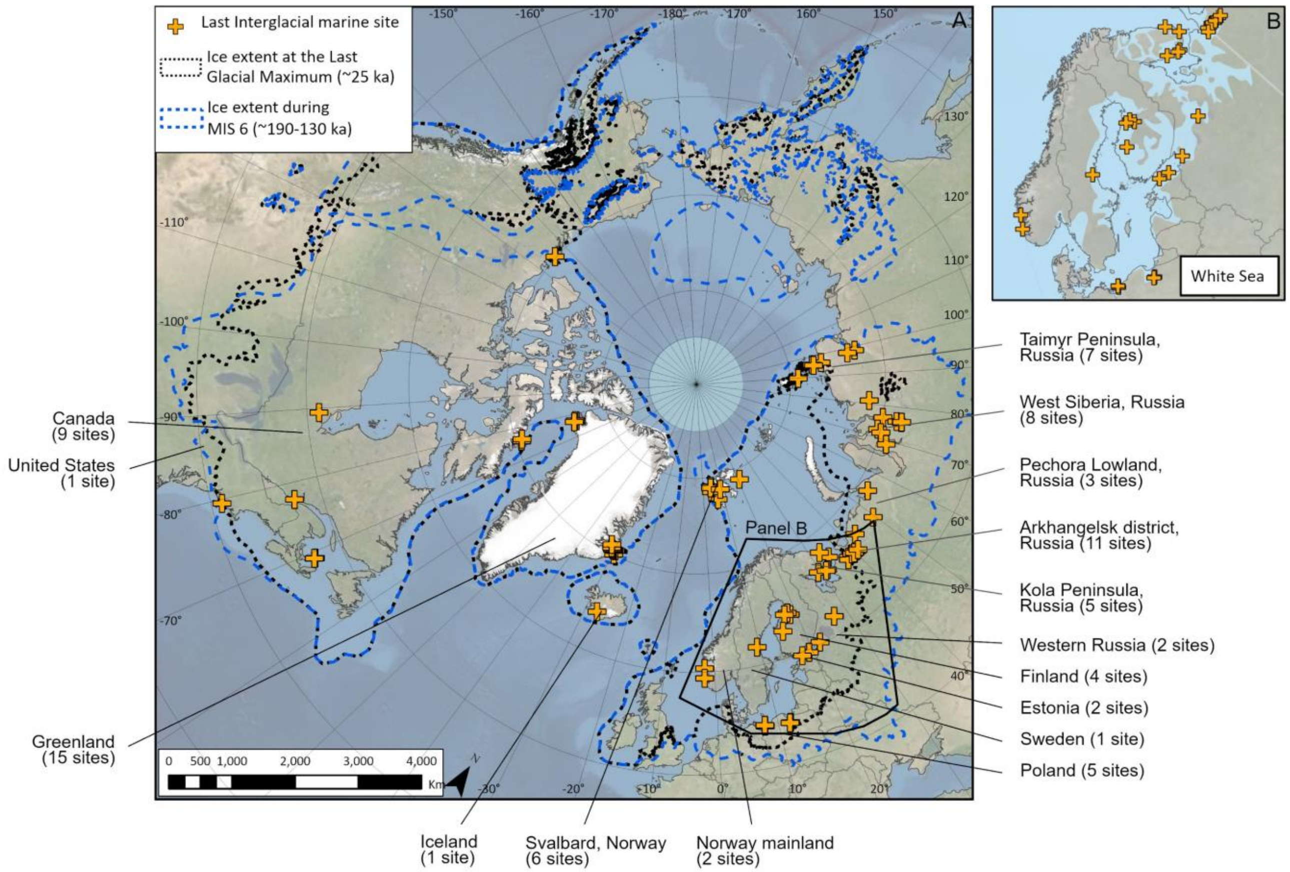

Figure. 1. Location of Last interglacial (LIG) marine sites in the formerly glaciated Northern Hemisphere, along with the extent of MIS 6 and Last Glacial Maximum ice sheets (Batchelor et al., 2019). Inset map shows extent of the LIG White Sea that inundated the isostatically depressed landscape of western Russia and northwestern Europe.

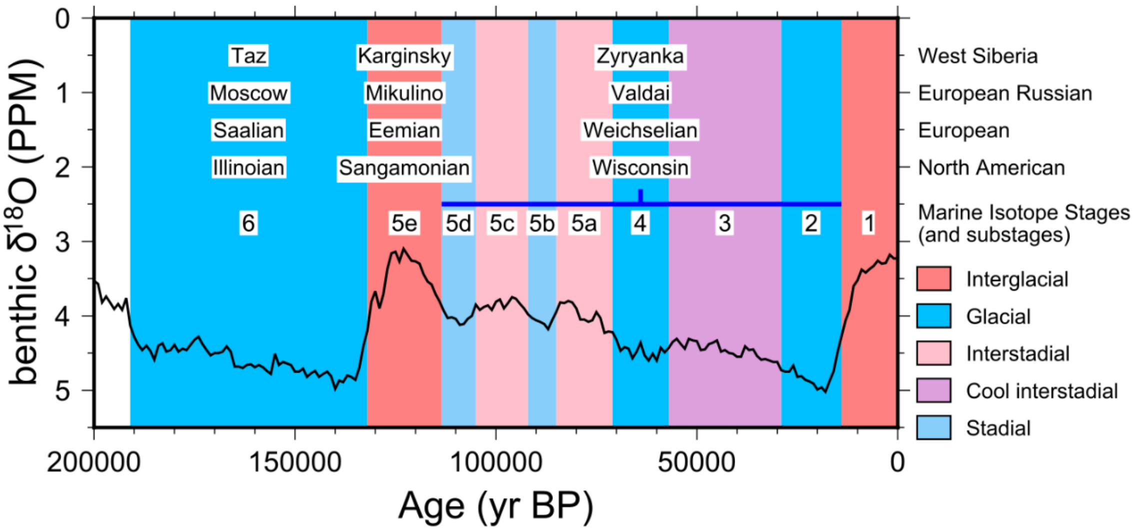

Figure 2. The timescales covered in this paper, along with regional nomenclature. The benthic $\delta^{18}O$ curve is the LR04 stack, from which the Marine Isotope Stages are derived (Lisiecki and Raymo, 2005).

