Aki Hakonen

SHORELINE DISPLACEMENT OF THE FINNISH BOTHNIAN BAY COAST AND THE SPATIAL PATTERNS OF THE COASTAL ARCHAEOLOGICAL RECORD OF 4000 BCE – 500 CE

Abstract
In regions where post-glacial isostatic land uplift is in effect, shoreline displacement chronology is a common and convenient tool for establishing relative dates for archaeological sites. In this paper, the spatial relationship between archaeological remains and their contemporary shorelines are studied on the Finnish Bothnian Bay. A commonly used shoreline displacement chronology for the region is evaluated by comparing its results to four diverse benchmarks. The shoreline displacement curves of the best fitting sea-level gauge-based variables are presented and the distances to concurrent shorelines from archaeological radiocarbon samples are measured in ArcGIS by using terrain elevation models to provide accurate topography. The results show that different types of coastal remains behave differently in relation to their distance from the sea. These observations offer further insight into the chronology and nature of the remains and shed light on related prehistoric activities. Additionally, recent geological land uplift models based on radiocarbon dated basin isolations are shown to be incompatible with archaeological data.

Keywords: Bothnian Bay, coastal archaeology, land uplift, prehistory, radiocarbon dating, shoreline displacement.

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INTRODUCTION

Regions of the world that were once covered by the Pleistocene ice sheets are affected by post-glacial isostatic land uplift. The rebounding effect is constantly in motion, lifting the depressed landmasses, with its rate slowing down from the onset. This forms unique shorelines for different time periods, a phenomenon known as shoreline displacement (Ekman 2009). It is strongest in the Hudson Bay region of North America and in the Gulf of Bothnia in northern Europe, where the effect has consistently outpaced eustatic sea-level rise. The extreme limit of the Fennoscandian uplift and its core region are illustrated in Fig. 1. In archaeology, the effect provides a useful tool for determining relative dates for ancient remains. Ideally, shoreline displacement provides a *terminus post quem*, or earliest possible date, but its accuracy is uncertain. In geology, land uplift poses a problem to be solved, especially regarding urban planning (Salonen et al. 2006: 217). With impending construction projects such as the coastal Hanhikivi nuclear power plant in Pyhäjoki, 20 km south of Raahe, the understanding of this combined effect is of utmost importance. Both archaeology and geology can benefit from related studies since all assessments of future land uplift and its effects are based on its past (see e.g. Vuorela et al. 2009; Berglund 2012; Johansson 2014).

This paper studies the spatiality of coastal archaeological sites in relation to contemporary shorelines. The shoreline elevations are determined with a sea-level gauge-based shoreline displacement chronology commonly used in Finnish archaeological studies of the coastal Bothnian Bay. Translated into archaeology by Jari Okkonen (1998: 52–7; 2003a: 85–8) from the study by geologist Marjatta Okko (1967), this relatively simple method provides estimations of the theoretical mean sea-levels for different time periods. It relies on a basic equation, for which long-term sea-level gauge observations provide the input variables. There are a total of 13 sea-level gauges in Finland, five of which are located in the study area, and these have provided accurate data since 1922 (Kääriäinen 1982).

The gauges, which are located on the shoreline, measure the mean sea-level. With long-term observations of sea-levels, the apparent land uplift, meaning the combined effect of eustatic sea-level rise and isostatic land-uplift, can be determined (e.g. Ekman 2009; Johansson 2014). The current apparent uplift can be extrapolated to estimate the past uplift. The method can be useful wherever post-glacial isostatic rebound has consistently remained stronger than sea-level rise.

Several other approaches have been adopted for studying post-glacial land uplift (see Siiriäinen 1978; Saarnisto 1981; Lambeck et al.

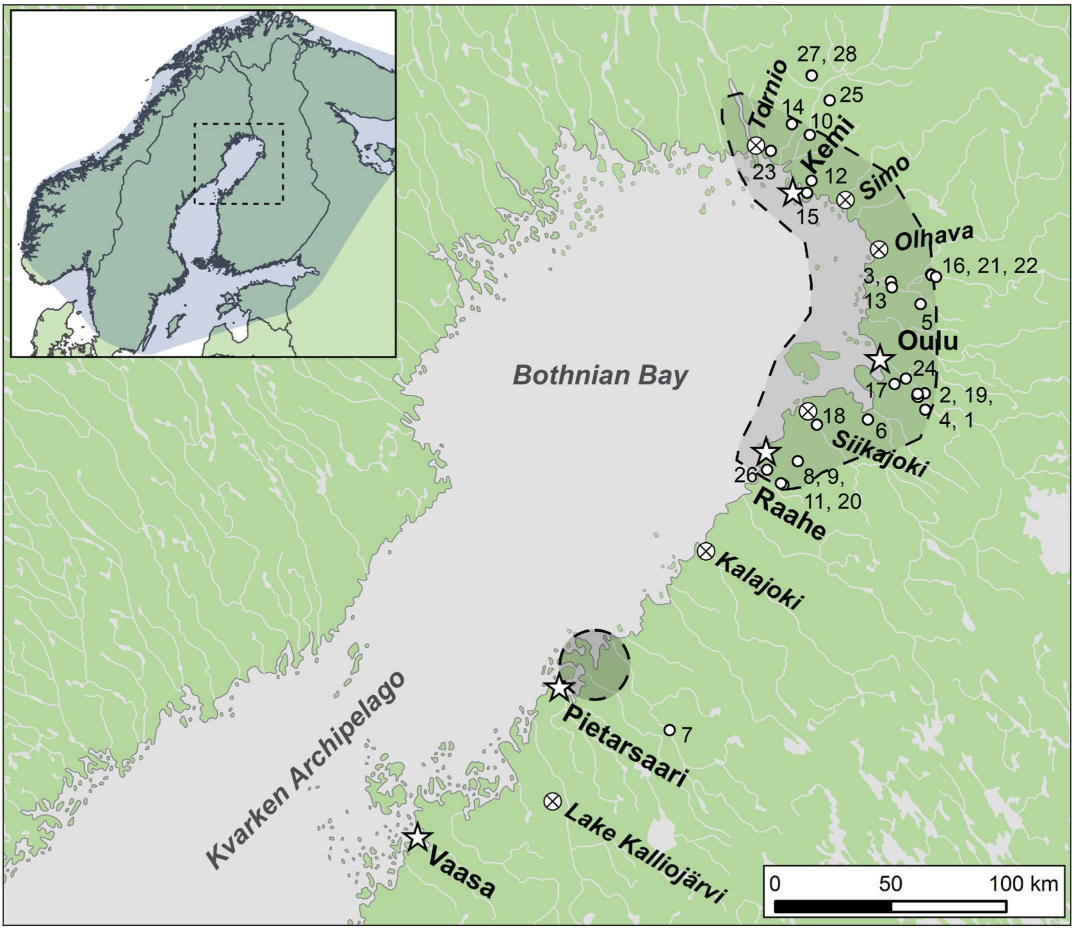

Fig. 1. The study area (highlighted from Tornio to Raahe) and pertinent locations. Sea-level gauges marked as stars, numbering corresponds with the list of sites in Appendix 2. Kokkola–Kruunupyy–Luoto region highlighted north-east of Pietarsaari. The shaded area in the smaller map is the approximate region currently affected by isostatic land uplift (based on Poutanen & Steffen 2014: Fig. 4). Map: A. Hakonen.

1998; Påsse 2001; Bergman et al. 2003; Ågren & Svensson 2007; Vuorela et al. 2009; Holmblad 2010; Vaneeckhout et al. 2012; Pesonen 2016), but for over a decade reference curves by Okkonen (2003a: Appendices 2–13) have been extensively used by archaeologists studying the Finnish Bothnian Bay region. The curves are often taken as granted and no further evaluations have been made (see e.g. Ylimaunu 1999; Ikäheimo 2002; 2005; 2015; Ojanlatva & Alakärppä 2002; Äikäs & Ikäheimo 2005; Koivunen & Rossi 2005; Kuusela 2009; 2013; Mökkönen 2012). The updated evaluation presented here aims to conclusively assert the relevance of the sea-level gauge-based chronology and make any necessary corrections to the existing land uplift curves. The most plausible curves are then compared with the elevations of radiocarbon dated archaeological remains, and the approximate distances from these to their respective shorelines are measured in ArcGIS to assess regular patterns.

The region in question is the Finnish coast of the Bothnian Bay (Fig. 1), where post-glacial rebound remains strong. Okkonen used the sea-level gauge-based method to determine shoreline dates of up to 2000 BCE, but for older shorelines he used the model by Glückert et al. (1993: 14, Fig. 4), which was based on five radiocarbon dated isolation basins. Recent studies suggest that the apparent land uplift in the area has remained nearly constant for the last 6000 years, with a relatively slow uplift deceleration rate (see e.g. Salonen et al. 2006: 31; Vuorela et al. 2009: 77–8). Based on this, the archaeological time periods for which the gauge-based shoreline displacement chronology remains applicable are from the Middle Neolithic until present day. Whether this is actually accurate prior to 2000 BCE requires further testing, which is provided by this study. The chosen timeframe is 4000 BCE to 500 CE. Since the uplift equation produces a slowly but exponentially growing curve, 4000 BCE is estimated as the absolutely oldest date when the curve can be expected to be in line with the actual trend. Earlier accelerated eustatic sea-level rise called Litorina transgression, caused by North American deglaciation, resulted in slower apparent land-uplift in the Baltic Sea region (Salonen et al. 2006: 29–30), which is not modelled by the equation.

ARCHAEOLOGICAL CONTEXTS AND RADIOCARBON DATES

Prehistoric communities surrounding the Gulf of Bothnia have often been interpreted as coastal, with shoreline displacement providing a relative dating method (see Okkonen 2003a: 106–10, 144–60; Vaneeckhout 2009: 35–6; Kuusela 2014: 223). Throughout the timeframe, the subsistence of these coastal communities was primarily based on foraging, i.e. hunting, fishing and gathering. Still, differences in subsistence strategies emerged, affecting the spatiality of remains. Pastoralism extended to Central Ostrobothnia from the south after 2800 BCE (Lavento 2012; Bläuer & Kantanen 2013). Later during the Bronze Age (1700–500 BCE), there is evidence of agrarian activities affecting settlement patterns near Vaasa, where habitation was situated closer to inland meadows than the coast (Holmblad 2010: 125–38, 163–6). The livelihood of these communities was evidently less dependent on coastal resources than in the northern Bothnian Bay region. Thus, the logic of shoreline connectedness of prehistoric communities is stronger in the northern regions than further south after the 4th millennium BCE. This study focuses on the northern forager region, where the dwelling patterns are more likely to give insight into temporally connected shoreline phases.

