The influence of impurities on the densification of firn a case study from North Greenland

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Introduction

Paleoclimatic records from polar ice cores provide unique information about past atmospheric conditions, like temperature from stable water isotopes and greenhouse gas concentrations. To investigate leads and lags of temperature, measured in the ice phase, with gas concentration the exact dating of gas and ice is important.

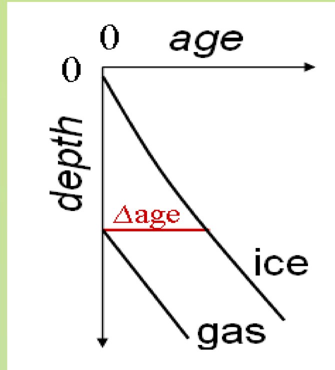

Fig. 1 Δage:age difference between gas kept in air bubbles and surrounding ice

However, the age difference, Δage (Fig. 1), between the air and the surrounding ice complicates the exact dating. After the deposition the age of the snow increases with depth, whereas the pores only close in a certain depth, so called close-off depth (COD). Thus, the knowledge of the COD is crucial for dating the gas (Fig. 4).

Fig. 2 Layered firn (Kohnenstation, EDML, Antarctica)

Snow accumulation rate and temperature are known as the main factors of firn densification.
But there must exist more factors.
Recently, a possible influence of impurities enclosed in the ice was found (M. Hörhold 2011).

Process of firn densification

<550 kg/m³: Settling and rearrangement

- Settling of crystals to the highest packagest by disordered jammed packings
- Afterwards no higher package by rearrangement possible

550-830 kg/m³: Plasitc deformation and recrystallization

- Deformation of crystals due to increasing pressure form overlaying snow
- Increasing density and contact area become maximum
- still open pore space

>830 kg/m³: Air bubbles

- Because of increasing density the pore space becomes single bubbles filled with air (firn-ice-transition)
- bubbles get smaler with depth

