results in
PHYSICS

Microarticle

Exploring ice core drilling chips from a cold Alpine glacier for cosmogenic radionuclide (^{10}Be) analysis

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ARTICLE INFO

ABSTRACT

Ice cores offer unique multi-proxy paleoclimate records, but provide only very limited sample material, which has to be carefully distributed for various proxy analyses. Beryllium-10, for example, is analysed in polar ice cores to investigate past changes of the geomagnetic field, solar activity, and the aerosol cycle, as well as to more accurately date the material. This paper explores the suitability of a drilling by-product, the so-called drilling chips, for ^{10}Be-analysis. An ice core recently drilled at a cold Alpine glacier is used to directly compare ^{10}Be-data from ice core samples with corresponding drilling chips. Both sample types have been spiked with ^{9}Be-carrier and identically treated to chemically isolate beryllium. The resulting BeO has been investigated by accelerator mass spectrometry (AMS) for ^{10}Be/^{9}Be-ratios to calculate ^{10}Be-concentrations in the ice. As a promising first result, four out of five sample-combinations (ice core and drilling chips) agree within 2-sigma uncertainty range. However, further studies are needed in order to fully demonstrate the potential of drilling chips for ^{10}Be-analysis in alpine and shallow polar ice cores.

1. Introduction

Ice cores are excellent climate archives as they offer a variety of proxy records, e.g., impurities, stable water isotopes and cosmogenic radionuclides. Due to their limited diameter (typically about 4″) ice core sample material is very precious and has to be carefully distributed for various analyses. One of these is the analysis of the cosmogenic radionuclide ^{10}Be ($t_{1/2}$ = 1.387 Ma [1]), which is produced by the interaction of cosmic rays with elements in the Earth's atmosphere, mainly nitrogen and oxygen. After production, it becomes attached to aerosol particles [2]. Coupled into the atmospheric transport processes of aerosols via precipitation, i.e., dry and wet deposition [3], beryllium isotopes are deposited in glacier archives [4].

Well-resolved analysis of ^{10}Be in ice cores is used to investigate past changes of the geomagnetic field, solar activity and the aerosol cycle (e.g., [5,6]), and has recently been used for advanced, highly accurate dating (e.g., [7,8]). Accordingly, ^{10}Be-analysis of ice samples has been shown to be a key factor for successful climate research with ice cores (e.g., [5,9,10]). For most proxy data (impurities, gases, ^{14}C, ...), taking clean samples from the inner core parts, e.g., not even exposed to ambient air after sampling, is an absolute necessity. However, for ^{10}Be-data there is no need to restrict core

sampling to the inner parts only since contamination – even of the outer parts – is very unlikely.

Hence, a pilot-study exploring the suitability of so-called ice core drilling chips for ^{10}Be-analysis has been initiated. Drilling chips are inevitable by-products when taking ice cores, resulting from ice that is continuously scraped-off by the rotating knives of the ice core drill. The chips are then transported and collected in a special repository within the drill. Since it is necessary to use "drilling fluid" to counteract borehole closure by hydrostatic pressure at deep polar drilling sites, drilling chips are chemically contaminated and usually regarded as "waste". However, due to the limited ice thickness of mountain glaciers (typically not exceeding 100 m), drilling fluids are not required here, which keeps the drilling chips less-contaminated and creates a potential material for, e.g., ^{10}Be-analysis. Notably, this also holds for shallow drillings at polar ice sheets, which may already cover several hundred to thousand years in Antarctica [11,12]. A positive result of our feasibility study using samples from a recently drilled ice core from a high Alpine glacier will influence future shallow drilling projects.

2. Experimental

Samples under investigation are from an ice core drilled 72 m to bedrock at the "Colle Gnifetti" glacier (45°55.74′N, 7°52.58′E, 4450 m asl, Swiss–Italian Alps). The ice core was drilled in several

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runs and drilling chips were retained throughout the entire procedure. Each run covers about 1 m depth for the upper 40 m of the ice core and about 0.5 m for the lower 32 m of the ice core. The corresponding drilling chips were collected in individual plastic bags for each run.

