Jan Eichler[1,2], Christian Weikusat[1], Anna Wegner[1], Birthe Twarloh[1], Melanie Behrens[1], Maria Hörhold[1], Daniela Jansen[1], Sepp Kipfstuhl[1], Frank Wilhelms[1,3] and Ilka Weikusat[1,2]

[1]Alfred-Wegener-Institute Helmholtz-Center for Polar and Marine Research; [2]Department of Geosciences, Eberhard Karls University Tübingen; [3]Department of Geosciences & Geography, Georg-August-University Göttingen

ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

Microparticles and crystal microstructure in polar ice sheets

Using Cryo-Raman Microscopy

The pollution input in polar ice sheets in Greenland and Antarctica is of atmospheric aeolian origin, just as all natural non-ice impurities. Aerosols found in ice are transported with atmospheric circulation and wind patterns and are deposited e.g. with precipitating snow. The impurity content in this so-called meteoric ice is relatively low compared to many other natural materials such as rocks (ppb to ppm range), because most aerosols in the atmosphere have been removed by fall-out or precipitation during transport from the impurities' sources to the remote ice sheet.

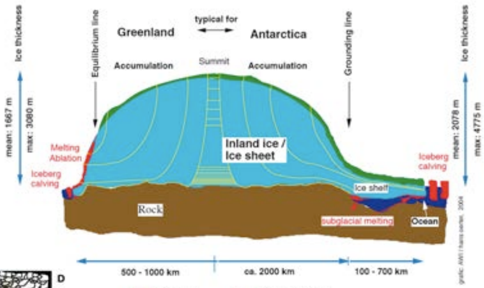

Fig.: Schematic ice sheet (1)

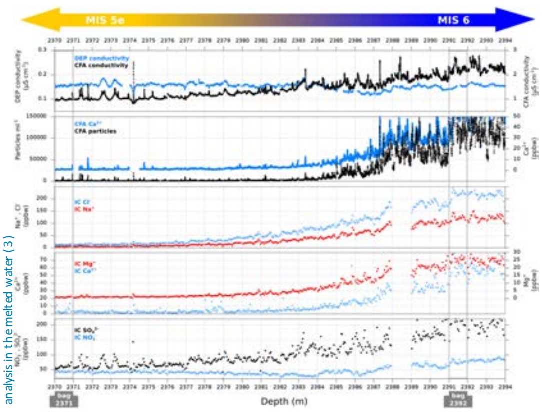

Fig.: Non-ice constituents in the EDML polar ice core (Antarctica) from chemical analysis in the melted water (3)

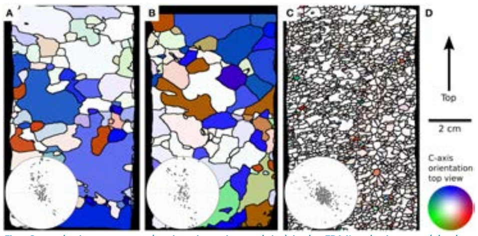

Fig.: Crystal microstructure (grain orientation and size) in the EDML polar ice core (depth in m: A) 2370.4, B) 2370.9, C) 2391.2) (3)

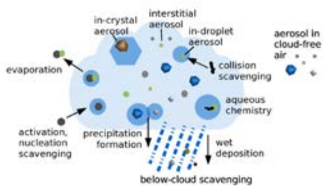

Fig.: Processes involved in the aerosol processing in clouds (2)

Non-ice constituents in polar ice cores have been studied in the last decades mainly for reconstructions of past atmospheric aerosol concentrations, in relation to issues that address global climate change. Despite the tiny concentrations, the interactions with and effects of impurities in the solid ice influence the physical properties of the as a whole: e.g. electric as well as dielectric response and, in particular, mechanical behaviour thus "softness" of the material seems to be strongly controlled by impurities. Smaller concentrations of impurities (up to a few ‰) do soften the material as a whole, while larger concentrations of particles harden it, depending on the type of impurities. The underlying processes are partly hypothesised for decades, but not yet proven or understood satisfactorily as the quest for ppb to ppm concentrations in solid matrix material is a search for a "needle in a haystack".

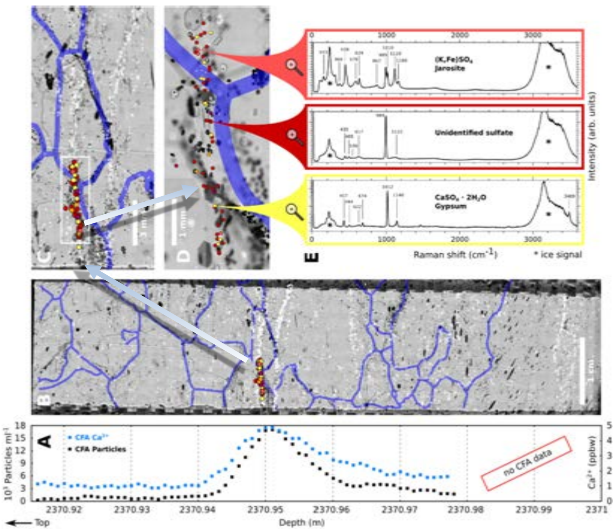

Fig.: A) Ca²⁺ concentration and number of insoluble particles from melted ice. B) Impurity map (white & coloured circles). Blue bands positions of grain boundaries at the focus depth of the micro-inclusions. C) Detail of B. D) Zoom into C. E) Raman spectra of selected micro-inclusions (3)

