# The drainage of the Baltic Ice Lake and a new Scandinavian reference $^{10}$Be production rate

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## Introduction

**The Baltic Ice Lake drained at the end of Younger Dryas** when the southern margin of the Fennoscandian Ice Sheet retreated past the northern end of Mount Billingen in SC Sweden (Figs. 1, 2). The rapid drainage (reducing the water level of the Baltic Ice Lake by c. 25 m) scoured a c. 3 km wide and 20 m deep zone and left gravelly deposits west of northern Mount Billingen (Fig. 2).

## Billingen $^{10}$Be prod rate

**We calibrate the reference $^{10}$Be production rate** by matching $^{10}$Be concentrations from bedrock surfaces, boulders, and cobbles (Fig. 3) against an independently derived calibration age of 11,673 ± 100 years before sampling in 2003 based on the clay varve record and correlation to the GRIP ice core record.

We use the CRONUS calculator code (Balco et al. 2008) to derive refeence $^{10}$Be production rates for the five CRONUS production rate scaling schemes and the two LSD (Lifton et al. 2014) production rate scaling schemes. All samples were submerged under water for the initial 129-940 years and we therefore model the production rate reduction during emergence through the water column (Fig. 4).


**Figure 1. The Baltic Ice Lake and the Fennoscandian Ice Sheet at the end of the Younger Dryas. The location of the Billingen study area and the four production rate calibration sites in Norway are marked.**