As a pilot study, five ice core samples and corresponding drilling chips were analysed for ^{10}Be. Thus, a constant volume fraction, which in each case covered the whole length of the run, was taken from five runs of the ice core (KCC-K07, KCC-K25, KCC-K48, KCC-K49, KCC-K50; Supplementary Table 1). For the corresponding drilling chips, samples of about 300 g of the available material were used in each case (KCC-M07, KCC-M25, KCC-M48, KCC-M49, KCC-M50; Supplementary Table 1). The samples were chemically treated for the isolation of beryllium by an improved method of the original work at the University of Heidelberg ([13], priv.com. D. Wagenbach, 2009). Basic steps are: (a) melting ice ($\sim$300 g each) in a plastic beaker containing 1 ml of HCl (32%) and $\sim$300 µg of a ^{9}Be-carrier at room temperature; (b) adjustment of pH to 4 by ammonia solution (25%); (c) binding of Be^{2+} onto a cation ion exchange column (Bio-Rad; DOWEX 50Wx8; 100–200 mesh; $\varnothing$: 8 mm; length: 40 mm); (d) dissolution of Be^{2+} by 25 ml HCl (1 Mol/L); (e) precipitation of beryllium hydroxide by ammonia solution (25%); (f) rinsing three times with dilute ammonia solution (pH 8–9); (g) drying and ignition to BeO at 900 °C; and (h) mixing with Nb-powder (1:4 by weight) and pressing into Cu-cathodes. The ten samples were accompanied by a processing blank, which was treated identically as the ice samples but was based on $\sim$321 g of deionised H_2O (18 MΩ) and ^{9}Be-carrier (Scharlau, Batch 11863301; 2% HCl, $c(^9Be) = (980.4 \pm 4.9)$ µg/g).

Accelerator mass spectrometry (AMS) was used at the DREAMS-facility [14] to determine the $^{10}Be/^9Be$-ratios in each sample. Results were quantified versus the in-house-standard SMD-Be-12 with a nominal $^{10}Be/^9Be$ of $(1.704 \pm 0.030) \times 10^{-12}$. The processing blank was measured together with the ten samples to take into account ^{10}Be resulting from the ^{9}Be-carrier and cross-contamination while chemical processing and within the AMS ion source. Further details of AMS-measurements at DREAMS can be found elsewhere [14].

3. Results and discussion

Results are presented in Supplementary Table 1 and Fig. 1. Uncertainties from the AMS-measurements are based on counting statistics (2110–4850 ^{10}Be-counts) and the uncertainty of the standard, summing up to 2.4–2.9%. The total uncertainty budget also includes a blank-correction in the order of 0.6–1.4% and the 0.5%-uncertainty of the ^{9}Be-concentration of the carrier. Beryllium-10 results are calculated from the weight of the ice sample and the ^{9}Be ($\sim$2 × 10^{19} atoms) from the carrier addition. The expanded uncertainty (2-sigma) is given for ^{10}Be-results. As can be seen in Supplementary Fig. 1, four out of five sample-combinations (core and drilling chips) agree within 2-sigma. Only the corresponding samples KCC-K07 and KCC-M07 from run 07 are not comparable.

According to preliminary dating – by tentative counting of annual layers in impurity profiles – of the ice core, run 07 covers roughly one year (summer 2003–summer 2004). However, at "Colle Gnifetti" wind erosion frequently leads to greatly reduced mass contribution of winter snow to the total seasonal net snow deposition [15]. This general characteristic in snow deposition was checked in detail for run 07. Using δ^{18}O and NH_4^+ as summer/winter indicator reveals an almost equal amount of snow from winter and summer for run 07. The concentration of ^{10}Be in winter snow corresponds to 55% of the concentration in summer snow [16]. Assuming, for the sake of a semi-quantitative evaluation that an identical amount of winter and summer snow is contained in run 07, the sub-sampling of the drilling chips for ^{10}Be-analysis would need to be biased by comprising 70% winter and 30%

summer snow in order to explain the observed discrepancy. Since the measured sub-sample only contains about one-tenth of the total drilling chips of run 07, this may not be entirely unrealistic.

