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Integrating Raman spectroscopy and LA-ICP-MS 2D imaging to decipher the localisation and chemistry of impurities on the micro-scale in Greenland ice: Consistencies and open question

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Impurities in polar ice play, among others, a crucial role as a proxy for the paleoclimate while at the same time impacting the internal deformation of ice on the micro-scale. In particular, solid and dissolved impurities can impact grain growth through Zener pinning or the drag of grain boundaries. Recent studies on natural ice from Antarctica and Greenland highlight the need for a multi-method approach to determine the differences in the localisation and chemistry of solid and dissolved impurities comprehensively, in order to ultimately gain a more holistic understanding. Here we report on a recent pilot investigation pursuing the direct integration of complimentary methods: microstructure-mapping, Cryo-Raman spectroscopy and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) with 2D impurity imaging. While LA-ICP-MS enables the fast mapping of cm-size areas with lateral resolution in the order of tens of µm, Raman spectroscopy is more suited to identify the mineralogical composition of individual solid inclusions at the single µm scale. We analysed samples from the Holocene and Last Glacial from the Northeast Greenland Ice Core Project (EGRIP) and the North Greenland Eemian Ice Drilling (NEEM) ice cores. We find that the general localisation patterns of impurities (e.g., low vs. high concentration) are similar for both methods. Furthermore, both methods show (clusters of) inclusions in the grain interior. These findings display that a holistic approach is needed to truly decipher the localisation of impurities in the ice microstructure. Combining the advantages of both methods gives a good overview of the localisation of impurities, both solid and dissolved, on the micro-scale. Localisation patterns are related to the chemistry of the analysed impurities displaying the need for high-resolution methods. For example, Na is strongly located in the grain boundaries, Al is preferentially located within the ice grains and Mg can be located in both regimes. We analyse the role of inclusions in relation to 1) their chemistry and 2) their proximity to grain boundaries. Our approach of 2D impurity imaging in concert with established techniques, such as microstructure mapping and Raman spectroscopy, provides a detailed insight into the impurity distribution throughout a broad range of depths in an ice core. We demonstrate the

potential of such an approach to carefully investigate the evolution of impurity localisation in ice cores, with special significance to ice deformation processes and the preservation of the climatic record.