

## **Geomorphology and cosmogenic exposure dating in West-Central Sweden**

Studies in the southern part of the Swedish mountains has shown that landforms were preserved during the last glacial stage. The purpose and intention of cosmogenic dating in this study was to obtaining information about exposure ages of boulders and outcrops on diagnostic landforms to provide guidance on the analysis of landform age. The samples were taken from various landforms, both in terms of formation and expected age. A total of 50 samples were collected for dating, almost all from quartz-rich boulders. A few samples were taken in quartz-rich outcrops and a few are from granitic blocks. The result of the laboratory work is given in an excel sheet. A geomorphological mapping with sampling sites and exposure ages is presented in eight maps. The mapping is based on air photo interpretation in color infrared images and field studies.

### **Samples and analytical techniques**

All samples were left in a 30%  $\text{H}_2\text{O}_2$  solution for 1-2 days and washed with double distilled water in order to remove any remains of organic matters and weathering effects on the surface. The samples were then dried at  $110^\circ\text{C}$  and crushed to separate the 0.25-1 mm fraction. About 200 g of this fraction was used for further purification and extraction of quartz. The purification procedures started by magnetic separation to remove undesired Fe-rich minerals. After the magnetic separation, the samples were treated with 50% ( $\text{HCl}/\text{HNO}_3=3/1$ ) solution under heating ( $40\text{-}50^\circ\text{C}$ ) and shaking for 1 day and washing with distilled water. This treatment was repeated several times until the samples are enriched with quartz. Each sample was then checked with a microscope for quartz portion and if the sample is dominated by quartz then no further treatment is performed.

The quartz-rich fraction is subjected to a new treatment using (2%  $\text{HF}/2\%$   $\text{HNO}_3$ ) and shaking at  $40\text{-}50^\circ\text{C}$  for a few hours followed by washing with distilled water. Additional treatment with (10%  $\text{HF}$ ) follows for about 2 hours or even more if the quartz fraction is still not pure. X-ray diffraction is used to check that the fraction is dominated by quartz. However, the X-ray diffraction technique cannot expose small amounts ( $<2\%$ ) of other minerals if any, and therefore another check is used to identify the purity of quartz fraction. A small amount (0.5g) of the quartz-rich fraction is dissolved in 45%  $\text{HF}$  and the samples is dried and dissolved in 1M  $\text{HCl}$  and diluted to 50 ml for determination of Al concentration using ICPOS. If the amount of Al is more than 500 ppm, the quartz-rich sample is then treated again with 10%  $\text{HF}$ , until further purity is achieved and the Al concentration dropped to below 300 ppm.

### **Extraction of $^{10}\text{Be}$ from the quartz fraction**

The extraction of beryllium-10 from the quartz fraction is achieved through 40%  $\text{HF}$  total dissolution of 75g samples after addition of 0,5 mg Be-carrier at  $85^\circ\text{C}$ . The sample is then washed with 1M  $\text{HCl}$  and transferred to a platinum crucible and left to dry at  $300^\circ\text{C}$  on a hot plate. The residue is diluted to 30 ml for further purification of Be by precipitation with  $\text{NH}_3$ . The solution is filtrated and what remains on the filter paper is dissolved in 6 M  $\text{HCl}$ . The final extraction of Be is achieved through column separation (Biorad Poly-Prep Prefilled Chromatography Columns) and precipitation of beryllium hydroxide with  $\text{NH}_3$  in a quartz tube and conversion into  $\text{BeO}$  at  $600^\circ\text{C}$ . The  $\text{BeO}$  powder is mixed with Nb and the mixture is pressed in copper holders for the analysis of  $^{10}\text{Be}$  by accelerator mass spectrometry (AMS).

Blank samples were subjected to exactly the same treatment as that of the quartz fraction described above.

The AMS measurement of  $^{10}\text{Be}$  has been done with the Uppsala 5 MV Pelletron AMS system using a terminal voltage of 4.5MV. The machine and statistical error were <3% at 1 sigma standard deviation and the machine background was at  $^{10}\text{Be}/^9\text{Be}$  of  $10^{-15}$ . NIST SRM 4325 ( $^{10}\text{Be}/^9\text{Be} = 3.03 \times 10^{-11}$ ) is used as a standard and all samples were corrected for chemistry background, which was <10%, through analysis of blanks.

### Calculation of exposure chronology

The calculation of exposure chronology is based on the equation given below using a modified version of Balco et al. (2008):

$$N = S_{thick} S_G P_{ref,sp,Xx} \int_0^T S_{Xx}(t) \exp(-\lambda t) \exp\left(\frac{-\varepsilon t}{\Lambda_{sp}}\right) dt + P_\mu \int_0^T \exp(-\lambda t) \exp\left(\frac{-\varepsilon t + z/2}{\Lambda_\mu}\right) dt \quad (1)$$

T is exposure time (in years);  $N$  is  $^{10}\text{Be}$  concentration (atoms  $\text{g}^{-1}$ );  $S_{thick}$  is thickness correction (dimension less);  $S_G$  is a correction for geometry shielding (dimension less),  $P_{ref,sp,Xx}$  is the production rate scaled to  $Xx$  (atoms  $\text{g}^{-1} \text{yr}^{-1}$ ),  $S_{Xx}(t)$  is a time dependent scaling factor (dimension less) using  $Xx$ ,  $\lambda$  is decay rate ( $\text{yr}^{-1}$ ),  $\varepsilon$  is erosion rate ( $\text{g cm}^{-2} \text{yr}^{-1}$ ),  $\Lambda_{sp}$  is attenuation rate in rocks ( $\text{g cm}^{-2}$ ),  $P_\mu$  is muons-related surface production ( $\text{g cm}^{-2}$ ),  $z$  is sample thickness (cm), and  $\Lambda_\mu$  attenuation of muons production ( $\text{g cm}^{-2}$ ).

To apply the equation above following assumption were considered:

- 1- Spallation production is exponential with depth.
- 2- Time constant muons-related production is independent of sample geometry and shielding.
- 3- No topographic correction for muons-related production.
- 4- Depth-related muons-related production is simplified by exponential decay, which is acceptable regarding the relatively slow erosion rate at the sampled sites.
- 5- Linear muons-related production through the sample, which is also acceptable considering sample thickness < 30 cm.