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RESEARCH ARTICLE

# Twigs date the second Holocene transgression in southwestern Norway

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## Abstract

Marine flooding events occasionally interrupted the everyday lives of prehistoric coastal populations. Identification of such events are important for studies of past population dynamics and adaptive strategies. However, short-term events are rarely identified in the geological record, which puts a severe limit on our archaeological interpretive framework. This paper explores the temporality of the second Holocene transgression in southwestern Norway (ca. 3500 BCE) and works under the hypothesis that it was not a slow geological process but rather one or multiple short-term events. A Bayesian approach is used to analyze multidisciplinary time series data collected from sites located in Norway and Shetland. The resulting chronological model supports the hypothesis that the second Holocene transgression in southwestern Norway was a rapid flooding event that occurred in the period 3445–3395 BCE (Early Neolithic II). It is also suggested, but not argued conclusively, that this flooding event could correspond to the Garth tsunami, a paleotsunami named after Garth Loch in Shetland. Considering the potential impact of such a flooding event on the everyday lives of local foragers who dwelled in southwestern Norway, it is anticipated that this study could form a starting point for future case studies.

## Introduction

An extreme marine event, such a tsunami wave, represented a potential catastrophic experience for prehistoric societies and therefore such events need to be studied as real sources of influence on the archaeological record (Bondevik et al. 2019, 2005; Mithen and Wicks 2021; Nielsen 2020; Nyland et al. 2021; Walker et al. 2022, 2024; Goff 2023). In 2005, Bondevik et al. (2005) reported on geological evidence of three prehistoric North Sea tsunamis, namely Storegga (ca. 8.1 ka BP), Garth (ca. 5.5 ka BP) and Dury Voe (ca. 1.5 ka BP). When the Storegga tsunami struck the western coastline of Norway during the Middle Mesolithic period, it probably damaged key resource bases, ecosystems, and coastal inhabitants, studies have hypothesized (Rydgren and Bondevik 2014; Sharrocks and Hill 2024; Walker et al. 2024). However, a recent technological analysis of changes in lithic reduction strategies within the impact zone of the Storegga tsunami in Norway, found "no major "dramatic breaks" in the Middle Mesolithic blade production concept during the period" (Nyland and Damlien 2024, 7). Recent demographic studies using statistical modeling of radiocarbon dates have also found inconclusive evidence of a demographic trough in the aftermath of the Storegga tsunami in Norway (Bergsvik et al. 2021; Lundström 2023).

The western coast of Norway was inhabited by foragers, or hunter-fisher-gatherers, when both the Storegga and Garth tsunami occurred. The effects of the Garth tsunami on coastal inhabitants in western Norway are less known but was recently explored by Nielsen (2020), who found that the most compelling evidence of its impact were in the southwestern and southernmost coastal regions. As

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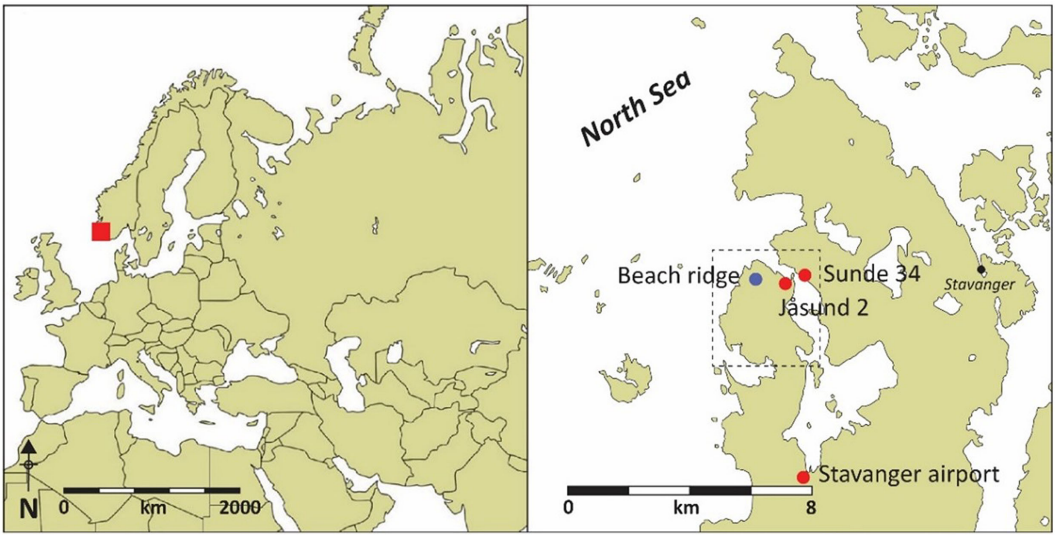



***Figure 1.*** *Map of the Tananger peninsula (stapled area) in Southern Norway and the archaeological (red) and geological (blue) sites discussed in the paper. Figure: Svein V. Nielsen.*

pointed out by Nielsen (2020, 9), the timing of the Garth tsunami in southwestern Norway "coincides with what geologists have termed a short-term sea level transgression which reached its maximum height at ~4800 BP/3550 cal BCE." This geological phenomenon is more commonly referred to as 'the second Holocene transgression' (Prøsch-Danielsen 2006). Prøsch-Danielsen (2006, 89, their Fig. 82) has presented 12 sites in southwestern Norway with evidence of this transgression in the form of beach ridges. In every case these beach ridges rested on humus, and in some cases Early Neolithic artifacts were incorporated in the beach gravel (Prøsch-Danielsen 2006, 86).

Thus, there are two geological phenomena initially discovered at different geographical locations (i.e. the Garth tsunami in eastern Shetland, and the second Holocene transgression in southwestern Norway), which occurred possibly simultaneously and could therefore represent the same underlying causal agent. This is also the starting point of this paper. Here we present a refined dating of the second Holocene transgression on the Tananger peninsula in southwestern Norway based on (a) contextual evidence from a recently excavated archaeological occupation site named Jåsund 2, and (b) a Bayesian analysis of multiple archaeological, botanical, and geological radiocarbon dates from the wider region under study. It then examines whether this event might mirror the Garth tsunami known from Shetland and discusses what impact this freak event might have had on local societies in southwestern Norway, as it coincided with the process of neolithization in the region.