We used µ-cryo-Raman spectroscopy to identify location, phase and composition of µm-sized inclusions in natural ice. The combination of Raman results with ice-microstructure measurements and impurity data allows for an approach interconnecting ice core chemistry and ice core physics.

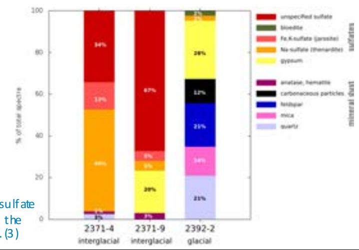

Fig.: Relative concentrations of identified species. While in the interglacial samples sulfate salts form 96% of the micro-inclusions, in the glacial ice mineral dust is most prevalent. (3)

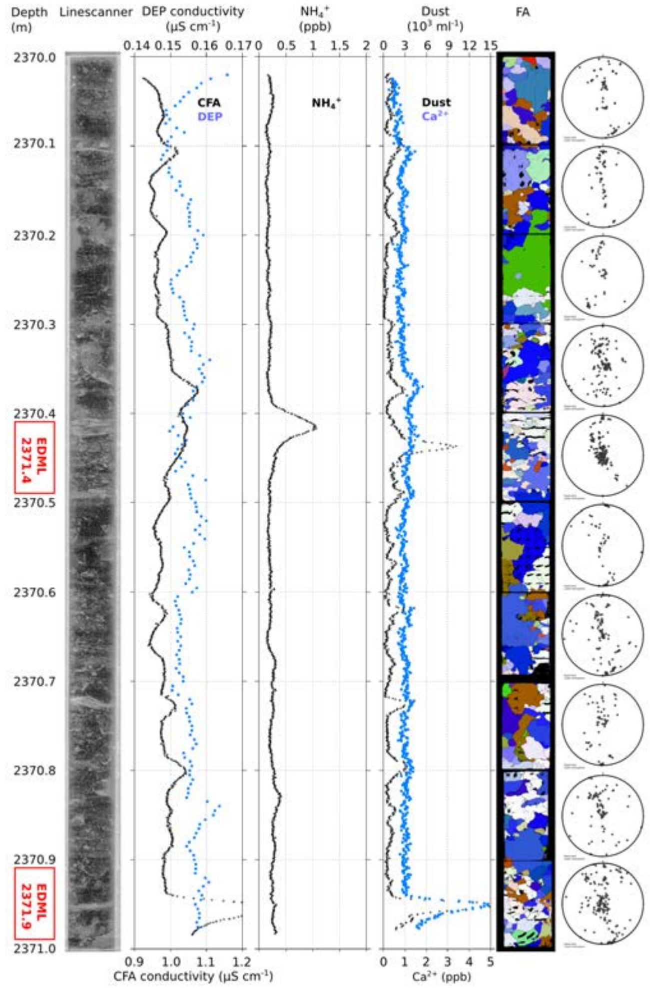

Fig.: From left to right: visual stratigraphy, Dielectric profiling & melt water conductivity, non-ice constituents (Ammonium, Dust, Calcium), and c-axis orientations as maps and as stereographic projections. (4)

References
(1) Oerter, H. 2004 Pers. Comm.
(2) Hoose, C.; Lohmann, U.; Bennartz, R.; Croft, B. & Lesins, G. Global simulation of aerosol processing in clouds *Atmospheric Chemistry and Physics*, **2008**, 8, 6939-6963
(3) Eichler, J.; Weikusat, C.; Wegner, A.; Twarloh, B.; Behrens, M.; Fischer, H.; Hörhold, M.; Jansen, D.; Kipfstuhl, S.; Ruth, U.; Wilhelms, F. & Weikusat, I. Impurity Analysis and Microstructure Along the Climatic Transition From MIS 6 Into 5e in the EDML Ice Core Using Cryo-Raman Microscopy *Frontiers in Earth Science*, **2019**, 7, 20
(4) Eichler, J.; Kleitz, I.; Bayer, M.; Jansen, D.; Kipfstuhl, S.; Shigeyama, W.; Weikusat, C. & Weikusat, I. Location and distribution of micro-inclusions in the EDML and NEEM ice cores using optical microscopy and in-situ Raman spectroscopy *The Cryosphere*, **2017**, 11, 1075-1090

EBERHARD KARLS UNIVERSITÄT TÜBINGEN
ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG
HELMHOLTZ GEMEINSCHAFT
GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN