Wave? What wave? Testing for impact of the Garth tsunami (3500 cal BCE) on Neolithic costal settlements in Western Norway

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Abstract

This paper evaluates to what extent archaeological settlement sites from the Norwegian west coast exhibit traces of a paleotsunami impact in the mid-4th mill BCE. The timing of the Garth tsunami (~3500 cal BCE), as inferred from lake basins in Eastern Shetland and in Western Norway, coincides with the Early-Middle Neolithic transition in the Western Norwegian chronology. Before and after the Garth tsunami, the west coast of Norway was populated by hunter-fisher-gatherers highly adapted to a marine environment. If the Garth tsunami had a direct impact on coastal settlements, the event could become an important mediating factor for research on the Early-Middle Neolithic transition in this region. The paper investigates radiocarbon dates and stratigraphic evidence from 15 coastal settlement sites. It applies Bayesian sequence calculation to test for congruence between site activity phases and the tsunami event, and a Monte Carlo based frequency analysis to test for population fluctuations. Results from these analyses do not support the hypothesis of a catastrophic impact on the hunter-fisher-gatherer population in Western Norway.

Key words

Garth tsunami; hunter-fisher-gatherers; Bayesian statistics; summed probability densities

1 Introduction

How did prehistoric hunter-fisher-gatherers react to tsunamis, and can archaeology test the level of catastrophe of known paleotsunamis? This paper explores vulnerability and resilience among prehistoric hunter-fisher-gatherers in face of a sudden and potentially catastrophic geological event. The setting is the west coast of Norway in the mid-4th millennium BC, and the event is the ~3500 cal BCE Garth tsunami (Bondevik et al., 2005). The timing of the Garths tsunami coincides with the transition from the Early to the Middle Neolithic periods in the Stone Age chronology for Western Norway (Table 1) (Bergsvik, 2003; Nærøy, 1994; Olsen, 1992). As discussed below, this transition is associated with significant changes in lithic technology and subsistence strategies. The Garths tsunami has the potential to become a highly relevant factor for future studies of this periodic transition – but only if a traceable effect of a paleotsunami in the archaeological record can be demonstrated. This paper sets out to evaluate if there are indications that archaeological settlement data from the Norwegian west coast were affected by a possible paleotsunami around ~3500 cal BCE.

Table 1. Chronological categories used in this paper.

Period	Abbreviation	Calendar dates
Early Neolithic	EN	4000-3500 cal BCE
Middle Neolithic A	MN A	3500-2800 cal BCE
Middle Neolithic B	MN B	2800-2350 cal BCE
Late Neolithic	LN	2350-1800 cal BCE

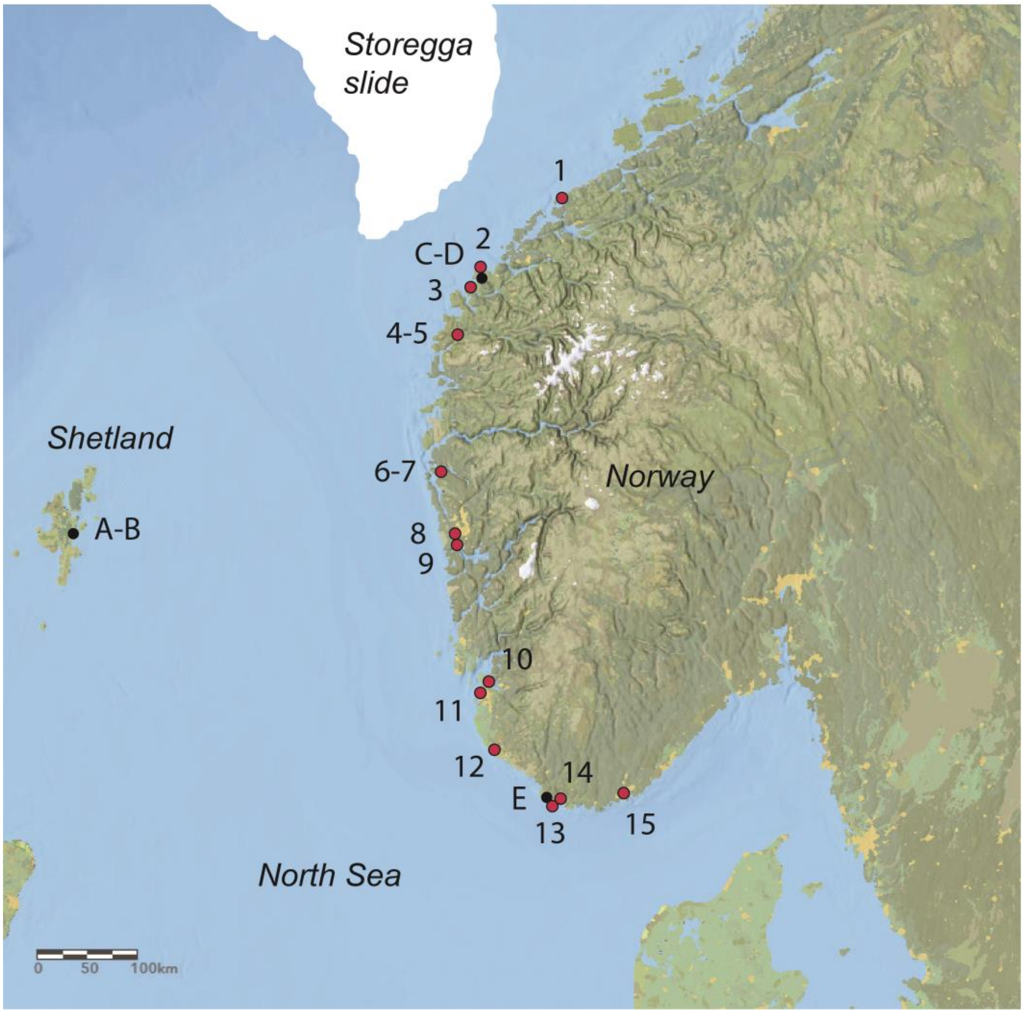

Figure 1. The archaeological (red dots) and geological (black dots) sites discussed in this paper. A: Garth Loch. B: Loch of Benston. C: Kjerringnesvatnet. D: Kulturmyra. E: Skjoldnesmyra. 1: Korsmyra 1. 2: Igesund. 3: Korsen. 4: Havnen 17. 5: Haukedal 1. 6: Ramsvikneset. 7: Kotedalen. 8: Håkonshella 8. 9: Nilsvika 4. 10: Austbø 12 A-B. 11: Stavanger airport. 12: Slettabø. 13. Grønnslettvika. 14: Skomrak. 15: Hamremoen. Background map based on open source maps at: www.arcgis.com.

There has lately been a growing interest among scholars in catastrophic events and their impact on hunter-gatherer societies in the past and in the present (Blankholm, 2018; Bøe et al., 2007; Cain et al., 2018; Cooper and Sheets, 2012; Damm et al., 2019; Riede, 2015; Smith et al., 2004; Waddington and Wicks, 2017). It is often anticipated that tsunamis represented catastrophes in the past (Bjerck, 2008). On the one hand, case studies have often found a high degree of resilience among prehistoric foragers (Fitzhugh, 2012). On the other hand, studies often stress methodological and empirical challenges, e.g. related to documentation, scales of analysis, and causation (Blankholm, 2018; Cain et al., 2018; Waddington and Wicks, 2017). This paper focus primarily on evaluating the archaeological record within a potential impact zone of a paleotsunami. It proceeds by analysing stratigraphic evidence and radiocarbon dates from 15 settlement sites located in close vicinity to the shore on the west coast of Norway around ~3500 cal BCE (Figure 1). The paper applies two different statistical methods, 1) first Bayesian sequence modelling in order to check for compliance between archaeological site phases and the paleotsunami event, and 2) a Monte Carlo based demographic analysis based on a larger dataset in order to test for fluctuations in a population proxy. The paper deals with two different site types: 1) archaeological occupation sites with cultural layers that enable high definition intra-site site chronologies, and 2) archaeological sites that remains poorly documented but which are still important for future research on this topic.

