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Research paper

The potential of historic rock avalanches and man-made structures as chlorine-36 production rate calibration sites

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ABSTRACT

Samples from three medieval rock avalanches from the French (Le Claps, Mont Granier) and Austrian Alps (Dobratsch) and a man-made structure, i.e. the Stephansdom in Vienna, have been analysed for in-situ produced ^{36}Cl by accelerator mass spectrometry (AMS). All four sampling sites of independently known exposure duration turned out to be not appropriate as calibration sites for the determination of the ^{36}Cl-production rate from Ca. Indeed, the determination of short exposure ages for dating rock avalanches and man-made structures by ^{36}Cl is hindered dramatically by inheritance, especially for samples characterized by high ^{nat}Cl-concentrations. Generally, there are hints that the theoretical calculation of ^{36}Cl-production from epithermal and thermal neutron-capture on ^{35}Cl is highly underestimated in all existing models, thus, asking for particular precaution if working on high-Cl samples for any project. Hence, this work evidences that potential high inheritance, even for samples reasonably shielded before exhumation, has to be considered especially when dealing with recently exposed surfaces such as glacially polished rocks, alluvial terraces, fault scarps etc.

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1. Introduction

Advances in the field of accelerator mass spectrometry (AMS) enable the determination of radionuclide concentrations as low as 10^4–10^5 atoms/g. This allows measurements of in-situ produced cosmogenic isotopes that are directed towards quantification of Earth's surface processes (Gosse and Phillips, 2001). But accurate application of this method is only possible, if production rates, i.e. how many atoms are generated in a certain environment over a certain time period, are exactly known. Unfortunately, this literature data, especially for the production of ^{36}Cl, differs up to several tens of percent (e.g. Zreda et al., 1991; Masarik and Reedy, 1995; Stone et al., 1996; Phillips et al., 2001; Swanson and Caffee, 2001; Kollár, 2003; Licciardi et al., 2008; Braucher et al., 2011; Schimmelpfennig et al., 2011).

To overcome this principal drawback, the European project "CRONUS-EU" (Cosmic Ray Produced Nuclide Systematics on Earth – the European contribution, Stuart and Dunai, 2009) focussed amongst others on the high-accuracy calibration of production rates by spallation. Generally, three modi operandi are possible for the determination of "new" production rates:

(a) following the "extraterrestrial approach" (Leya and Masarik, 2009), numerical simulations based on experimentally determined cross-sections for the underlying nuclear reactions and Monte-Carlo calculations for the evolution of secondary particle within thick targets, i.e. bulk rock (Masarik and Reedy, 1995; Kollár, 2003)
(b) simultaneous determination of more than one cosmogenic nuclide in one target mineral – stable and/or radioactive – or of the same nuclide in two different targets, as has been successfully demonstrated e.g. for ^{10}Be/^{21}Ne/^{26}Al in SiO_2 (Goethals et al., 2009) and ^{26}Al in SiO_2/$CaCO_3$ (Merchel et al., 2010)
(c) measurement of cosmogenic nuclides from independently dated surface, i.e. by another method than in-situ dating, such as e.g. radiocarbon-dating of organic material closely associated with the sudden surface production (e.g. Stone et al., 1996; Licciardi et al., 2008; Fenton et al., 2011; Schimmelpfennig et al., 2011; Goehring et al., 2012) or radiometric K–Ar-dating

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of the surface minerals itself (e.g. Blard et al., 2006; Schimmelpfennig et al., 2011).

Most production rate studies to date have addressed the problem by working on natural calibration sites, i.e. they have employed one of the latter two approaches above. As discrepancies between published production rates are largest for ^{36}Cl, this study focuses on the determination of it from $CaCO_3$. Calcite has the advantage of minimising the abundance of other target elements than Ca, i.e. Cl, K, Ti, Fe, producing also ^{36}Cl.

The above mentioned option (b) is not possible for $CaCO_3$, as no other cosmogenic nuclide production rate is satisfactorily well constrained for that matrix. Option (c) using independent radiometric data introduces additional relatively large uncertainties (Schimmelpfennig et al., 2011), which must be included in the overall uncertainty budget of the ^{36}Cl-production rate, moreover the method is not applicable at all for $CaCO_3$. Option (c) using radiocarbon-dating would have the advantage of generally lower uncertainties by the primary method (in most cases $<2\%$). However, very often the search for datable organic material in calcite surroundings is a very challenging task and the reliability of radiocarbon-dates for e.g. rock avalanches has been often questioned due to doubts about the required close connection with the organic material.