## Background

The Tananger peninsula is located on the southwestern coast of Norway (Figure 1), on the western side of Hafrsfjord, where the well-known Battle of Hafrsfjord took place in the 9th century CE. The peninsula was until the 20th century CE divided into seven farms, of which the Jåsund farm was in the northeast. While research on early Holocene tsunami events in the North Sea area is relatively recent (Bondevik et al. 2005; Cain et al. 2018; Nielsen 2020; Romundset et al. 2015), knowledge of a marine flooding event at the Tananger peninsula around 3500 BCE is considerably older. In previous research, the data pertaining to this flooding event was interpreted as representing a second Holocene transgression and as such a relatively slow geological process (Andersen 1960), but this model is now questioned by research (e.g. Creel et al. 2022, 21). Consequently, there is reason to explore whether the

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***Figure 2.*** *Photo of the Jåsund beach ridge, investigated by use of an excavator in 1980. Photographed towards the northeast. Photo: Hanne Thomsen (Prøsch-Danielsen 2006, 54, their Fig. 48a).*

flooding in this region was caused by a short-term freak event (as proposed by Prøsch-Danielsen 2006; Nielsen 2020).

The research history starts in 1902 when Fægri (1940) discovered a beach ridge at Jåsund (17.5–19 m.a.s.l.) (Figure 2), which was investigated in 1980 as part of land development plans (see also Helliesen 1902; Prøsch-Danielsen 2006, 52–53). Two layers of gravel, round pebbles (diameter 3–5 cm) and minerogenic materials packed with sand and gyttja (mud) were documented. The upper layer down to ca. 50 cm depth contained macroscopic twigs of birch (*Betula pubescens*), alder (*Alnus glutinosa*), willow (*Salix sp*.), and oak (*Quercus sp*.). Pollen analysis discovered oak (*Quercus*), elm (*Ulmus*), birch, alder, and hazel (*Corylus*), as expected from the Atlantic or Subboreal period. A sample of twigs dated to 3765–2780 BCE (95% probability, T-4017: 4580±190 BP). Height difference between seashore and the ridge was ca. 10 m (i.e. 9 m higher than today).

Thomsen (1982) had first suggested that the flooding event, or rising sea level, at Jåsund was caused by a local differential faulting on the peninsula, but Prøsch-Danielsen (2006) rejected this hypothesis with reference to absence of such evidence in sediments from a nearby lake (Kvitamyr, 12 m.a.s.l.). She proposed tentatively, but not conclusively, that "A tsunami event could have eroded the lumps and the twigs and transported them to an old beach ridge and deposited them in reworked gravel on top of the ridge" (Prøsch-Danielsen 2006, 54–55). A scenario of multiple storm events was also proposed as a possible cause.

Supporting evidence of one or several short-term flooding events emerged in 1980 at an open-air settlement site located on the eastern side of the Hafrsfjord strait (Figure 3) (Braathen 1985). The site called Sunde 34 was position about 9–10 m.a.s.l. and about 150 m from the contemporary coastline. The excavation documented ca. 6200 lithic artifacts within a 5–15 cm thick anthropogenic layer, covering about 55 $m^2$. The layer rested on top of compressed peat and was covered by a ca. 50 cm thick beach ridge. A bottom peat sample dated to 8165–6465 BCE (95% probability, T-3716: 8260±320 BP), and five charcoal samples from the anthropogenic layer pointed to Mesolithic activity (Bang-Andersen 1995, 117, their Table 2). However, one charcoal sample collected from a hearth within the same stratum dated to 4245–3105 BCE (95% probability, T-3714: 4930±210 BP), documenting an additional Neolithic activity phase before the formation of the beach ridge (Prøsch-Danielsen 2006, 49). Artifacts from this layer, such as cylindrical blade cores, transverse arrowheads, and tanged points of flint and rhyolite, also reflected an Early Neolithic activity phase (Nielsen 2020).

In 1984–1985, an open-air settlement site was excavated near Stavanger airport (Figure 4) (Nielsen 2020; Prøsch-Danielsen 2006; Prøsch-Danielsen and Selsing 2009; Skar 1985). The site was covered with aeolian sand, measuring as much as 2 m in depth (Prøsch-Danielsen and Selsing 2009). The stratigraphy in one of the deepest trenches, called trench B, showed in the bottom a layer of gyttja containing Early Neolithic artifacts (called layer 3). On top of this was a gravel layer also containing

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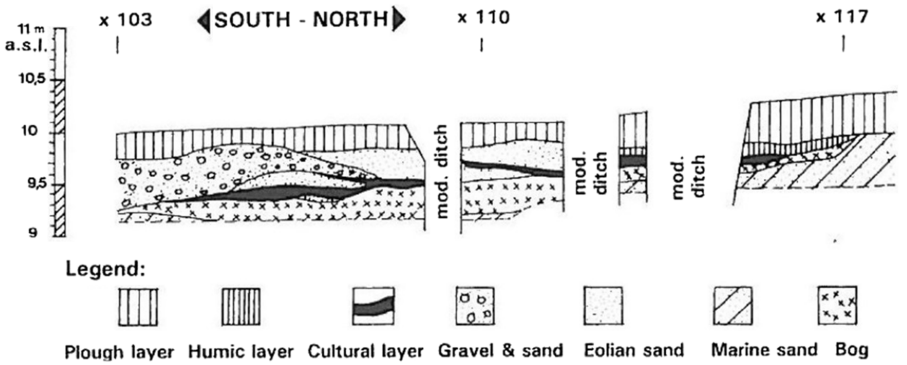



***Figure 3.*** *Soil profile from the open-air occupation site Sunde 34, located northwest of the Tananger peninsula (Bang-Andersen 1995, 116, their Fig. 7).*



***Figure 4.*** *The Sola airport site, here being excavated in the mid-1980s. Photographed towards the east. Photo: Terje Tveit (Prøsch-Danielsen and Selsing 2009, 37, their Fig. 25).*

Early Neolithic artifacts (called layer 4), followed by an "erosion contact zone" (called layer 5) and then a peat layer (called layer 6), which contained artifacts and other traces of human activity from the Middle Neolithic and the Bronze Age (Prøsch-Danielsen and Selsing 2009, 47).