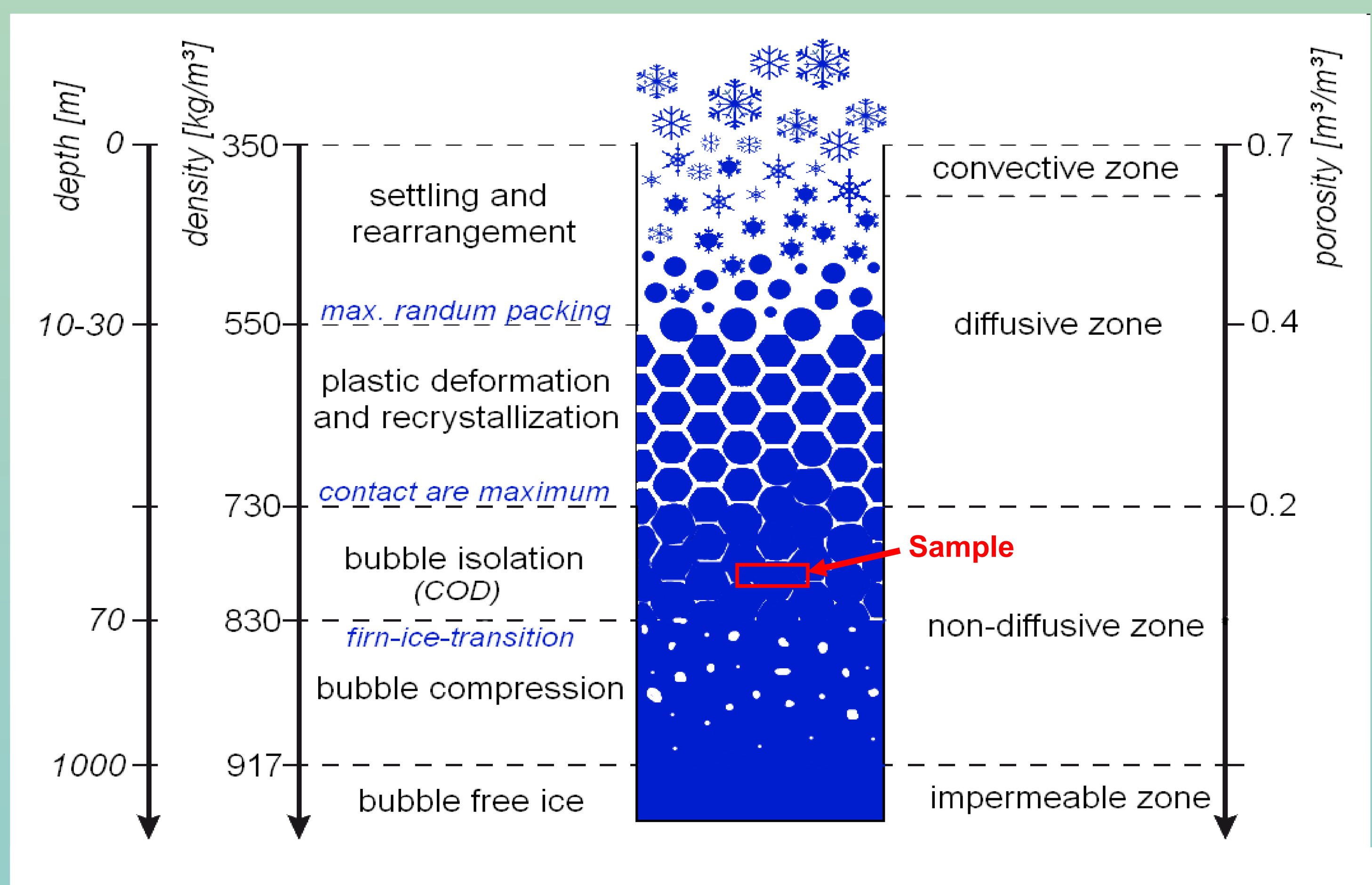

Fig. 4 Process of firn densification (modiefied after Blunier and Schwander)

Motivation

For the first time the relationship between impurity load and firn porosity is studied with a minimum of spatial uncertainty in the data sets.

Results

The correlation between the porosity and the dust proxies (Fig. 6) indicates that the dust particle or some other process linked to the dust proxies, have an influence on the densification of firn. However, the mechanism of densification is not clearly understood yet.

