**Supplementary material - OYB manuscript August 2019**

Table S1. Climate and snow thickness data for Øyberget and Øybergsurdi, upper Ottadalen.

Text elaborating on corrections

**Table S1.** Mean monthly and mean annual air temperature, precipitation, and snow thickness for the sites in this study. Data for Gjeilo-i-Skjåk meteorological station (378 m asl) is retrieved from eKlima ([http://sharki.oslo.dnmi.no/](http://sharki.oslo.dnmi.no/portal/page?_pageid=33,6979,33_30898:33_30902&_dad=portal&_schema=PORTAL)), and modelled data is retrieved from SeNorge ([http://www.senorge.no](http://www.senorge.no/)).

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Elevation**  **(m a.s.l.)** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** | **Annual** |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Air temperature (°C)** | | | | | | | | | | | | | |
| *Site-adjusted meteorological station data (1961-1990)* | | | | | | | | | | | | | |
| 520 (Lobe 2, 3) | -10.2 | -9.7 | -3.8 | 1.3 | 7.4 | 11.4 | 12.9 | 12.0 | 7.1 | 2.5 | -3.8 | -7.3 | **1.6** |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *From modelled data (1961-1990)* | | | | | | | | | | | | | |
| 456 (Lobe 2, 3) | -7.2 | -6.9 | -3.4 | 0.9 | 7.0 | 11.2 | 12.5 | 11.5 | 7.2 | 3.4 | -2.4 | -5.6 | 2.4 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *From modelled data (1958-2017)* | | | | | | | | | | | | | |
| 456 (Lobe 2,3) | -6.4 | -6.1 | -2.9 | 1.6 | 7.0 | 11.0 | 13.0 | 11.9 | 7.8 | 3.1 | -2.0 | -5.2 | 2.7 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Precipitation (mm)** | | | | | | | | | | | | | |
| *From adjusted met station data (1961-1990)* | | | | | | | | | | | | | |
| 520 (Lobe 2, 3) | 24 | 13 | 14 | 8 | 16 | 28 | 44 | 34 | 30 | 32 | 25 | 27 | **295** |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *From modelled data (1961-1990)* | | | | | | | | | | | | | |
| 456 (Lobe 2, 3) | 48 | 33 | 35 | 16 | 21 | 37 | 51 | 43 | 53 | 59 | 49 | 56 | 502 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *From modelled data (1958-2017)* | | | | | | | | | | | | | |
| 456 (Lobe 2, 3) | 53 | 38 | 35 | 19 | 26 | 38 | 53 | 49 | 47 | 55 | 53 | 59 | 525 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **Snow thickness/depth (cm)** | | | | | | | | | | | | | |
| *From modelled data (1961-1990)* | | | | | | | | | | | | | |
| 456 (Lobe 2, 3) | 32 | 37 | 38 | 20 | 1 | 0 | 0 | 0 | 0 | 0 | 6 | 18 | 13 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *From modelled data (1958-2017)* | | | | | | | | | | | | | |
| 456 (Lobe 2, 3) | 31 | 37 | 35 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 18 | 12 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *From modelled data (1961-1990)* | | | | | | | | | | | | | |
| 1172 (Summit) | 63 | 76 | 83 | 83 | 44 | 3 | 0 | 0 | 1 | 5 | 22 | 43 | 35 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *From modelled data (1958-2017)* | | | | | | | | | | | | | |
| 1172 (Summit) | 60 | 72 | 80 | 77 | 38 | 2 | 0 | 0 | 0 | 4 | 19 | 40 | 33 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |

**Text describing relevant corrections, summarised in Table 2.**

The continental climate of the region (Table S1), combined with angularity of boulders in the rock glacier lobes suggests very low Holocene erosion rates. No thin quartz veins protruding from horizontal rock surfaces were observed, only thicker quartz-rich lenses. These suggest about 5 mm total erosion since the deglaciation (c. 10.5 ka, cf. Hughes et al., 2016; Stroeven et al., 2016). This amounts to c. 0.48 mm ka-1, substantially lower than lowering rates of 4.8 ± 1.0 mm ka-1 from pyroxene-granulite gneiss surfaces in Jotunheimen (Matthews and Owen, 2011), but comparable to 0.55 mm ka-1 from schists and gneisses on Hardangervidda (Nicholson, 2008). An erosion rate of 0.48 mm ka-1 has been applied to all samples, except sample ØYB 1309 (quartz). The impact of erosion, based on local observations, translates to an increase in age of less than 0.5% (Table 2).

