REPORT ON PROJECT ME 291 : 3D Study of open to closed porosity ratio of Antarctic firn.

The goals of this project were :

- To reconstruct and follow the evolution of the porosity of snow, firn and ice samples taken at Vostok (Antarctica)
- To look at the spatial distribution of the microparticles in the polar ice.
- To test filling fluids in order to study the snow structure.

Porosity reconstruction : This part of the project was the follow up of the experiment HS-688 in which we had tested successfully the X ray microtomography to study the evolution of the open and closed porosity of polar firn.. The samples, were cylinders of 1.5 cm diameter, instead of cubes with edges of about 18 mm for the HS 688 experiment. This shape gave better contrast in local tomography and also is easier to prepare. They were placed in a refrigerated cell at about -60°C, put under the X ray beam of the ID19 line with an energy of ranging from 14 to 18 Kev depending on the sample size and density . By rotating the cell 900 images were taken in order to make a local tomography and thus reconstruct the 3 D structure of the sample porosity.

30 samples taken between 15 and 161 m depth on a Vostok (Antarctic) core, thus covering the entire range of the firn and ice density, have been analysed. No problem was encountered during the experiment and the sample cooled cell worked perfectly in a “routine “ mode.

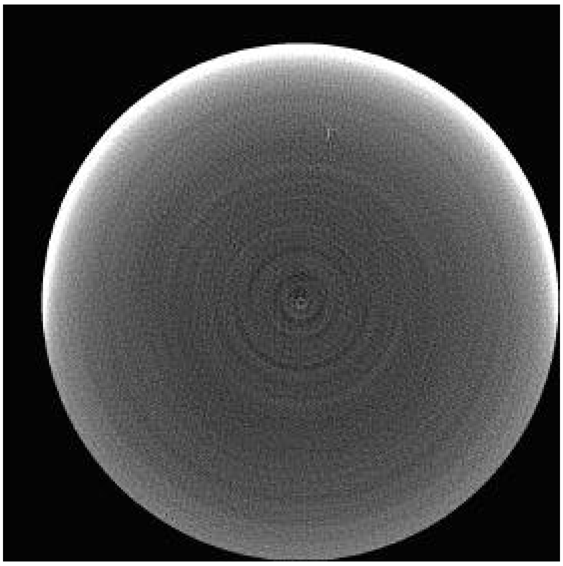
Experiment HS-681 had shown detailed images of the shape of the pores near their closure and in particular for the first time unambiguously, very small bubbles which were certainly formed well before the "close-off". The extension of the reconstruction to the whole firn show that these micro bubbles are present on the entire firn depth. The shallowest samples exhibit “normal“ bubbles already closed which seem to disappear with depth possibly with grain growth and rearrangement. The preliminary reconstruction obtained show the power of this technique, even if information on ice crystals are not available. In particular the high resolution of the image and the time required are valuable advantage of the ESRF compared to commercial micro tomographs. Quantitative studies are in progress in particular to look at the closed to open porosity ratio and to look at the specific surface of our samples.

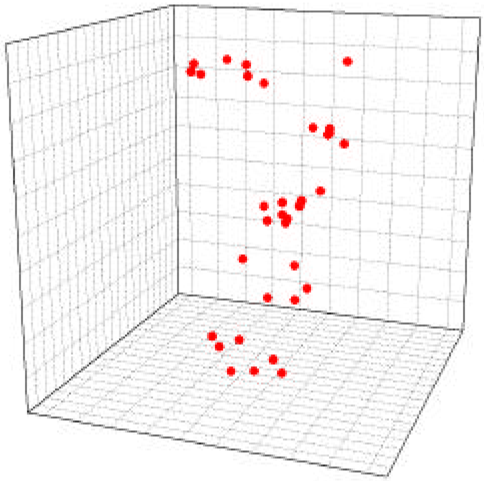
Particles distribution : The aim of this part of the project was to study the repartition of the dust particles in the ice in order to know whether they are located at the grain boundaries or randomly distributed in the ice matrix. The main constraints of the experiment were linked to :

- the particles size, centered just around 1µm. To get a compromise between the resolution and the size of the image, we worked with a resolution of 1µm and got only the largest particles.
- the size of the reconstructed image (diameter of 1mm) compared to the cristal (diameter of about 1mm too) and sample size. For mechanical reasons and also to have a chance to get a grain boundary in the sample, we had cylindrical samples of about 5 mm of height and diameter.