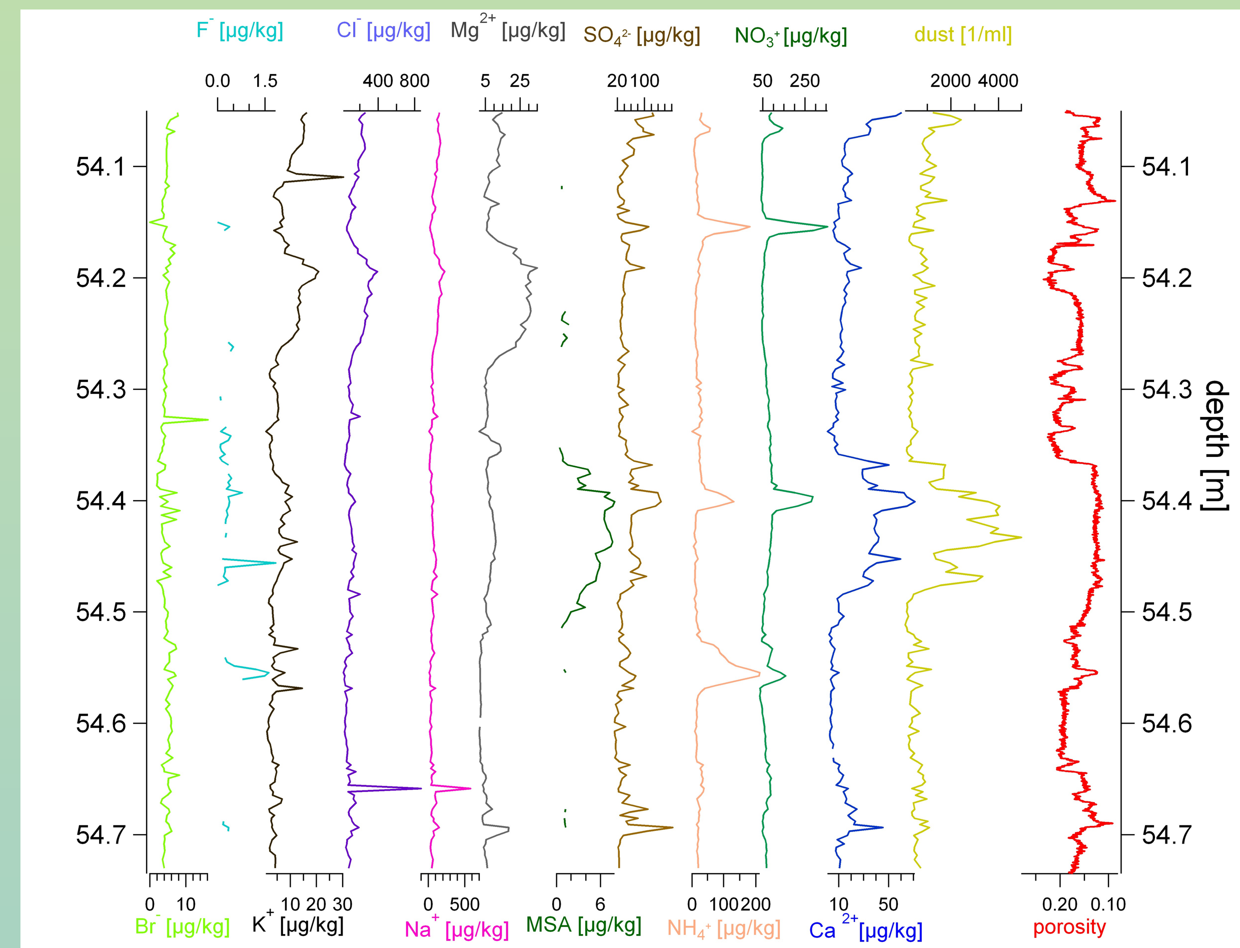

Fig. 5 All measured ions compared with the porosity of the firn core B22

Correlation coefficients between other ion concentrations and the porosity range from r = -0.04 (F^-) to r = 0.27 (NO_3^-). Only sulphur components (sulphate and MSA) show also higher correlations to the porosity of the firn (r~0.5).

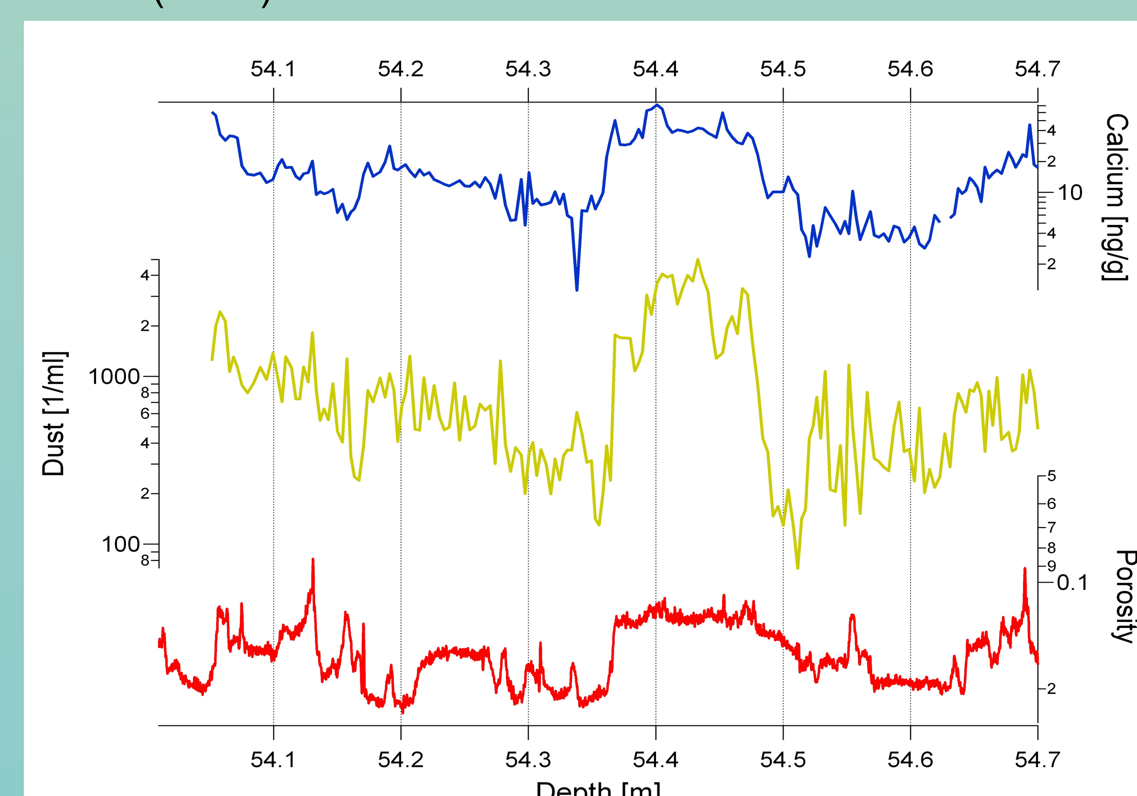

Fig. 6 We found the highest correlations between the dust proxies (particle concentration and Ca^{2+}-concentration), r = 0.6, indicating an influence of these impurities on the densification of firn.