It was suggested that finds of Early Neolithic artifacts in layers 3 and 4 meant that waste from settlements had been intentionally thrown to sea in the Early Neolithic (Skar 1985, 238). Prøsch-Danielsen and Selsing (2009) rejected this hypothesis and proposed that layer 4 (gravel layer) was shaped by a "short-lived marine episode" close to 4800 BP (ca. 3500 BCE), meaning that the Early Neolithic artifacts from layer 4 and 3 had been "washed into the marine sediments when seawater swept over" (Prøsch-Danielsen and Selsing 2009, 62). They identified layer 4 type gravel up to 9 m.a.s.l. around the site through a series of boreholes, indicating a runup of the episode in this area to roughly 3 m.

The open-air site Jåsund 2 was surveyed and excavated in 2010–2011. It was located about 10 m.a.s.l., and the excavation documented a total of 13191 finds, artifacts and samples included (Fyllingen 2012, 2015). From the start, an excavator removed the turf within an area of ca. 17 × 21 m, and a cultural layer covering most of the western side of the excavated area was investigated further. Three stratigraphic layers were discernible; directly below the turf was a 15–30 cm thick anthropogenic layer interpreted as disturbed by modern ploughing. Two samples, dating to the Early Bronze Age (Beta-312820: 3430±30 BP) and the Late Mesolithic (Beta-312919: 6910±40 BP), confirmed its mixed

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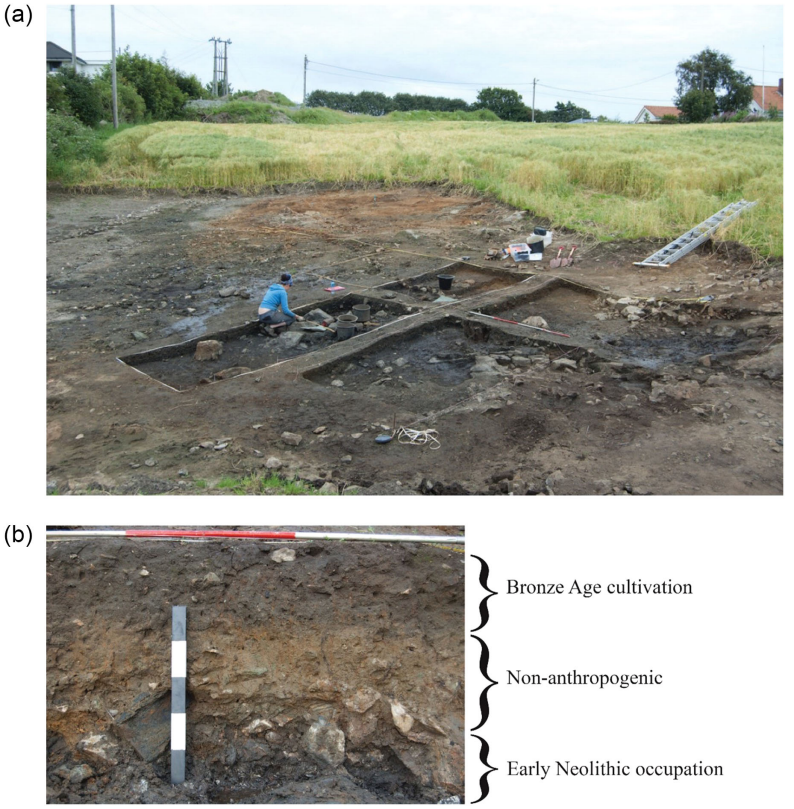



***Figure 5.*** *(a) The open-air occupation site Jåsund 2 towards the end of the excavation in 2011, with archaeologist Henriette Hope excavating the bottom Neolithic occupation layer. Photographed towards the southwest. (b) Soil profile towards the west, showing the upper Bronze Age cultivation layer, the non-anthropogenic layer with sand and small stones beneath, and the lowest Early Neolithic occupation layer. Photos: Hilde Fyllingen, Museum of Archaeology, University of Stavanger, Sf104466, Sf104499 (Licence: CC BY-NC-ND 4.0).*

character. By all probability, the layer was formed by farming on top of Mesolithic and Neolithic occupation areas during the Bronze Age or later periods. Both Mesolithic and Neolithic artifacts occurred in this mixed layer.

In the western end of the site, a 25 cm thick layer consisting of sand and small stones, was positioned below the upper mixed Bronze Age anthropogenic layer. This non-anthropogenic sand layer covered 9 $m^2$ and contained very few finds (Fyllingen 2015, 51). Below it, there was a third layer consisting of small rocks and marine gravel that measured only 4 × 5.5 m (Figure 5). This third and deepest layer was dense in lithic artifacts and was documented as mechanical layer 6–7 on the site. Two charcoal samples collected from the bottom layer dated to 3520–3195 BCE (95% probability, Beta-306553: 4620±40 BP), most likely 3520–3335 BCE (probability at 93.7%) and 3510–3350 BCE (95% probability, Beta-312921: 4620±30 BP), most likely 3515–3425 BCE (probability at 66.8%).