2 Geological evidence

The Garth tsunami is named after Garth Loch in South Nesting, Shetland (Bondevik et al., 2005). From this basin, the event was dated by samples collected from lacustrine gyttja positioned above and below a mixed gravel layer interpreted as a tsunami deposit (Table 2). The two levels were dated to 3635-3121 cal BCE and 3933-3522 cal BCE respectively. At the Loch of Benston basin, which is located in the same area as Garth Loch on Shetland, a sample collected from within the tsunami deposit was dated to 3941-3645 cal BCE. Bondevik et al. (2005) estimated a runup for the Garth tsunami on Shetland to at least ~10 meters.

Retrospectively, however, evidence of the Garth tsunami was first identified (though not conclusively at that time) in the two lake basins Kulturmyra and Kjerringnesvatnet, at the island Bergsøya on the northwestern coast of Norway (Bondevik et al., 2005, 1997). In these basins the tsunami deposits took the shape of sand layers measuring 7-30 cm in thickness with a sharp lower boundary containing gravel particles (>3 cm) and terrestrial plan fragments. The layers themselves were not radiocarbon dated, but an age estimation to ~3500 cal BCE was calculated based on presumed constant sedimentation rate (Bondevik et al., 2005). Kulturmyra and Kjerringnesvatnet are situated 3-2.5 m above present day sea level and were probably isolated slowly from the sea in the period 3400-2500 cal BCE (4600-4000 BP), meaning both basins were located below sea level at the time of the Garth tsunami.

A more recent study of the Skjoldnesmyra basin, ~500 km distance from Sundmøre, identified an ‘ungraded sandy gravel deposit’ positioned between layers of gyttja (Romundset et al., 2015). Four radiocarbon dates collected from three different cores, each taken from the gyttja directly above the gravel layer, gave a combined age of 4656±19 BP (3515-3367 cal BC). Thus, Romundset et al. (2015, p. 8) concluded that ‘the sorted gravel layer was deposited near to, or shortly after, 5500 years ago’. They estimated the timing of the isolation of Skjoldnesmyra from the sea to ~1900 cal BCE, meaning that this basin was also located below sea level at the time of the Garth tsunami, in this case about 1 m below. Thus, none of the geological sites from Norway indicates a terrestrial runup of the Garth tsunami.

Table 2. Previously published radiocarbon dates associated with the Garth tsunami.

Country	**Site name**	**Sample ID**	**BP**	**SD**	**Cal BCE (95.4 %)**	**δC13**	**Context**	**Material**	**Reference**
Shetland	Garth Loch	Tua-3430	4895	70	3933-3522	-29,4	Gyttja	Leaf fragments, twigs	Bondevik et al. 2005
Shetland	Garth Loch	Tua-3431	4645	65	3635-3121	-27,8	Gyttja	Twigs	Bondevik et al. 2005
Shetland	Loch of Benston	Tua-3909	4965	55	3941-3645	-29,6	Gyttja	Twig with bark (*Betula*)	Bondevik et al. 2005
Norway	Skjoldnesmyra	Poz-52941	4695	35	3630-3370		Gravel layer (Core site 1)	Needle, leaves (*Pinus, Betula*)	Romundset et al. 2015
Norway	Skjoldnesmyra	Poz-52942	4555	35	3485-3103		Gravel layer (Core site 3)	Needle, leaves (*Pinus, Betula*)	Romundset et al. 2015
Norway	Skjoldnesmyra	Poz-52943	4705	35	3632-3372		Gravel layer (Core site 7)	Leaves and stalks	Romundset et al. 2015
Norway	Skjoldnesmyra	Poz-52944	4670	40	3627-3362		Gravel layer (Core site 7)	Twig (*Betula*)	Romundset et al. 2015

3 Archaeological materials

Many Neolithic settlement sites have been excavated along the west coast of Norway (see recent review in Nielsen et al., 2019), often in connection with cultural heritage management and land use planning. Some of these sites have revealed archaeological remains in the form of lithic scatters and cultural layers with a high organic content attesting to multiple occupation phases in the Neolithic based on radiocarbon dates. This chapter presents the sites (Figure 1) from which stratigraphic observations and radiocarbon dates are used in statistical analysis of site phases (see below).

3.1 Korsmyra 1

Located c. 91 km northeast from Bergsøya (i.e. where facies from the Garth tsunami are documented in Kulturmyra and Kjerringnesvatnet) is the open-air and multi-phased settlement site Korsmyra 1 (Bryn and Sauvage, 2018). The excavations in 2013 and 2016 revealed a cultural layer measuring 218m^2 with a maximum thickness of 40 cm that contained charcoal, stone tools and burnt bones. A large portion of the bones occurred in a waste layer on the northern and lowest part of the site. A pit-house was documented in the southern and highest elevated part. Soil analysis of the earth profile within the pit-house showed seasonal occupations with intermediary periods of erosion and peat formation. Radiocarbon dates from the deepest 10 cm-levels within the cultural layer (i.e. layers 3-4) showed occupations starting around 4000 cal BCE. The youngest sample from this phase dated to 3696-3637 cal BCE. Dates from the upper excavation levels (i.e. layer 1-3), including the pit-house feature itself, showed Middle Neolithic occupations. The oldest sample from this second phase dated to 3618-3370 cal BCE, while samples retrieved from the waste layer dated to both phases (Bryn and Sauvage, 2018, p. 73). Stone tools from the site were made of polished slate, while most production debris was from flint reduced with bipolar technique, and most flint artefacts were fire damaged. The site was located 11-8 meters above sea level and presumed to have been located 3-0 meters above sea during occupations.

3.2 Haukedal 1

The multi-phased open-air settlement site Haukedal 1 at Skatestraumen, located c. 55.5 km southwest of Bergsøya, was investigated in 1991 and 1995-6 (Bergsvik, 2002). Four occupation phases (i.e. phases 2-5) dated to the Neolithic, all of which had cultural layers as reference. Phase 3 had its youngest sample dated to 3982-3712 cal BCE, while phase 5 had its oldest sample dated to 3338-2880 cal BCE. The lithic assemblage from phase 3 contained cylindrical cores and simple tanged points, typical of the Early Neolithic. Between phase 3 and 5 was layer P, which consisted of highly compact sand, interpreted as a natural deposit used as a floor for subsequent site activity. Layer P had artefacts typical of phase 3 in its middle section, and polished slate artefacts typical of the Middle Neolithic in the top section (Bergsvik, 2002, p. 108). That layer P represented both the Early and Middle Neolithic was supported by radiocarbon dates. One sample from excavation level 5 (i.e. phase 3) dated to 4037-3711 cal BCE (5090±70 BP), while one sample from excavation level 2 (i.e. phase 4) dated to 3497-3027 cal BCE (4540±60 BP). Frequency of artefacts was low in layer P compared to cultural layers from phase 3 and 5, suggesting a hiatus in occupations. The site was located 10-8 meters above sea level and presumed to have been located 6.5-4.5 meters above sea level during occupations.

3.3 Havnen 17

The open-air and multi-phased settlement site Havnen 17, located ca. 2 km north-west from Haukedal 1, was excavated in 1992-1995 (Bergsvik, 2002). Excavations identified three Neolithic occupation phases (i.e. phases 3-5) represented by cultural layers covering a total of 75m^2 and maximum 25 cm depth. Artefacts from phase 3 occurred on top of a Late Mesolithic activity area called phase 2C. Peat and silt had accumulated on top of the layers from phase 2C, but artefacts interpreted as belonging to phase 3 were also found inside these layers. One charcoal sample retrieved from layer Ae2 (i.e. phase 3) dated to 4242-3635 cal BCE (5080±140 BP, Beta-67993) showed that soils from phase 3 and 2C was partly mixed. However, most artefacts from phase 3 occurred inside cultural layers positioned above phase 2C (Bergsvik, 2002, p. 194). These layers gave two dates predating 3500 cal BCE and four dates that were slightly younger. In terms of lithic assemblages, phase 3 contained cylindrical cores, polished slate points, and vestlands- and vespestad adzes (i.e. local rock axes), suggesting occupations in both the Early and the Middle Neolithic.

Phases 4-5 had three Middle Neolithic dates based on samples retrieved from various cultural layers on the site, including those used to date phase 3. Phase 4 had only one small cultural layer, measuring 3m^2 and 5 cm thickness, which contained polished slate points with hanging barbs, typical of the Middle Neolithic (Bergsvik, 2002, p. 195). Bergsvik (2002, p. 190) suggested that the cultural layers from phase 3 were formed by several occupations between 4900 and 4500 BP. The site was located 11-9.2 meters above sea level, and presumed to have been located 7.5-6 meters above sea level during occupations.