With these constraints we performed local tomography and got images similar to the one’s shown below on the left, where the track of a particle is visible in the upper part of the photo.

The contrast is not very nice, but it could be reinforced by diminishing the diameter of the sample (here only 4% of the sample area is used).



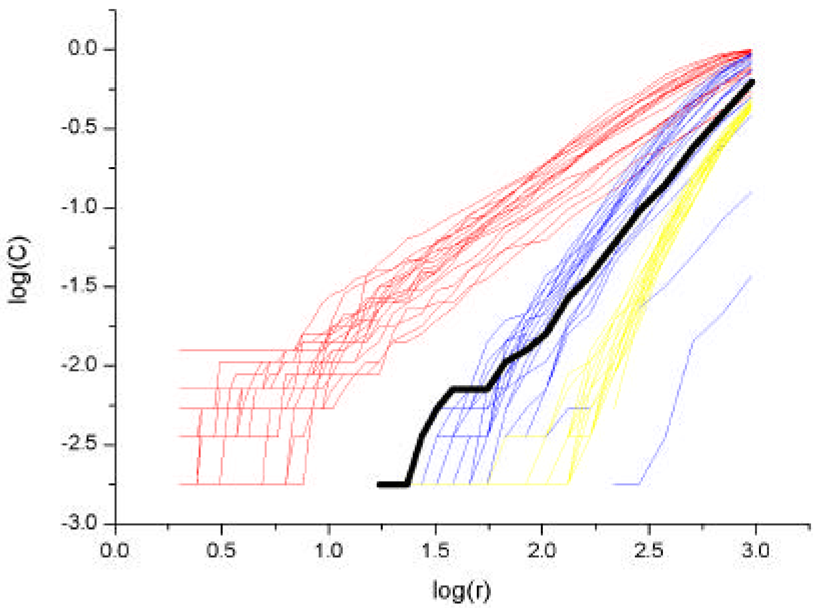


X-ray tomography of Antarctic ice samples from the last glacial maximum, a period of large atmospheric dust concentration, have been performed. This gave series of 2-D images of the sample used to reconstruct three dimensional image of the analyzed volume (a cylinder with a radius and a height of 1024 pixels, with a resolution of 0.92 µm/pixel). Then, by doing a vertical scanning of the ice sample, we have enlarge the analyzed volume.
In this way, we obtained a final 3-D image of 3000 pixels height, which corresponds to approximately 3 mm of ice in which 33 particles were present (right image).

In these 3-D images, only a limited number of particles are visible (the largest ones). Therefore, it is difficult to discern a visible structure. Instead we performed a correlation analysis of the particles positions, in order to characterize the dimension of the support :

$$C(r) = \frac{2}{n(n-1)}\,?\,(R < r)$$

where n is the number of positions considered, and N(R<r) the number of pairs of positions with a distance R smaller than r.



The scaling of C(r) gives the fractal dimension of the distribution, $C(r) \sim r^D$. For the dust particles, we find $D \approx 2$. In order to confirm this result and to test the effect of the geometry of the sample, we simulated three types of random spatial distributions. In red, the particles are randomly distributed in all the volume of a cylinder (Poisson distribution), The blue corresponds to particles randomly distributed along a line and the yellow, along a line. The experimental data (thick black curve) are comparable with the planar random distribution. This indicates that the particles are not randomly distributed in all the volume but have a two dimensional structure, as if they were located on a surface. This confirms the hypothesis on the spatial distribution of insoluble particles on the grain boundaries.

This work has been presented at the 2002 meeting of the European Geophysical Society in Nice.

TEST ON SNOW : Fresh snow is not strong enough to be machined in order to study its structure and the samples have to be strengthened. This is performed by filling the sample with a fluid which must have specific characteristics regarding its melting point, hardness and X ray attenuation.
Three fluids have been tested the best one being the 1-chloronaphtalène. Although bubbles were still present indicating that all the voids were not filled, this technique has been used succesfully in the experiment ME-390 in June 2002.