Results support the thesis, that trace elements influence the densification process because of their correlation in depth. But depending on the high spatial resolution we had expected a stronger correlation. Is no stronger correlation possible? Are there other processes influencing the densification process?

Working area

NGT 30- B22

Area	North Greenland
Ice core	NGT 30 (B22) 79.341°N 45.192°W
Drilled	1994

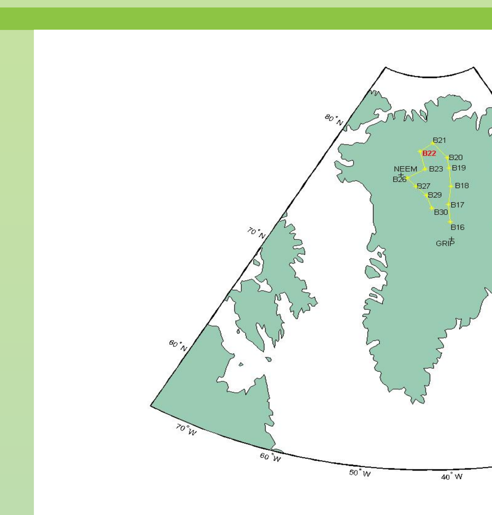
Fig. 3 The ice core used for analysis,B22, is from north Greenland

Conclusion

- **Correlation between dust proxies and porosity of firn**
- **No significant correlation between porosity of firn and the other (expect calcium) measured ion concentrations**
- **Calcium concentration as proxy for the impurity influence**
- **Impurity influence must be considered in the densification models**

Method

We have analyzed 80 cm from an unbroken firn core segment from north-west Greenland from a depth of ~54 m, next to the firn-ice transition. Here the porosity is of very high variability. We can differentiate between layers of different densities in spite of the same temperatures and snow accumulation rates and its deep enough to analyse the influence of trace elements.
We measured the density using a new full core X-ray computer tomograph with a resolution of 113 µm. We analysed major ions (SO_4^{2-}, $CH_3SO_3^-$, NH_4^+, NO_3^-, F^-, Br^-, Na^+, Cl^-, K^+, Ca^{2+} and Mg^{2+}) and dust particles on discrete samples in 3-4 mm resolution and compared the obtained concentration profiles with the porosity of the firn (Fig. 5). The uncertainty in depth correspondence is less than 1 mm, thus a comparison on this level is possible for the first time.

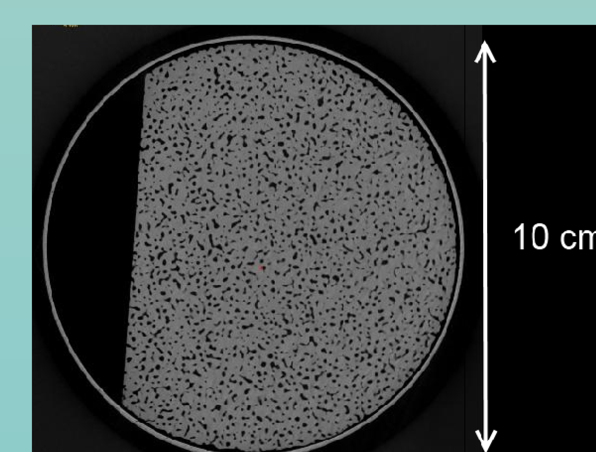

Fig. 7 Horizontal section of reconstructed firn core B22. Lighter parts show ice matrix and the sample tube, darker parts show air

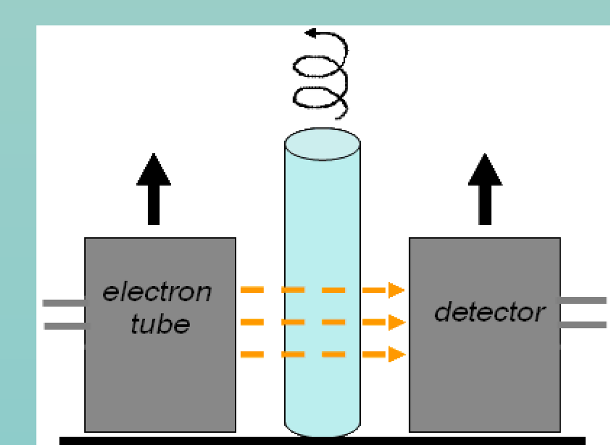

Fig. 8 schematic illustration of ice core comuter tomatograph

Reference

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Hörhold M., Kipfstuhl S., Wilhelms F., Freitag J. and Frenzel A., The densification of layerd polar firn. Journal of GEophysical reseach, Vol. 116, F01001