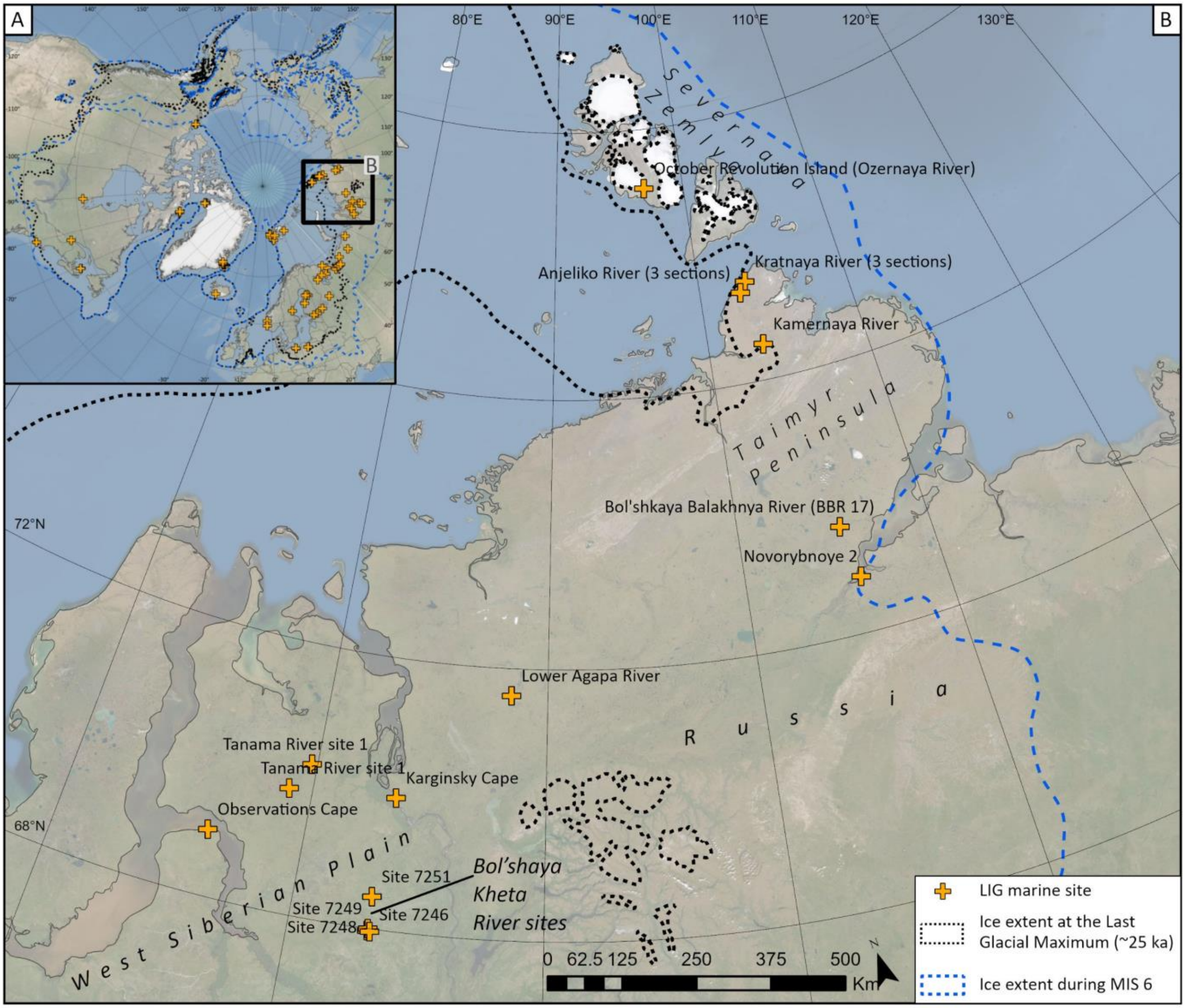

Figure 3. The location of LIG marine sites in the Taimyr Peninsula and Western Siberian Plain, Russia. Panel A situates the sites in the Northern Hemisphere, whereas Panel B provides a regional map. Sites plotted on this map are detailed in Sections 6.1–6.11. Extent of MIS 6 and Last Glacial Maximum ice sheets after Batchelor et al., (2019). Scale calculated at centre of mapped area. Base layer: ArcGIS World Imagery.

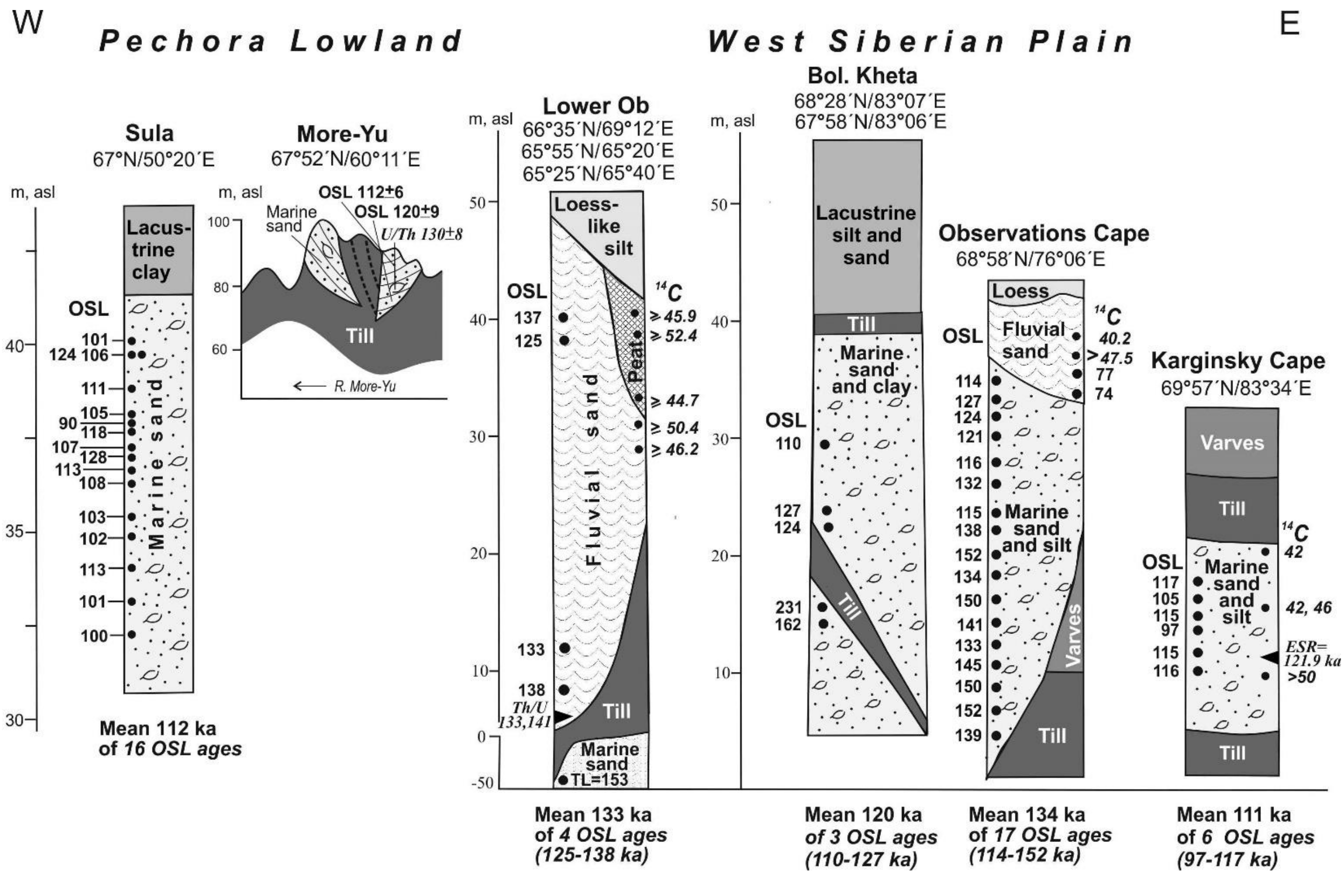

Figure 4. An overview of the best dated sections of the LIG in the Russian Arctic mainland. Numbers along the columns are geochronometric ages in ka. Relative positions of samples are shown by black dots: large ones – dated by optical luminescence, smaller ones – by radiocarbon; black triangles indicate dates by U/Th and ESR methods. Sources of information: Sula (Murray et al., 2007), More-Yu (Astakhov and Svendsen, 2002), Nadym Ob (Astakhov et al., 2004, 2005), Observations Cape (Astakhov and Nazarov, 2010a, b), Bol. Kheta (Nazarov et al., 2020), Karginsky Cape (Astakhov, 2013; Nazarov et al., 2020). These stratigraphic sections are sometimes summaries of several sites; see text for details. Comprehensive documentation of each site (including detailed sea level measurements and chronological data) is available at https://doi.org/10.5281/zenodo.5602212 (Dalton et al., 2021).

