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Research Paper

Regional ^{10}Be production rate calibration for the past 12 ka deduced from the radiocarbon-dated Grøtlandsura and Russenes rock avalanches at 69° N, Norway

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A B S T R A C T

Two rock avalanches in Troms County – the Grøtlandsura and Russenes – were selected as CRONUS-EU natural cosmogenic ^{10}Be production-rate calibration sites because they (a) preserve large boulders that have been continuously exposed to cosmic irradiation since their emplacement; (b) contain boulders with abundant quartz phenocrysts and veins with low concentrations of naturally-occurring ^{9}Be (typically < 1.5 ppb); and (c) have reliable minimum radiocarbon ages of $11{,}424 \pm 108$ cal yr BP and $10{,}942 \pm 77$ cal yr BP (1σ), respectively. Quartz samples ($n = 6$) from these two sites contained between 4.28×10^4 and 5.06×10^4 at ^{10}Be/g using the 1.387 Myr ^{10}Be half-life. Determination of these concentrations accounts for topographic and self-shielding, and effects on nuclide production due to isostatic rebound are shown to be negligible. Persistent, constant snow and moss cover cannot be proven, but if taken into consideration they may have reduced ^{10}Be concentrations by 10%. Using the ^{10}Be half-life of 1.387 Myr and the Stone scaling scheme, and accounting for snow- and moss-cover, we calculate an error-weighted mean total ^{10}Be production rate of 4.12 ± 0.19 at/g/yr (1σ). A corresponding error-weighted mean spallogenic ^{10}Be production rate is 3.96 ± 0.16 at/g/yr (1σ), respectively. These are in agreement within uncertainty with other ^{10}Be production rates in the literature, but are significantly, statistically lower than the global average ^{10}Be production rate. This research indicates, like other recent studies, that the production of cosmogenic ^{10}Be in quartz is lower than previously established by other production-rate calibration projects. Similarly, our findings indicate that regional cosmogenic production rates should be used for determining exposure ages of landforms in order to increase the accuracy of those ages. As such, using the total ^{10}Be production rate from our study, we determine an error-weighted mean surface-exposure age of a third rock avalanche in Troms County (the Hølen avalanche) to be 7.5 ± 0.3 kyr (1σ). This age suggests that the rock avalanche occurred shortly after the 8.2 kyr cooling event, just as the radiocarbon ages of the Grøtlandsura and Russenes avalanches confirm field evidence that those rock-slope failures occurred shortly after deglaciation.

1. Introduction

Numerous late Pleistocene and Holocene rock slope failures are mapped in Troms County, northern Norway, and they are grouped in distinct zones (Fig. 1; Blikra, 2002). The largest concentration is found in an area stretching from Balsfjorden in the south to Oldervikdalen and Storslett in the north. There is also a less well-pronounced zone in the southern part of the county from Grovfjorden to Sørreisa. Most of the events originated in bedrock,

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predominantly fractured and jointed quartz-mica schists and quartz-mica gneisses. The slope failures pose substantial threat, particularly when they occur in populated areas and if they reach fjords or lakes, thus causing displacement waves, which often have several tens of meters run up along the shore for tens of kilometers. The frequency at which these slope failures occur can only be determined through age dating at multiple sites; however, age determinations of these rock avalanches are scarce and are typically only carried out if organic material is found in relation to rock-avalanche deposits.

Cosmogenic ^{10}Be dating is ideal in this quartz-rich region for determining the timing of these rock avalanches, provided that the production rate is accurate for northern Scandinavia. Regional production rates are sometimes more accurate and more preferable than global average cosmogenic nuclide production rates (Stone, 2000; Gosse and Phillips, 2001; Licciardi et al., 2006; Balco et al., 2009; Fenton et al., 2009; Putnam et al., 2010). The total cosmogenic ^{10}Be production rate, at any given location, is a sum of spallogenic and muogenic ^{10}Be production. Spallogenic ^{10}Be dominates the total production of cosmogenic ^{10}Be in the near sub-surface and this production varies all over the world, as a function of latitude (i.e., geomagnetic field strength), elevation (i.e., atmospheric depth), and time (i.e., changes in the strength of the geomagnetic field; e.g. Gosse and Phillips, 2001). Production of ^{10}Be via muons (from negative muon capture and fast muon interactions) is a small fraction of the total ^{10}Be production, and this fraction (a few percent or $\sim$0.20 at/g/yr at sea level) is only elevation dependent, but independent of a sample site's global location (Heisinger et al., 2002a,b; Balco et al., 2008). To date, no regional production rate for cosmogenic ^{10}Be in Norway has been reported. Systematic natural-calibration of worldwide production rates of different terrestrial cosmogenic nuclides, including ^{10}Be, was one of the main goals set by the CRONUS-EU research network [Cosmic Ray Produced Nuclide Systematics on Earth – The European Contribution], and was a driving force behind this study.