3.4 Kotedalen

The open-air and multi-phased site Kotedalen, located on the central western coast, was investigated in the late 1980’s (Olsen, 1992). Five Neolithic occupation phases were identified (i.e. phases 12-16). Phases 12-13 were initially interpreted as older than 3500 cal

BCE, and the phases 14-16 as younger (Olsen, 1992, p. 82). In terms of lithic assemblages, layers from the phases 12-13 contained cylindrical cores, simple tanged points, local rock axe types, and use of rhyolite for cores and blade production. After 4700 BP, frequency of raw materials changed from rhyolite focused to quartz/quartzite focused. Core reduction also changed from cylindrical before to bipolar after, while tanged points of rhyolite were replaced by polished slate points. Locally produced pottery decorated with cord-stamp imprints also occurred in Middle Neolithic layers. A charcoal layer from two lake basins located about 100 m from the site (dated to 3701-3351 cal BCE and 3707-2701 cal BC respectively) indicated intensified activity in the area after 3500 cal BCE (Kaland, 1992, p. 82). The site itself was located 13-9.2 meters above sea level and presumed to have been located about 2 meters above sea level during occupations.

3.5 Ramsvikneset

The open-air and multi-phased settlement site Ramsvikneset, located about 100 meters from Kotedalen, was excavated in 1962-63 (Bakka, 1993; Olsen, 1992, p. 16). The site had two cultural layers positioned at different levels in the landscape, separated by a low rocky ridge. A thin cultural layer was also documented on top of the ridge. A height difference between the two main layers indicated age difference, which was confirmed by stone tool analysis (Bakka, 1993, pp. 30–31) and radiocarbon dates (Nærøy, 1994). The cultural layers were homogenous (i.e. no internal stratigraphy was documented), and had a maximum thickness of 120 cm at the lower level and 80 cm at the upper level. The top soil in the general area was cultivated, but at the upper excavation level a layer described as ‘brownish buff soil’ of maximum 8 cm thickness occurred between the top soil and the cultural layer. According to Bakka (1993, p. 25), this layer had accumulated after the Neolithic occupations on that level had ended. This layer was not found on the lower level.

In terms of lithic assemblages, the cultural layer on the upper level contained cylindrical cores and simple tanged points made from rhyolite. This was also found in the deepest 10 cm excavation levels (i.e. levels 8-9) at the lower cultural layer. Soil with these artefacts represented an early occupation phase, according to Bakka. Excavation levels 1-7 in the lower cultural layer had slate artefacts and pottery, no rhyolite, and was named the late occupation phase. Similar to Kotedalen, this site was located 11.5-9.5 meters above sea level, and had probably also originally been located 2 meters above sea level.

3.6 Håkonshella 8

The multi-phased and open-air settlement site Håkonshella 8, located some km west of Bergen city, was investigated in 2011-12. The results are not published, but one case study of the soil morphology found that the Mesolithic cultural layers were covered by spots of a soil layer (i.e. layer 2) consisting of colluvium sediments with ‘grey sand with silt, stones, charcoal and burned hazelnut shells’ (Puy et al., 2016, p. 509). One charred nutshell from layer 2 was dated to 3516-3108 cal BCE, but no layer (including layer 2) on the site contained Neolithic artefacts. The soil morphology analysis of the upper 3 layer on the site found decreased amounts of fine material and soil aggregates in layer 2, and concluded that the layer was probably ‘formed after an energetic event of erosion and deposition’ (Puy et al., 2016, p. 515). The excavation area was located 14 meters above sea level. With reference to the sea level interpretation from Nilsvika 4 (see below), Håkonshella 8 was probably located 9.5-10 meters above sea level when layer 2 was formed.

3.7 Nilsvika 4

The open-air and multi-phased settlement site Nilsvika 4, located about 1.5 km southwest from Håkonshella 8, was excavated in 1992 (Kristoffersen, 1995). The site had two excavation areas, one upper level and one lower level in the landscape. The Neolithic occupation layers at the upper level was covered by a 10 cm thick layer of sand. A hearth inside the sand layer was dated to the Bronze Age, and six circular pit-houses measuring 5-6 meters in diameter were discovered below the sand. One pit-house was older than 3500 cal BCE (house 30), while the rest were younger (house 10, 29, 34, 20, 19).

House 30 and 19 related directly in the stratigraphy (Figure 2). House 30 was lowest, and had two dates to 3781-3520 cal BCE and 3637-3036 cal BC. The upper house, i.e. house 19 had one date to 3339-2584 cal BCE. The layers followed each other in the stratigraphy, with no natural layers in between. In terms of lithic assemblages, house 30 had cylindrical cores and simple tanged points of flint and rhyolite, and one vespestad adze (Kristoffersen, 1995, p. 75). Raw materials consisted of rhyolite, flint and quartzite. House 19 had cylindrical cores, vespestad- and vestlands adzes, simple and more elaborately retouched tanged points, as well as polished slate points (Kristoffersen, 1995, pp. 70–71). Inside house 30, two sherds of pottery were found. In the transition between house 30 and 19, 46 sherds were found, while only two sherds occurred inside house 19. At the lower excavation level, a layer measuring maximum 100 cm in thickness was documented, containing waste from the Neolithic occupations (Kristoffersen, 1995, p. 43). The site was located 10 meters above sea level, and presumed to have been located 5.5-5 meters above sea level during occupations.

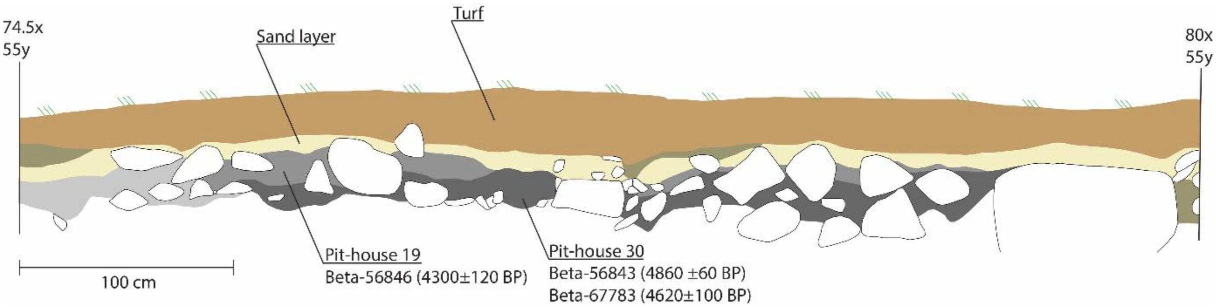

Figure 2. Profile from the 55y axis at Nilsvika 4, showing the stratigraphic relation between pit-house 30 and pit-house 19. Note the lack of naturally deposited layers between the two pit-house horizons. The sand layer covering both features was dated to the Bronze Age. Radiocarbon dates do not mark the original position of sample extraction. Illustration based on Fig. 36 in Kristoffersen (1995, p. 54).

3.8 Austbø 12 A-B

The open-air settlement site Austbø 12, located on the island Hundvåg on the southwestern coast, was excavated in 1988-9 (Juhl, 2001). The site had two excavation areas, both located in sloping terrain. The upper level (field A) had a cultural layer measuring 5-15 cm in thickness but was partly damaged by modern farming. Field B was lower in the landscape and had a cultural waste layer measuring maximum 40 cm in thickness (Juhl, 2001, pp. 40–41).

One pit on field A dated to 3938-3375 cal BCE and one charcoal sample retrieved from the cultural layer dated to 3649-3375 cal BC. The remaining dates from field A and B were Middle Neolithic. The natural soil profile in the area surrounding the settlement had, from top to bottom, modern ploughing (30 cm), late glacial sand (55 cm), late glacial marine clay (50 cm) (Juhl, 2001, pp. 67–68). The site was located 11.5-7.5 meters above sea level, and presumed to have been located 4-0 meters above sea level during occupations.