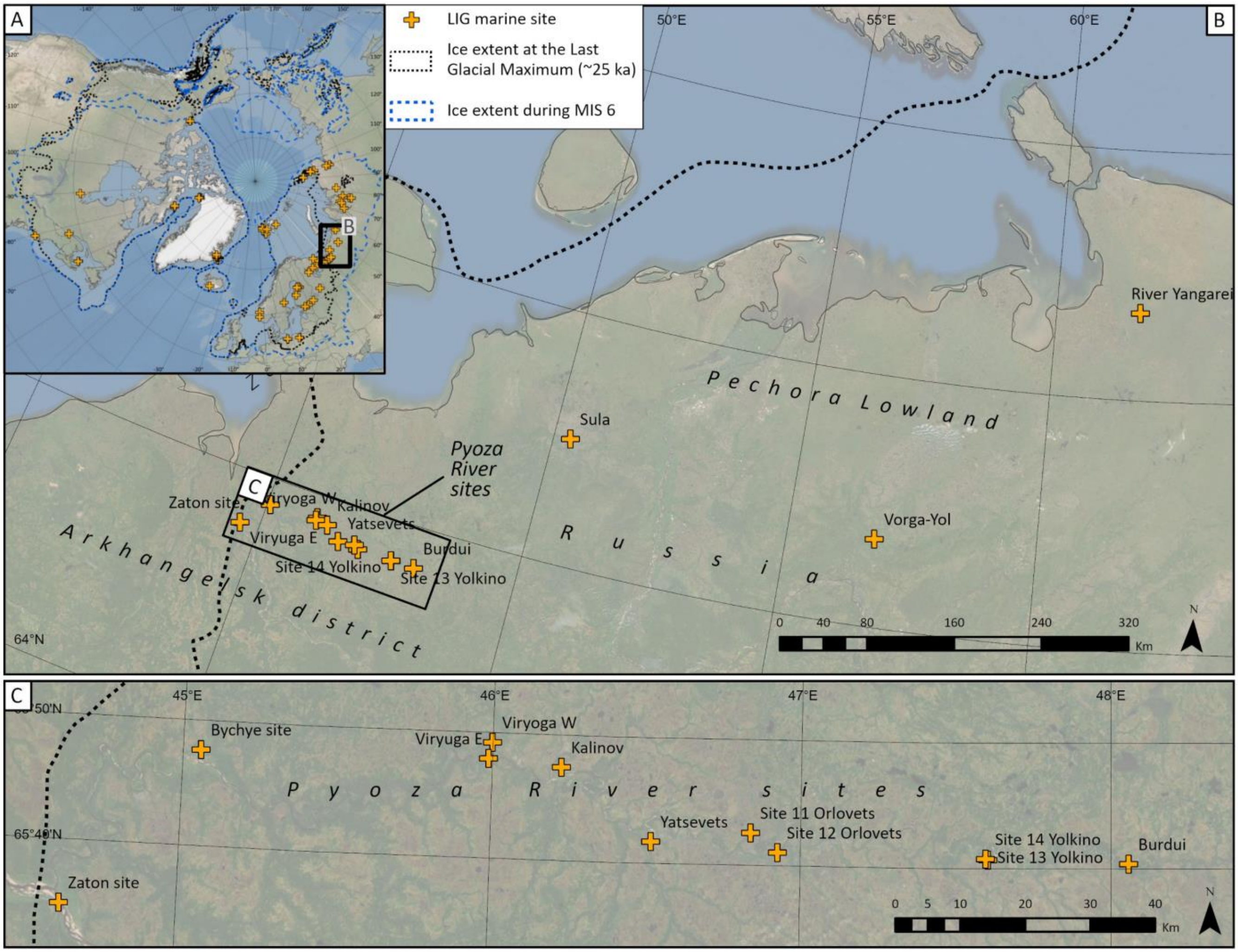

Figure 5. The location of LIG marine sites in the Arkhangelsk district and Pechora Lowland, Russia. Panel A situates the sites in the Northern Hemisphere, whereas Panels B and C provide regional maps. Sites plotted on this map are detailed in Sections 6.12–6.15. Extent of MIS 6 and Last Glacial Maximum ice sheets after Batchelor et al., (2019). Scale calculated at centre of mapped area. Base layer: ArcGIS World Imagery.

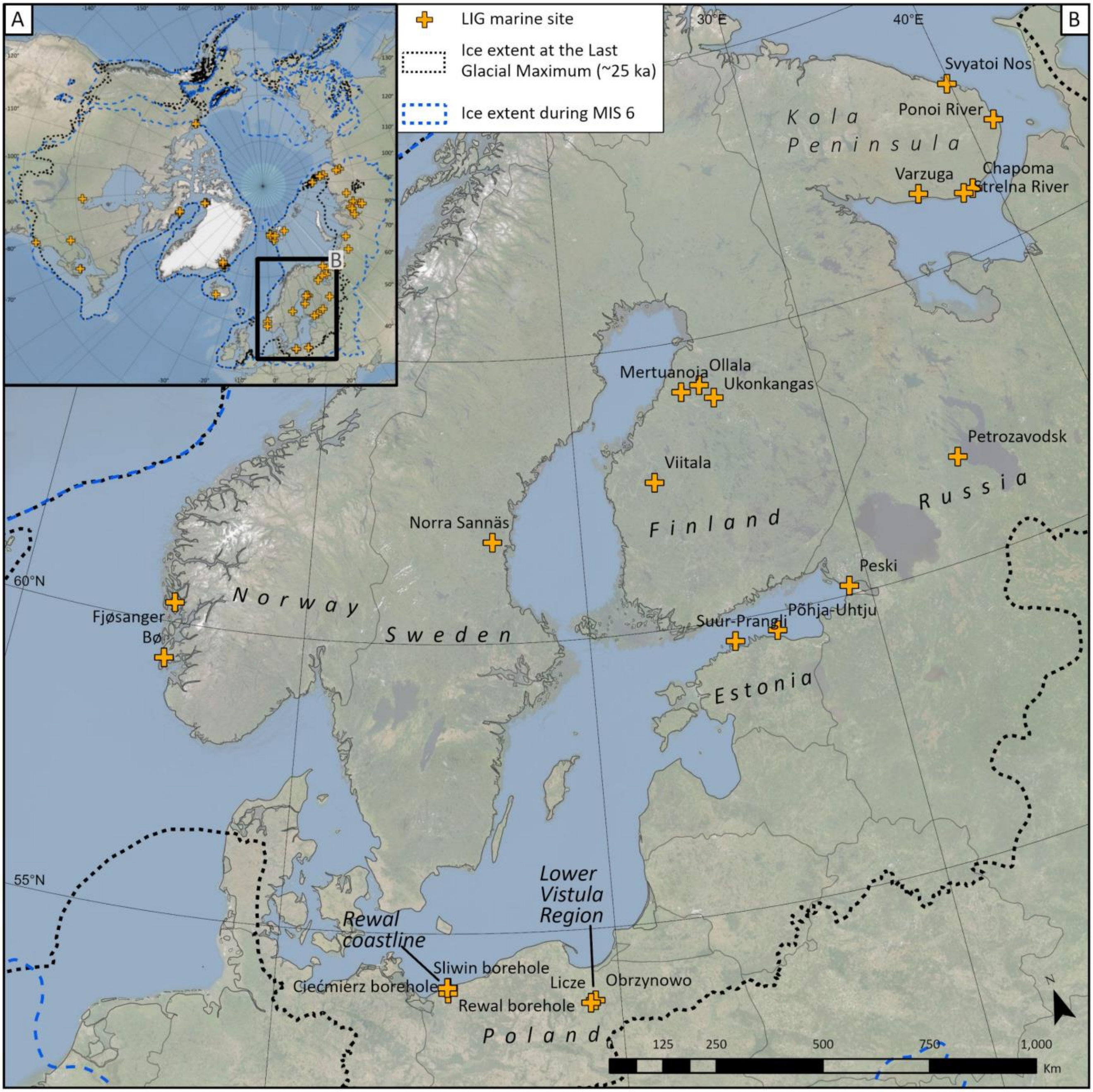

Figure 6. The location of LIG marine sites in western Russia, Estonia, Poland, Finland, Sweden and Norway. Panel A situates the sites in the Northern Hemisphere, whereas Panel B provides a regional map. Sites plotted on this map are detailed in Sections 6.16–6.33. Extent of MIS 6 and Last Glacial Maximum ice sheets after Batchelor et al., (2019). Scale calculated at centre of mapped area. Base layer: ArcGIS World Imagery.

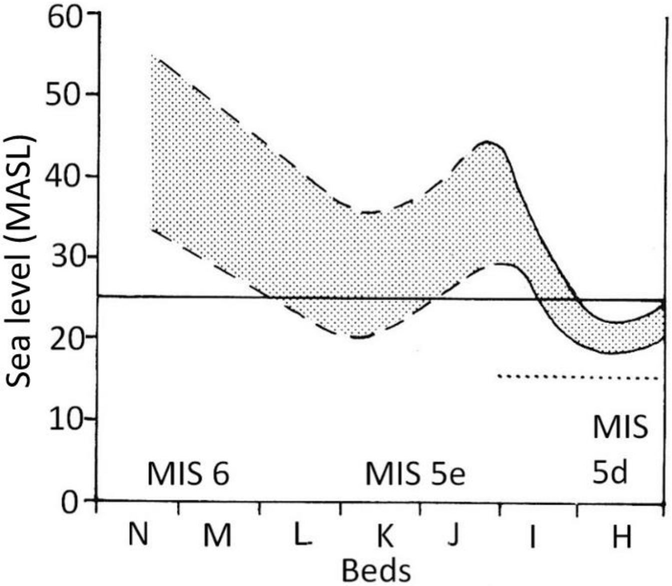

Figure 7. Relative sea-level curve for Fjøsanger during the LIG, shown as a dotted uncertainty band. The dashed part of the curve is considered most uncertain. The line at 25 MASL shows the threshold in the Bergen Valley; when sea level was higher than this threshold the fjord turned into a sound that was open in both ends. The dotted line at 15 MASL shows the top of the LIG marine sediments and thus the minimum altitude of the RSL during the entire LIG. Modified from Mangerud et al., (1981).