We present data establishing the first local ^{10}Be production rate calibration for Norway, in the Troms county region, which is located above the Arctic Circle. Two rock avalanches – the Grøtlandsura and Russenes (Fig. 1) – were chosen for this study because of existing independent radiocarbon age-constraints and defined geomorphic boundaries which solidly bracket their depositional ages. The radiocarbon ages presented in this manuscript are by definition "minimum" in nature, in that the dates reflect the post-depositional and posthumous ages of the mollusc shells attached to avalanche boulders. Though we consider the radiocarbon ages of the Grøtlandsura and Russenes Avalanches to be accurate, the ages in turn produce "maximum" ^{10}Be production rates. A third avalanche – the Hølen (Fig. 1) – yielded a radiocarbon age that was far younger than expected, based on ^{10}Be concentrations measured in the samples, and was used to calculate a maximum total production rate for ^{10}Be for this region. Only the Grøtlandsura and Russenes rock avalanches proved to be successful, accurate calibration sites.

2. Rock avalanche locations and descriptions

2.1. The Grøtlandsura and Russenes avalanches

Approximately 11.5 ka, a slope failure 420 m above sea level produced the Grøtlandsura avalanche, which was deposited on the lower slope of and spread into the Salangen Fjord (Blikra et al., 2006). The deposit is now preserved as a peninsula on the north side of the fjord (Figs. 1 and 2). The avalanche deposit consists of quartz-mica gneiss boulders (Fig. 3) and is still mainly clast-supported. Near the base of the avalanche, the interstitial spaces in the deposit are filled with fine-grained sediment, which includes mollusk shells. The presence of these shells indicates a previously

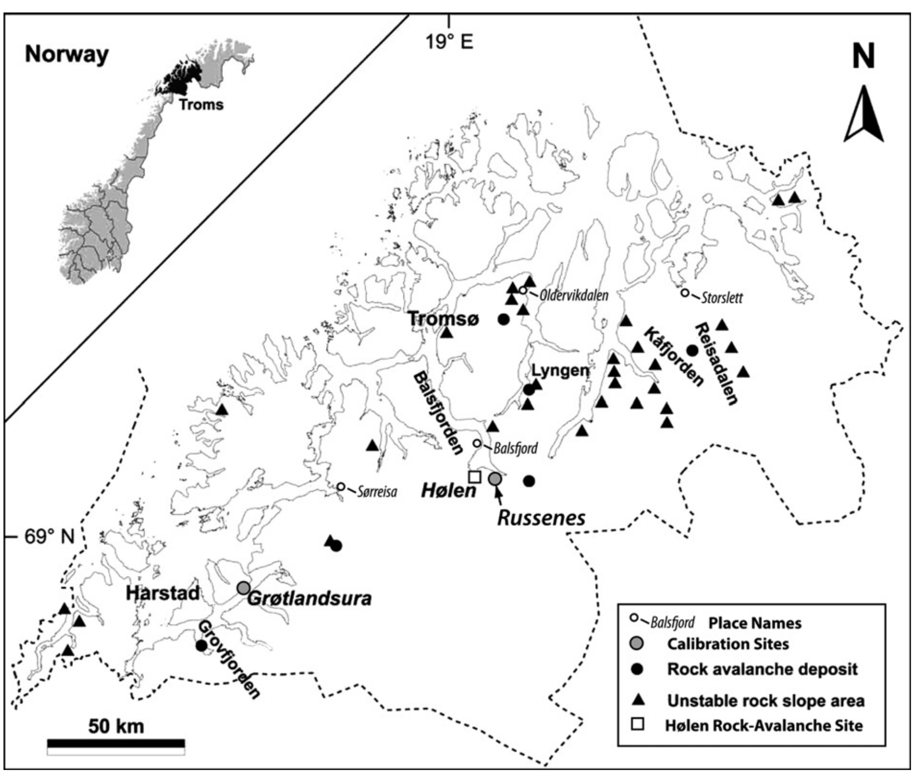

Fig. 1. Regional map of Troms County, northern Norway, showing documented rock-slope failures and more specifically, the locations of the Grøtlandsura, Russenes, and Hølen rock avalanches. The dashed line represents the border of Troms County.