It is important to stress the fact that the third and deepest layer at Jåsund 2 was not identified by the initial survey project, and had it not been for the mixed upper layer and the excavation of this unit, the third layer would have never been identified by the subsequent excavation project. No further stratification was visible in the soil profile, but polish from weathering had not affected the finds from deepest layer and several artifacts had still sharp edges preserved, suggesting that the sand and stone layer on top had effectively encapsulated the soil in excavation layers 6–7. At the centre, the excavators discovered a 1 $m^2$ hearth containing a concentration of burnt bones and nutshells (*Corylus*). A soil

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***Figure 6.*** *Photo of selected Neolithic artifacts from Jåsund 2. All tanged points of flint and rhyolite (row 1–4) and note that some of these were found in the upper mixed cultivation layer and some inside the bottom Early Neolithic layer. Below are pottery sherds, exclusively from the mechanical excavation layers 6–7 (row 5–6). The four sherds with ornamentation, i.e. with cord and other small imprints, are placed on the left side. Figure: Svein V. Nielsen.*

sample from this feature also contained bedstraw (*Galium*), an edible plant that probably grew naturally in the surroundings. Scattered more generally inside the bottom layer were unburnt and well-preserved teeth from wild boar (*Sus scrofa*) and deer (*Cervus elaphus*), as well as a lump of resin. In the lithic assemblage from the bottom anthropogenic layer (archived at the Archaeological Museum, University of Stavanger as id 144505/S12761), there were 1482 artifacts. Flint was the dominating raw material (99%), and most artifacts were identified as debris from tool production (n = 1132). In addition, there were flint blades and exhausted cores, tanged points of flint, scrapers, and pottery sherds (Figure 6).

The pottery sherds were badly preserved, which is normal on open-air Neolithic sites in the region, but impressions in the clay of cord and lines of small imprints were visible on five sherds. Impressions of cord in horizontal lines below the rim (n = 1) is previously known from other Early Neolithic pottery assemblages from Southern Norway (Glørstad and Sundström 2014; Nielsen 2021a). The small

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impressions (n = 4) on some sherds corresponded to what Eva Koch (1998, 77) termed "short vertical lines" within the "simple ornamentation" style, common on type II vessels of the Funnel Beaker Culture in Southern Scandinavia. Type II vessels in Denmark date to the EN period (4000–3300 BCE), which fits well with the directly dated samples from layers 6–7 at Jåsund 2.

## Methods

Anthropogenic radiocarbon dates from the western coast of Norway relevant for the study of the ca. 3500 BCE marine flooding event was recently published by Nielsen (2020). The table of dates presented here focus on the southwestern coastal region, where the Jåsund peninsula is located (Figure 7a). We have also added one date from Helganes D, an open-air coastal site located on the northwest coast of the island Karmøy (Solberg 2014), which we believe is relevant for future research on this period. The excavation in 2011 documented a circular dwelling with an anthropogenic layer dated on charcoal to 3710–3535 BCE (95% probability, Beta-319748: 4870±30 BP). Among the lithic artifacts discovered, there were fragments from two thin-butted flint axes (Early Neolithic type), several locally produced rock axes, production waste of flint and rhyolite, tanged points, and a few polished slate arrowheads. This site could be important for future research because it was located on the outer western coast, and the artifacts and radiocarbon date suggest it was occupied shortly before the flooding event.

To obtain a realistic age estimation of the sequences of events represented by the dated samples representative of our region, we applied Bayesian chronological modeling using OxCal 4.4 (Bronk Ramsey 2023), like the approach in Bondevik et al. (2012; Bronk Ramsey 2009, 2023). In the model presented here, we proposed the following sequence of events: (a) dates from Jåsund 2 and the youngest date from layer 3 at the site Slettabø, (b) the Jåsund beach ridge, (c) gyttja above the tsunami deposits at Skjoldnesmyra, and finally (d) the oldest date from layer 2 at Slettabø. We propose with this model that the encapsulating sand and stone layer at Jåsund 2, covering the excavation layers 6–7, and the sand layer positioned between cultural layers 2 and 3 at Slettabø, were deposited by the tsunami event.

In a previous study, layer 3 at Slettabø was interpreted as post-dating the flooding event (Nielsen, 2020). However, here we apply a different interpretation of the stratigraphy (Glørstad 1996, 65; Nielsen 2021a; Prøsch-Danielsen and Selsing 2009, 72), which argue that the sand layer dislodged between layer 3 and 2 at Slettabø was a short-time event dating to ca. 3400–3200 BCE, and that the ages of two specific charcoal samples (T-1780; T-561) mark the latest and oldest events. By applying this interpretation of the stratigraphy at Slettabø, we are exploring if the sand layer between layer 3 and 2 could had been caused directly or indirectly by the marine event under study here.

For outlier control, we applied two Outlier Models, using the standard distributions for these cases as described by Bronk Ramsey (2009): One Outlier Model for the charcoal samples ("Charcoal", Probability of 100%), and the other ("General") for the non-charcoal samples (with standard probability of 5%), with a higher probability (50%) for the sample from layer 3 at Slettabø, T-1780. Using a standard Charcoal Outlier Model for this sample results in ZERO distributions for the model, as well as an individual poor agreement for that sample with an A-value of 30.3. The threshold for unreliable models is 60 (Bronk Ramsey 1995, 427–428), meaning that the sample T-1780 implied a low index of Agreement, and that the posterior radiocarbon result is a possible statistical outlier (i.e. close to 2 standard deviations from the true radiocarbon age) (Bayliss et al. 2013, 85). Using the General Outlier Model results in a satisfying general Agreement (Amodel=113.8, Aoverall=113) as well as for the individual date (A=61.2), with a posterior probability of 65% to be an outlier.

We assumed that Jåsund 2 and layer 3 at Slettabø represent the archaeological contexts closest in time to the moment before the tsunami, and that the twig collected from inside the Jåsund beach ridge is closer to the actual event, as it was deposited by the flooding event but had grown naturally in the area shortly before. The gyttja dates from Skjoldnesmyra represented sediments formed shortly after the marine event (Romundset et al. 2015), and here we followed the combination of uncalibrated ages by Nielsen (2020). Further on, we approached the oldest sample from layer 2 at Slettabø as representing the archaeological context in this region closest in time after the tsunami.