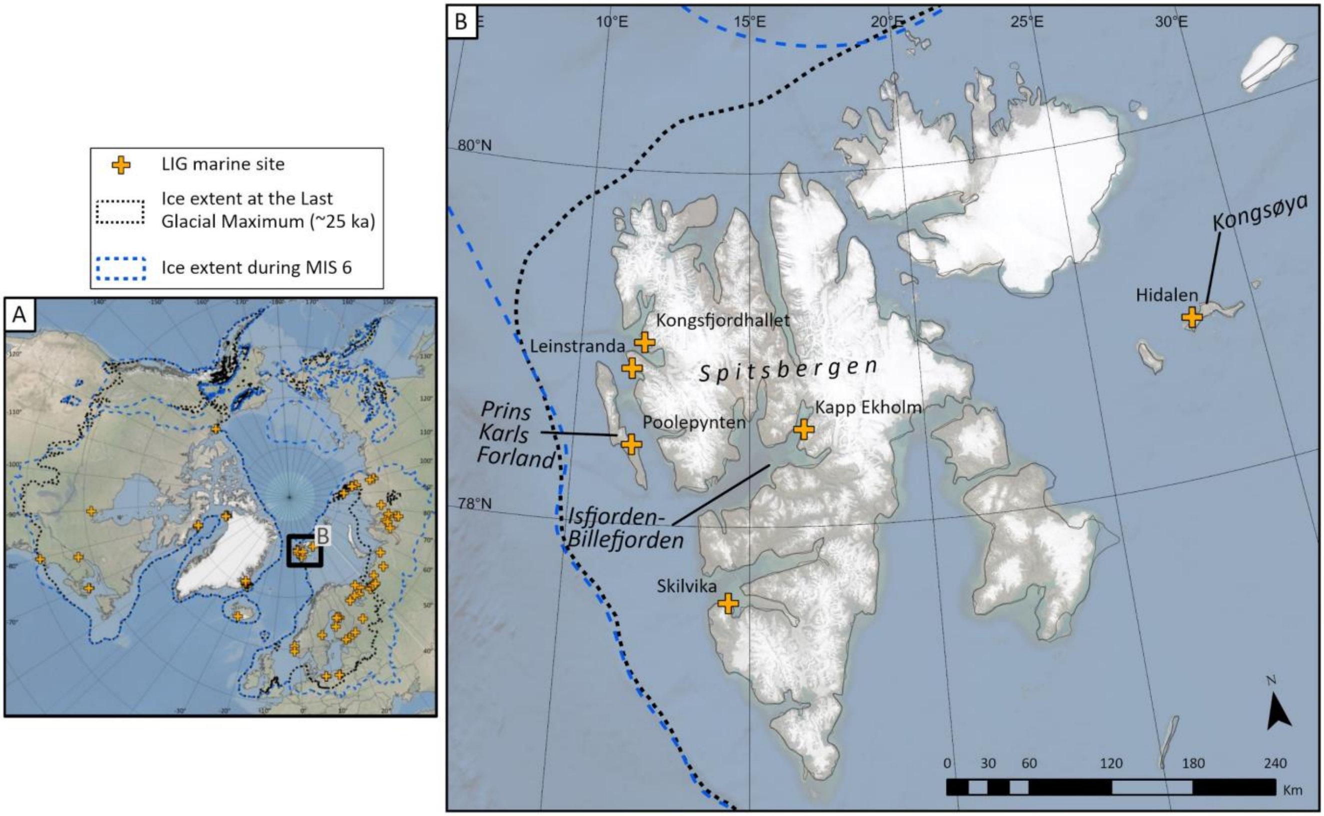

Figure 8. The locations of LIG marine sites in Svalbard, Norway. Panel A situates the sites in the Northern Hemisphere, whereas Panel B provides a regional map. Sites plotted on this map are detailed in Sections 6.34–6.39. Extent of MIS 6 and Last Glacial Maximum ice sheets after Batchelor et al., (2019). Scale calculated at centre of mapped area. Base layer: ArcGIS World Imagery.

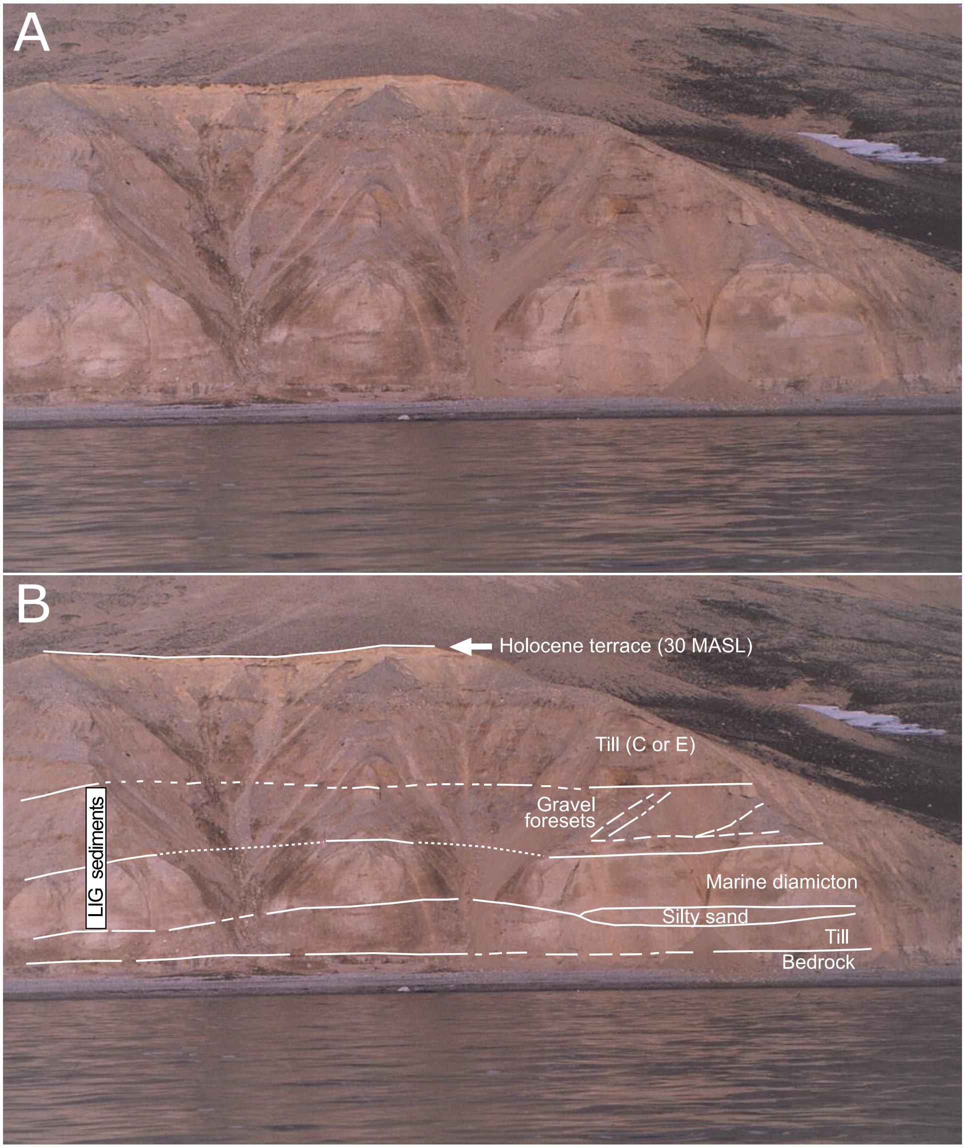

Figure 9. Photograph of Section II at Kapp Ekholm, Svalbard. Panel A is original photograph, and panel B shows stratigraphic units. Solid white line indicates a confirmed stratigraphic contact; dashed line indicates inferred stratigraphic contact (largely due to sediment slumping). The LIG sediments (indicated by the white text box) are about 10 m in thickness. Most *Mytilus edulis* were found in the lower part of the marine diamicton. Photo J. Mangerud 1988.