Hence, at this stage one has to conclude that incomplete mixing of drilling chips in each bag has to be considered as a possible bias and source of error. Due to the seasonality of ^{10}Be in precipitation, some results, primarily the ones for the upper part of the ice core, where each run contains just a few years, can be biased by incomplete sampling. Therefore, it is suggested to further investigate and quantify this effect by analysing several sub-samples from the same bag of drilling chips. Alternatively, for future projects the whole drilling chips material of each run can be used for ^{10}Be-analysis to avoid the problem. However, parts of the samples investigated here were retained for testing the suitability for other analyses as well, e.g., ^{210}Pb. In the future, one has to develop a more homogeneous and representative sub-sampling strategy for different analytical methods.

4. Conclusion and outlook

The results of our pilot study show that ice-core drilling chips have a promising potential for use for ^{10}Be-analysis in ice cores taken without drilling fluids at polar or mid-latitude sites. It is therefore strongly recommended to keep and carefully document the drilling chips of the upper part of future cores, keeping the highest depth- and time-resolution.

Encouraged by the findings outlined above and the easy availability of the drilling chips, further investigations of about $\sim$100 samples of drilling chips and selected ice-core samples from "Colle Gnifetti" are planned for the very near future. Potential valuable age information may come from ^{10}Be-analysis of ice core samples in search of the well-known cosmic ray event of 774–775 AD, which has already been found in polar ice cores (e.g., [8,17,18]).

Appendix A. Supplementary data

Supplementary data (incl. Acknowledgements) associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.rinp.2016.01.002.

References

[1] Korschinek G et al. Nucl Instr Meth Phys Res 2010;B268:187.
[2] Muscheler R, Beer J, Wagner G, Laj C, Kissel C, Raisbeck GM, Yiou F, Kubik PW. Earth Planet Sci Lett 2004;219:325.
[3] Davidson CI. The environmental record in glaciers and ice sheets. In: Oeschger H, Langway Jr CC, editors. Dahlem Conference. Chichester: J Wiley and Sons; 1989. p. 29.
[4] Raisbeck GM, Yiou F, Fruneau M, Lieuvin M, Loiseaux JM. Nature 1978;275:731–3.
[5] Beer J, Siegenthaler U, Bonani G, Finkel RC, Oeschger H, Suter M, Wölfli W. Nature 1988;331:675.
[6] Elsässer C, Wagenbach D, Weller R, Auer M, Wallner A, Christl M. Tellus B 2011;63(5):920.
[7] Horiuchi K, Uchida T, Sakamoto Y, Ohta A, Matsuzaki H, Shibata Y, Motoyama H. Quat Geochron 2008;3:253.
[8] Sigl M et al. Nature 2015;523:543.
[9] Muscheler R, Snowball I, Joos F, Muller S, Beer J, Vonmoos M. Quat Sci Rev 2007;27:82.
[10] Usoskin IG, Horiuchi K, Solanki S, Kovaltsov GA, Bard E. J Geophys Res 2009;114:A03112.
[11] Morgan VI. Climatic Change 1985;7(4):415.
[12] Barnola JM, Anklin M, Porcheron J, Raynaud D, Schwander J, Stauffer B. Tellus B 1995;47(1–2):264.
[13] Stanzick A. Diploma thesis. University Heidelberg; 1996.
[14] Akhmadaliev S, Heller R, Hanf D, Rugel G, Merchel S. Nucl Instr Meth Phys Res 2013;B294:5.
[15] Wagenbach D, Bohleber P, Preunkert S. Geografiska Ann: Ser A, Phys Geogr 2012;94:245.
[16] Heikkilä U, Beer J, Alfimov V. J Geophys Res 2008;113:D11104.
[17] Miyake F, Suzuki A, Masuda K, Horiuchi K, Motoyama H, Matsuzaki H, Motizuki Y, Takahashi K, Nakai Y. Geophys Res Lett 2015;42(1):84.
[18] Mekhaldi F et al. Nat Commun 2015;6:8611.