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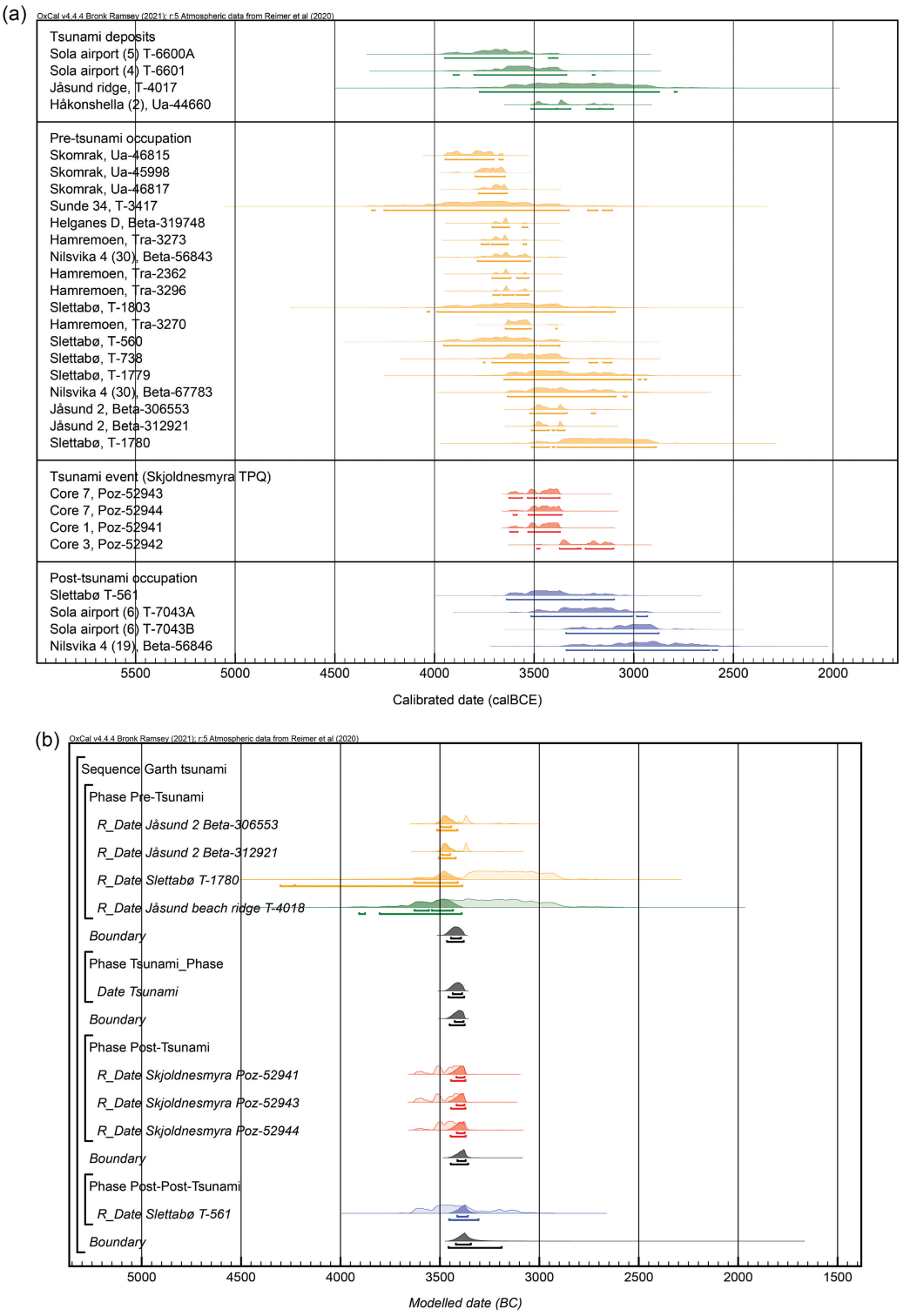



***Figure 7.*** *(a) Plot of calibrated radiocarbon dates discussed in the paper, made with OxCal 4.4 (Bronk Ramsey 2023). The dates are organized in four groups; tsunami deposits (green probability distributions) are dated samples from contexts interpreted as caused by a flooding event*

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To reconcile our results with the evidence for the Garth tsunami on the Shetland Islands, we performed a second Bayesian chronological modeling, in which we included the relevant data from Garth Loch and Loch of Benston. Available dates come from samples collected above and below the tsunami layer at Garth Loch, and one piece of wood collected from within the tsunami layer at Loch of Benston. Due to the short-lived nature of the twig from the Jåsund beach ridge in southwestern Norway, we have modeled this sample to represent the age of the flooding. This second analysis in OxCal also produced a stable model (Amodel=130, Aoverall=127.8). All charcoal data are again handled as charcoal outliers, while the date from Slettabø (T-1780) is again handled with the General Outlier Model with 50% (all other dates General Outlier 5%). This gives a posterior probability of this date to be an outlier of 65%, with an A-value of 60.2.

## Results

According to our first Bayesian analysis (Figure 7), the marine flooding event in southwestern Norway is now estimated to have happened sometime between 3460–3380 BCE (95% probability). This estimation is derived directly from the date function in the OxCal model. Although we cannot accurately estimate the closeness in time between the underlying human activity at the archaeological sites Jåsund 2 and Slettabø before and after the event, it is reasonable to expect that maximum distance in time was 49 years (95% probability), most likely 0–18 years (68% probability). A more precise evaluation of closeness in time is not possible now.

In our second analysis (Figure 8), we receive a date of the twig from the Jåsund beach ridge of 3460–3380 BCE (95% probability). The duration of the tsunami interval is estimated to 0–49 years (95% probability), most likely 0–20 years (68% probability). These results are in line with the results from the first analysis, supporting the dating of the flooding event to have happened around 3460–3380 BCE (95% probability), but more probably between 3445–3395 BCE (68% probability) (Figure 8c). It is also worth stressing here the posterior results of the dates from Slettabø. Despite their large standard deviations, we can now, through these Bayesian analyses, get a more realistic view of their true ages. The youngest date from layer 3 now dates to 4310–3390 BCE (95%), and the oldest date from layer two now dates to 3450–3370 BCE. Consequently, the sand deposit dislodged in between these two layers was formed between these dates, and as we have seen above, this deposition is possibly related to a marine flooding event in the region.