Figure 10. Preserved *Mytilus edulis* in the LIG sediments at Kapp Ekholm, Svalbard. This mollusc requires warmer water than the conditions around Svalbard for the last millennia, until it immigrated in 2004. Photo J. Mangerud 1988.

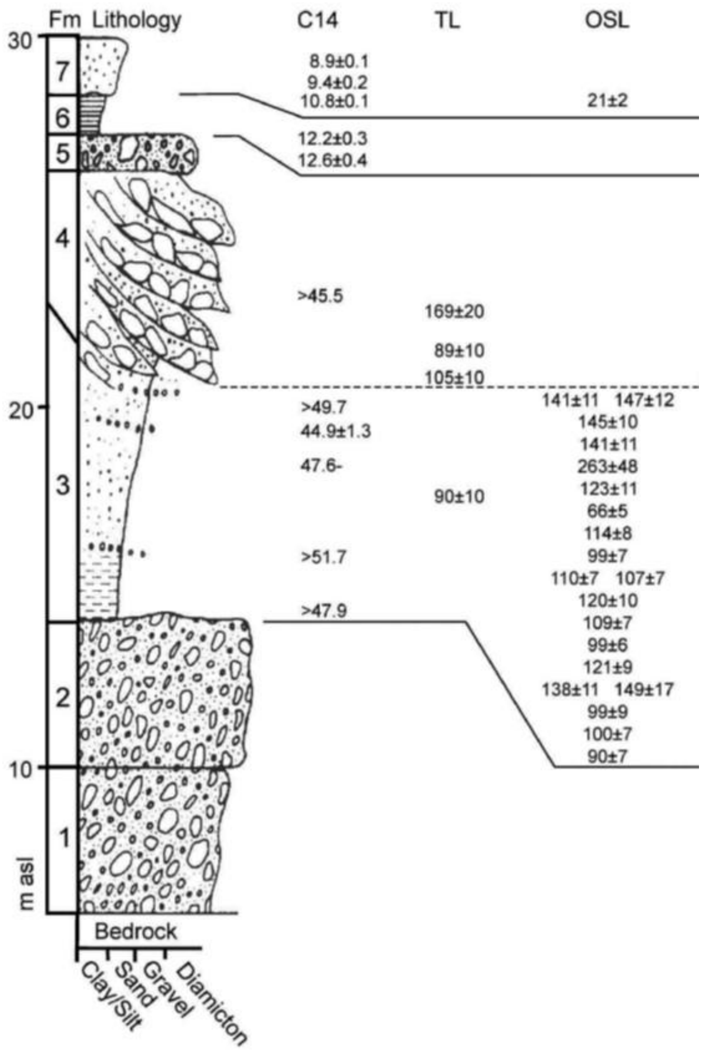

Figure 11. Composite log of the Skilvika exposure with luminescence (TL and OSL in ka) and radiocarbon ages (in cal. ka for ages > 40 ka, un-calibrated for younger ages). Formations (Fm) 3 and 4 are the candidates for the LIG (from Alexanderson and Landvik, 2018).

Figure 12. The upper half of the photo shows the extremely coarse foresets in Formation 4 at Skilvika. Note how the foresets interfinger with the sand and gravel beds in Formation 3. Photo J. Mangerud 1984.

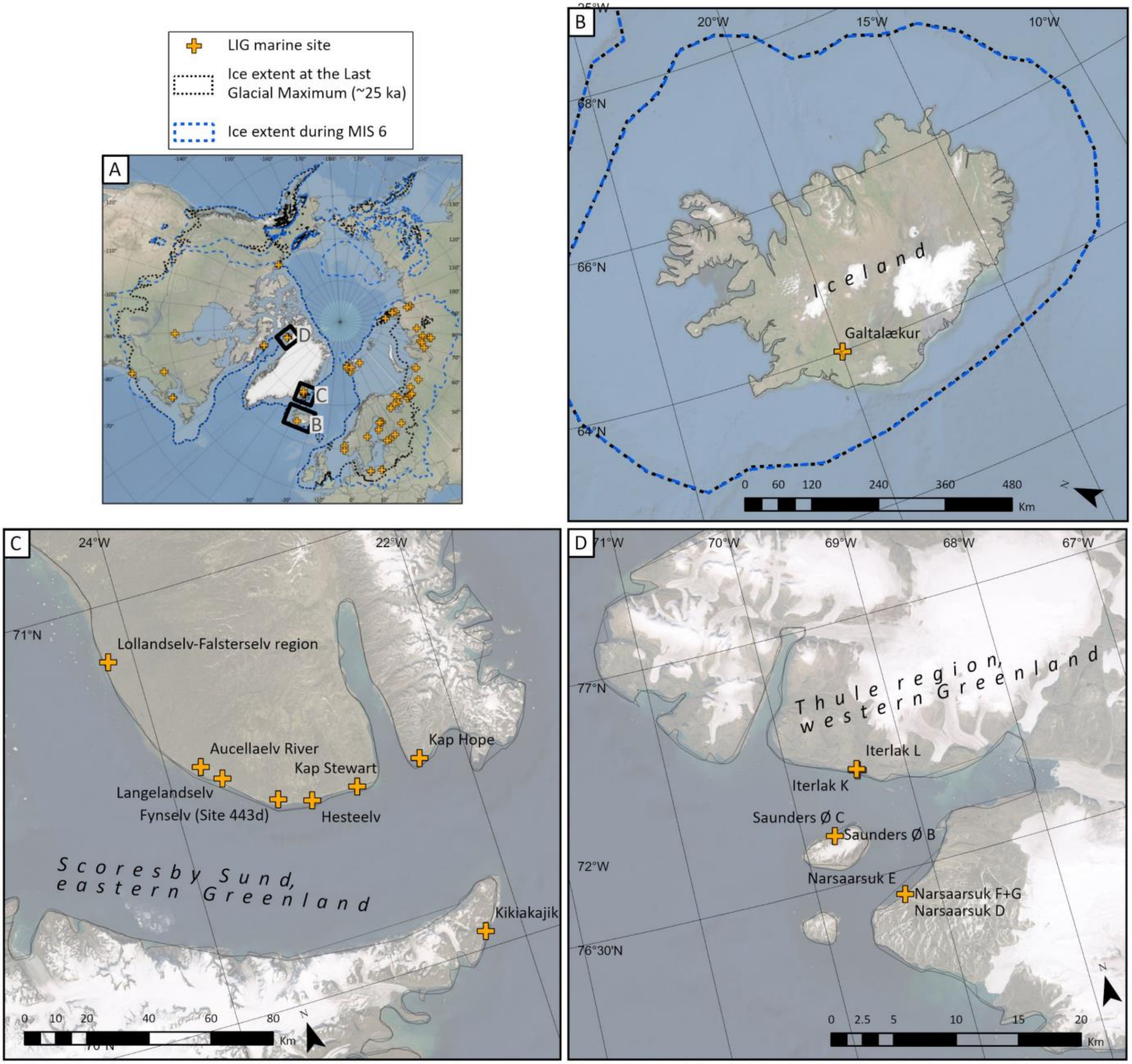

Figure 13. The locations of LIG marine sites in Iceland and Greenland. Panel A situates the sites in the Northern Hemisphere, whereas Panels B, C and D provide regional maps. Sites plotted on this map are detailed in Sections 6.40–6.42. Extent of MIS 6 and Last Glacial Maximum ice sheets after Batchelor et al., (2019). Scale calculated at centre of mapped area. Base layer: ArcGIS World Imagery.