The 65 archaeological radiocarbon dates (Appendix 1) used in this study are from 28 sites (Appendix 2) dating from 3800 calBC to calAD 450. The sites are located along the arc from Tornio to Raahe, with the addition of Kangas (Fig. 1). Although for the current purposes it is not relevant to summarize the whole prehistory of the region, it is necessary to consider the contexts of the radiocarbon dates. The largest number of dates, 38, are from dwelling sites. These include activity sites, mainly identified by stone and pottery refuse, but without any clear dwelling remains. Exemplifying these are the oldest phase of Kauniinmetsänniitty 1, c 3500 BCE (Pesonen 2013a), Hangaskangas E, 2200–800 BCE (Pesonen 2013b), and Halosentörmä, 1800–700 BCE (Ikäheimo 2015), and similar later sites like Rakanmäki, 100–500 CE, where also iron production and cairn burying was practiced (Mäkivuoti 1988). Dwelling depressions, or the remains of pit houses, are also represented by the dwelling site category. Some structures are individual, such as Peurasuo, c 1500 BCE (Alakärppä et al. 1998), while some are part of larger assemblages, the Neolithic villages, which may contain up to several hundred dwelling depressions. These include Kangas (Halinen 1997a), Kuuselankangas (Halinen 1997b), Purkajasuo Korvala (Schulz 1996), Siirtola (Kankaanpää 2002), and Törmävaara (Schulz 1995). In general, the villages date roughly from 4000 to 2000 BCE (Núñez & Okkonen 1999: 106–7; Okkonen 2003a: 168–72; Vaneeckhout 2009; Mökkönen 2011). The radiocarbon dated material of the dwelling context is varied, consisting of charcoal, burnt animal bone, chewing resin, and pottery crust. Adjacent to Purkajasuo, Korvala is a prehistoric bay containing the site of Purkajasuo where wooden fish traps were constructed either underwater or at the water's edge around 3500–3000 BCE. Similarly, most Neolithic villages are assumed to be coastal (Pesonen 1999; see Herva & Ylimaunu 2014: 189–90).

The second most numerous sample context is cooking pits, with 15 dates. The dates range from 1000 calBC to calAD 500. Sometimes cooking pits occur individually or just a few at the same site, as in Metsokangas (Äikäs & Ikäheimo 2005), Kiimamaa (Okkonen 1994), and Kortejärvenkangas (Alakärppä et al. 1997a), but also in larger groups, like in Sanginkangas E (Ikäheimo & Ylimaunu 2000) and Kiviharju (Korteniemi 1999), of up to a hundred pits. The pits are generally two to three metres wide and 1 to 1.5 metres deep, containing burnt rocks, soot, and charcoal. The radiocarbon samples are usually taken from charcoal, but on rare cases dates can be acquired from pottery crust, as in Kiimamaa. In Oulu the distribution of nearly 300 cooking pits roughly matches the shoreline of the ancient river estuary, implying that cooking pits were mostly dug close to the shore (e.g. Okkonen 2003a: Appendix 33; Okkonen & Äikäs 2006: 21–3; Äikäs 2009; Kuusela 2014: 223–7).

In the third millennium BCE, large stone enclosures, or giant's churches (Fi. jätinkirkko), were built along the south-eastern coast of the Bothnia Bay and the Kvarken Strait. Several sites contain not only giant's churches but also dwelling depressions, activity sites, and various stone cairns (Huurre 1983: 171–6; Forss 1991; 1998; Núñez & Okkonen 1999: 107–9; Okkonen 2003a: 30, 123–4; 2014a). These include debris cairns, such as those dated at Kettukangas and Kastelli Linnakangas to c 2800 BCE. These two sites in question contain dozens of debris cairns, consisting mostly of burnt rocks, situated in rows that run along the ridge at the same elevation. They may indicate a contemporary shoreline, although matching it with a specific date is problematic, since the samples taken from charcoal show significant variation.

Radiocarbon dates of three burial cairns or stone settings were also included in the study. These are Kiimamaa (Okkonen 1994; Kuusela 2013: Appendix 1), Rakanmäki (Mäkivuoti 1987: 4–5) and Tervakangas (Jarva 1999), dating from 400 calBC to calAD 400. The two former samples were cremated human bone and the Tervakangas date is from pottery crust. Two other radiocarbon dated burials are included, the Hangaskangas Early Bronze Age cremation burial, c 1700 calBC, (Ikäheimo 2005: 180–1) and the Neolithic Kangas inhumation burial, c 3900 calBC (Halinen 1997a; 1997c: 53). The former sample was taken from cremated bone and the latter from charcoal.

Although radiocarbon dating offers a method for establishing absolute dates, there are several uncertainties which undermine its reliability (Taylor & Bar-Yosef 2014: 43–64). The most universal uncertainty is caused by changes in atmospheric ^{14}C ratios, which causes a disconnection between radiocarbon and calendar years. This is corrected with a calibration curve, which is constantly refined, thus causing the calibrated dates to vary slightly with each update of the curve. The dates of this study are calibrated with CALIB v. 7.10, using the IntCal13 calibration curve for terrestrial samples (Stuiver et al. 2016; Reimer et al. 2013). Also the radiocarbon dates of isolation basins were calibrated with the terrestrial data set, since 'the samples were assumed to be non-marine' (Vuorela et al. 2009: Appendix 3). However, there are indications that in some cases the isolation dates, especially when taken from bulk sediment, may be affected by reservoir effect (Hedenström & Possnert 2001). This effect, caused by the mixing of temporally varying carbon in aquatic environments (Taylor & Bar-Yosef 2014: 27–8, 60–1, 150–3), might result in affected radiocarbon dates appearing to be several centuries – in extreme cases even several millennia – older than they actually are (Philippsen 2013). Reservoir effect in the Gulf of Bothnia has been evaluated as relatively weak, and even weaker in the Bothnian Bay (Lougheed et al. 2013), but the research has thus far been only preliminary. Nevertheless, all original dates used in this study are calibrated as terrestrial, with all perceived anomalies noted in Appendix 1.

Out of 66 dates 42 are AMS and 24 are conventional, the latter having a higher error margin. The ^{13}C ratios of most samples are indicated in Appendix 1, since a ratio between -21.5‰ and -12.5‰ may indicate transferred reservoir effect resulting in older apparent age (Palincaş 2017; also Taylor & Bar-Yosef 2014: 61, 153–4). In this study, this may especially affect some of the dated bone and pottery crust with marine origins, adding up to several centuries to their date. A similar effect on charcoal is related to the lifespan of wood. The heartwood of a living tree may also be several centuries older than the outer living layer (Thomas 2003: 55–6, 242–5, 256–8), and in many cases deadwood may have been used as fuel. Thus, the cautious assumption is that all charcoal samples in fact predate the actual burning at least by some decades (Palincaş 2017), but the margins in the current cases are unknown. In some cases, this effect may even be transferred to bone during burning (Olsen et al. 2013).

Assigning earliest possible dates to archaeological sites based on the dating of the nearest shoreline phase is an easy method to use, but it contains significant risks. These include absolute errors, such as incorrect shoreline displacement estimates, and relative errors, i.e. overemphasizing the shore-boundedness of sites and ignoring short term sea-level variations. The aim of the following procedure is to evaluate the validity of this method by determining the best fitting shoreline curves and analysing the compatibility of shoreline displacement chronology and radiocarbon dated archaeological records. The last stage is the evaluation of the shore-boundedness of sites based on their radiocarbon dates.

SHORELINE DISPLACEMENT EQUATION

The most valid shoreline displacement curves are determined through four benchmarks. The first benchmark is the isolation basin date of Lake Kalliojärvi in Kauhava. This is an update of the test conducted previously by Okkonen, who used this as the only absolute benchmark (Okkonen 1998: 57; 2003a: 87), and thus, it is necessary to see that it is still valid despite the changes in calibration curves and the increased accuracy of elevation data. The second benchmark is a collection of more recent isolation basin dates from the vicinity of Pietarsaari. The third is the archaeological site of Purkajasuo in Oulu. Here the locations of three underwater samples are compared with sample from the adjacent dwelling site, which is used to establish the position of the related shoreline. The final benchmark is the apparent land uplift curve of the Rauma region, which was interpolated by Vuorela et al. (2009) based on a continuous isolation basin record. The best fitting gauge value sources are determined through these four comparisons.

The equation published by Marjatta Okko (1967), where change in altitude (y) over a timespan (t) at a given location can be calculated when one knows the current rate of uplift (v) and the past deceleration in uplift (d), is as follows:

$$y = (v*t) - (0.5*d*t^2)$$

> …in which *y* is the altitude (amount of uplift), *v* the present rate of land uplift […], *t* the time in centuries, and *d* the change in rate. Because *d* is known to have a retarding effect on *v*, it has a negative sign when time before the present is referred to. (Okko 1967: 17)

To determine *v*, Jari Okkonen (1998; 2003a) used two sets of average values obtained from sea level gauges by Kääriäinen (1982) and Vermeer et al. (1988). These values represent current apparent land uplift. The difference between the two studies is that Kääriäinen based his values on observations from 1923–80, while the values of Vermeer et al. are based on 1923–85. Kääriäinen's values are slightly higher than those of Vermeer et al., which have a wide standard deviation-based error margin (Table 1; for the Oulu region, Okkonen probably used

Location/values	Kääriäinen (1982: 158) m/century	Vermeer et al. (1988: 63) m/century
Kemi	0.750±0.021	0.735±0.04
Simo (averages)	0.7365±0.016	0.7125±0.04
Oulu–Olhava	0.723±0.012	0.69±0.04
Siikajoki (averages)	0.743±0.013	0.716±0.04
Raahe	0.763±0.014	0.742±0.04
Kalajoki (averages)	0.8015±0.0105	0.7715±0.04
Pietarsaari	0.840±0.007	0.801±0.04
Kalliojärvi (averages)	0.8235±0.0065	0.7875±0.04
Vaasa	0.807±0.006	0.774±0.04
Rauma	0.57±0.008	0.545±0.04

Table 1. Land uplift rate derived from sea-level gauges, from north to south.