3.9 Stavanger airport

The multi-phased and open-sir site Stavanger airport, located on southwestern coast, was excavated in 1984-5 (Skar, 1985). The site was located within an Aeolian region (Klemsdal, 1969; Prøsch-Danielsen and Selsing, 2009) and was covered by c. 2 meters of sand. Only a small part of the site was investigated (300m^2 of total 2ha) (Skar, 1985). At the lowest excavation level, in trench B, the following stratigraphy was documented from top to bottom (see also Figure 3):

- Aeolian sand.
- Occupation layer (Middle Neolithic artefacts, Neolithic-Bronze Age dates).
- Marine sand (no dates, no artefacts).
- Marine gravel (Early Neolithic artefacts and dates.)
- Occupation layer (Early Neolithic artefacts and dates).
- Marine gyttja (Mesolithic artefacts and dates).

Soil samples from 39 boreholes in the surrounding area informed of overall lithostratigraphy (Prøsch-Danielsen and Selsing, 2009). In figure 3, top of layer 3 (marine gyttja) and layer 4 (gravel) represent the Early Neolithic phase as defined by Skar (1985). The Middle Neolithic-Bronze Age occupations are represented by layer 6 (peat), a layer that was positioned above the sand layer and ‘an erosion contact zone’ defined as layer 5. Dates from the gravel and the base of the peat overlap in age. Prøsch-Danielsen and Selsing (2009, p. 47) argued that the gravel was formed by a ‘short-lived marine episode’ sometime between 4900 and 4800 BP. As the gravel occurred in boreholes up to 9 meters above sea level in the area, and sea level at 3500 cal BCE was estimated to had been about 6 meters above contemporary levels, (Prøsch-Danielsen and Selsing, 2009, p. 61 Fig. 56), the event creating layer 4 (gravel) would have had a ‘runup’ of roughly 3 meters. The site was located 14-8 meters above sea level, and presumed to have been located 4-0 meters above sea level during occupations.

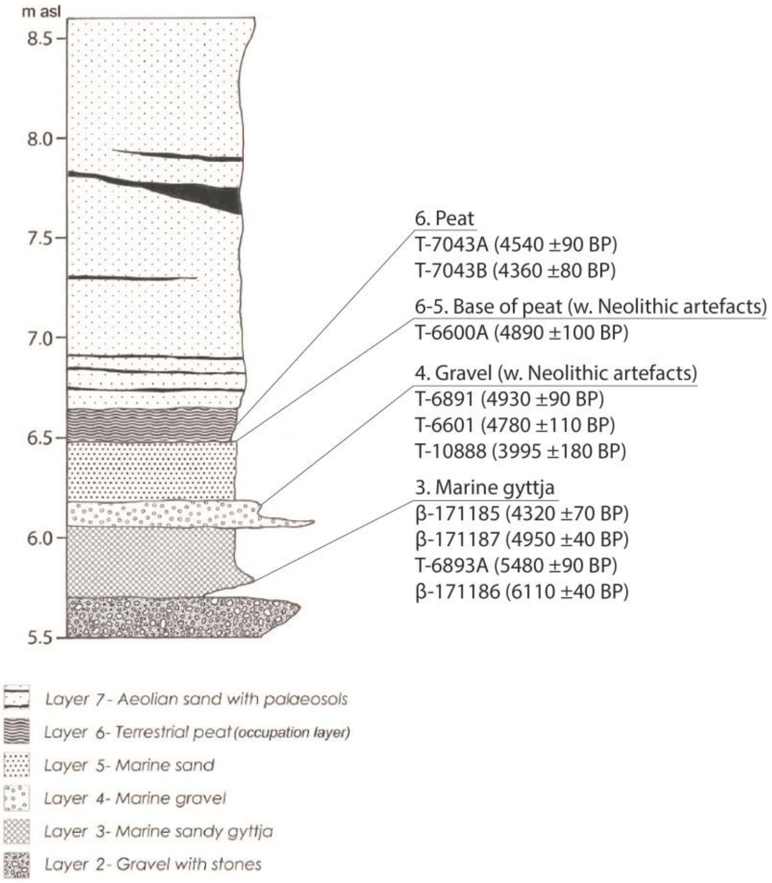

Figure 3. Stratigraphic sequence inferred from trench B at the Stavanger airport site. Location of sample extraction for radiocarbon dates as shown with straight lines are not accurate but refer only to correct layer. Model reworked from Figure 28 in Prøsch-Danielsen and Selsing (2009, p. 40), reprinted here with permission by the authors.

Figure 4. Profiles from the Slettabø site. The thin charcoal layer in the bottom is layer 3, followed by layer 2 and layer 1 on the top. Photo: Sf162962, Museum of Archaeology in Stavanger. License: CC BY-NC-ND 3.0.

3.10 Slettabø

The open-air and multi-phased settlement site Slettabø, located on the southwestern coast, was excavated in 1963, 1965-6 and 1968 (Skjølsvold, 1977, p. 22). The site had three cultural layers with levels of sand positioned between (Figure 4). The cultural layers were named from top to bottom layer 1, 2 and 3. From the lithic assemblages, layer 1 dated to the Bronze Age, and radiocarbon dates confirmed this. Layer 2 and 3 belonged typologically to the Middle Neolithic due to finds of pottery on both levels. Radiocarbon dates suggested two phases with a hiatus of roughly 800 years, during which the sand layer between layer 2 and 3 was formed (Skjølsvold, 1977, pp. 177–178). As argued Skjølsvold (1977) and later also by Glørstad (1996), one date from layer 2 is contemporary with site activity from layer 3, thus indicating some degree of mixing between the two layers, or that the sand layer was formed relatively quickly. A subsequent study of lithostratigraphy around the Slettabø site found evidence of continuous aeolian activity from c. 5400 cal BCE until present day, and that the sand below occupation layer 3 was also aeolian (Prøsch-Danielsen and Selsing, 2009, p. 71). The site was located 9-5 meters above sea level, and presumed to have been located maximum 1 meters above sea level during occupations.

3.11 Grønnslettvika

The open-air settlement site Grønnslettvika, located on the southernmost coast, was excavated in 2005 (Melvold, 2015). The site was located c. 150 m southwest of Skjoldnesmyra, where facies from the Garth tsunami have been documented. Grønnslettvika had a cultural layer with a maximum thickness of 50 cm, with no sand or gravel layers present. One hearth was dated to 3890-3647 cal BC, while one sample retrieved from the cultural layer was dated to 3086-2888 cal BC. These age estimations were confirmed by the lithic assemblage, which attested to multiple occupation in the Early and Middle Neolithic periods (Melvold, 2015, pp. 114–116). Thus, Grønnslettvika represents a mixed cultural layer. The site was located 9-6 meters above sea level, and presumed to have been located maximum 2 meters above sea level during occupations.

3.12. Skomrak

The open-air settlement site Skomrak, located on the southernmost coast, was investigated in 2012 (Bjørkli and Mjærum, 2016). The site had three excavation fields whereof fields 2 and 3 are relevant here. At field 3, samples retrieved from a circular pit-house indicated occupation between 4400 and 3600 cal BCE (Bjørkli and Mjærum, 2016, p. 67). At field 2, which was located slightly lower in the landscape, a homogenous cultural layer with lithic tools and pottery was radiocarbon dated to the Middle Neolithic. The following stratigraphy was observed above the pit-house, from top to bottom; c. 80-120 cm modern cultivation soil, c. 40 cm dark anthropogenic soil, c. 5-10 cm natural sand. The Middle Neolithic cultural layer at field 2 was covered only by modern cultivation soil. The site itself was located 10-6 meters above sea level, and the areas discussed here were presumed to have been located about 2 meters above sea level during occupations.

3.13. Hamremoen

The ritual enclosure site located at Hamremoen, outside the city of Kristiansand, was excavated in 2010 (Glørstad and Solheim, 2015; Glørstad and Sundström, 2014). Based on the radiocarbon dates, site activity was estimated to the period 4040-3530 cal BCE. The artefact assemblage consisted of flint and stone tools, as well as a rich inventory of pottery (Glørstad and Solheim, 2015). The site was located at the outlet of the river Otra, and the activity area was discovered in stratigraphic layer 3 at the site. The youngest features at this level were covered with 60-100 cm level of sand. On top of this sand, Middle Neolithic artefacts were found. Sundström and Darmark (2013, p. 86) argued that the sand layer represented a swift event based on the relatively short age difference between activity in layer 3 and on top of the sand. However, annual storms and wave patterns could also had caused its formation (Glørstad and Sundström, 2014 with references). The site was located 10-9 meters above sea level, and presumed to have been located 1-0.5 meters above sea level during occupations.