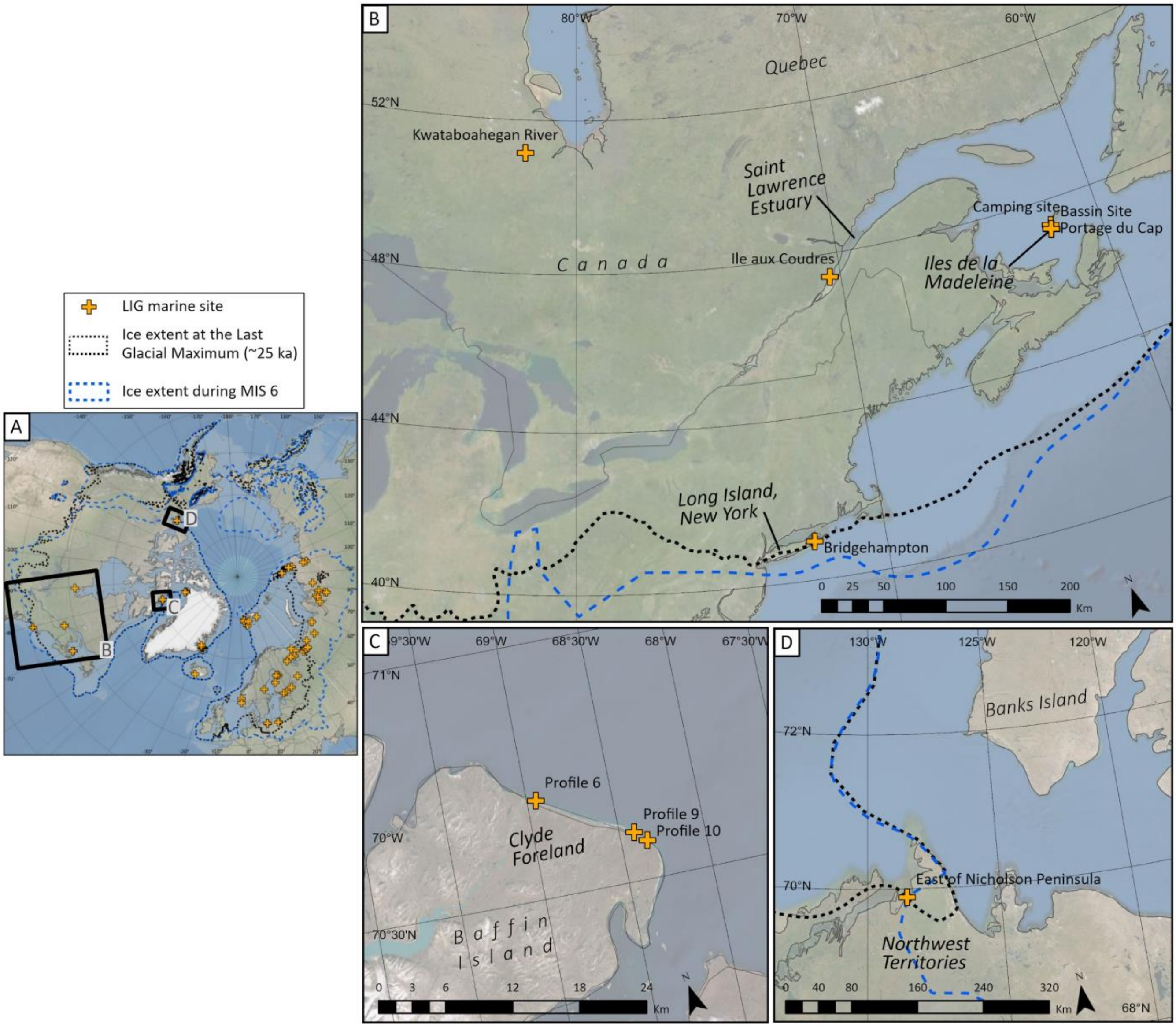

Figure 14. The locations of LIG marine sites in North America. Panel A situates the sites in the Northern Hemisphere, whereas Panels B, C and D provide regional maps. Sites plotted on this map are detailed in Sections 6.43–6.48. Extent of MIS 6 and Last Glacial Maximum ice sheets after Batchelor et al. (2019). Scale calculated at centre of mapped area. Base layer: ArcGIS World Imagery.

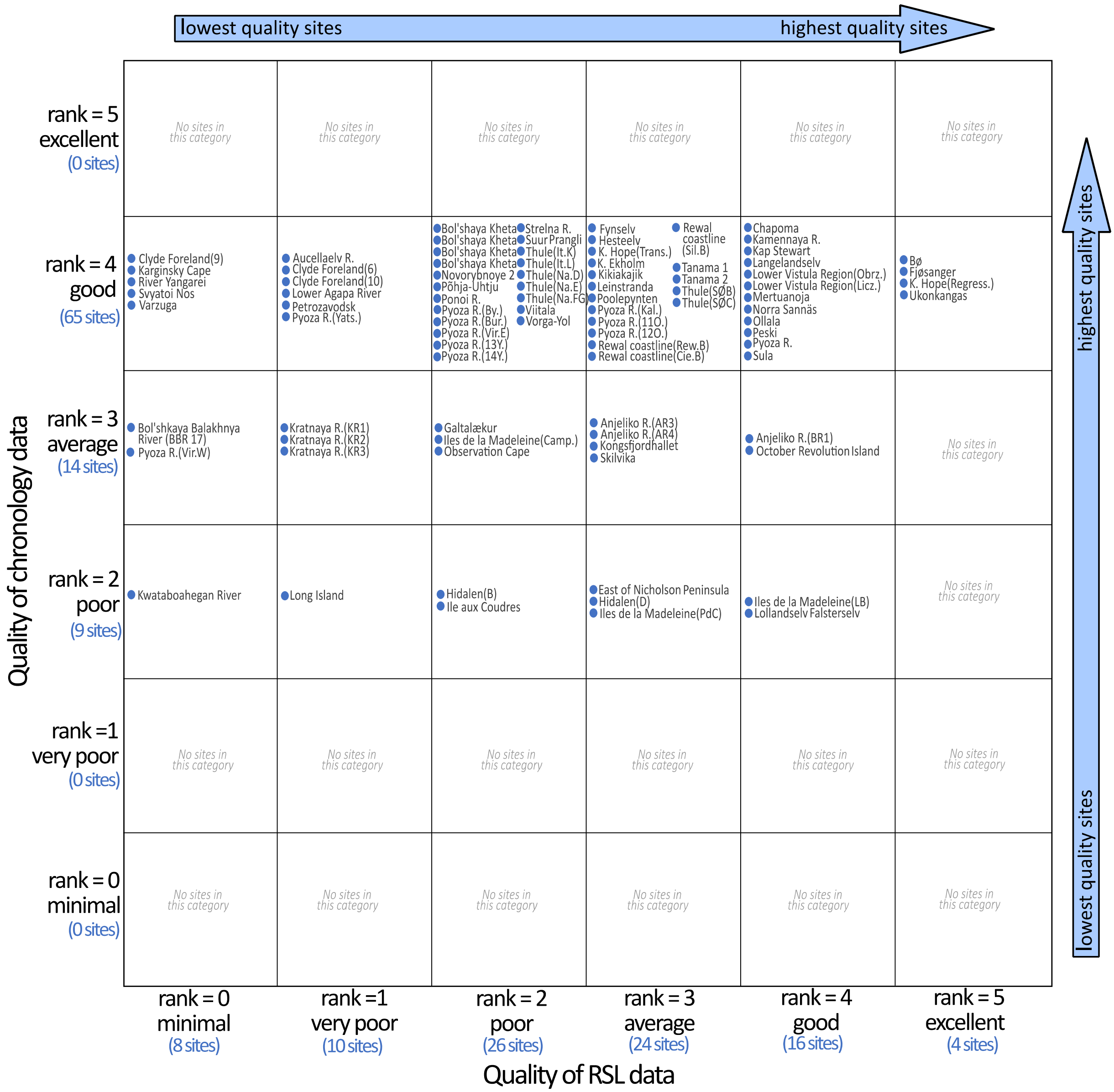

Figure 15. Schematic diagram showing each site with quality scores for the RSL data (horizontal axis) and chronology data (vertical axis).