Kääriäinen's average values from 1913–80, which Kääriäinen regarded as unreliable, cf. Okkonen 2003a: 85 footnote 4; Kääriäinen 1982: 157–8). Using later sea-level gauge observations in predicting past land uplift is questionable, because since the 1980s mean sea-level has fluctuated erratically (Johansson 2014: 43). The reason for this may be global warming, which affects wind patterns and causes accelerated eustatic sea-level rise (Church et al. 2001; Johansson 2014: 47). The original values of Table 1 were presented as millimetres per year and have been converted to metres per century for the current study. *d* is a crucial part of the equation, since without it the deceleration of the uplift rate is not included, giving the false impression that apparent land uplift was of the same magnitude 6000 years ago as it is today. To determine *d,* Okkonen (1998) used the linear deceleration rate of 1.5% per century. This is converted as follows for the equation: $d = v * -0.015$.

As an example, the process of calculating the theoretical mean sea level of the Oulu region in 2000 BCE is presented below. For present uplift rate (v) we will arbitrarily choose the Vermeer et al. median (0.69 m/century in Table 1). Since the elevation data used here is from 2011, it is set as the present year. Thus t, or time in centuries, will be 40.11.

$$(0.69*40.11) - (0.5 * (0.69 * -0.015) * (40.11^2))$$
$$27.6759 - (0.5 * -0.01035 * 1608.8121)$$
$$27.6759 + 8.32560 = 36.0015$$

Thus, the theoretical mean sea level in 2000 BCE is 36 metres above the current mean sea-level. To find the deviation, the high and low values of 0.73 and 0.65 must also be used.

THE VALIDITY TESTS

The shoreline displacement curves presented in this paper were drawn in Microsoft Excel by establishing elevations at hundred-year intervals from 2000 CE to 4000 BCE. Maps by Jari Mäkinen (Vuorela et al. 2009: 20, Fig. 6) of the Finnish National Land Survey and by the Swedish Lantmäteriet (Ågren & Svensson 2007: 96, Fig. 4:3; Poutanen & Steffen 2014: 57, Fig. 5a), which show the apparent land uplift rates in Fennoscandia, were used to estimate the relative uplifts of locations that are situated between sea-level gauges. Thus, the same values are used for the area from Oulu to Olhava, since according to both maps this stretch of the coast has roughly the same uplift rate (also Vestøl 2006: 256, Fig. 10), while other liminal locations use the average value of the two nearest gauges.

Isolation of Kalliojärvi – Benchmark 1

To establish the validity of a given shoreline displacement curve, it needs to be compared with absolute shoreline dates. Radiocarbon dates of lake isolation core samples provide suitable benchmarks. This method works by identifying in the stratigraphy of lakebed core samples the moment when the basin rose above sea level, indicated by a shift from marine sediment to brackish and freshwater sediments. By dating organic matter in the related stratum, an isolation date can be determined. However, this contains significant uncertainty, largely related to common issues with radiocarbon dating, such as error margins and the possibility of reservoir effect (see above). The formation of the stratigraphy of isolated basins is also uncertain. Due to the constant fluctuation of sea levels, it is not entirely clear at which point an isolated basin is no longer affected by the flows (Eronen et al. 2001: 23–6; Miettinen 2011: 81; see also Long et al. 2011). Nevertheless, this method is used here since it is commonly used in land uplift studies (see Vuorela et al. 2009).

The shoreline displacement curves were tested against the isolation date of Lake Kalliojärvi in Alahärmä, Kauhava. The same test was already conducted in the late 1990s by Okkonen (1998; 2003a), but it is repeated here due to increased accuracy in elevation measurements and ^{14}C calibration curves. The basin's isolation was radiocarbon dated by Glückert et al. (1993) to 3370±90 BP (TKU-57), or 2-sigma 1669±200 calBC. This previous study used 36.2 m asl. as the isolation level, even though the marshy and modified terrain, including several drainage ditches, must have made it difficult to establish. The elevation measurement tool used in the study had an accuracy of 1 metre (Glückert et al. 1993: 10). The isolation elevation has also increased naturally since the original study by at least 20 cm due to recent land uplift. The presently used elevation model shows that the isolation process began at 37.7 m a.s.l. According to the Atlas of Finland (1986; cited in Eronen et al. 2001: 23; Miettinen 2011: 81), the Baltic Sea experiences up to 2.8 metres of variation in sea level (or ±1.4 m). Therefore, in order to simulate frequent non-extreme variation, estimated through Finnish Meteorological Institute's sea-level variation graphs of 2016 (see Ilmatieteen laitos – Vedenkorkeus n.d.), a metre is subtracted from the elevation to determine the isolation threshold, the point when regular high water no longer discharged marine deposits into the basin. This should take into account tides and recurring winds while leaving extreme short-term variation, such as storms, out of the equation. Thus 36.7 m asl. is used as the isolation threshold level. As Lake Kalliojärvi is located between two sea level gauges, Pietarsaari and Vaasa, the average values of these gauges are applied (see Table 1).

As shown in Fig. 2, the closest match for the calibrated radiocarbon median of 1669 BCE is the Vermeer et al. (1988) median value curve, which intersects with the median date. Since the dated deposit cannot have formed before the isolation of the basin, or when the water level was above the isolation level, the Vermeer et al. low value curve is the only other plausible candidate.

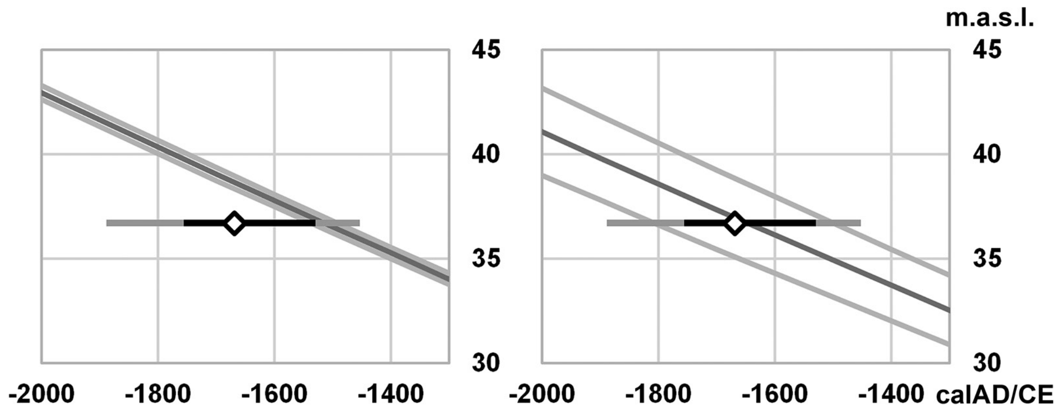

Fig. 2. Isolation of Kalliojärvi basin according to Kääriäinen (1982; left) and Vermeer et al. (1988; right) sea-level gauge values (high, median and low deviations). Calibrated radiocarbon date represented as a diamond (median) and black (1-sigma) and grey (2-sigma) horizontal lines.

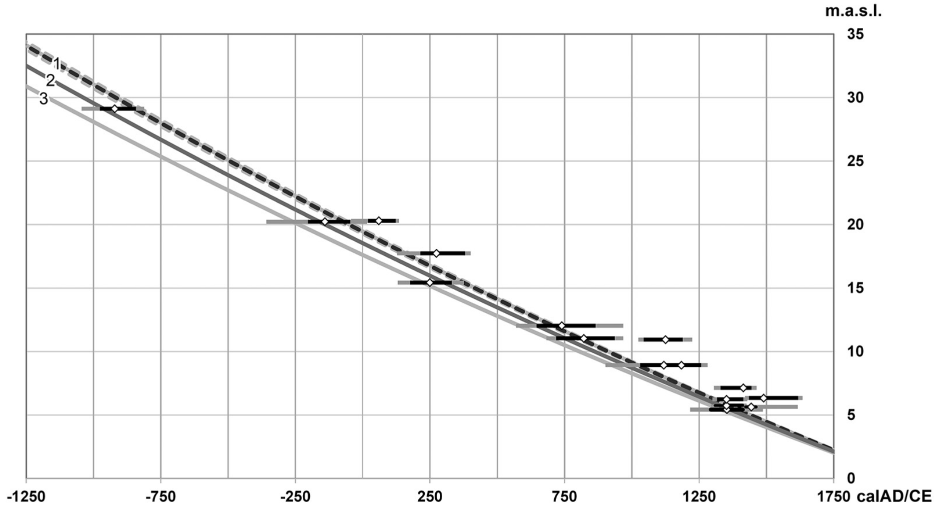

Fig. 3. Kokkola–Kruunupyy–Luoto isolation basins. Land uplift curves: 1) All values of Kääriäinen (1982) and the high value of Vermeer et al. (1988); 2) Vermeer et al. (1988) median value; 3) Vermeer et al. (1988) low value.

Thus, all three curves of Kääriäinen (1982) and the high value curve of Vermeer et al. (1988) do not fit the date since they indicate that Lake Kalliojärvi was below the mean sea-level during its isolation.

Basins of Kokkola–Kruunupyy–Luoto region – Benchmark 2

There are few isolation basin dates from the main study area around the Finnish Bothnian Bay that apply to our timeframe beginning from 4000 BCE. The northernmost area with a larger set of dates is the Kokkola–Kruunupyy–Luoto region, with 17 dated isolation basins in close proximity (numbered by Vuorela et al. 2009 as 221, 276–89, 313–5). The elevations of these basins derive from Vuorela et al. (2009: Appendices 1&4, N2000 values). Fig. 3 shows the relationship between the uplift curves and radiocarbon dates. The best fitting curves are those that run through the 1-sigma probability values.