3.14 Sites with future research potential

Two sites should be of interest for future explorations of the Garth tsunami in Western Norway. Firstly, a number of artefacts from the Igesund farm on Bergsøya attests to Neolithic activity close to Kulturmyra (c. 1.5 km separation). Polished four-sectioned stone axes and adzes and one saddle shaped grinding stone could indicate Early Neolithic occupations (Hallgren, 2008, pp. 210–211), while polished slate points attest to Middle Neolithic activity. Secondly, the open-air site Korsen, located on the island Voksa (c. 14 km southwest of Bergsøya), was excavated in 1917 (Bjørn, 1921). Finds of rhyolite indicated Early Neolithic activity, while polished slate arrowheads and knives attest to Middle Neolithic activity (Skjølsvold, 1977). The stratigraphy at Korsen had two cultural layers separated by ca. 60 cm of sand. Unfortunately, all artefacts from the dig were classified and catalogued in one single batch (Bjørn, 1921, p. 31). Both sites are located in terrain elevated maximum 10 meters above present sea level.

4 Methods

4.1 Sequence calculation

In terms of timing, carboniferous samples are highly suitable for solving time-sensitive questions in archaeology, as radiocarbon dating provides observations on estimations of past events. Further on, the ‘noise’ or variability each observation comes with enables application of Bayesian statistical inference, where the calibration process from ^{14}C-age to calendar years takes into account prior (archaeological) interpretations (Bayliss, 2009; Buck et al., 1992). This paper used the sequence function in OxCal online in order to implement a Bayesian approach (Bronk Ramsey, 2018, 2009). The function departs from the 2-event situation, where one start and one end of the phase in question defines based on the radiocarbon dates and a set of constraints. The events are called boundary events, and the models assume that all events between these boundaries are equally likely to occur anywhere within the time period (Bronk Ramsey, 2009). Three statistics evaluate the result for each model: 1) an agreement index for single dates, 2) an overall index for the model ($A_{overall}$), 3) and thirdly an index for convergence (A_{model}) (Bayliss et al., 2007, p. 6; Bronk Ramsey, 1995, p. 429). Each index has a value of 100 % (sometimes higher or lower), but the model does not support the prior interpretations when lower than 60 % (Bronk Ramsey, 1995). This threshold is analogous to the 0.05 significance level of a chi square test (Bayliss et al., 2007; Bronk Ramsey, 1995).

Radiocarbon dates from 11 Neolithic occupation sites from Western Norway were modelled in contiguous sequence models in OxCal. In almost every case, the dates represented charcoal samples where species is unknown or multiple species were used in the dating process, the only exception being Stavanger airport where one bone from *Cervidae* (T-6601) and two samples of peat (T-7034 A and B) were used. Maximum number of dates for each archaeological site phase was four, and all dates with standard deviations >120 years were excluded from analyses. Data from Skjoldnesmyra was used as the tsunami boundary event. Instead of using all four dates from the gyttja from Skjoldnesmyra as representative of the event, as Romundset et al. (2015) suggested, one date with a considerably younger age (i.e. Poz-52942) was excluded here. The three remaining dates gave the combined value of 4692±22 in OxCal, which calibrates to 3499-3372 cal BCE (68.2 %) using the IntCal13 calibration curve (Reimer et al., 2013). Thus, the mean 'terminus post quem' age for the Garth tsunami in this paper is 3456 cal BCE (Figure 2). For each intra-site model, dates were interpreted as belonging to a pre or post tsunami phase:

- Korsmyra 1: Based on the hiatus, the early occupation phase was defined as pre and the late phase as post.
- Haukedal 1: Based on the hiatus (layer P), phase 3 was modelled as pre and the phases 4-5 as post.
- Havnen 17: Based on the excavators interpretation of the stratigraphy, two samples from phase 3 (Beta-67994, Beta-67986) were interpreted as pre, while the remaining dates from the phases 3-5 were interpreted as post.
- Kotedalen: Phase 13 was interpreted as pre and phase 14 as post. Sample T-7522 from phase 14 was regarded as an early outlier due to a stratigraphic deviation, as argued by the excavator (Olsen, 1992, p. 217).
- Ramsvikneset: The early phase was interpreted as pre and the late phase as post.
- Nilsvika 4: House 30 was interpreted as pre and house 19 as post.
- Austbø 12 A-B: The two early dates from field A were interpreted as pre, and the remaining dates as post.
- Stavanger airport: Presuming layer 4 (gravel) was formed by the Garth tsunami, layer 4 (T-6601, T-6691) as interpreted as pre and layer 5-6 (only dates from layer 6) as post. Sample T6600A from layer 6 was excluded due to an observed stratigraphic intrusion by subsequent cultivation, as argued by the excavators (Prøsch-Danielsen and Selsing, 2009, p. 41).
- Slettabø: Based on the presence of pottery, layer 3 was interpreted as post.
- Skomrak: The pit-house at field 3 was interpreted as pre and the cultural layer at field 2 as post.
- Hamremoen: All dates were interpreted as pre.

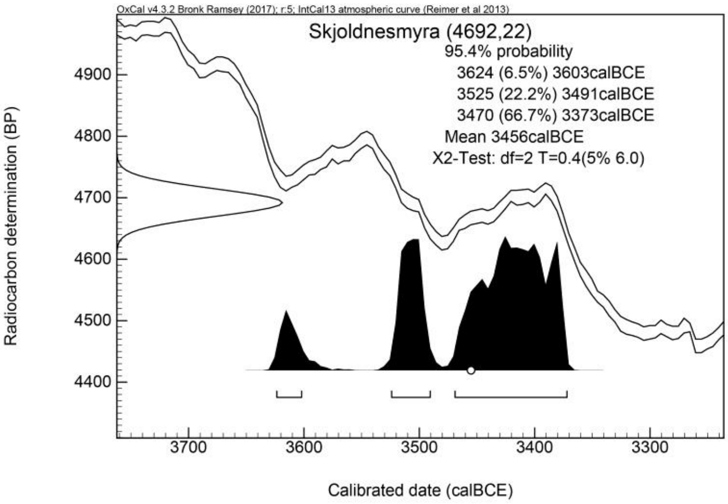

Figure 5. Calibrated 'terminus post quem' age of the Garth tsunami used in this paper, based on the combined value of three samples of gyttja retrieved directly above the tsunami facie in the Skjoldnesmyra basin in Agder County, Norway.

Ideally, typological and stratigraphic information is informative in Bayesian sequence modelling because it provides logical statements (rather than probabilistic) concerning the events that formed the archaeological record. In this sense, stratigraphy and radiocarbon dated events are informative in both ways, as stratigraphy can in some cases shed light on the accuracy of events, i.e. when they are based on radiocarbon dates (Steier and Rom, 2000). However, the level of accuracy from stratigraphy in this paper varied between sites due to several factors, e.g. extents of excavations, post-depositional taphonomic processes, level of accuracy and post-excavation expert analyses. For instance, micro-morphological soil analysis from cultural occupation layers were only available from two sites, Korsmyra 1 and Håkonshella 8. In both cases, results from soil analyses became important for the archaeological interpretations discussed below. Mixing of cultural layers due to taphonomic processes as well as by Neolithic site activity, particularly at Korsmyra 1 and Havnen 17, enforced interpretations of site phases based partly on stratigraphy and typological expectations to lithic assemblages. When such considerations were applied in this paper, they were based on interpretations from previous publications and excavation reports. In three cases, i.e. Stavanger airport, Skomrak and Hamremoen, were the pre tsunami cultural layers stratigraphically sealed off by natural layers.