TABLES

Table 1: Measurement techniques used to establish the elevation of LIG marine deposits (Rovere et al., 2020). GPS= Global positioning system.

Measurement technique	Description	Typical accuracy
Barometric altimeter	Difference in barometric pressure between a point of known elevation (often sea level) and a point of unknown elevation. Not accurate and used only rarely in sea-level studies	Up to ±20% of elevation measurement
Cross-section from publication	The elevation was extracted from a published sketch/topogrpahic section.	Variable, depending on the scale of the sketch or topographic section.
Differential GPS	GPS positions acquired in the field and corrected either in real time or during post-processing with respect to the known position of a base station or a geostationary satellite system (e.g. Omnistar). Accuracy depends on satellite signal strength, distance from base station, and number of static positions acquired at the same location.	±0.02/±0.08 m, depending on survey conditions and instruments used (e.g., single-band vs dual-band receivers)
Distance from top of drill core	Distance from the top of drill core.	Depending on coring technique and sampling procedures
Handheld GPS	Commercial hand-held GPS	Dependent on model and satellite coverage but could be as low as 1-2 m.
Inclinometer	Elevation measured with inclinometer starting from a point of known altitude.	Variable depending on the distance between reference and measured point.
Metered tape or rod	The end of a tape or rod is placed at a known elevation point, and the elevation of the unknown point is calculated using the metered scale and, if necessary, clinometers to calculate angles.	Up to ±10% of elevation measurement
Not reported	The elevation measurement technique was not reported, most probably hand level or metered tape.	20% of the original elevation reported added in root mean square to the sea level datum error
Theodolite and rod	Elevation derived from triangulation with a theodolite.	Usually very precise, centimetric accuracy, depending on distance.
Topographic map and digital elevation models	Elevation derived from the contour lines on topographic maps. Most often used for large-scale landforms (i.e. marine terraces). Several meters of error are possible, depending on the scale of the map or the resolution of the DEM	Variable with scale ofmap and technique used to derive DEM.

Table 2. Sea level datums reviewed in this study (Rovere et al., 2020).

Datum name	Datum description
Mean Sea Level / General definition	General definition of MSL, with no indications on the datum to which it is referred to. A datum uncertainty can be established on a case-by-case basis.

Table 3. Quality scores for sea level proxies.

Description	Quality rating
Sedimentary sequence confidently shows a regression from deep (> 10 m) marine to terrestrial conditions, or the deposit provides, via age constraints, a limiting elevation for a long portion of the interglacial. Elevation measurements are well documented to be within 3 m.	5 (excellent)
Same as above, but details of elevation measurements are not well documented.	4 (good)
Sedimentary sequence is regressive, but it is less certain that sea level fell below the elevation of the top of the sequence (*e.g.* beach sediments).	3 (average)
Sedimentary sequence is marine limiting, but there is evidence that sea level was within 10 m of the top of the sequence (*e.g.* shoreface and wave influenced littoral sediments).	2 (poor)
Sedimentary sequence is marine limiting, but there is evidence of sea level fluctuations.	1 (very poor)
The sequence is marine or terrestrial limiting, and there is no information on potential sea level position.	0 (minimal)

Table 4. Quality scores for age, from the WALIS documentation (Rovere et al., 2020)

Description	Quality rating
Very narrow age range, e.g. a few thousands of years, that allow the attribution to a specific timing within the LIG (MIS 5e; e.g. 117 ± 2 ka)	5 (excellent)
Narrow age range, confidently dated to the LIG	4 (good)
The RSL data point can be attributed only to a generic interglacial (e.g. MIS 5)	3 (average)
Only partial information or minimum age constraints are available	2 (poor)
Different age constraints point to different interglacials	1 (very poor)
Not enough information to attribute the RSL data point to any Pleistocene interglacial.	0 (rejected)

Table 5. Summary of LIG sites from the glaciated Northern Hemisphere that contain RSL indicators. Further details are available in Dalton et al., (2021). AAR = Amino Acid Racemization; Lum.= Luminescence; ESR = Electron Spin Resonance; ChrStrat.= Chronostratigraphy. Comprehensive documentation of each site (including detailed sea level measurements and chronological data) is available at https://doi.org/10.5281/zenodo.5602212 (Dalton et al., 2021).

Section in manuscript	WALIS RSL ID	Site name	Subsite	Country	Lat. (DD)	Long. (DD)	RSL indicator elevation (m)	RSL indicator elevation error (m)	Age attribution	Quality of RSL data	Quality of age data
6.1	4123	Novorybnoye 2	Unit F	Russia	72.83	105.79	24	2	Lum.; ESR	2	4
6.2	4124	Bol'shkaya Balakhnya River (BBR 17)	Unit A	Russia	73.62	105.36	13	2	ESR; ChrStrat.	0	3
6.3	4091	Kamennaya River		Russia	76.53	103.52	132.6	10	ChrStrat.	4	4
6.4	4088	Kratnaya River	KR1	Russia	77.51	103.21	43.3	2	Lum.; ESR; Other dating	1	3
6.4	4089	Kratnaya River	KR2	Russia	77.51	103.20	39.1	2	Lum.; ESR; Other dating	1	3
6.4	4090	Kratnaya River	KR3	Russia	77.50	103.20	36.2	2	Lum.; ESR; Other dating	1	3
6.5	4085	Anjeliko River	AR3	Russia	77.35	102.73	58.5	2	Lum.; ESR; Other dating	3	3
6.5	4086	Anjeliko River	AR4	Russia	77.36	102.68	59.2	2	Lum.; ESR; Other dating	3	3
6.5	4087	Anjeliko River	Bolotniy River BR1	Russia	77.39	102.66	48.8	2	Lum.; ESR; Other dating	4	3
6.6	4000	October Revolution Island	Ozernaya River, highest beach ridge	Russia	79.12	96.92	140	5	AAR; Lum.; ESR; Other dating	4	3
6.7	4139	Lower Agapa River		Russia	71.60	88.30	63	5	ChrStrat.	1	4
6.8	4140	Karginsky Cape		Russia	69.95	83.57	21	5	Lum.; ESR; ChrStrat.	0	4
6.9.1	4147	Tanama	Tanama 1	Russia	70.24	79.76	65	5	Lum.; ChrStrat.	3	4
6.9.2	4148	Tanama	Tanama 2	Russia	69.83	79.00	65	5	Lum.; ChrStrat.	3	4
6.10.1	4255	Bol'shaya Kheta	Site 7251	Russia	68.47	83.12	30	0.5	Lum.; ChrStrat.	2	4
6.10.2	4256	Bol'shaya Kheta	Site 7248	Russia	67.97	83.10	30	0.5	Lum.; ChrStrat.	2	4
6.10.3	4257	Bol'shaya Kheta	Site 7249	Russia	68.00	83.13	30	0.5	Lum.; ChrStrat.	2	4
6.10.4	4258	Bol'shaya Kheta	Site 7246	Russia	67.96	83.21	30	0.5	Lum.; ChrStrat.	2	4
6.11	4151	Observation Cape		Russia	68.97	76.10	35	5	Lum.	2	3
6.12	4152	Sula	Sula 21/22	Russia	67.00	50.34	50	5	Lum.; ChrStrat.	4	4
6.13	4153	River Yangarei	Yangarei-1	Russia	68.70	61.83	70.5	5	Lum.; ChrStrat.	0	4
6.14	4154	Vorga-Yol		Russia	66.70	56.75	91	5	Lum.	2	4
6.15.1	4188	Pyoza River	Zaton site	Russia	65.58	44.63	10	2	AAR; ESR; ChrStrat.	4	4
6.15.2	4189	Pyoza River	Bychye site	Russia	65.79	45.06	23	4.6	ChrStrat.	2	4
6.15.3	4190	Pyoza River	Viryuga W.	Russia	65.82	46.00	49	9.8	ChrStrat.	0	3
6.15.4	4191	Pyoza River	Viryuga E.	Russia	65.82	46.00	63	10	ChrStrat.	2	4
6.15.5	4192	Pyoza River	Kalinov	Russia	65.79	46.22	37	7.4	ChrStrat.	3	4

