The use of ^{137}Cs and ^{210}Pb to model erosive processes in high altitude settings; The Muttsee (Switzerland) example

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Introduction

The Muttsee area, situated in the eastern Swiss Alps has been chosen as a test site to investigate the use of ^{210}Pb and ^{137}Cs in semi-quantifying erosion and soil dating. The lake is located at 2446 m altitude and has a surface of 4.2 × 105 m^2 with a maximum depth of 60 m. The catchment area, 2.0 × 10^6 m^2, is mainly composed by Eocene shale, its highest peaks approach 3000 m. A small plateau south of the lake consists of calcareous shale. Hydrogeologic work has shown that most of the precipitation of the catchment area reaches the lake. The only output for water is a duct used for hydroelectric purposes. Soil development is sparse and soil thickness does not surpass 40 cm.

We have sampled and measured by γ-spectroscopy soil sections and running water within the catchment area, lake surface water and duct water, in addition to lake sediment cores. With these samples we have information about all important transfer and output reservoirs. The input function for the anthropogenic radionuclides ^{137}Cs is roughly known both for the atmospheric bomb testing period (maximum in 1963 of 5.5 kBq/m^2) and for Chernobyl (1986; 2.3 kBq/m^2). For ^{210}Pb, the input function can be estimated based on long term measurements within Switzerland to 140 Bq/m^2. Both reach the lake and the catchment area atmospherically. We are therefore dealing with a system, which is fully determined and will help us to critically evaluate our knowledge on erosion processes and radionuclide transfer.

Erosion rates

The sedimentation rates in the lake between 1950 and 1986 and between 1986 and 1992 were determined based on the Cs peaks of 1963 and 1986 to 0.57 and 0.31 cm/a. Erosion rates in the catchment area can thus be determined, using the classical geomorphologic method, for both periods to 0.4 mm/a (=2200tons/a) and 0.8 mm/a (=4100tons/a), respectively.

^{137}Cs-radionuclide budget

Cs is readily adsorbed to clay minerals, in particular illite. Catchment surface run-off is particle filtered and has no measurable Cs radionuclide activity. Thus Cs is transported into the lake in particular form. Lake surface water contains 1.6 Bq/m^3 ^{137}Cs, duct water leaving the lake 0.3 Bq/m^3. Input of ^{137}Cs to the lake and the catchment area due to atmospheric bomb testing is estimated to 1.3 × 10^{10} Bq. In sediments deposited between 1963 and 1986 a total of 1.2 × 10^{10} Bq is stored, indicating that almost all ^{137}Cs deposited in the catchment area reached the lake during this period. For ^{137}Cs from Chernobyl the calculation is comparable, 5.5 × 10^9 Bq were deposited and 6.0 × ^{10} Bq have been found in sediments. The surplus results from atomic bomb ^{137}Cs not removed from the catchment area by 1986. These results indicate that clay/soil particles have a residence time of only a few years. Actual ^{137}Cs determination in soils indicate maximum concentrations of 9.5 Bq/kg, compared to > 200 Bq/kg in particles from 1986.

^{210}Pb-radionuclide budget

(All data given are for $^{210}Pb_{excess}$.) Pb behaves similar to Cs, adsorbing quickly to particles, thus surface run-off contains again no measurable ^{210}Pb. ^{210}Pb in lake surface water equals 9.4 Bq/m^3, in duct water leaving the lake the activity is 2.1 Bq/m^3, in a yearly budget 11.6 × 10^6 Bq leave the system via the duct. Atmospheric input directly into the lake amounts to 58.8 × 10^6 Bq/a. The total output into sediments is 315.4 × 10^6 Bq/a, thus 269 × 10^6 Bq enter the lake in particular form. This is carried in by 4100 tons particles. The average model activity of 210Pb of these particles equals 65 Bq/kg. Based on the input model

$$^{210}Pb_{excess} = \frac{q}{\lambda}(1-e^{-\lambda T})$$

where q = input function (140 Bq/m^2/a) and λ =

decay constant of ^{210}Pb (0.031/a). T, the model age of the particles can be estimated to 12 ± 4 years. Actual ^{210}Pb in soil particles is even lower (~ 30 Bq/kg), indicating that the soil is quite young. In other words, the soil formed in this high mountain settings has only a short life before being eroded.