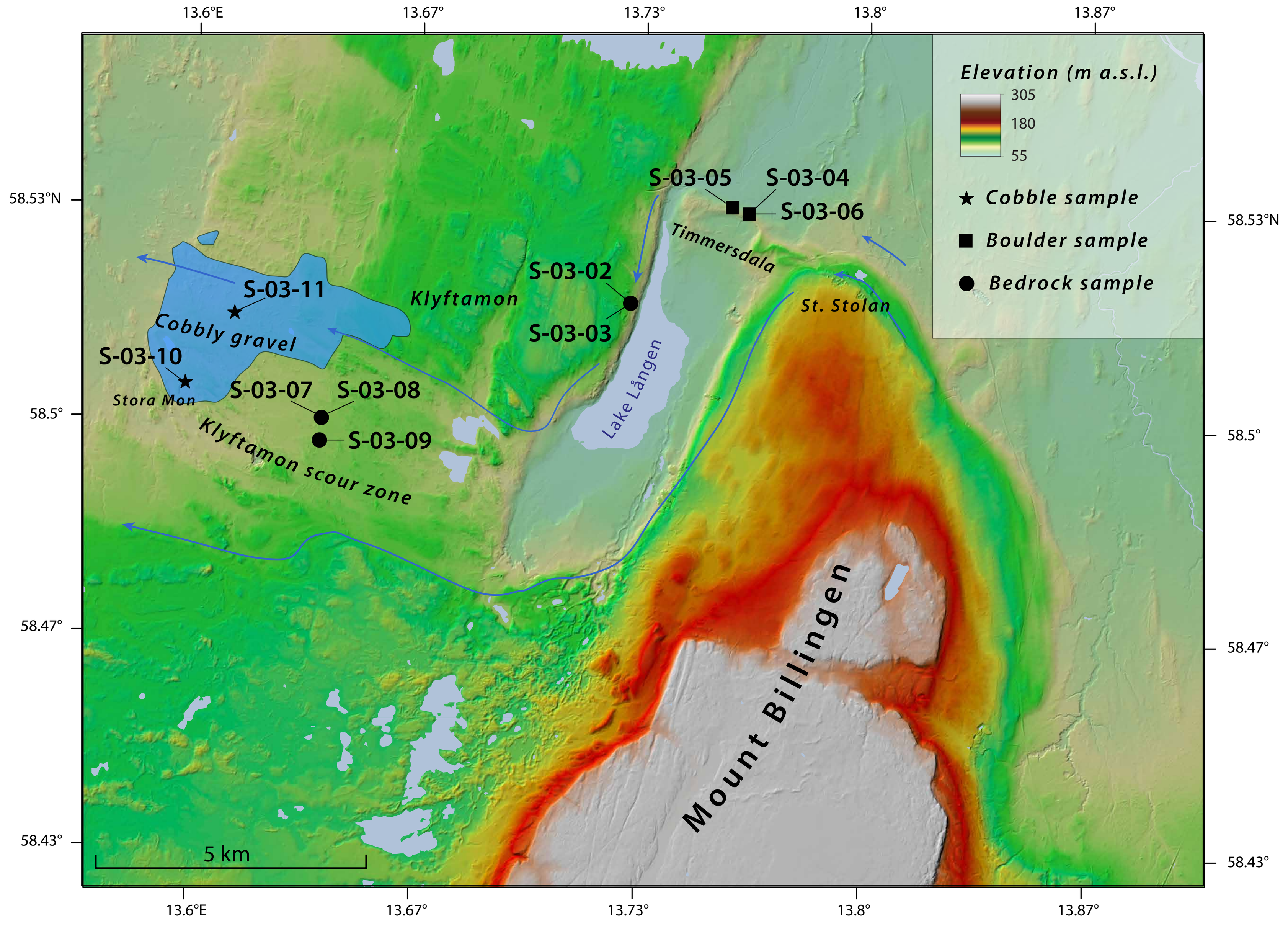


**Figure 2. Topographic map of the Mount Billingen area based on a LiDAR DEM with sample locations and the width of the Baltic Ice Lake catastrophic drainage path marked with blue arrows.**


**Figure 3. Flood-scoured and streamlined bedrock surfaces (a, b). Sampling bedrock surfaces (c, e) and a boulder (d).**

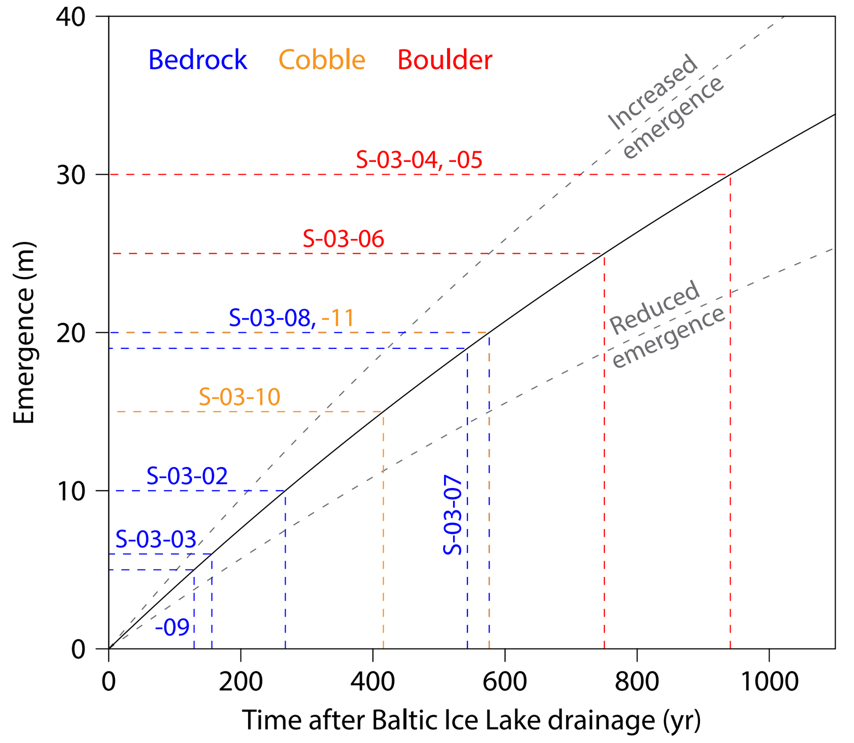


**Figure 4. Sample emergence through water after the Baltic Ice Lake drainage event.**

## Norway recalibration

**We recalibrate the reference $^{10}$Be production rate** for four sites in Norway (Figs. 1, 5; Fenton et al. 2011; Goehring et al. 2012) using the CRONUS and the LSD production rate scaling schemes.