6.15.6	4193	Pyoza River	Yatsevets	Russia	65.70	46.52	38	7.6	ChrStrat.	1	4
6.15.7	4194	Pyoza River	Site 11 Orlovets	Russia	65.71	46.84	43.5	8.7	ChrStrat.	3	4
6.15.8	4195	Pyoza River	Site 12 Orlovets	Russia	65.69	46.93	43.5	8.7	ChrStrat.	3	4
6.15.9	4196	Pyoza River	Site 13 Yolkino	Russia	65.68	47.60	51	10	ChrStrat.	2	4
6.15.10	4197	Pyoza River	Site 14 Yolkino	Russia	65.68	47.60	51	10	Lum.; ChrStrat.	2	4
6.15.11	4198	Pyoza River	Burdui	Russia	65.67	48.06	60	10	ChrStrat.	2	4
6.16	4155	Ponoi River	Unit 2	Russia	67.08	41.13	11.5	2.3	Lum.; ESR; ChrStrat.	2	4
6.17	4156	Svyatoi Nos		Russia	68.02	39.87	16	3.2	Lum.; ChrStrat.	0	4
6.18	4157	Chapoma		Russia	66.11	38.97	10	2	ESR; ChrStrat.	4	4
6.19	4158	Strelna River		Russia	66.10	38.52	35.5	7.1	ESR; ChrStrat.	2	4
6.2	4159	Varzuga	S1	Russia	66.40	36.64	14	2.8	ChrStrat.	0	4
6.21	4160	Petrozavodsk		Russia	61.77	34.40	40	8	ChrStrat.	1	4
6.22	3712	Peski		Russia	60.15	29.29	13.5	8	ChrStrat.	4	4
6.23	3711	Põhja-Uhtju		Estonia	59.68	26.51	-49	1	ChrStrat.	2	4
6.24	3985	Suur-Prangli		Estonia	59.62	25.01	-61	1	ChrStrat.	2	4
6.25.1	3987	Lower Vistula Region	Obrzynowo	Poland	53.78	19.27	-3.5	10	ChrStrat.	4	4
6.25.2	3986	Lower Vistula Region	Licze	Poland	53.75	19.13	-8	10	ChrStrat.	4	4
6.26.1	3990	Rewal coastline	Rewal borehole	Poland	54.09	15.03	-5.5	0.4	ChrStrat.	3	4
6.26.2	3991	Rewal coastline	Ciećmierz borehole	Poland	53.99	15.03	-6.5	4	ChrStrat.	3	4
6.26.3	3989	Rewal coastline	Sliwin borehole	Poland	54.08	15.01	6.3	0.8	ChrStrat.	3	4
6.27	4161	Ollala	Borehole F	Finland	64.18	25.35	116.5	1	ChrStrat.	4	4
6.28	4162	Ukonkangas		Finland	63.91	25.85	105.7	1	ChrStrat.	5	4
6.29	4163	Viitala		Finland	62.60	23.00	84.5	1	ChrStrat.	2	4
6.3	4164	Mertuanoja		Finland	64.113	24.59	60	1	Lum.; ChrStrat.	4	4
6.31	3988	Norra Sannäs		Sweden	61.78	16.69	27.65	9	ChrStrat.; Other dating	4	4
6.32	3708	Fjøsanger		Norway	60.34	5.33	15	0.1	AAR; Lum.	5	4
6.33	3709	Bø		Norway	59.36	5.28	-1	0.1	AAR; ChrStrat.	5	4
6.34	3833	Hidalen	Unit D	Norway (Svalbard)	78.90	28.13	83	2	AAR	3	2
6.34	3834	Hidalen	Unit B	Norway (Svalbard)	78.90	28.13	64	2	AAR; Lum.	2	2
6.35	3787	Kapp Ekholm	Formation B	Norway (Svalbard)	78.55	16.55	22	0.1	AAR; Lum.; ChrStrat.	3	4
6.36	3810	Skilvika	Formation 3	Norway (Svalbard)	77.57	14.44	28	0.5	Lum.	3	3
6.37	3799	Kongsfjordhallet		Norway (Svalbard)	79.03	11.88	34	1	Lum.	3	3
6.38	3809	Poolepynten	Unit A1	Norway (Svalbard)	78.45	11.66	5	2	AAR; Lum.; Other dating	3	4
6.39	3788	Leinstranda		Norway (Svalbard)	78.88	11.56	19.2	0.5	Lum.; ChrStrat.	3	4
6.4	3710	Galtalækur		Iceland	63.99	-19.96	120	10	ChrStrat.; Other dating	2	3
6.41.1	4168	Kikiakajik	Beach	Greenland	70.04	-22.25	9.75	3.4	Lum.; ChrStrat.; Other dating	3	4
6.41.2	4166	Kap Hope	Regressive sequence	Greenland	70.46	-22.32	8	2.23	Lum.; ChrStrat.; Other dating	5	4

6.41.2	4167	Kap Hope	Transgressive sequence	Greenland	70.46	-22.32	15	1	Lum.; ChrStrat.; Other dating	3	4
6.41.3	4169	Kap Stewart		Greenland	70.44	-22.78	40	8	Lum.; ChrStrat.	4	4
6.41.4	4170	Hesteelv		Greenland	70.44	-23.10	35	7	Lum.; ChrStrat.	3	4
6.41.5	4172	Fynselv	443d	Greenland	70.46	-23.32	21.5	4.3	Lum.; ChrStrat.	3	4
6.41.6	4254	Langelandselv	composite section	Greenland	70.55	-23.64	70	10	AAR; Lum.; ChrStrat.	4	4
6.41.7	4181	Aucellaelv River	Location 72	Greenland	70.59	-23.76	16	3.2	AAR; Lum.; ChrStrat.	1	4
6.41.8	4182	Lollandselv-Falsterselv		Greenland	70.87	-24.18	20	4	ChrStrat.	4	2
6.42.1	4199	Thule	Iterlak K	Greenland	76.71	-69.41	27.5	5.5	AAR; ChrStrat.; Other dating	2	4
6.42.2	4200	Thule	Iterlak L	Greenland	76.71	-69.42	14	2.8	Lum.; ChrStrat.	2	4
6.42.3	4201	Thule	Saunders Ø B	Greenland	76.60	-69.74	20	4	Lum.; ChrStrat.	3	4
6.42.4	4202	Thule	Saunders Ø C	Greenland	76.60	-69.74	12	2.4	Lum.; ChrStrat.	3	4
6.42.5	4203	Thule	Narsaarsuk D	Greenland	76.45	-69.29	6	1.2	AAR; ChrStrat.	2	4
6.42.6	4204	Thule	Narsaarsuk E	Greenland	76.45	-69.29	6	1.2	AAR; Lum.; ChrStrat.	2	4
6.42.7	4205	Thule	Narsaarsuk F+G	Greenland	76.45	-69.29	9	1.8	AAR; Lum.; ChrStrat.	2	4
6.43.1	3661	Iles de la Madeleine	Camping	Canada	47.35	-61.88	14	4	Lum.	2	3
6.43.2	3640	Iles de la Madeleine	Portage du Cap	Canada	47.25	-61.91	17	4.88	ChrStrat.; Other dating	3	2
6.43.3	4183	Iles de la Madeleine	Le Bassin	Canada	47.23	-61.90	2	1	ChrStrat.; Other dating	4	2
6.44.1	4185	Clyde Foreland	Profile 6	Canada	70.69	-68.95	28	5.6	ChrStrat.; Other dating	1	4
6.44.2	4186	Clyde Foreland	Profile 9	Canada	70.60	-68.41	11	5.6	U-Series; AAR; ChrStrat.	0	4
6.44.3	4187	Clyde Foreland	Profile 10	Canada	70.58	-68.35	2.5	0.5	AAR; ChrStrat.	1	4
6.45	3639	Ile aux Coudres	Site du Forage	Canada	47.41	-70.42	-2	0.4	ChrStrat.; Other dating	2	2
6.46	3680	Long Island	Bridgehampton - core S59793	United States of America	40.94	-72.31	-23	1.4	AAR; ChrStrat.	1	2
6.47	3637	Kwataboahegan River	Marine unit	Canada	51.14	-82.12	90	18	AAR; Other dating	0	2
6.48	4184	East of Nicholson Peninsula	VH-83-050	Canada	69.89	-128.52	2	0.4	AAR; ChrStrat.; Other dating	3	2