Since the dates show significant variation, land uplift curves that take into account all the isolation dates cannot be drawn. For example, some of the younger dates, from 900 to 1650 CE, are surprisingly recent for their elevations. Whether this is a local anomaly or an effect of wider climate fluctuations is beyond the scope of this study. The high value curve of Vermeer et al. (1988) and all three curves of Kääriäinen (1982) are clearly unaligned with the isolation

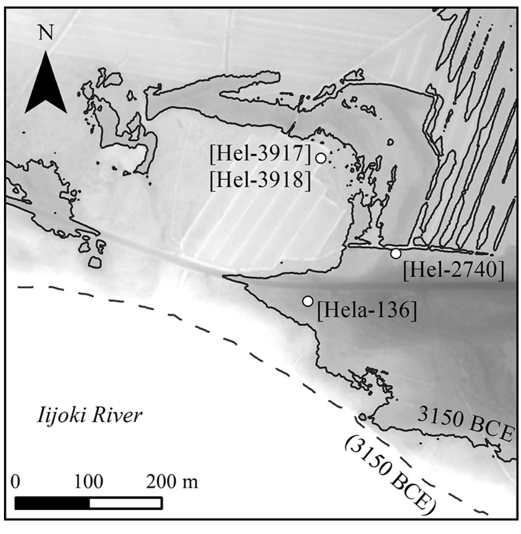

Fig. 4. Purkajasuo and its four radiocarbon dates on a 2-m elevation map. Shorelines based on Kääriäinen's (1982) high value (solid line) and Vermeer's et al. (1988) median (dashed line, parenthesis). Map: A. Hakonen.

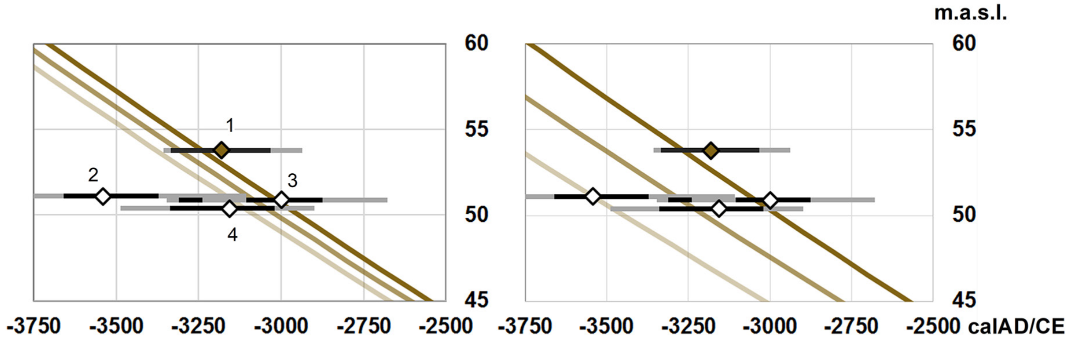

Fig. 5. Purkajasuo dates and Kääriäinen's (1982; left) and Vermeer's et al. (1988; right) high, median and low value curves. Horizontal lines are the distributions of calibrated radiocarbon dates: 1) Hela-136; 2) Hel-2740; 3) Hel-3917; 4) Hel-3918. Diamonds indicate dates' medians and horizontal lines 1-sigma (black) and 2-sigma (grey) deviations.

trend. The Vermeer et al. median value curve runs below all but three sample medians, while the low value curve runs below all but one. The implication is that the Vermeer et al. median and low value curves are the best fit for the data, since isolation cannot happen below sea-level. This is in contrast with the four uplift curves for the region drawn by Vuorela et al. (2009: Fig. 49, 51) which reach elevations between 32 and 29 m a.s.l. at 1000 BCE, matching all except the Vermeer et al. low value curve. The Vermeer et al. median value curve is thus the overall best fit.

The Purkajasuo fish traps – Benchmark 3

The third benchmark is archaeological. Purkajasuo and Purkajasuo, Korvala in Oulu are sites with a total of four radiocarbon dates (Fig. 4; Appendix 1). The sample from Purkajasuo, Korvala, Hela-136, is from food crust on a piece of pottery from inside the stone embankment of a dwelling depression or a possible giant's church, and the three Purkajasuo samples, Hel-3917, Hel-3918, and Hel-2740, are from underwater contexts (Schultz 1996: 17, 20). The elevations of the samples were determined from the excavation report of 1996 and the current 2 m terrain elevation model. As the samples were taken from wooden structures of probable fish traps that had collapsed in the direction of the waves and were preserved by the oxygenless marsh, it has been concluded that the traps were situated underwater and remained *in situ* (see Koivisto 2012; 2017; Koivisto & Nurminen 2015). It is also unlikely that they were made of deadwood since durability is a key attribute in such structures. That said, the heartwood of a healthy tree may have been dead for centuries (Thomas 2003: 55–6, 242–5, 256–8). It is nonetheless likely that the radiocarbon dated traps were made of younger and thinner wood. A dendrochronological analysis has shown that the ages of 12 sampled wooden remains at the site ranged from 35 to 80 years, with the trees felled within 19 years of each other (Zetterberg & Kinnunen 2009). The dwelling site sample and the three underwater samples provide a useful benchmark for the location of the related shoreline, especially Hela-136 and Hel-3918, which share similar median dates of 3180 and 3160 calBC. The shoreline must have been above Hel-3917 at 3000 BCE and Hel-2740 at 3540 BCE. The terrestrial Hela-136 is located at 53.8 m asl., while the underwater Hel-3918 is at 50.4, so the related shoreline must be situated between these levels.

The relationship between the samples and the projected shoreline displacement curves is presented in Fig. 5. It seems that Hel-3917 does not quite fit. Its median is almost at the same shoreline trajectory as Hela-136, showing the inherent uncertainty in using median ^{14}C dates. Part of the problem could be related to the nature of Hela-136. Taken from the crust on a broken ce-

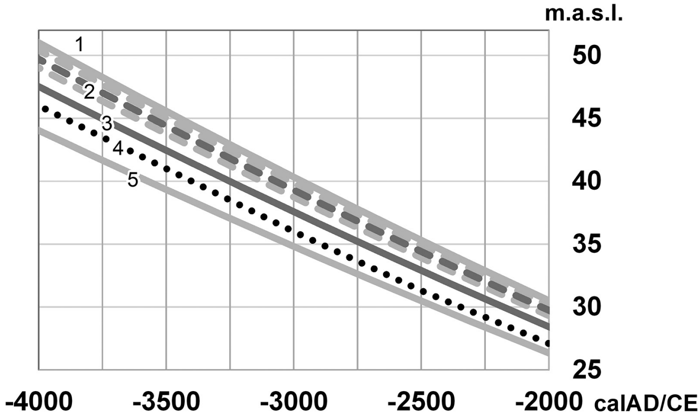

Fig. 6. Competing shore displacement curves for Rauma region: 1) Vermeer's et al. (1988) high value curve; 2) Kääriäinen's (1982) curves; 3) Vermeer's et al. (1988) median value curve; 4) Vuorela's et al. (2009: Fig. 57) curve; 5) Vermeer's et al. (1988) low value curve.

ramic vessel *inside* the stone embankment, and thus from a secondary context, it could very well be older than the dwelling itself. It is therefore more relevant to have Hel-3917 underwater than Hela-136 on dry land. Evaluated on this basis, the high value curve presented by Kääriäinen (1982) is preferable, although it still leaves Hel-3917 above water with considerable probability. Nevertheless, it performs slightly better than the high value curve by Vermeer et al (1988). Kääriäinen's median and low value curves place the underwater Hel-3917 above water with high probability, so they do not match the benchmark.

Shoreline displacement in Rauma – Benchmark 4 and verdict

The final evaluation of the validity of the equation is the comparison of the curves of the Rauma region to the curve of Vuorela et al. (2009: Fig. 57). This curve is based on 48 different basin isolation dates and is the most complete basin isolation-based curve within the Gulf of Bothnia. The area has a special significance due to the Olkiluoto nuclear power plant. All curves conform to the same trajectory, with the largest deviation at the high end of the scale at 4000 BCE. Thus, only the late period of the sea level gauge-based curves, 4000–2000 BCE, is compared to reveal the greatest deviation and the closest match to the established curve. The closest matches are the median and low value curves based on Vermeer et al. (1988) (see Fig. 6).

In collating the benchmark tests, it is notable that benchmarks 1, 2, and 4 heavily favour the Vermeer et al. (1988) median value curves, and low value to a slightly lesser extent, in three different regions. In contrast, benchmark 3 with its sampling of an elaborate archaeological site matches closely with the high values of both sets. The median values of Vermeer et al., the overall best fit in the isolation basin-based tests, ranks fifth in the archaeological benchmark test (Fig. 5). The reason why the high values are favoured by benchmark 3 could be related to higher observed global sea-level rise during the 20th century in relation to previous centuries (Johansson et al. 2003: 57–8). Since the sea-level gauge values were obtained during 1922–80/85, strong eustatic sea-level rise during this time causes the apparent land uplift rate of the time period to be lower than it was in the past. Thus, high end values could be expected to best represent long term change. Why the tests based on basin isolation dates give contradicting results to benchmark 3 is unknown. In the next phases of the study, both Kääriäinen (1982) high and Vermeer et al. (1988) median are used.

SELECTED SHORELINE DISPLACEMENT CURVES AND ARCHAEOLOGICAL DATA

In Fig. 7 the Kääriäinen's high and the median value curves of Vermeer et al. for the Oulu–Olhava region are compared with 22 radiocarbon dates from 11 archaeological sites from the municipalities around Oulu. The region was chosen because it contains the majority of the radiocarbon dated sites in the study area. These sites were undoubtedly above sea-level during their use. The positions of the samples were geolocated in ArcGIS from various field reports and published data (see Appendix 2), and the elevations were determined using the two-metre resolution elevation map by the National Land Survey of Finland (Maanmittauslaitos n.d.). The horizontal accuracy of the samples is ±5 m and the vertical approximately ±0.5 m. If a considerable proportion of these locations were situated below the shoreline indicated by the curve, the method would prove to be inaccurate. Thus, recalibration should be conducted and previous research adjusted accordingly. However, all the radiocarbon dates are situated above their calculated shorelines with majority probability.

