Correlating absorption and diffraction contrast tomography on earth and space materials

Olivia Barbee[1], Jette Oddershede[1], Matthew Pankhurst[2], Florian Bachmann[1], Stephen Hall[3], Jonas Engqvist[3], Rhian Jones[4], Anders Svensson[5], Erik Lauridsen[1], Jun Sun[1]

[1]Xnovo Technology ApS, Køge, Denmark, [2]ITER/INVOLCAN, Tenerife, Spain, [3]Lund University, Lund, Sweden, [4]The University of Manchester, Manchester, UK, [5]University of Copenhagen, Copenhagen, Denmark

Background incl. aims
Minerals in polycrystalline rocks on Earth have formed over durations spanning solar system formation up to our present geosphere and cryosphere. The conditions of rock and ice formation are recorded in the relative crystallographic orientations, sizes, shapes, defects, and distributions of their crystals or grains that, together with chemistry, chronicle planetary dynamics over timescales of seconds to billions of years. The three-dimensional (3D) mineral architectures are therefore fundamental to understanding celestial bodies and the solid earth, while providing crucial context within which we explore the origins of life on our planet and the interactions between its cryosphere, biosphere, and atmosphere. Observations, however, have long been restricted by 2D analyses and the destructive sample preparation required for 2D analytical techniques, as well as an inability to directly observe textural or mineralogical evolution. Maintaining 3D and time-dependent contexts of microstructures is vital to fully understand the dynamic formation and efficient exploitation of earth materials, both as recorders of earth processes and to support environmentally sustainable innovation.

Methods
Minerals are defined by both composition and crystallographic structure. X-ray absorption contrast tomography (ACT) is ideally suited to derive information on porosity and to characterize boundaries between higher- and lower-density phases. However, many minerals have similar X-ray attenuation, and some mineral systems have little or no variation in mineral type (e.g., ice), leading to minimal image contrast. Complimentary to ACT, lab-based diffraction contrast tomography (DCT) produces 3D maps of the grain morphologies and crystallographic orientations for the different constituent phases. ACT and DCT, both non-destructive in nature, can be performed on the same micro-CT system, and combining the two can provide earth and planetary scientists with unprecedented new knowledge – in 3D – while keeping the often rare or precious samples intact.

Results
We present different examples of combined ACT and DCT studies on earth and space materials to illustrate some of the current imaging capabilities. Results from an olivine chondrule inside a carbonaceous chondrite, a type of meteorite that can host organic compounds thought to contain the ingredients for life, reveal previously unobserved relationships between grain shape, size, composition, and chemical zoning that inform models of melting during short heating events in the proto-planetary disc. Ice is also explored with the goal of characterizing the 3D microstructural and porosity evolution of glacial ice, which contextualizes chemical and isotopic measurements used to extract climate records from ice cores.

Conclusion
Together, quantitative ACT and DCT can be combined to create 3D petrography: a non-destructive method of identifying and characterizing multiphase materials (rocks, alloys, etc.) without a priori knowledge. As a step towards that goal, this work is developing the utilization of joint ACT and DCT in addressing different challenges in geoscience.

Keywords:

Lab-based DCT, absorption contrast tomography