Dating of lava flows and landslides in the Chilean and Argentine Andes using cosmic-ray-produced ^{3}He and ^{21}Ne

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The determination of a rock's surface exposure time using concentrations of cosmic-ray-produced ('cosmogenic') nuclides is a relatively new – and sometimes the only – dating method for various geomorphic features. We have employed this technique to determine eruption ages of young lava flows from the Central Volcanic Zone (CVZ) in Northern Chile (23°–25°S) and the chronology of a group of superimposing Quaternary landslides at Sierra Laguna Blanca, Argentina (67°W, 26.5°S), using the noble gas isotopes ^{3}He and ^{21}Ne.

Dating of lava flows from the Central Volcanic Zone, Chile

Samples from four andesitic to dacitic lava flows of the volcanoes Overo, Lastarria, Llullaillaco, and Láscar were investigated for their noble gas inventories. Whereas the Ne, Ar, Kr, and Xe isotopic compositions are atmospheric in all rocks, distinct excesses of ^{3}He have been found in the Overo, Lastarria, and Llullaillaco lavas. Only the sample derived from the 1993 eruption of Láscar has a $^{3}He/^{4}He$ ratio consistent with the atmospheric value 1.4×10^{-6} within error limits. ^{4}He abundances are very low in all samples (~$2-34 \times 10^{-10}$ cm^3 STP/g).

To assess the amount of cosmogenic ^{3}He, it is essential to know the isotopic ratio in the He component originally trapped in the erupting lavas. In principle, trapped He could be of mantle, crustal, or atmospheric origin, and consequently $^{3}He/^{4}He$ ratios might be between ~1×10^{-8} and 1.1×10^{-5}. However, in the subaerially erupted, differentiated and degassed lavas of the CVZ, which have ascended through ~70 km of continental crust, a substantial contribution of mantle He is very unlikely. An uptake of crustal He during magma ascent is possible, but most probably the trapped He component has an approximately atmospheric isotopic composition. This contention is not only supported by the result from the recent Láscar flow, but, at least for Llullaillaco, also by elemental ratios which are close to those in the atmosphere except for a striking overabundance of Ne by an order of magnitude.

In Table 1, we present concentrations of cosmogenic ^{3}He ($^{3}He_c$) calculated under the assumption of an atmospheric $^{3}He/^{4}He$ for the trapped component. Assuming a crustal ratio of 1×10^{-8} would increase these numbers by 1.5-5%. Production rates P_3 given in Table 1 are based on the experimental determination of Poreda and Cerling (1992) of 109 atoms/g a at sea level and high geomagnetic latitudes, which has been converted to respective altitudes and latitudes using the method of Lal (1991). The resulting exposure ages T_3 (Table 1) must be regarded as minimum ages. As the samples had not been collected especially for the purpose of exposure dating, documentation was not sufficient to assess exact shielding depths, surface dip angles, or the possibility of partial shading. Furthermore, the whole rock samples used for our study contained minerals such as quartz and feldspar, which are known not to retain ^{3}He quantitatively.

The most interesting result from Table 1 is the 300 years minimum age (taking into account the error limit) of Llullaillaco: The lava flow from which the sample was taken has been attributed to a series of eruptions in the years 1854-1877, which were observed from the surroundings of the cities of Arica and Antofagasta (González-Ferrán, 1995). There were, however, no direct eyewitnesses. Our minimum age of 300 a is obviously not compatible with an eruption in the 19th century. To confirm that discrepancy and to determine the true age of the lava flow, we have collected several well-documented samples in October 1996. These rocks were crushed to a grain size of 125–360 μm and subsequently introduced into a magnetic Frantz separator, where in particular the nonmagnetic minerals quartz and feldspar were removed. X-ray diffraction analysis