Here a discrepancy was noticed between the geological and the archaeological radiocarbon dates. According to the land uplift graphs produced by Vuorela et al. (2009: Fig. 45, 47, 51), who used a collection of isolation basin dates at different elevations to create interpolated baseline curves for different regions, several archaeological dates of dwelling sites such as Halosentörmä, Hangaskangas E, Siirtola and Törmävaara (see Appendix 1 for dates and elevations) end up underwater. In Oulu region this is explained by the lack of dated basins in certain elevations (Vuorela et al. 2009: 79) but having the same discrepancy in surrounding regions implies a categorical error either in the archaeological or geological radiocarbon record. Since the related archaeological samples are taken from different materials, including charcoal, burnt bone, birch resin, and pottery crust, a categorical error in the archaeological contexts is less likely. On the other hand, the possibly related geological categorical errors include sampling of the isolation stratigraphy, dating of marine or aquatic sediments vis-à-vis terrestrial, and the interpolation of dates. This problem is further highlighted by tests conducted with Central Ostrobothnian material.

CONTRADICTING LAND UPLIFT OF CENTRAL OSTROBOTHNIA

Serious mismatching occurs when using Pietarsaari sea-level gauge values with the equation and radiocarbon dates of the Neolithic village site of Kangas [1–5; numbers given in square brackets refer to numbering of dated samples at the sites, see Appendix 1] in Kaustinen as benchmarks (see Fig. 8). The comparison places the site below the mean sea-level with high probability. The most optimal shoreline displacement curve of Vuorela et al. (2009: 82, Fig. 51, Kronoby Case4 v2) fares better, but also places the major probability distribution of the dates underwater. Based on the dates from the Kangas site, this area of Central Ostrobothnia seems to have very similar shoreline displacement behaviour as the Oulu–Olhava region. Comparing the Kangas dates with the Kääriäinen high Oulu–Olhava curve places the dates accurately above the mean sea-level. This is contrary to the current trend, indicated in Table 1 by sea-level gauges (see also Ekman 2001: 4; Vuorela et al. 2009: 20, Fig. 6), according to which the Kvarken Strait experiences the strongest land uplift in the Gulf of Bothnia (see Poutanen & Steffen 2014). Perhaps

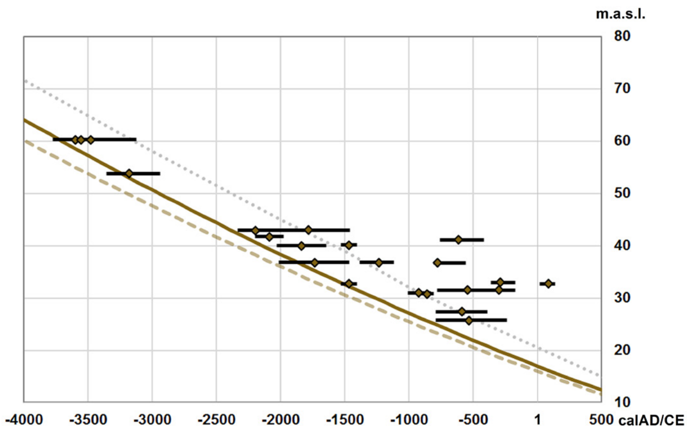

Fig. 7. Oulu–Olhava shore displacement curves based on the Kääriäinen's (1982) high (solid) and Vermeer's et al. (1988; dashed) median values. The radiocarbon dates show 2-sigma deviation (black horizontal lines) and medians (diamonds). The dotted line is the shore displacement curve for the Oulu region by Vuorela et al. (2009: Fig. 47).

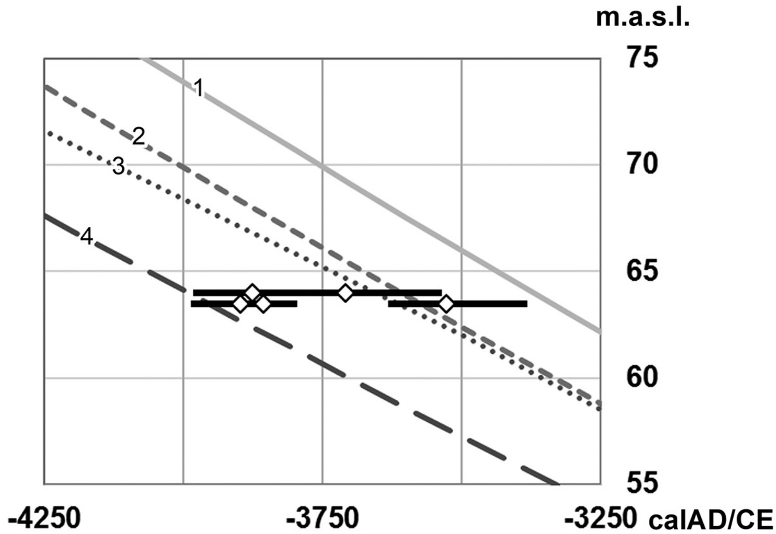

Fig. 8. Different shore displacement chronologies and radiocarbon dates of Kangas in Kaustinen. The dates are presented as medians (diamonds) and 1-sigma deviations (black horizontal lines). Shoreline displacement curves: 1) Kääriäinen's (1982) high value curve (Pietarsaari); 2) Vermeer's et al. (1988) median value curve (Pietarsaari); 3) Vuorela's et al. (2009: Fig. 51) uplift curve for Kruunupyy; 4) Kääriäinen's (1982) high value curve (Oulu–Olhava).

this trend is fairly recent and was not in effect five to six millennia ago. In this case, by matching the sea-level gauge values of Pietarsaari and the ^{14}C dates of Kangas, the deceleration of the region's apparent uplift would have to be closer to 0.8% per century, instead of the approximated 1.5%. This indicates that the interregional rate of land uplift has varied significantly (see Eronen et al. 2001: 29; Miettinen 2011: 82–4 for further indications).

MEDIAN RADIOCARBON DATES AND SHORELINE DISTANCE

Fifty-eight radiocarbon dates from 27 archaeological sites are used here in order to study their placement relative to their theoretical shorelines indicated by the calibrated median ^{14}C dates. Using the median dates is not ideal but taking into account the deviations of the dates would practically triple the amount of data, making the results too disjointed for presentation in the current format. The uncertainty created by the absence of radiocarbon date deviations is balanced by the amount of dates and the use of two different shorelines, based on the Kääriäinen (1982) high and the Vermeer et al. (1988) median value shoreline displacement curves. The 2-sigma deviations for the most error prone samples in relation to the curves are seen in Fig. 7. The studied attribute is the distance from the sample to the nearest shoreline. The sites are presented in Figs. 10–3 in four categories, divided based on the contexts. It should be noted that the dwelling category, in particular, is likely to contain sites with completely different functions, such as related to production and crafting. Mostly samples with precise horizontal spatial data (±5 metres) were chosen, except the Kauniinmetsänniitty 1 and Pirttihauta 1 samples, whose inaccuracies in Fig. 9 are ±10 metres and ±20 metres respectively.

Some samples are from the same remains, such as the two samples from a cooking pit in Kiimamaa [1, 3]. These samples produced dates differing by two centuries, indicating either reutilization of the pit or the burning of deadwood. To maintain a systematic approach, the older samples of Metsokangas [1] and Kettukangas [2] were also included, although both samples have been interpreted as deadwood (Äikäs & Ikäheimo 2005: 8; Okkonen 2014b: 12). A fourth likely deadwood sample is Törmävaara 30 [3], since its date is two centuries older than the bulk of Törmävaara 30 samples [1, 5, 6] and Törmävaara 41.

The distances from dwelling sites to theoretical shorelines show a clear pattern (Fig. 9). Twenty-seven out of 32, including three anomalous dates, are located within 250 metres of the shore; 24 are within 100 metres and 16 within 50 metres. Using the Vermeer et al. median value curves, 25 out of 31 are within 250 metres, while 16 are within 100 metres, and 7 within 50 metres. Cairns and burials (Fig. 10) seem to follow a similar pattern, but too few sites are included for a conclusive result. Even with the less optimal Vermeer et al. median value curves, two out of four are within 100 metres of the shoreline, with the third at 110 metres. This supports Okkonen's (2001; 2003a) already convincing interpretation of the shore-boundedness of cairns,