4.2 Monte Carlo summed probability density

A suitable approach to evaluate a degree of catastrophe is to test if the event inflicted the demographic composition on the west coast. To test this, the method called Monte Carlo Sum Probability Distribution (MCSPD) was used (Shennan et al., 2013; Silva and Vander Linden, 2017). The method uses radiocarbon dates as a proxy data for a population within a certain geographical area. In this case, a summed probability density (SPD) of radiocarbon dates is compared to a high number of simulated SPDs based on random age values picked from the same time span. In this way, the combined area of the simulated SPDs work as a critical envelope, or a null model of predicted population growth, onto which the archaeological SPD compares for deviations. The *modelTest* in the rcarbon workpackage for RStudio was used for this analysis (Bevan and Crema, 2018; RStudio, 2019). Although there are different versions of the method available through recent publications (Edinborough et al., 2017; Silva and Vander Linden, 2017), the rcarbon workpackage represent an easily applicable and replicative tool. An open and available database of radiocarbon dates from south Norway was used (https://github.com/sveinvn/STAGED). Only dates from the Counties Møre og Romsdal, Vestlandet, Rogaland, and former Vest-Agder was used (n dates=870). Dates older than the Tapes transgression on the west coast were not included, which excluded dates older than 7000 BP. The chosen archaeological dates were combined in order to account for sampling bias using a 100 year limit, resulting in 489 bins. The *modelTest* was set to run with 1000 simulations, and to create an exponential fitted model. Scripts used for analysis in RStudio are available in Supplementary data 1.

5 Results

5.1 Constraints on activity phases

Sequence modelling showed high degree of unanimity between activity phases and the event (Table 3, Figure 3), and agreement indexes were well above the 60 % critical level. The posterior density values from critical transitions within the dataset (from youngest pre tsunami dates to the Garth event, and from the latter to the oldest post tsunami dates) are presented in Figure 4. Notably are the sites Korsmyra 1 and Kotedalen, where models suggests a correction of the dating of the tsunami event to within 3622-3497 cal BCE and 3627-3501 cal BCE respectively. This contrasts results from all other sites, where the dating of the event is modelled to have been probably sometime after 3500 cal BCE. This latter dating is more in line with our prior expectation, considering the combined age determination from Skjoldnesmyra. Thus, coastal sites from the northwestern and central coastal regions do exhibit congruence, but suggests a dating of the event closer to ~3520 cal BCE (Figure 8).

The tendency to push the event towards post-3500 cal BCE is mostly present in the southwestern region, where the event itself coincides with what geologists have termed a short-term sea level transgression which reached its maximum height at ~4800 BP/3550 cal BCE (Prøsch-Danielsen and Selsing, 2009, p. 12). Evidence of this transgression exists along the outer coast in the southwestern region, but not in the inner fjord areas, e.g. not at Austbø 12 A-B (Prøsch-Danielsen, 2006, p. 40). This peculiar regional character suggests that the transgression itself could rather represent the impact of a paleotsunami, an interpretation that wold support the hypothesis of identified sand layers at four sites in the southwestern region as formed by a tsunami event. The layers in question are, 1) the sand layer (i.e. layer 5) at Stavanger airport, 2) the sand layer below cultural layer 3 at Slettabø (though this has previously been interpreted as aeolian), 3) the sand layer covering the pit-house feature at Skomrak, and 4) the sand layer covering stratigraphic layer 3 at Hamremoen.

5.2 Monte Carlo test

The *modelTest* produced an SPD for the period in question that was well within the upper and lower boundaries of the simulated and exponential envelope (Figure 9). There is a tendency towards a lowered signal from the radiocarbon date sample in the period of roughly ~3750-3600 cal BCE, but these variations are not considered significant in the model. After 3500 cal BCE, the combined signal from the archaeological sample develops very much in line with steady growth as predicted by the exponential and simulated model.

Sequence		Sample	cal BCE	modelled cal BCE (68.2 %)	Agreement
Hamremoen	Pre	Tra-3273	3695-3645	3690-3644	111.3
		Tra-2363	3695-3636	3659-3640	136.3
		Tra-3269	3692-3541	3651-3635	146.9
		Tra-3270	3639-3560	3648-3540	94.9
	Skjoldnesmyra		3499-3372	3503-3436	98
Skomrak	Pre	Ua-46815	3923-3712	3794-3711	105.6
		Ua-45998	3773-3695	3757-3691	108.8
		Ua-46817	3710-3647	3697-3652	116.9
		Ua-45996	3650-3536	3657-3541	102
	Skjoldnesmyra		3499-3372	3500-3372	98.5
	Post	Ua-46001	2866-2639	2875-2686	100.5
Slettabø	Skjoldnesmyra		3499-3372	3501-3433	100
	Post	T-738	3635-3377	3453-3359	90.5
		T-1780	3351-3016	3469-3273	83.4
Stavanger airport	Pre	T-6891	3906-3638	3763-3540	102.8
		T-6601	3692-3378	3664-3521	114.2
	Skjoldnesmyra		3499-3372	3516-3378	102.8
	Post	T-7043A	3370-3096	3368-3117	112.5
		T-7043B	3096-2894	3335-2970	78
Austbø 12A-B	Pre	T-8443	3771-3523	3681-3526	113.3
		T-8438	3638-3385	3634-3515	107.4
	Skjoldnesmyra		3499-3372	3511-3377	104.6
	Post	T-8439	3370-3096	3373-3194	116.9
		T-8444	3348-3096	3352-3093	109.6
		T-8366	3261-2697	3339-2977	78.2
Nilsvika 4	Pre	Beta-56843	3708-3536	3687-3528	98.1
		Beta-67783	3626-3120	3633-3467	97
	Skjoldnesmyra		3499-3372	3441-3376	105.3
	Post	Beta-56846	3262-2681	3356-2889	83.2
Ramsvikneset	Pre	T-1903	3938-3644	3787-3664	122.9
		T-1904	3772-3645	3732-3648	121.9
		T-1908	3891-3541	3701-3634	127.8
		T-1906	3644-3381	3661-3551	106.8
	Skjoldnesmyra		3499-3372	3519-3380	99.8
	Post	T-1910	3506-3116	3372-3100	91.5
		T-1909	2884-2632	2911-2682	90.9
Kotedalen	Pre	T-7336	3982-3535	3731-3655	139.2
		T-7509	3906-3652	3712-3653	118.3
		T-7337	3761-3649	3694-3647	120.4
		T-7052	3708-3536	3676-3635	139.5
	Skjoldnesmyra		3499-3372	3627-3501	62.2
	Post	T-7390	3644-3378	3620-3409	112.4
		T-3264	3628-3370	3617-3394	115
		T-7508	3626-3372	3614-3377	106.5
		T-7531	3628-3361	3612-3366	116.5
Havnen 17	Pre	Beta-67994	3695-3520	3651-3518	112.8
		Beta-67986	3636-3386	3603-3503	104.9
	Skjoldnesmyra		3499-3372	3521-3379	104
	Post	Beta-48164	3626-3359	3501-3353	119.3
		Beta-67992	3621-3131	3497-3340	134.9
		Beta-78324	3486-3111	3493-3324	115.1
		Beta-78319	3355-3020	3492-3291	97.7
Haukedal 1	Pre	Beta-82835	3963-3800	3961-3816	109.7
		Beta-82832	3956-3801	3901-3774	99.4
	Skjoldnesmyra		3499-3372	3519-3379	98.6
	Post	Beta-82831	3364-3106	3355-3099	102.9
		Beta-82830	3262-2897	3324-2985	88.5
		Beta-83490	3091-2893	3261-2904	99.7
Korsmyra 1	Pre	Tra-11182	3695-3651	3673-3649	112.1
		Tra-11170	3694-3646	3665-3648	119.8
		Tra-11189	3694-3645	3661-3646	125.7
		Tra-11179	3662-3639	3656-3642	129.6
	Skjoldnesmyra		3499-3372	3622-3497	79.7
	Post	Tra-11178	3512-3375	3511-3440	109.2
		Tra-11184	3515-3374	3507-3432	116.3
		Tra-11193	3511-3374	3504-3426	112.6
		Tra-11180	3351-3373	3503-3418	112.5

Amodel = 175.7

Aoverall = 167.4

Table 3. Tabular result from sequence calculation of radiocarbon dates from 11 coastal settlement sites in Western Norway.