Another so far undiscussed possibility for an independent age "determination" is historical tradition, i.e. the use of primary or secondary sources. Schimmelpfennig et al. (2011) already analysed a historical lava flow from the 17th century and deduced in combination with other calibration studies, a common ^{36}Cl-production rate from it. Dates for historical events like volcano eruptions or rock avalanches can be as accurate as giving the exact hour of a certain day, thus, beating even the high precision of ^{14}C-results.

Working on surfaces from historical timescale also has the big advantage that influences by erosion are negligible, thus, reducing another uncertainty. The only real disadvantage is that the total production of ^{36}Cl-atoms, i.e. the ^{36}Cl-concentration in the $CaCO_3$ sample, is very low. Even though using large amounts of material (100–300 g) and drawing special attention to low-contamination during chemistry, the resulting ^{36}Cl/Cl-values are expected to be close to the detection limit of present-day accelerator mass spectrometry. To see if historical rock avalanches might have potential as calibration sites, calcite-rich samples from three individual medieval, landslide areas in the Alps have been investigated. All events had been mentioned in detail, including individual dates, in ancient historical documents.

As a second feasibility study, a single sample from a historical building, the "Stephansdom" in Vienna (Austria), together with a corresponding "blank" from a quarry has been analysed for ^{36}Cl. Maybe man-made structures could turn out to be promising calibration site objects for the future?

2. Experimental

2.1. Samples

Sample information including individual location and shielding parameters is summarized in Table 1. Whenever the bedrock of a rock avalanche was accessible for sampling, samples had been taken as those are less influenced by post-rock avalanche events such as boulders turning over a second time.

2.1.1. Le Claps

A fresh bedrock surface, which was previously shielded by about 17 m of rock, was produced in 1442 AD by a rather small rockslide in the Drôme Valley in the Southern French Alps (44°36′N; 5°28′E). The total volume of the "Le Claps" (also named "Claps de Luc" or "Claps de Luc-en-Diois") rockfall has been calculated to $2 \cdot 10^6$ m^3 (Couture et al., 1997). In 2005, four surface bedrock samples (altitude: 800–900 m; dip: 28–45°; three samples 5 cm thick, one sample 20 cm thick) and one sample from the ceiling of a small cave-like overhang directly at the edge of the scar exposed by the rock avalanche have been taken (Fig. 1). The latter sample was

Table 1
Sample information including shielding factor taken into account surroundings and dip. Density data are mainly mean values of measurements of several pieces by Archimedes' principle.

	Year of sampling/Start of exposure → exposure age	Sample name	Latitude/Longitude	Altitude [m]	Shielding factor	Sample depth [cm]	Density [g/cm^3]	Remarks
Le Claps	2005/1442 AD → 563 a	Claps 1	44°36′N/5°28′E	800	0.959	0–5	2.648	Bedrock (dip: 28°)
		Claps 2		800	0.959	0–20	2.648	Bedrock (dip: 28°)
		Claps 3		815	0.892	0–5	2.669	Bedrock (dip: 39°)
		Claps 4		898	0.841	0–5	2.678	Bedrock (dip: 45°)
	2005/?	Claps μ		897 + 15	"1"	~1500	2.635	Ceiling from small cave-like overhang (2 m height, 1 m inside), shielding by ~15 m
Mont Granier	2006/1248 AD → 758 a	MG1	45°30′N/5°58′E	348	0.9995	0–5	2.702	Boulder (Fig. 2)
		MG2		348	1	0–5	2.663	Same boulder as MG1 (Fig. 2)
		MG3		338 + 10	0.5	0–5	2.701	Same boulder as MG1 (Fig. 2)
		MG4		328	1	0–5	2.654	From top of boulder
		MG5		397	0.999	0–5	3.019	Boulder (dip 30°)
		MG6		417	0.999	0–5	2.503	From top of boulder
		MG7		352	1	0–5	2.667	Boulder (next to MG8)
		MG8		354	1	0–5	2.538	Boulder (next to MG7)
Dobratsch	2007/1348 AD → 659 a	DOB1	46°34′N/13°44′E	553	0.991	0–3	2.689	Boulder surrounded by trees (Fig. 3)
		DOB2		551	0.991	~205	2.704	Same boulder as DOB1, but shielded by 2.05 m (Fig. 3)
		DOB4		581	0.991	0–4	2.688	Very big boulder
		DOB5		556	0.991	0–2	2.693	Smaller boulder
		DOB6		553	0.916	0–2	2.682	Smaller boulder (dip: 35°)
		DOB7		547	0.991	0–3	2.697	Boulder surrounded by trees
Stephansdom	2006/1400–1410 AD → 596–606 a	Wien 2	48°12′N/16°22′E	172 + 72	0.5	0–7 (mean)	2.126	72 m above ground level (Fig. 4)
Mannersdorfer quarry	2006/steady-state	Wien 1	47°58′N/16°36′E	306	"1"	~3100	2.347	Shielded by 31 m

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