*(cf. Nielsen 2020). Samples in this group should therefore be older than the event itself. Pre-tsunami occupations (yellow probability distributions) are dated samples from occupation sites that should be older than the event. The tsunami event dates (red probability distributions) refers to the dated ages of the gyttja samples positioned directly above the gravel layer in the lake basin at Skjoldnesmyra, Southern Norway, which were interpreted by Romundset et al. (2015) at reflecting the Garth tsunami. These ages provide the most accurate terminus post quem of the event in Norway available today. Post-tsunami occupations (blue probability distributions) are dates from occupation sites that should be younger than the tsunami event. (b) The first Bayesian model with only Norwegian sites. The flooding event is structured by immediately before (i.e. charcoal from layer 3 at Slettabø, charcoal from the hearth at Jåsund 2, and twig from the Jåsund beach ridge) and immediately after (i.e. mud samples from the Skjoldnesmyra basin and then charcoal from layer 2 at Slettabø). Here we show the 95% probability of before (yellow and green) and after (red and blue) calibrated probability distributions from the Bayesian analysis. The dating of the flooding event is reflected by a Date function, 3460–3380 BCE (95% probability), the duration of that phase is reflected by an interval query (0–45 years, 95% probability). Figure: Svein V. Nielsen & Martin Hinz.*

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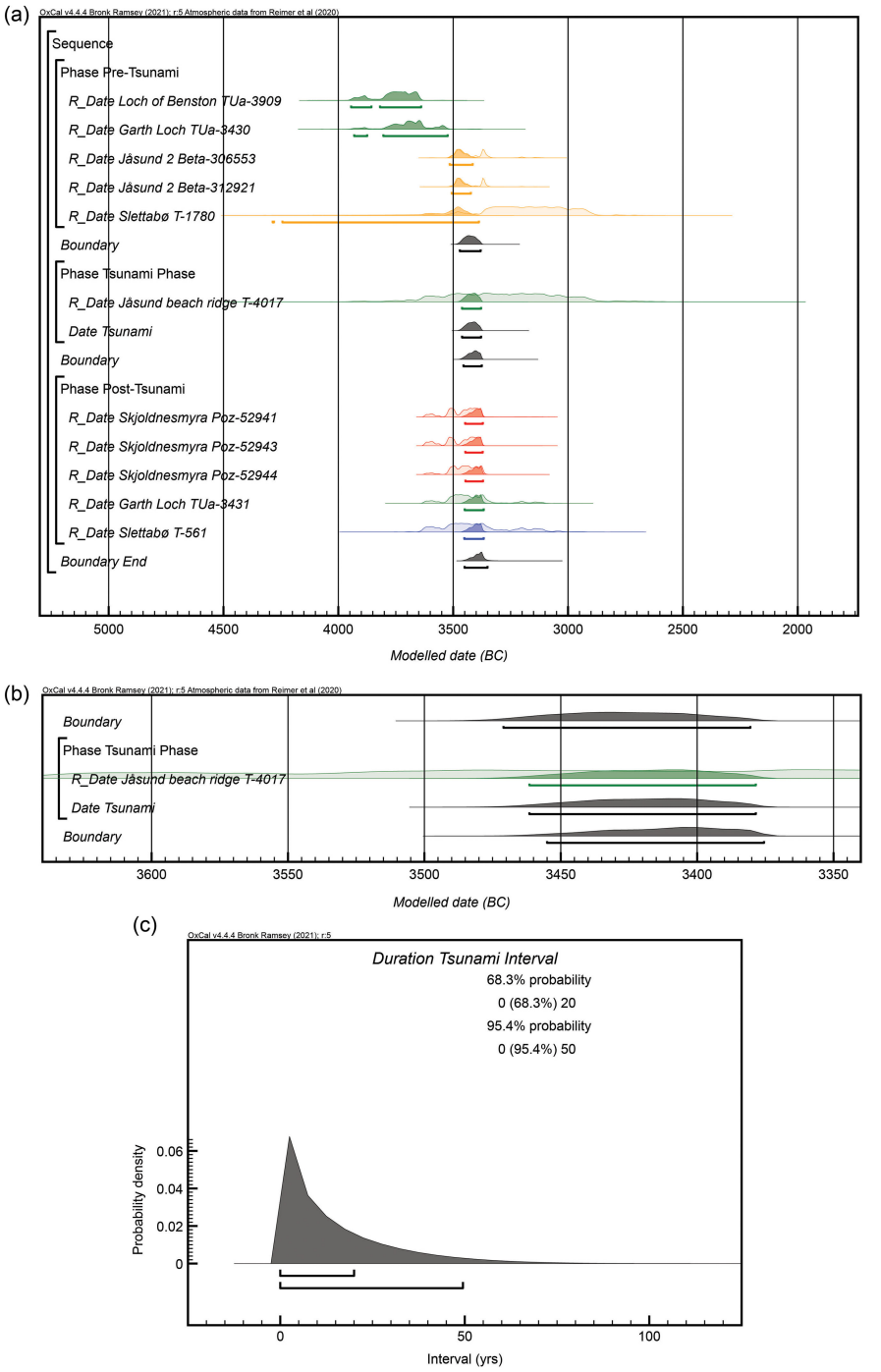



***Figure 8.*** *(a) The second Bayesian model where sites from southwestern Norway and eastern Shetland are included. The flooding event is structured by allowing the short-lived twig from the Jåsund beach ridge represent the age of the flooding, with and interval and boundaries added before and after. The dating of the flooding event is again given by a Date function, 3460–3380 BCE (95% probability). (b) Posterior probability distributions of the boundary events and the dated twig from the Jåsund beach ridge in southwestern Norway as shown in (a). (c) Posterior probability distribution of the duration of the Tsunami interval. Figure: Svein V. Nielsen & Martin Hinz.*

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## Discussion

### *Does the flooding event reflect the Garth tsunami?*

In 2005, Bondevik et al. dated two twigs collected from gyttja positioned directly above a tsunami deposit level in Garth Loch, South Nesting in Shetland, to 3630–3110 BCE (95% probability, TUa-3431: 4645±65 BP). A twig found inside the tsunami deposit in Loch of Benston, also in Shetland, was dated to 3945–3640 BCE (TUa-3909: 4965±55 BP). The event is known in the literature as the Garth tsunami (cf. Long and Wilson 2007). It should, however, be noted that similar evidence has not been found on the east coast of England, nor in northwestern Jutland (cf. Bennike et al. 2019; Brew et al. 2015; Shennan et al. 2018).