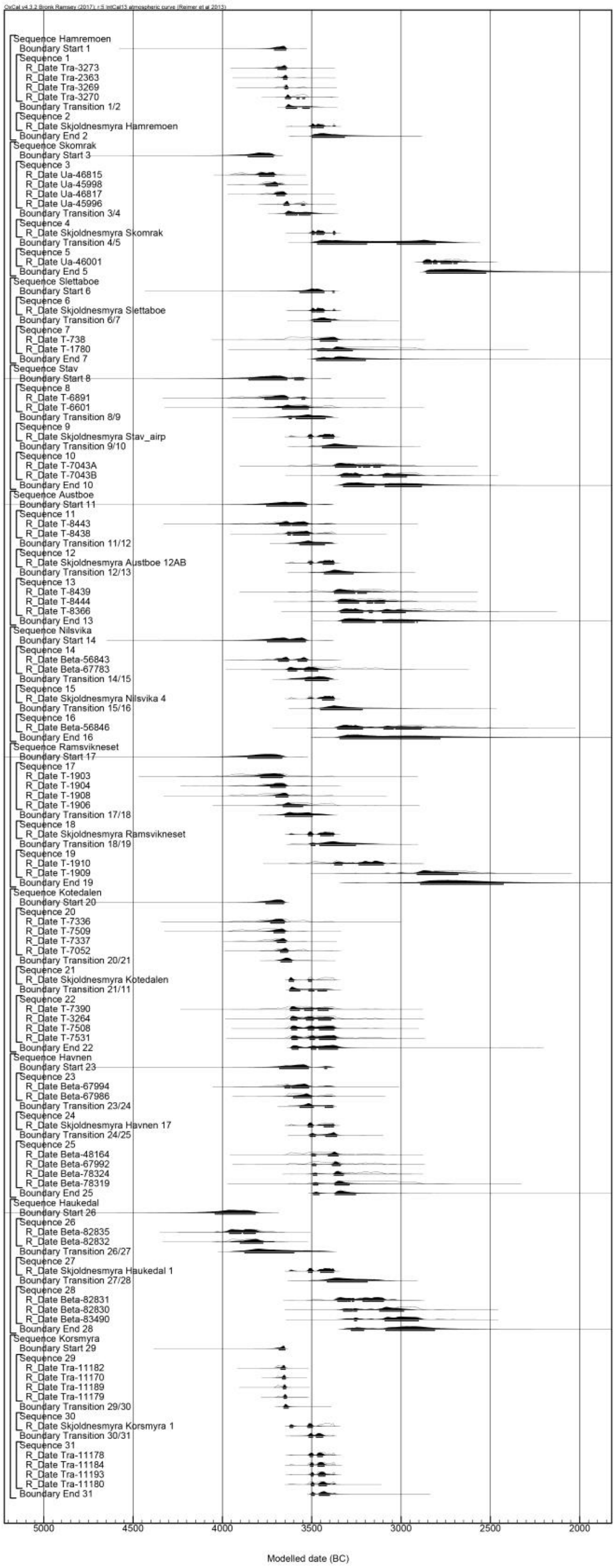

Figure 6. Visual result from sequence calculations of radiocarbon dates from 11 coastal settlement sites in Western Norway.

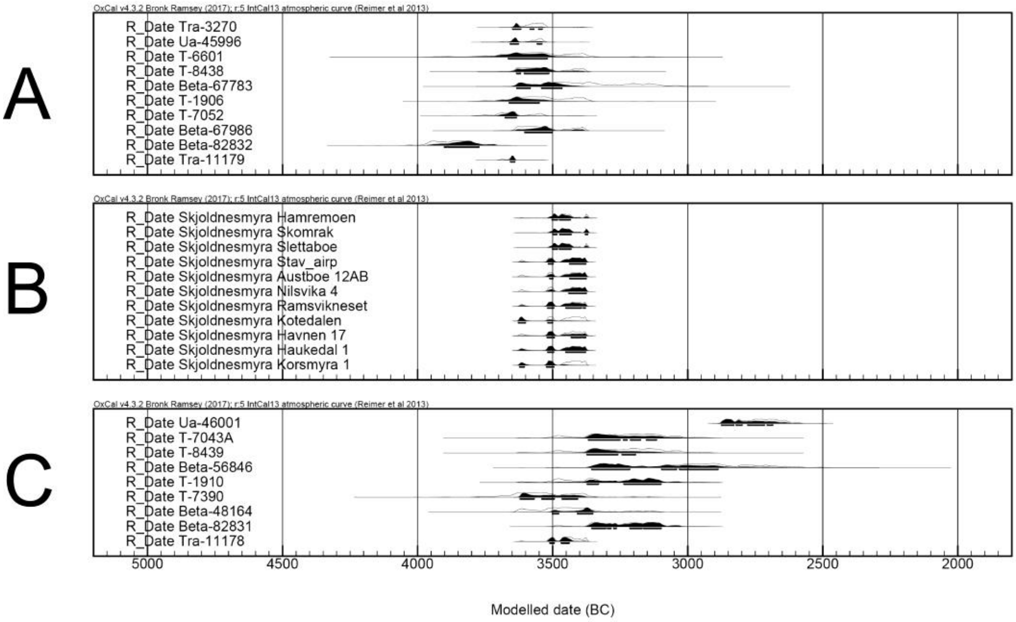

Figure 7. Posterior calibrated density values of the youngest pre tsunami dates (A) and the oldest post tsunami dates (C) from settlements, with the posterior calibrated Skjoldnesmyra combined dates in between (B).

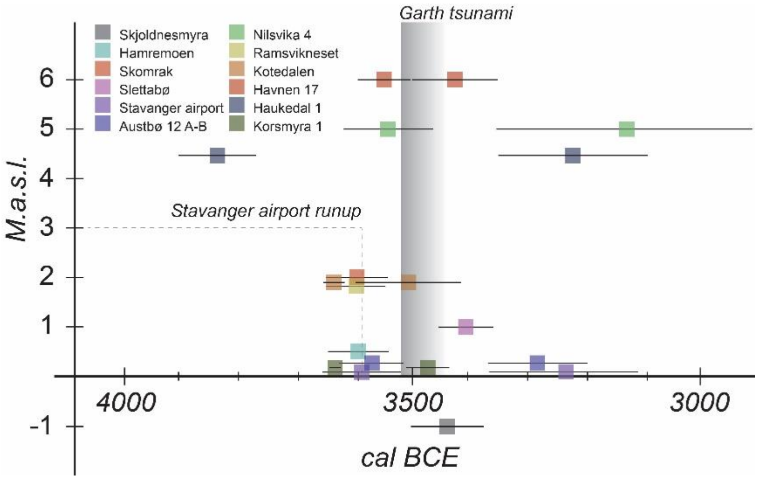

Figure 8. Plot of the Skjoldnesmyra combined age and the posterior date distributions from 11 settlement sites after Bayesian sequence modeling. For each settlement site, the youngest predates and the oldest postdates are plotted. Sites are plotted in accordance to meter above sea level around 3500 cal BCE, at the lowest possible level following previous research and excavation reports. Overlapping sites on the Y-axis have been moved slight, for correct elevation see main text. Vertical shaded grey column suggests ~3520 cal BCE as a likely date for the Garth tsunami event, when taking into account both geological and archaeological information.

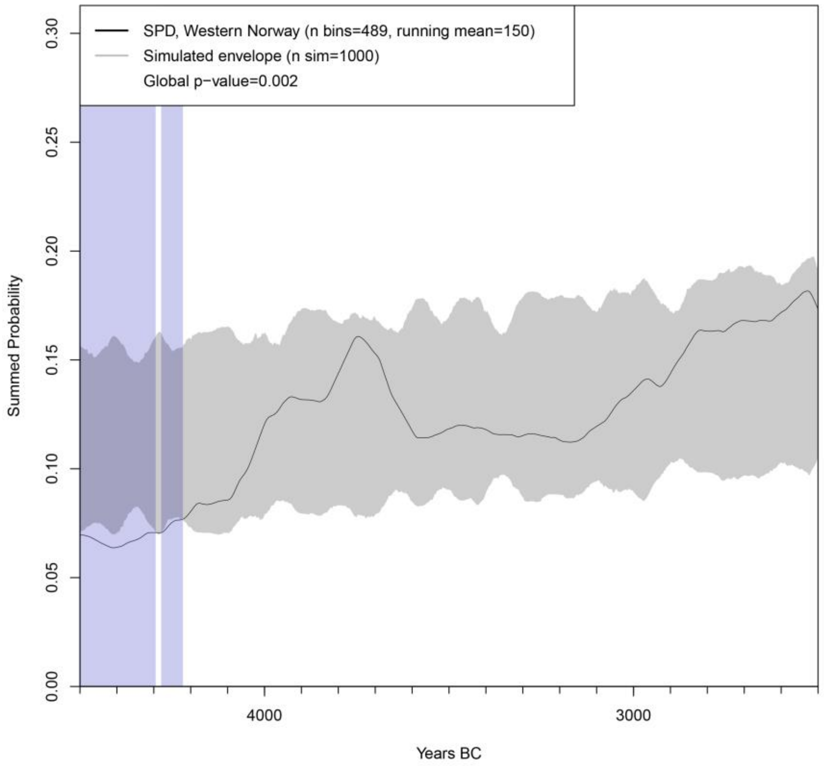

Figure 9. Visual result from the simulation test. The model does not detect any significant deviations in the archaeological sample that deviates from the model of expected growth.