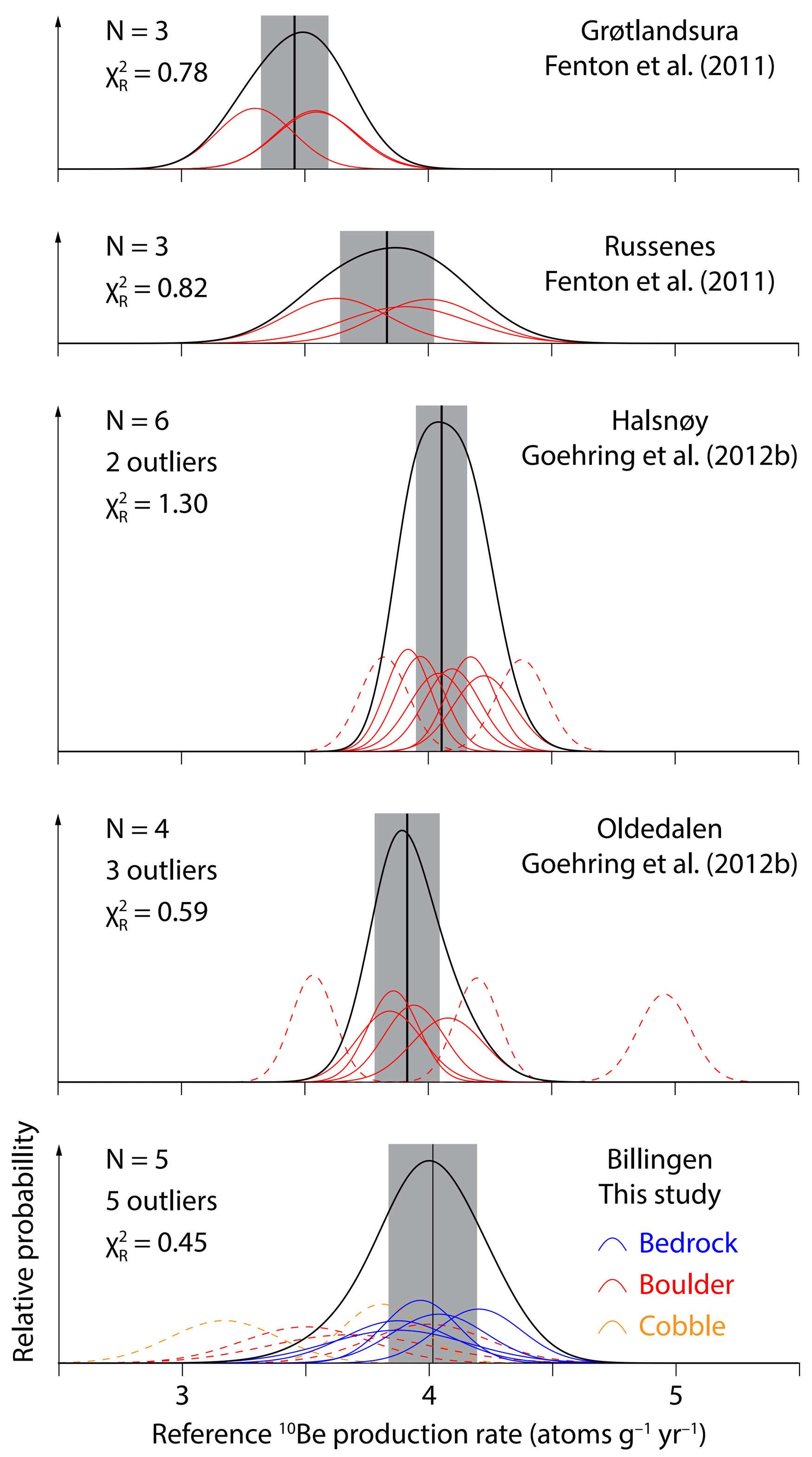


**Figure 5. Individual sample and location reference $^{10}$Be production rates as probability density plots using the nuclide specific LSDn scaling scheme for five locations in Scandinavia. We use the well-clustered production rate from the bedrock surfaces for Billingen and we exclude outliers for the two western Norway locations to yield a $\chi^2_R < 1.5$.**

## Scandinavian prod rate

**We combine the well-clustered Billingen bedrock surface reference $^{10}$Be production rate** with the recalibrated reference production rates from three sites in Norway (one site excluded as an outlier) to derive a tightly clustered regional Scandinavian reference $^{10}$Be production rate (Fig. 6).