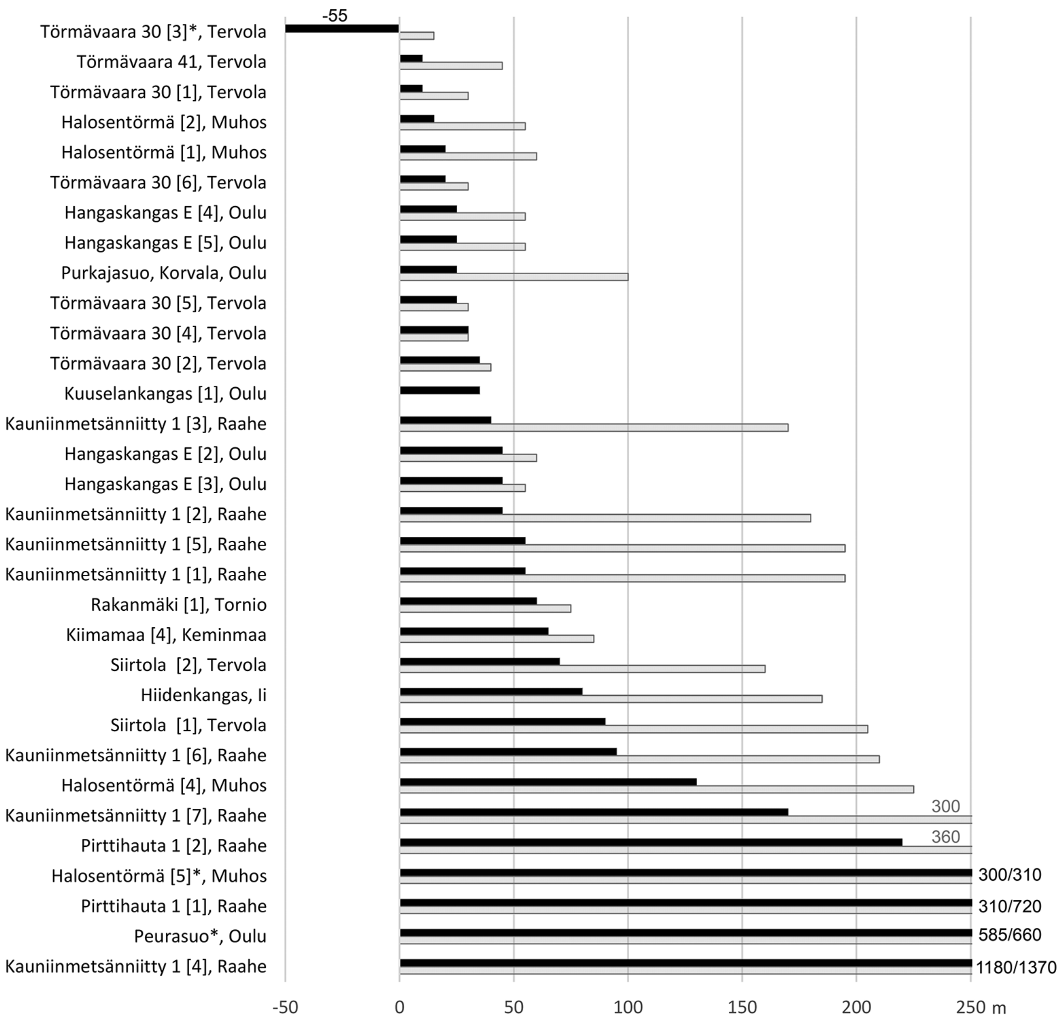

Fig. 9. Dwelling site radiocarbon samples and their distance (in metres) to the shoreline indicated by their calibrated median dates. Shorelines determined using the Kääriäinen's (1982) high (black bars) and Vermeer's et al. (1988) median (grey bars) value curves. Anomalous samples are marked with an asterisk.

Site, municipality	Distance to coast (m)	Context	Notes
Halosentörmä [3], Muhos	1050	Cooking pit	150 metres to a river
Jauholaarinkangas, Liminka	250	Cooking pit	30 metres to a wetland
Keronmäki, Keminmaa	235	Cooking pit	50 metres to a stream
Kiimamaa [1], Keminmaa	325	Cooking pit	100 metres to a wetland
Kiimamaa [2], Keminmaa	225	Cairn	100 metres to a wetland
Kiimamaa [3], Keminmaa	110	Cooking pit	100 metres to a wetland
Kiviharju [1], Ii	290	Cooking pit	125 metres to a wetland
Kiviharju [2], Ii	630	Cooking pit	125 metres to a wetland
Korkiamaa 3, Keminmaa	5800	Cooking pit	100 metres to a wetland
Metsokangas [1], Oulu	250	Cooking pit	60 metres to a wetland
Metsokangas [2], Oulu	400	Cooking pit	60 metres to a wetland
Papinkangas, Siikajoki	550	Cooking pit	130 metres to a wetland
Peurasuo, Oulu	585	Dwelling	80 metres to a field

Table 2. Radiocarbon samples from sites located closer to other bodies of water than the sea.

which he defined loosely as a proximity of up to 2 km to the shore. Only Kiimamaa [2] might be related more closely to other bodies of water, even though it is also only 225 m from the seashore (Table 2).

Cooking pits, on the other hand, behave quite differently (Fig. 11). According to the Kääriäinen high value curve, only six out of 15 cooking pit samples were located within 250 metres of their shorelines, with two within 100 metres and none within 50 metres. In fact, 11 samples from 9 cooking pits were closer to other bodies of water than the sea and most were clearly not located near the coastline (Table 2). This probably does not apply to all the cooking pits in the area, of which there are more than a thousand. Obviously 15 samples from 13 pits is not a representative sample. Further evidence of the distance between cooking pits to their contemporaneous shorelines has been found in the Jätinhaudanmaa region in Laihia. Here several cooking pits have been dated to 1000–500 BCE, when the distance to the coast was more than a kilometre. These cooking pits were closely connected to an agrarian dwelling site (Holmblad 2010). There is yet no evidence of agrarian activity related to the northern cooking pits (Okkonen 2003a; Äikäs 2009; Kuusela 2014). Nevertheless, especially considering the varying contexts of cooking pits, it is advisable to exercise increased scepticism when dating cooking pit sites through shoreline displacement chronology.

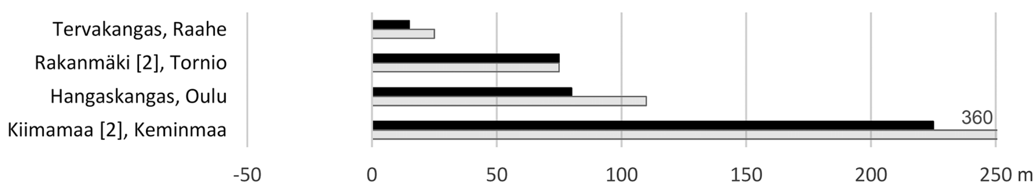

Fig. 10. Cremation and burial cairn radiocarbon samples and their distance (in metres) to the shoreline indicated by their calibrated median dates. See Fig. 9 for information.

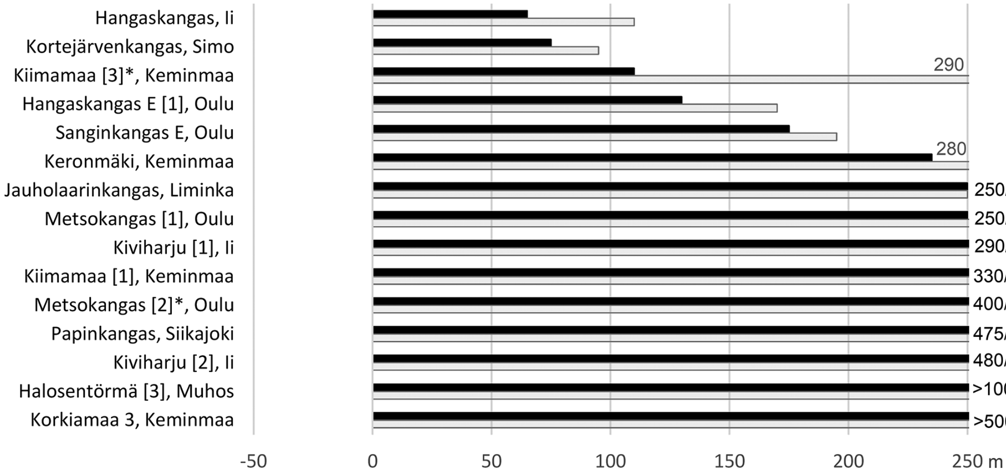

Fig. 11. Cooking pit radiocarbon samples and their distance (in metres) to the shoreline indicated by their calibrated median dates. See Fig. 9 for information.

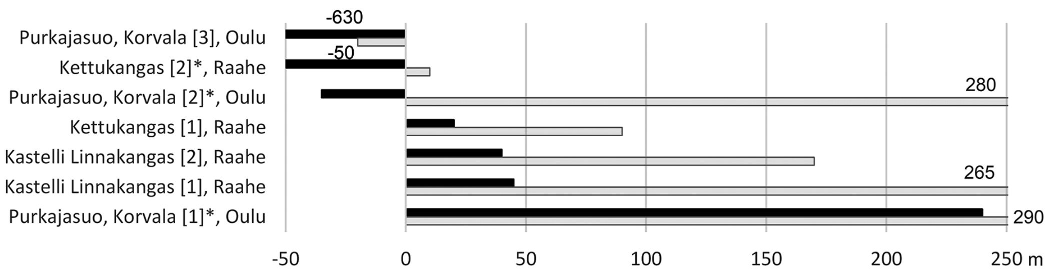

Fig. 12. Debris cairn and underwater radiocarbon samples and their distance (in metres) to the shoreline indicated by their calibrated median dates. See Fig. 9 for information.

Without radiocarbon dates, some dwelling sites, such as Pirttihauta 1 and Kauniinmetsänniitty 1, would have been dated with too much emphasis on their shoreline phases. The same is true for Peurasuo. It is possible that during its use the site was located next to a small cove, but the elevation of the former seabed has risen due to recent farming. This causes the site to appear to be hundreds of metres from the theoretical shoreline during its use, although this was probably not the reality.

Purkajasuo [3], the oldest of the site's ^{14}C dated fish traps, seems to be an outlier (Fig. 12). According to the Kääriäinen high value curve, it was underwater and more than 600 metres from the closest shoreline, which seems excessively distant, but rather than being considered erroneous, it may be explained as trapping behaviour. It could be related to an earlier phase of the site when the islet of Korvala was still rising from the sea. The oldest fish traps may have been constructed during low tide when the islet was either above or just below the water surface, the discernible land acting as a marker for the traps. Later, when land uplift had had a sufficient effect, the site became occupied. The uplift curve based on Vermeer et al. (1988) median values places the same sample quite plausibly underwater only 20 metres from the shore but places the other underwater samples incorrectly on dry land.

The unreliability of the curves is noticeable in the Kemi-Tornio-Tervola region around 3500 BCE. Especially samples Törmävaara 30 [1] and Törmävaara 41, which are located just 10 metres from the theoretical mean shoreline, indicate that the error margins in both radiocarbon dates and shoreline displacement chronologies may cause serious mismatches when using median values. The significance of this depends on the scope of the study. When studying the topography of a single site, deviations in dating and land uplift should not be concealed as metadata. On the other hand, large datasets presented as averages carry their own intrinsic logic, since the larger the dataset, the less importance can be afforded to individual variables.

CONCLUSIONS

The study supports the continued use of this specific sea-level gauge-based shoreline displacement chronology as a method for studying landscapes and temporalities. The analysis indicates that the method is applicable to a wider timeframe than was previously assumed, from 4000 BCE till present. Even the haphazard method of using median radiocarbon dates and theoretical mean sea-levels works surprisingly well, although this should be used with caution. The recommended shoreline displacement curves for the Finnish Bothnian Bay are presented in Appendix 3. While the Kääriäinen's (1982) high values were evaluated as the best fitting variables for the region based on archaeological data, isolation basin dates were more supportive of the median values of Vermeer et al. (1988). The contradiction probably relates to the differences in formation processes between the geological and archaeological benchmarks. Future geological studies should use archaeological radiocarbon dates as upper limit benchmarks, to prevent contradictions, where dated archaeological sites are indicated to situate below the mean sea-level.