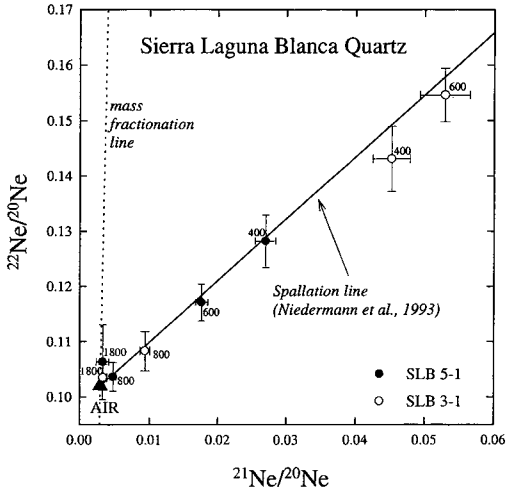

FIG. 1. Ne three-isotope plot for preliminary stepwise heating data of Sierra Laguna Blanca quartz separates. Labels denote extraction temperatures in °C. No blank corrections have been applied to these data.

and optical inspection under a binocular microscope revealed that the remaining material contained predominantly glass, pyroxene, and small feldspar crystals completely embedded in glass. Therefore, we are confident that ^{3}He retention in these mineral separates has been complete. Indeed, ~2.5 times more $^{3}He_c$ was found in a sample from the very surface of the lava flow than in the whole rock split (Table 1), and consequently the true age of the Llullaillaco lava flow can be settled at 930 ± 140 a. In comparison, an equally treated sample taken from a crevice contained three times less $^{3}He_c$, reflecting the higher shielding depth. These results clearly exclude a correlation of the lava flow with eruptions observed in the 19th century.

Chronology of landslides at Sierra Laguna Blanca, Argentina

In Northwestern Argentina (24–27.5°S, 65.5–67.5°W) there are 53 known depositions of Quaternary landslides, 90% of which have occurred in locally confined groups of 4–9 single events (Hermanns *et al.*, 1997). Seven or eight individual landslides are superimposed laterally upon each other at Sierra Laguna Blanca (SLB). Unlike other examples in the region, there are no connected sediments containing volcanic ashes or fossils which could be dated radiometrically. However, owing to the high altitude of the depositions, the very low erosion rate, and the possibility to obtain clean quartz separates from the granitic or phyllitic host rocks, they are well suited for cosmic-ray exposure dating. The determination of the individual ages of landslide events is important to judge what mechanisms have caused their discharge. A rhythmical distribution would favour seismic triggering, whereas temporal accumulations during certain episodes could indicate a climatic reason for the collapse of these mountain faces.

Here we present preliminary results for ^{21}Ne exposure dating of quartz separates from the depositions of the two stratigraphically youngest SLB landslides (SLB 5-1 and SLB 3-1). Fig. 1 is a Ne three-isotope plot showing that relatively large excesses of ^{21}Ne as well as ^{22}Ne (compared to atmospheric abundances) have been found by stepwise degassing experiments of both samples. Data points are aligned along the spallation line for quartz as determined by Niedermann *et al.* (1993); only for two heating fractions of SLB 3-1 a slight deviation from that line may be indicated, which could be due to a small contribution of nucleogenic ^{21}Ne from the $^{18}O(\alpha,n)^{21}Ne$ reaction. However, in both samples ^{4}He concentrations are so low ($\leqslant 2 \times 10^{-9}$ cm^3 STP/g) that most probably nucleogenic Ne can be neglected.

Resulting concentrations of $^{21}Ne_c$ are (30.5 ± 2.1) × 10^6 atoms/g for SLB 5-1 and (37.2 ± 2.7) × 10^6 atoms/g for SLB 3-1. The production rate of ^{21}Ne in quartz has been determined earlier (Niedermann *et al.*, 1994). Again, their value of 21 atoms/g a at sea level and high latitudes is converted to the sampling altitudes of 3970 m (SLB 5-1) and 4010m (SLB 3-1) and the geomagnetic latitude of 15°S according to Lal (1991), yielding 177 and 180 atoms/g a, respectively. Using these production rates, we calculate exposure ages of 172,000 ± 12,000 a for SLB 5-1 and 207,000 ± 15,000 a for SLB 3-1. The stratigraphic evidence for two distinct landslides is thus confirmed; the events are separated by a time interval of 35,000 ± 19,000 a. Dating of the other landslides at SLB is currently in progress. However, since the two samples studied are from the stratigraphically youngest depositions, we preliminarily conclude that the dynamics of landslides at SLB has not been influenced by recent climate variations.

References

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