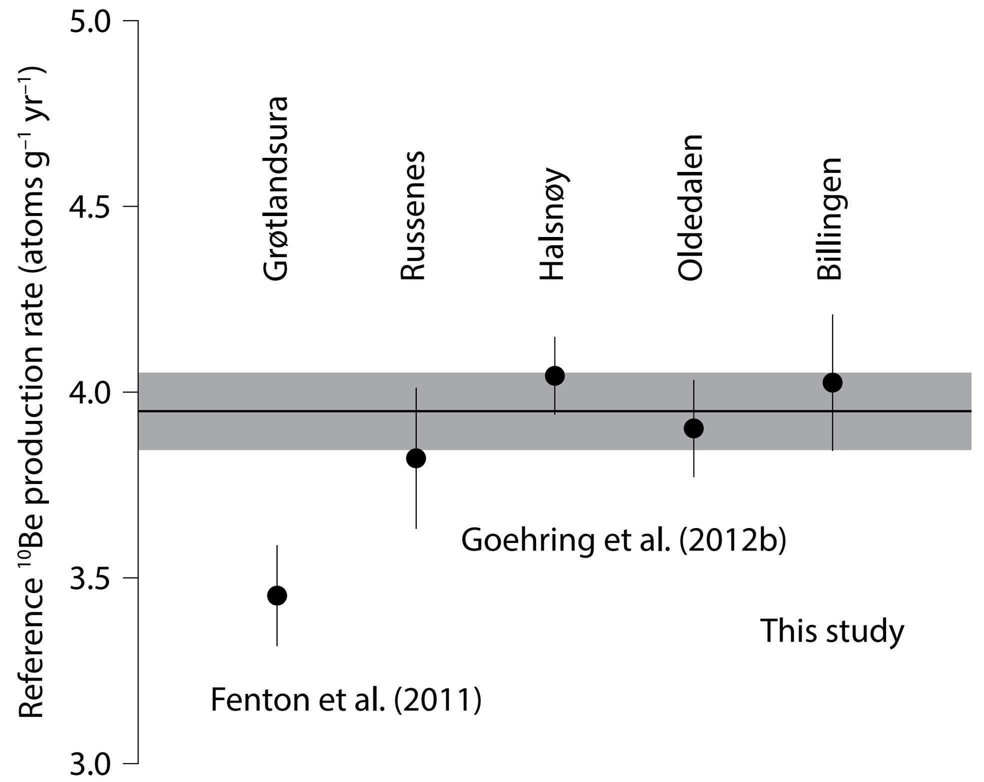


**Figure 6. Local reference $^{10}$Be production rates for the $LSD_n$ scaling scheme and arithmetic mean and standard deviation (horizontal black line and gray band). The Grøtlandsura reference production rate is excluded as an outlier. The production rates at Russenes (Fenton et al., 2011), Halsnøy and Oldedalen (Goehring et al., 2012b), and Mount Billingen (this study) for the $LSD_n$ scaling scheme average to a new Scandinavian reference $^{10}$Be production rate of 3.95 ± 0.10 atoms g$^{-1}$ yr$^{-1}$.**

## Outcome

- **Billingen reference $^{10}$Be production rate:**

  $LSD_n$: 4.02 ± 0.18 atoms g$^{-1}$ yr$^{-1}$

  CRONUS Lm: 4.19 ± 0.20 atoms g$^{-1}$ yr$^{-1}$

- **Billingen reference $^{10}$Be production rate:**

  $LSD_n$: 3.95 ± 0.10 atoms g$^{-1}$ yr$^{-1}$

  CRONUS Lm: 4.13 ± 0.11 atoms g$^{-1}$ yr$^{-1}$

**References**

Balco G, Stone JO, Lifton NA, Dunai TJ, 2008. A complete and easily accessible means of calculating surface exposure ages or erosion rates from $^{10}$Be and $^{26}$Al measurements. *Quaternary Geochronology* 3, 174-195.

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Goehring BM, Lohne ØS, Mangerud J, Svendsen JI, Gyllencreutz R, Schaefer J, Finkel R, 2012. Late glacial and Holocene $^{10}$Be production rates for western Norway. *Journal of Quaternary Science* 27, 89-96.

Lifton N, Sato T, Dunai TJ, 2014. Scaling in situ cosmogenic nuclide production rates using analytical approximations to atmospheric cosmic-ray fluxes. *Earth and Planetary Sciences Letters* 386, 149-160.