Especially noteworthy is the observation of anomalous past apparent land uplift of Central Ostrobothnia, which does not seem to conform to the current trend. Clear archaeological indicators of different shoreline elevations in the region are prehistoric boat landings, but these are scantly documented and, thus far, none have been absolutely dated. In future studies these could offer more precise benchmarks. Additional benchmarks will not necessarily absolve shoreline displacement chronology of its inherent inaccuracies, especially concerning local short-term variation caused by temporary sea-level fluctuations.

Using Kääriäinen's high values, which were favoured by the archaeological benchmark test, none of the relevant non-anomalous samples end up below the theoretical mean sea-level and the curves placed the related shorelines within 100 metres from the dwelling site samples 24 out of 32 times. The same logic is echoed in comparisons based on the median values of Vermeer et al. (1988). This has long been the assumed preference and this study adds concrete evidence of this behaviour. The comparison also reveals less systematic distances to shore for samples from cooking pits, which were nearly always related to completely different bodies of water than the sea. This indicates that the dating of cooking pits through shoreline displacement chronology is extremely inaccurate. A more context-based approach is needed to reliably date cooking pits, even though radiocarbon dating has its own flaws, e.g. deadwood, deviations, and reservoir effect may cause serious discrepancies. Further site-by-site comparisons of shoreline displacement and absolute dates not only strengthen our understanding of specific sites, but also offer further insight into prehistoric behaviour and postglacial geology.

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APPENDIX 1

Sample [no], municipality	Lab-index	BP	±	Median calBC/AD	Dated material
Halosentörmä [1], Muhos	Hela-154	3420	105	-1733	Chewing resin
Halosentörmä [2], Muhos	GrA-63520	3195	35	-1469	Chewing resin
Halosentörmä [3], Muhos	GrA-63518	1915	30	87	Charcoal
Halosentörmä [4], Muhos	GrA-63888	3000	35	-1236	Burnt bone
Halosentörmä [5], Muhos	GrA-63519	2565	30	-777	Charcoal
Hangaskangas E [1], Oulu	Ua-45452	2460	30	-615	Charcoal
Hangaskangas E [2], Oulu	Ua-45451	2710	35	-861	Charcoal
Hangaskangas E [3], Oulu	Ua-45447	2775	40	-922	Pottery crust
Hangaskangas E [4], Oulu	Ua-45450	3695	35	-2086	Seal bone
Hangaskangas E [5], Oulu	Ua-45449	3775	40	-2199	Seal bone
Hangaskangas, Ii	Hel-3833	2400	90	-534	Charcoal
Hangaskangas, Oulu	Hela-498	3510	75	-1836	Cremated human bone?
Hiidenkangas, Ii	Hel-2786	3460	130	-1786	Charcoal
Jauholaarinkangas, Liminka	Beta-14101	2360	60	-467	Charcoal
Kangas [1], Kaustinen	Hel-3999	4910	100	-3709	Charcoal
Kangas [2], Kaustinen	Hel-4000	5090	100	-3876	Charcoal
Kangas [3], Kaustinen	Hela-161	5115	85	-3898	Charcoal
Kangas [4], Kaustinen	Hela-172	5060	65	-3857	Pottery crust
Kangas [5], Kaustinen	Hela-173	4740	65	-3600	Pottery crust
Kastelli Linnakangas [1], Raahe	Hela-521	4185	60	-2763	Charcoal
Kastelli Linnakangas [2], Raahe	Hela-522	4125	60	-2710	Charcoal
Kauniinmetsänniitty 1 [1], Raahe	Hela-1708	4805	40	-3572	Charcoal
Kauniinmetsänniitty 1 [2], Raahe	Hela-1709	4830	40	-3597	Charcoal
Kauniinmetsänniitty 1 [3], Raahe	Hela-1710	4835	40	-3633	Charcoal
Kauniinmetsänniitty 1 [4], Raahe	Hela-1711	3935	35	-2424	Chewing resin
Kauniinmetsänniitty 1 [5], Raahe	Hela-1712	4770	40	-3567	Birch tar in pottery
Kauniinmetsänniitty 1 [6], Raahe	Hela-1713	4730	40	-3527	Pottery crust
Kauniinmetsänniitty 1 [7], Raahe	Hela-1714	4690	40	-3457	Burnt seal bone
Keronmäki, Keminmaa	Hel-3234	2220	110	-268	Charcoal
Kettukangas [1], Raahe	Hel-4033	4280	120	-2902	Charcoal
Kettukangas [2], Raahe	Hel-4032	4520	110	-3214	Charcoal
Kiimamaa [1], Keminmaa	Hel-3236	2210	100	-259	Pottery crust
Kiimamaa [2], Keminmaa	Hela-2995	2320	31	-393	Cremated human bone?
Kiimamaa [3], Keminmaa	Hel-3682	2370	80	-493	Charcoal

List of radiocarbon samples.

δ13C	Elevation (m asl.)	Context	Anomalies	Reference
N/A	36.8	Dwelling		Ikäheimo 1999: 6
-26.67	32.7	Dwelling		Ikäheimo 2001a; pers. comm. 2016
-25.92	32.7	Cooking pit		Ikäheimo 2001a; pers. comm. 2016
N/A	36.8	Dwelling		Ikäheimo 2001b; pers. comm. 2016
-25.59	36.7	Dwelling		Ikäheimo 2015; pers. comm. 2016
-25.3	41.1	Cooking pit		Pesonen 2013b: 39
-26.3	30.8	Dwelling		Pesonen 2013b: 39
-27.0	31.0	Dwelling		Pesonen 2013b: 39
-27.7	41.7	Dwelling		Pesonen 2013b: 39
-28.4	42.9	Dwelling		Pesonen 2013b: 39
-25.1	25.7	Cooking pit		Ylimaunu 1999: 6; Junger & Sonninen 2004: 43
-21.4	40.0	Cremation	Reservoir effect?	Kuusela 2013: Appendix 4; Ikäheimo pers. comm. 2015
-25.6	43.0	Dwelling		Jarva & Okkonen 1990: 10; Junger & Sonninen 1998: 3
N/A	27.3	Cooking pit		Korteniemi 2000: 9
-26.2	64	Dwelling		Halinen 1997a; 1997c: 53
-24.7	64	Dwelling		Halinen 1997a; 1997c: 53
-22.5	63.5	Burial	Deadwood?	Halinen 1997a; 1997c: 53
N/A	63.5	Dwelling		Halinen 1997a; 1997c: 53
N/A	63.5	Dwelling		Halinen 1997a; 1997c: 53
N/A	53.3	Debris cairn		Okkonen 2003b: 8 footnote 14
N/A	52.6	Debris cairn		Okkonen 2003b: 8 footnote 14
-25.5	63.7	Dwelling		Pesonen 2013a: 533; 2007
-27.6	63.7	Dwelling		Pesonen 2013a: 533; 2007
-25.1	63.7	Dwelling		Pesonen 2013a: 533; 2007
-27.5	63.7	Dwelling		Pesonen 2013a: 533; 2007
-29.6	63.7	Dwelling		Pesonen 2013a: 533; 2007
-25.4	63.7	Dwelling		Pesonen 2013a: 533; 2007
-19.6	63.7	Dwelling	Reservoir effect?	Pesonen 2013a: 533; 2007
-23.7	31.0	Cooking pit		Kuusela 2013: Appendix 2; Junger & Sonninen 1998: 57
N/A	55.2	Debris cairn		Okkonen 2003a: 67 footnote 36
N/A	55.2	Debris cairn	Deadwood?	Okkonen 2003a: 67 footnote 36
-24.2	30.5	Cooking pit		Okkonen 1994: 10; Junger & Sonninen 1998: 58
N/A	32.5	Cairn		Kuusela 2013: Appendix 1
-25.2	30.5	Cooking pit	Deadwood?	Okkonen 2003a: 210 footnote 65

List of radiocarbon samples.

Sample [no], municipality	Lab-index	BP	±	Median calBC/AD	Dated material
Kiimamaa [4], Keminmaa	Hela-50	2695	115	-871	Pottery crust
Kiviharju [1], Ii	Beta-123180	2410	80	-542	Charcoal, pine
Kiviharju [2], Ii	Beta-123181	2270	60	-301	Charcoal, pine
Korkiamaa 3, Keminmaa	Hel-3824	2000	80	-12	Charcoal?
Kortejärvenkangas, Simo	Hel-3826	1610	80	449	Charcoal
Kuuselankangas [1], Oulu	Hela-162	4830	80	-3601	Chewing resin
Kuuselankangas [2], Oulu	Hela-163	4695	85	-3478	Chewing resin
Kuuselankangas [3], Oulu	Hela-164	4780	80	-3557	Chewing resin
Metsokangas [1], Oulu	Beta-184632	2610	70	-781	Charcoal
Metsokangas [2], Oulu	Beta-183716	2450	70	-587	Charcoal
Papinkangas, Siikajoki	Hel-2940	2690	110	-865	Charcoal, conifer
Peurasuo, Oulu	GrA-36890	3195	35	-1469	Burnt seal bone
Pirttihauta 1 [1], Raahe	Hela-1715	3640	35	-2005	Burnt bone
Pirttihauta 1 [2], Raahe	Hela-1716	3725	35	-2121	Burnt bone
Purkajasuo, Korvala [1], Oulu	Hel-3917	4340	100	-3000	Waterlogged wood
Purkajasuo, Korvala [2], Oulu	Hel-3918	4460	100	-3156	Waterlogged wood
Purkajasuo, Korvala [3], Oulu	Hel-2740	4770	130	-3541	Waterlogged wood
Purkajasuo, Oulu	Hela-136	4475	60	-3182	Pottery crust
Rakanmäki [1], Tornio	Hel-2224	1640	90	408	Charcoal
Rakanmäki [2], Tornio	Hela-2996	1679	30	366	Cremated human bone?
Sanginkangas E, Oulu	GrA-63522	2185	30	-288	Charcoal
Siirtola [1], Tervola	Hela-340	4295	70	-2923	Charcoal
Siirtola [2], Tervola	Hela-342	4340	75	-2989	Charcoal
Tervakangas, Raahe	Hela-88	1920	75	86	Pottery crust
Törmävaara 30 [1], Tervola	Hel-2151	4850	110	-3638	Charcoal
Törmävaara 30 [2], Tervola	Hel-2152	4500	130	-3198	Charcoal
Törmävaara 30 [3], Tervola	Hel-2153	5010	110	-3811	Charcoal
Törmävaara 30 [4], Tervola	Hel-2154	4650	130	-3407	Charcoal
Törmävaara 30 [5], Tervola	Hel-2155	4780	110	-3553	Charcoal
Törmävaara 30 [6], Tervola	Hel-2156	4820	110	-3591	Charcoal
Törmävaara 41, Tervola	Hel-2157	4780	100	-3554	Charcoal?