In 2015, Romundset et al. dated the above mentioned gyttja samples above a tsunami deposit in Skjoldnesmyra, southernmost Norway. Their collected age is 3625–3375 BCE (Nielsen 2020). Here we have demonstrated that the evidence of a marine flooding event on the Tananger peninsula (ca. 3445–3395 BCE, 68% probability) in southwestern Norway is congruent with a short term event rather than a long-term transgression (max. 49 years, rather max. 20 years), and that the age estimation of the event is congruent with the expected age of the Garth tsunami (Bondevik et al. 2005; Nielsen 2020; Romundset et al. 2015). In southwestern Norway, during the mid-fourth millennium BCE, the sea was positioned about 9 m above present level due to post-glacial rebound, and our present knowledge points to a run-up of the flooding event that varied from 7–10 m at the exposed Jåsund peninsula, to ca. 3 m at the Stavanger airport site. Bondevik et al. (2005) also proposed a run-up of the Garth tsunami in eastern Shetland to about ten meters.

### *Impact on affected societies*

In Shetland, the Garth tsunami event co-occurred with the neolithization process. The forager occupation site named West Voe (ca. 4000–3500 BCE) in southern Shetland has been interpreted as encapsulated be sediments moved by the Garth tsunami (Cain et al. 2018; Gillmore and Melton 2011). Like at the site Slettabø in Norway, the occupation level at West Voe was covered by sand, and a sedimentary analysis found that it was "not typical of wind-blown sediments" (Gillmore and Melton 2011, 80). After the sand deposition at West Voe, there followed a widespread Neolithic settlement in Shetland. In a review of the radiocarbon date record from Orkney, MacInnes (2019) observed a spike in the density signal after 3500 BCE. Investigator bias could be a likely cause of this, while taphonomic loss of sites from the centuries before the flooding event, and thus dateable materials, due to the tsunami, is also a likely explanation.

In a study of land-cover changes in Orkney during the Neolithic period, Bunting et al. (2022) found a significant shift from ca. 3400 BCE, with the introduction of farming and a marked fall in woodland indicators. In the case of Shetland and Orkney, Cain et al. (2018, 27) expected "a high death toll, rapid burials, resource depletion and settlement abandonment" as realistic consequences from the Garth tsunami. Similarly, Gillmore and Melton (2011, 81) argued that the production of several sand deposits in Shetland around 3500 BCE would have forced "a temporary abandonment of areas of land that had been laid waste."

The neolithization process in Norway starts with the appearance of the Funnel Beaker Culture (TRB) in the Oslo fjord region, eastern Norway, around 3900 BCE. The geographical extent of this neolithization is partly reflected in the spatial distribution of imported flint axes, stone battle axes and pottery, which show concentrations around Oslo and west to Telemark, with marked falloff patterns further west and north (Nielsen 2021b). In a review of imported Early Neolithic flint axes in western Norway, including the Tananger area, Bergsvik and Østmo (2011) found a pronounced concentration in the southwestern region, where they also identified the largest variation in imported axe types. Several axes were originally deposited in wet environments, while a few indicated depositions in flat graves, which were typical within the early TRB in Southern Scandinavia. The common interpretation of the

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four-sided flint and stone axes of the TRB is that they were excellent for felling of trees, a central activity for early cultivation.

However, though the impact of the early TRB is clearly visible in the material culture recovered from settlements in southwestern Norway, there is no direct evidence of cultivation in this region that predates the Garth tsunami. In a few cases, indirect evidence such as single pollen (e.g. *Plantago lanceolata*) point to stock keeping or cultivation before the event (Prøsch-Danielsen and Selsing 2009). At Jåsund 2, there is only evidence of foraging through the lithic arrowheads and scrapers, as well the consumption of hazelnuts, bedstraw, wild boar, and deer. A similar impression is inferred from the sites Sunde 34 and layer 3 at Slettabø (Skjølsvold 1977, 267). Yet evidence of contact and cultural transmission, in the form ceramic vessels of TRB types at Jåsund 2 and Slettabø, as well as polished flint axes at Helganes D, do point to affiliations with the Early Neolithic Funnel Beaker Culture.

From the centuries after the marine flooding event, we know from the charcoal samples collected from layer 2 at Slettabø that people returned to this site after some time. However, the cultural deposits from layer 2 stem from centuries of occupation events, throughout the Middle (3300–2350 BCE) and Late Neolithic (2350–1700 BCE) periods (Glørstad 1996). There is additional evidence of human occupations along the west coast of southwestern Norway at two other archaeological sites: Holeheia and Stangelandshelleren, and both were located along the Figgjo river, several kilometers south of the Tananger peninsula. These sites were separated by ca. 4 km and were excavated in the early 20th century. Already by 1911, the rock shelter site Stangelandshelleren was in terrible condition due to multiple small-scale excavations (Brøgger 1911; Gjessing 1920, 126–130). The artifact inventory stem from multiple occupations, spanning from the Mesolithic to even modern times, but includes also Neolithic arrowheads. More recently, an ox tooth (*Bos domesticus*) recovered by an early excavation was dated to 3335–2905 BCE (95% probability, TUa-2854: 4405±65 BP) (Høgestøl and Prøsch-Danielsen 2006), showing stock keeping practices ca. 300–400 years after the tsunami event. The open-air occupation site Holeheia was also investigated several times, starting in 1898 (Gjessing 1920, 102–110; Skjølsvold 1980). Radiocarbon dated charcoal samples from the most recent excavation spanned ca. 3350–3050 BCE, but studies of the lithic and ceramic artifacts also point to occupations in the 3rd millennium BCE (Nielsen 2021a). There is only evidence of foraging activities at Holeheia, reflected in artifacts such as flint arrowheads and scrapers.