6 Discussion

6.1 The relevance of the Garth tsunami for the Neolithic in Western Norway

The timing of the Garth tsunami to ~3500 cal BCE is conspicuous because it coincides with important prehistoric events on the west coast of Norway. While research on the eastern region of Norway implement the South Scandinavian Neolithic chronology as a standard frame of reference, an independent chronology based on local events is developed for the western coast (Bergsvik, 2003; Nærøy, 1994, 1988; Olsen, 1992, p. 83 with references). These local chronological changes have little to do with the introduction of a Neolithic economy, but refer primarily to changes in lithic and ceramic inventories as they have been documented on occupation sites. In Southern Scandinavia, the start of the Neolithic (4000 cal BCE) is a floating limit, determined by the earliest evidence of farming and stock keeping, while he Middle Neolithic transition at 3300 cal BCE reflects important changes in funerary rites and material culture (Iversen, 2014; Koch, 1998; Lagergren-Olsson, 2003; Sørensen, 2014). Within the independent chronology for Western Norway, the Neolithic transition at 4000 cal BCE refers to the following technological transitions:

- Mesolithic microblade technology and slotted bone points disappear; cylindrical core technology and tanged points (bow-and-arrow technology) appear.

- Mesolithic pecked and polished core axes disappear; semi-four-sided axes (‘Vespestadadzes’) appear, sometimes in large numbers on settlements.
- Knapped rhyolite (i.e. a local siliceous material) and polished slate arrowheads appear.

There are of course regional variations along the western coast, e.g. slate and bipolar technology is more common in the northwest, rhyolite and cylindrical cores on the central coastal area, and flint was more widely used in the southwest. According to the independent chronology, 500 years after the Mesolithic-Neolithic transition is the transition from Early to Middle Neolithic. This transition refers to the following changes:

- Locally produced pottery appear, primarily in the southwestern and central region.
- Polished, four-sided rock adzes (‘Vestlandsadzes’) appear.
- Cylindrical core technology decreases; bipolar core technology increases.
- Knapped rhyolite decreases; polished slate tools increases.

Thus, the characteristics of the Early and Middle Neolithic periods in Western Norway refer to changes in lithic and ceramic technology, i.e. not a Neolithic economy. The prevalent interpretation of these societies is that of a hunter-fisher-gatherer population (Bergsvik, 2012). The question of early farming, i.e. contemporary with early farming in Southern Scandinavia, has been debated for many years (Bergsvik, 2012; Glørstad, 2012; Hjelle et al., 2006; Høgestøl and Prøsch-Danielsen, 2006; Olsen, 1992; Prescott, 1996). Bergsvik et al. (2020) recently presented a new model of low-level agriculture for the west coast population starting already around 4000 cal BCE, but which intensified slowly during the Middle Neolithic A period. As they point out, farming was probably introduced in the southwestern (i.e. Aeolian) region first and was then spread through hunter-fisher-gatherer social networks further north.

Explanations as to why changes appear in lithic technology on the west coast of Norway around 3500 cal BCE are often made with reference to theories of internal social developments. Some scholars have suggested a geographical sub-division of the west coast into tribal territories during the Early and Middle Neolithic based on distribution maps of lithic artefacts and raw materials (Bergsvik, 2011, 2010, 2003; Nyland, 2015, pp. 283–285; Olsen and Alsaker, 1984). In terms of mobility, seafaring is often suggested to had played a central role in these developments, as the slate technology that appear in the Early Neolithic probably came from further north, while the Middle Neolithic pottery technology probably came from the southeast (Olsen, 1992, pp. 143–144; Østmo, 2010). Thus, dominant explanatory theories on the changes in technology on the western coast around 3500 cal BCE point to social rivalry among hunter-fisher-gatherers, presumably unaffected by demographic events and transitions in Southern Scandinavia.

6.2 The impact of the Garths tsunami on the west coast

On this background, it could be hypothesized that a paleotsunami wave hitting the western coast of Norway around 3500 cal BCE, such as the known Garth tsunami, could had caused demographic fluctuations (e.g. bottle necks) leading to the formation of new social ties, which could explain the technological changes associated with the Early to Middle Neolithic transition. In a climatological perspective, the effects of a tsunami are immediate. Tsunami waves are known to cause massive erosion on vegetation, soil surfaces and coast lines (Waddington and Wicks, 2017, with references). For a hunter-gatherer population occupying primarily the near tidal zone, with a complex system of hunting camps and more stable base camps, a tsunami event could easily erase life necessities such as buildings, tools, food caches, as well as members of the communities (discussed in Rydgren and Bondevik, 2014). Bergsvik (2004) has argued that the west coast of Norway during the Early Neolithic was possibly inhabited by ~50-60 kin-based groups, which again were organized in regionally based ethnic groups. This social system was structured and reproduced through constant interaction and possibly intermarriage relations between groups. Considering the older Storegga tsunami, Hill et al. (2017) argued that a run-up of ~5 meters would had caused a fundamental catastrophe for any coastal forager population. In comparison, the Storegga tsunami had wave heights of ~10-20 meters in parts of Norway, while the Garth tsunami had a documented run-up of ~10 meters on Shetland (Bondevik et al., 2005). With such an anticipated effect on the west coast of Norway, some of the 15 sites analysed in this paper could had been washed over by at least 2.5 meters high tidal waves. If the runup of 3 meters indicated at the Stavanger airport site is representative, then 9 sites would have been washed over. A more thorough topographical analysis of the various sub-regions of Western Norway could shed light on local variations from this expected mean wave height.

Figure 10. Map with geological sites documenting the Garth tsunami on Shetland and in Norway (black dots) as well as archaeological sites with some evidence from stratigraphy of a high-energy event around 3500 cal BCE (red dots) as well as sites without such evidence (round circles). 1: The charred nutshell from the sand layer (i.e. layer 2) at Håkonshella 8 was dated to 3516-3108 cal BCE. 2: The two samples retrieved from the gravel layer (i.e. layer 4) at Stavanger airport dated to 3906-3638 cal BCE and 3692-3378 cal BCE. 3: The youngest sample from the occupation level below the sand layer at Skomrak dated to 3650-3536 cal BCE. 4: The youngest sample from the occupation level below the sand layer at Hamremoen dated to 3639-3560 cal BCE. Background map based on open source maps at: www.arcgis.com.

There is, however, no need to continue to theorize vulnerability and resilience within such hunter-fisher-gatherer societies if the empirical record does not show any traces of impact or catastrophe. Analysis of occupation phases, as inferred from radiocarbon dates, at coastal settlements in Western Norway show congruence with but no direct evidence of the Garth tsunami. However, the stratigraphy from these sites show depositions primarily in the southwestern and southernmost regions (Figure 10). Finally, the simulated demographic model disclaims the hypothesis of the Garth tsunami causing significant negative impact on the hunter-fisher-gatherer population.

7 Conclusion

This paper set out by questioning whether archaeology can test the level of catastrophe of paleotsunamis. Although this is probably true, as there are methods useful to explore such a question as long as suitable data is available, no secure indication of catastrophe was documented by this study of the Garth tsunami on the west coast of Norway. The paper tested 15 coast near archaeological occupation sites for traces of impact of a paleotsunami event. Even though Bayesian sequence modelling could not positively disclaim the hypothesis of an impact, stratigraphy and a simulated demographic argued against it. Still, a better understanding of the relation between prehistoric hunter-fisher-gatherers and paleotsunami events in northwestern Europe should continue to be pursued by future research. Application of soil chemistry and micro-morphological analysis of cultural layers, and a precise radiocarbon dating strategy of both anthropogenic and natural soils, could make significant contributions to this research. In the case of the Garth tsunami impact in Norway, the southwestern and southernmost coastal regions stand out as the most interesting for future research.

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