List of radiocarbon samples.

δ13C	Elevation (m asl.)	Context	Anomalies	Reference
-19.3	30.5	Dwelling	Reservoir effect?	Okkonen 2003a: 210 footnote 66
N/A	31.5	Cooking pit		Korteniemi 1999: 8: 14
N/A	31.5	Cooking pit		Korteniemi 1999: 11: 14
-25.0	36.5	Cooking pit		Alakärppä et al. 1997a: 24; Junger & Sonninen 2004: 43
-25.6	16.6	Cooking pit		Alakärppä et al. 1997b: 10; Junger & Sonninen 2004: 43
-27.2	60.3	Dwelling		Halinen 1997b: Appendix 3
-26.7	60.3	Dwelling		Halinen 1997b: Appendix 3
-28.0	60.3	Dwelling		Halinen 1997b: Appendix 3
-25.0	27.4	Cooking pit	Deadwood?	Äikäs & Ikäheimo 2005: 8; Beta Analytic Inc. n.d.
-25.0	27.4	Cooking pit		Äikäs & Ikäheimo 2005: 8; Beta Analytic Inc. n.d.
-25.6	31.2	Cooking pit		Korteniemi 1992: 106, Appendix XV
N/A	40.1	Dwelling	Modified terrain	Alakärppä et al. 1998; Niskanen 1998: 29; Ikäheimo pers. comm. 2016
N/A	45.7	Dwelling		Pesonen 2013a: 535; Karjalainen 2007
N/A	45.7	Dwelling		Pesonen 2013a: 535; Karjalainen 2007
-27.9	50.9	Underwater	Modified terrain	Schulz 1996: 20, Appendix 5
-24.6	50.4	Underwater	Modified terrain	Schulz 1996: 20, Appendix 5
-23.6	51.1	Underwater		Junger & Sonninen 1996: 92; Schulz 1996: 20
-28.8	53.8	Dwelling		Schulz 1996: 20, Appendix 5
N/A	18.9	Dwelling		Mäkivuoti 1987: 4–5
N/A	23.7	Cairn		Kuusela 2013: Appendix 1
-25.55	33	Cooking pit		Ikäheimo & Ylimaunu 2000; Ikäheimo pers. comm. 2016
N/A	54	Dwelling		Kankaanpää 2002: 69
N/A	54	Dwelling		Kankaanpää 2002: 68
N/A	20.1	Cairn		Jarva 1999: 98
N/A	62.0	Dwelling		Schulz 1995: Appendix 2
N/A	62.0	Dwelling		Schulz 1995: Appendix 2
N/A	62.0	Dwelling	Deadwood?	Schulz 1995: Appendix 2
N/A	62.0	Dwelling		Schulz 1995: Appendix 2
N/A	62.0	Dwelling		Schulz 1995: Appendix 2
N/A	62.0	Dwelling		Schulz 1995: Appendix 2
N/A	61.5	Dwelling		Schulz 1995: Appendix 2

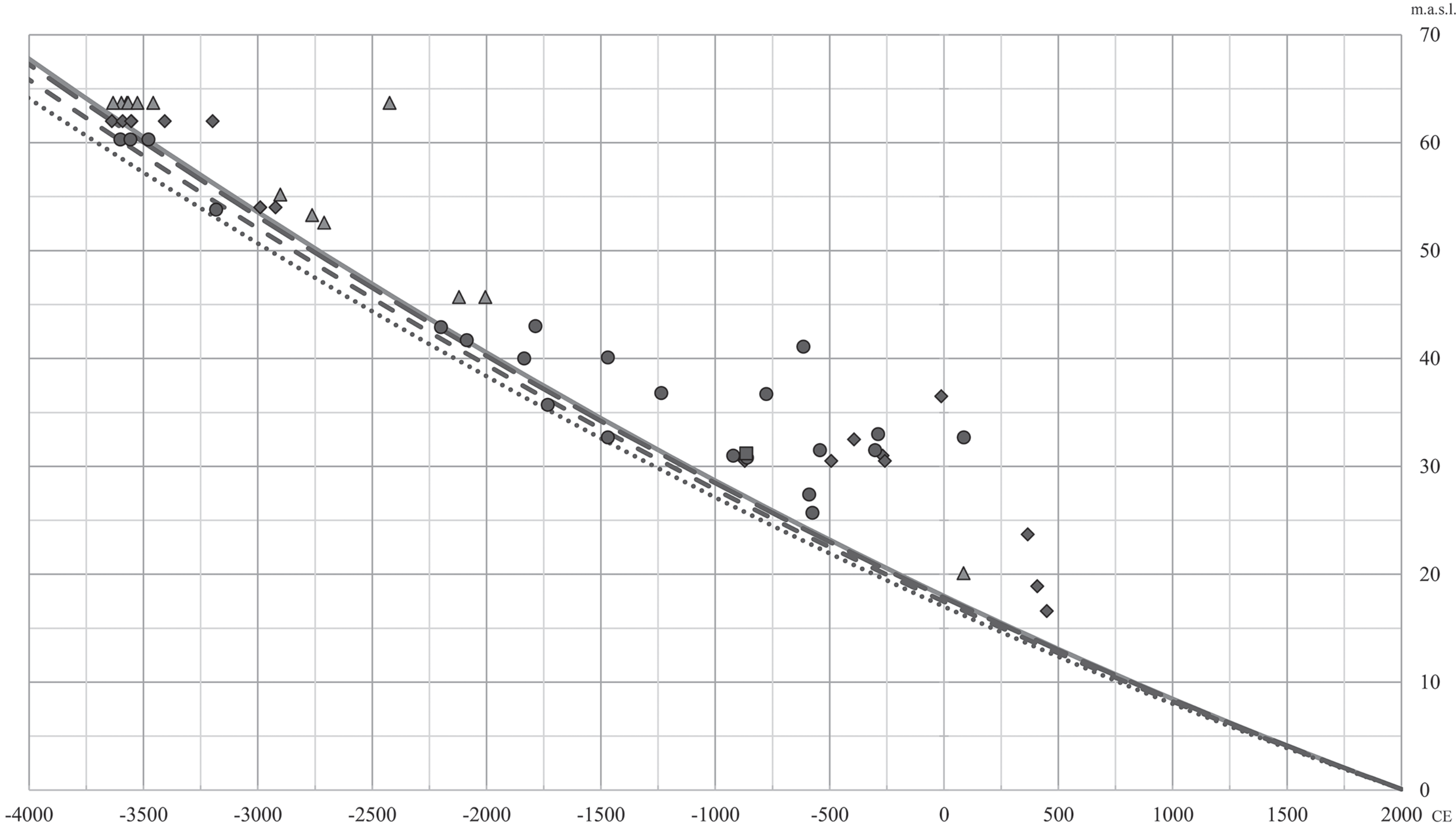
List of radiocarbon samples.

APPENDIX 2

Map no	Archaeological site, municipality	Site registry no.	Remains
1	Halosentörmä, Muhos	494010040	Activity area
2	Hangaskangas E, Oulu	1000006785	Activity area with cooking pits
3	Hangaskangas, Ii	139010035	Cooking pits
4	Hangaskangas, Oulu	564010051	Cremation burial
5	Hiidenkangas, Ii	84010022	Dwelling
6	Jauholaarinkangas, Liminka	425010041	Cooking pits
7	Kangas, Kaustinen	236010002	Dwelling depressions
8	Kastelli Linnakangas, Raahe	582010001	Giant's church, cairns and debris cairns
9	Kauniinmetsänniitty 1, Raahe	1000007636	Activity area and dwelling depression
10	Keronmäki, Keminmaa	241010002	Cooking pit
11	Kettukangas, Raahe	494010081	Giant's church, cairns and debris cairns
12	Kiimamaa, Keminmaa	241010023	Cooking pits, cairns and dwelling site
13	Kiviharju, Ii	139010012	Cooking pits
14	Korkiamaa 3, Keminmaa	241010077	Cooking pit
15	Kortejärvenkangas, Simo	1000018071	Cooking pit
16	Kuuselankangas, Oulu	972010043	Dwelling depressions
17	Metsokangas, Oulu	564010039	Cooking pit
18	Papinkangas, Siikajoki	748010001	Cooking pits
19	Peurasuo, Oulu	564010048	Dwelling depressions
20	Pirttihauta 1, Raahe	1000007560	Activity area
21	Purkajasuo, Korvala, Oulu	972010038	Dwelling depressions
22	Purkajasuo, Oulu	972010012	Fishing traps
23	Rakanmäki, Tornio	851010002	Activity area and cairns
24	Sanginkangas E, Oulu	564010084	Cooking pits
25	Siirtola, Tervola	845010094	Dwelling depressions
26	Tervakangas, Raahe	678010017	Cairns
27	Törmävaara 30, Tervola	845010030	Dwelling depressions
28	Törmävaara 41, Tervola	845010041	Dwelling depressions

List of related archaeological sites.

APPENDIX 3



Shore displacement curves of the Kääriäinen's (1982) high values and the related radiocarbon sample medians: Raahe (solid line, triangles), Kemi–Tornio (long-dashed line, diamonds), Siikajoki (short-dashed line, squares), and Oulu–Olhava (dotted line, circles).