Thus, we cannot say that the flooding event in southwestern Norway paved the way for the neolithization process, as it did in Shetland and Orkney. However, archaeological excavations have indicated a lowered intensity in coastal settlement activity during the first centuries after the flooding. Whether or to what extent these observations reflect an underlying cultural process remains uncertain, but we anticipate that our study can inspire future research on this period to form new models of neolithization or mobility that accounts for the effects of the Garth tsunami in this region of Norway.

## Conclusion

In this paper, it has been argued that the second Holocene transgression in southwestern Norway was one or several short-term flooding events, rather than a slow geological process. By applying Bayesian chronological modeling, it was possible to apply the relevant radiocarbon dates from archaeological and geological sites located in Norway and Shetland and construct a stable chronological model of a chain of events. However, it is necessary to add that the model presented here is not completed. With new data, the model could be improved, or indeed falsified, by future research.

It is hard to say exactly how, or to what extent, a marine flooding event that occurred between 3445–3395 BCE (68% probability) changed the course of (pre-)history in southwestern Norway. Here we have presented a robust chronological model of a chain of events that increases the probability that the event did have an impact on the local population. Settlements in this region were flooded, some were even covered by sediments to the extent that they practically "disappeared" from the Neolithic landscape, with the site Jåsund 2 being one example. Consequently, such sites have proven hard to

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discover by archaeologists as well. Due to various taphonomic processes, we cannot at this stage of research conclude that these places for habitation were revisited by people directly after the flooding event. The possible exception is Slettabø, where radiocarbon dates from occupation layer 2 (deposited on top of the sand layer fixed above layer 3) showed that people returned relatively swiftly, or at least within decades after. Further, we have no knowledge of sites that were completely washed away by the flooding. However, here we have increased our knowledge of the timing of the flooding event, and it will be up to future research to explore how the event might have changed the lives of local foragers. Another important task for future research will be to apply the necessary field techniques to discover more sites affected by the flooding event, such as Jåsund 2.

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## Appendix

### *OxCal code for first Bayesian analysis*

```
Plot()
{
Outlier_Model("General",T(5),U(0,4),"t");
Outlier_Model("Charcoal",Exp(1,-10,0),U(0,3),"t");
Sequence("Garth tsunami")
{
Phase("Pre-Tsunami")
{
R_Date("Jåsund 2 Beta-306553", 4620, 40)
{
color="orange";
Outlier("Charcoal", 1);
};
R_Date("Jåsund 2 Beta-312921", 4620, 30)
{
color="orange";
Outlier("Charcoal", 1);
};
R_Date("Slettabø T-1780", 4470, 120)
{
Outlier("General", 0.5);
color="orange";
};
R_Date("Jåsund beach ridge T-4018", 4580, 190)
{
color="green";
Outlier("General", 0.05);
};
};
Boundary();
Phase("Tsunami_Phase")
{
Date("Date Tsunami");
Interval("Interval Tsunami");
};
Boundary();
Phase("Post-Tsunami")
{
R_Date("Skjoldnesmyra Poz-52941", 4695, 35)
{
color="red";
Outlier("General", 0.05);
};
R_Date("Skjoldnesmyra Poz-52943", 4705, 35)
{
color="red";
Outlier("General", 0.05);
```

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```
};
R_Date("Skjoldnesmyra Poz-52944", 4670, 40)
{
color="red";
Outlier("General", 0.05);
};
};
Boundary();
Phase("Post-Post-Tsunami")
{
R_Date("Slettabø T-561", 4650, 100)
{
color="blue";
Outlier("Charcoal", 1);
};
};
Boundary();
};
};
```

**OxCal code for second Bayesian analysis**

```
Plot()
{
Outlier_Model("General",T(5),U(0,4),"t");
Outlier_Model("Charcoal",Exp(1,-10,0),U(0,3),"t");
Sequence()
{
Phase("Pre-Tsunami")
{
R_Date("Loch of Benston TUa-3909", 4965, 55)
{
color="green";
Outlier("General", 0.05);
};
R_Date("Garth Loch TUa-3430", 4895, 70)
{
color="green";
Outlier("General", 0.05);
};
R_Date("Jåsund 2 Beta-306553", 4620, 40)
{
color="orange";
Outlier("Charcoal", 1);
};
R_Date("Jåsund 2 Beta-312921", 4620, 30)
{
color="orange";
Outlier("Charcoal", 1);
};
R_Date("Slettabø T-1780", 4470, 120)
{
Outlier("General", 0.5);
```

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```
color="orange";
};
};
Boundary();
Phase("Tsunami Phase")
{
R_Date("Jåsund beach ridge T-4017", 4580, 190)
{
color="green";
Outlier("General", 0.05);
};
Interval("Duration Tsunami");
Date("Date Tsunami");
};
Boundary();
Phase("Post-Tsunami")
{
R_Date("Skjoldnesmyra Poz-52941", 4695, 35)
{
color="red";
Outlier("General", 0.05);
};
R_Date("Skjoldnesmyra Poz-52943", 4705, 35)
{
color="red";
Outlier("General", 0.05);
};
R_Date("Skjoldnesmyra Poz-52944", 4670, 40)
{
color="red";
Outlier("General", 0.05);
};
R_Date("Garth Loch TUa-3431", 4645, 65)
{
color="green";
Outlier("General", 0.05);
};
R_Date("Slettabø T-561", 4650, 100)
{
color="blue";
Outlier("Charcoal", 1);
};
};
Boundary("End");
};
};
```

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