Temporal shielding will reduce the flux of cosmic ray particles and hence a lower 10Be production rate (e.g. Gosse and Phillips, 2001; Dunai, 2010). Production of cosmogenic nuclides depends in part on the attenuation of cosmic-ray particles in the atmosphere (e.g. Dunai, 2010). During periods with lower elevation than the present one, nuclide production was reduced, and not taking this into account will lead to underestimated surface exposure ages. A simplified uplift correction is applied here to compensate for the change in 10Be production. Based on a total uplift of the area of 125 m since 12 ka (Lyså et al., 2008), of which at least half occurred prior to 8 ka, one can assume a steady-state uplift for the two intervals 12-8 ka and 8-0 ka. This can be argued to cause an over-estimation since the rate of uplift most likely decreased exponentially, rather than being a linear trend. The total maximum uplift correction for the 12-0 ka interval amounts to 4.1% for the Summit site, 4.4% for the Up-valley site, and 4.6% for Lobe 2 and 3 (Table 2).

Snow cover will absorb some secondary cosmic ray particles, and the effect of snow shielding on the 10Be production rate has been constrained using modelled snow-cover data available at SeNorge (<http://www.senorge.no/>) (Table S1). The pixel size of the model makes it impossible to select any given elevation: in our study area the closest options were 456 m a.s.l. for Lobe 2 and 3, and 1172 m a.s.l. for the Summit. Data compiled for the years 1958-2017 suggests an average monthly snow cover of 12 cm per year for Lobe 2 and 3, and 33 cm per year at the Summit. We use the 12-cm estimate for the Up-valley site for simplicity. Based on the accumulation and melting patterns revealed by the dataset, we interpret snow cover to consist predominantly of intermediate density snow, and we use 0.2 g cm-3 as density. Snow shielding correction factors have been calculated for the two elevations from their monthly snow depth data, an attenuation length of 160 g cm-2, and an assumed snow density of 0.2 g cm-3 (see references in Gosse and Phillips, 2001). This amounts to reductions in 10Be production of about 1.5% for the Up-valley and Lobe sites, and 2.0% for the Summit site (Table 2).

Forests will reduce the 10Be production rate because trees absorb secondary cosmic ray particles (e.g. Gosse and Phillips, 2001). Cerling and Craig (1994) estimated a 4% absorption by boreal (or similar low-density) forest. Plug et al. (2007) modelled cosmic ray flux for three-dimensional temperate forests assuming statistical uniformity through time and found a mean shielding of 2.25±0.6% for Acadian/boreal forest. This includes shielding by canopies (20%), stems (60%) and floor litter (20%). The floor biomass component is most likely underestimated for our site because (i) the local pine forest differs from the Acadian/boreal forest with respect to species diversity, and (ii) it does not take into account the lichen/shrub dominated vegetation. Moreover, although secondary to the stem shielding, the canopy component is also likely to be underestimated because upper Ottadalen has been pine dominated since early after the deglaciation (cf. Paus, 2010; Paus and Haugland, 2017). The present-day pine-tree limit in the region is about 950 m a.s.l. Pine grew at least up to 1270 m a.s.l. (present elevation) between 9.8 and 7.7 cal. ka BP (Paus and Haugland, 2017; Paus et al. submitted), hence a short duration of pine forest at the summit of Øyberget cannot be ruled out. However, we only assume forest shielding for the up-valley site since c. 9.5 ka resulting in an average reduction in 10Be production of about 2% (Table 2). The estimated impact of forest shielding does not include the surface shielding imposed by forest floor vegetation and thin soils. This would be complex to quantify, however, the fact that the sampled bedrock outcrops are relative high points in the local relief should minimise this effect.

**References**

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