ESRF	**Experiment title:** Micro-porosity and pore structure of ordinary chondrite meteorites using synchrotron radiation micro-tomography	**Experiment number**: ES-932
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Report:

The aim of this experiment was to reveal the micro-porosity and its structure within fall ordinary chondrite samples using synchrotron radiation micro-tomography, which allows quantitative determination of porosity properties. A deeper insight into the structure and texture of porosity may elucidate the formation and metamorphism of chondrites in the early solar system. In addition, thermal properties are highly dependent on porosity and thus investigation of porosity properties is necessary for quantitative modelling of thermal evolution, thermal transport properties as well as present state of meteorite parent bodies, asteroids, and small bodies.

High-resolution synchrotron radiation micro-tomography measurements of micro-porosity of meteorites are reported in e.g. [1], [2], and [3]. Due to the resolution of those measurements, only the large volume porosity was detected. However, a sizable portion of the chondrite porosity is due to 1–3 orders of magnitude smaller pore volumes, which can be detected by using high-resolution μ-CT available at ID19 at the ESRF.

The samples in this experiment are all unweathered falls. Two thirds of their average composition is comprised of olivine and pyroxenes and one third of iron-nickel alloys and sulfides. Prior to the experiment at ID19, we characterized the samples by conducting 1) optical studies using thin sections, (2) Backscattered electron (BSE) image studies that provide 2D images of pore structures present on smooth sample surfaces, (3) nitrogen pycnometer measurements that approximate the total porosity value of the bulk samples, (4) bulk thermal conductivity and diffusivity measurements, and (5) bulk and grain density/volume measurements [4]. The samples are several cm in the smallest dimension and thus require high energies to have sufficient transmission through the samples. Worldwide ID19 offers a unique combination of high flux at high energies and the possibility to image details at sub-micron level, which are necessary conditions due to the high absorption in the samples and the small size of the pores.

In the experimental sessions, we used two imaging configurations, one for low-resolution (LR) and another for high-resolution (HR) imaging. LR imaging provides an overview of the sample, while imaging at HR reveals the detailed porosity structure in a smaller sub-volume. A filtered pink beam was used to generate a polychromatic energy spectrum that illuminates the sample with a peak energy of ~65 keV (LR) or ~78 keV (HR). To form propagation-based phase contrast that enhances the edges, such as between a pore space and a solid phase, and allows quantitative density measurement, the X-ray detector was placed downstream from the sample (2.82 m for LR and 0.1 m for HR). Applied optics had either 1x magnification resulting in 6.5 µm pixel size (LR) or 10x magnification resulting in 0.65 µm pixel size (HR). The size of the field of view for the LR scans was 16 mm x 10 mm and 1.6 mm x 1.4 mm for the HR scans.

Preliminary results and their significance in the respective field of research

We obtained novel results of three-dimensional porosity properties of chondrites and relationships between them. Figure 1 shows an example of the pore volume distribution of a sub-volume of ordinary chondrite Jelica (LL6).

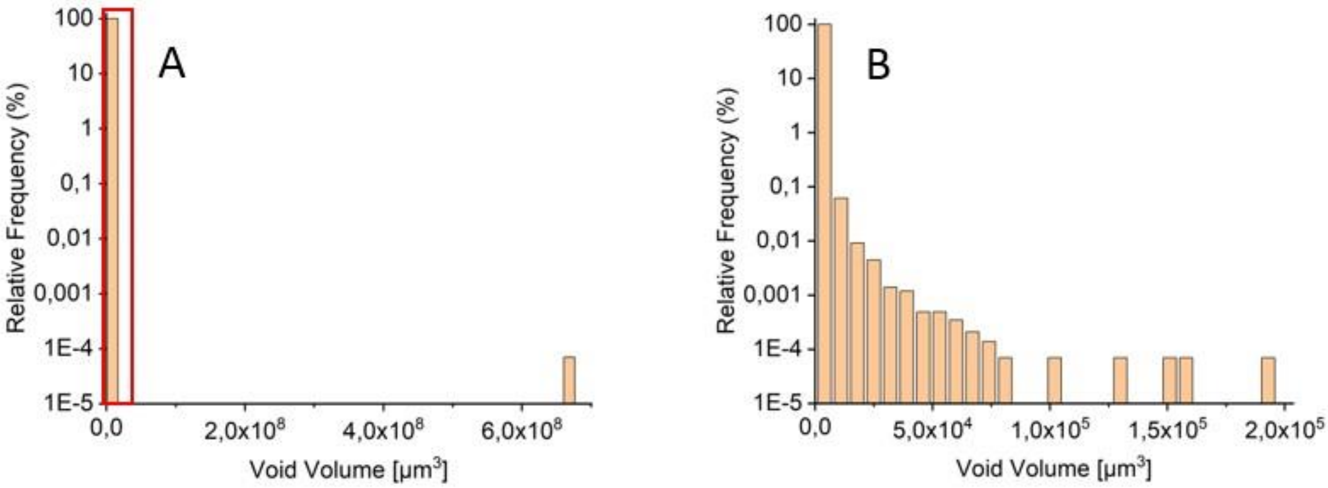

Figure 1. Example of the pore volume distribution of a sub-volume of ordinary chondrite Jelica (LL6) imaged at high-resolution. Plot A shows the entire range of void volumes and plot B shows the detailed distribution of the void volumes defined with the red box that have high relative frequency. The large void volume in plot A represents the largest void volume component within the sub-volume and is illustrated in 3D in Figure 2.

Three-dimensional imaging shows the distribution and types of porosity within the chondrite samples. Further, for many of the chondrites imaged in this experiment, quantified 3D pore properties have not been reported in previous studies. It is expected that the major portion of the porosity volume can be detected using high-resolution micro-tomography, although it is highly likely that pores below the detection limit exist. The results reveal the contribution of intra- and intergranular void spaces to the total porosity as well as the connectivity of the pore spaces. Connected component analysis shows that the major portion of the total porosity volume frequently exists in only one component (Figure 2), which may reflect the bulk porosity measured using a gas pycnometer.

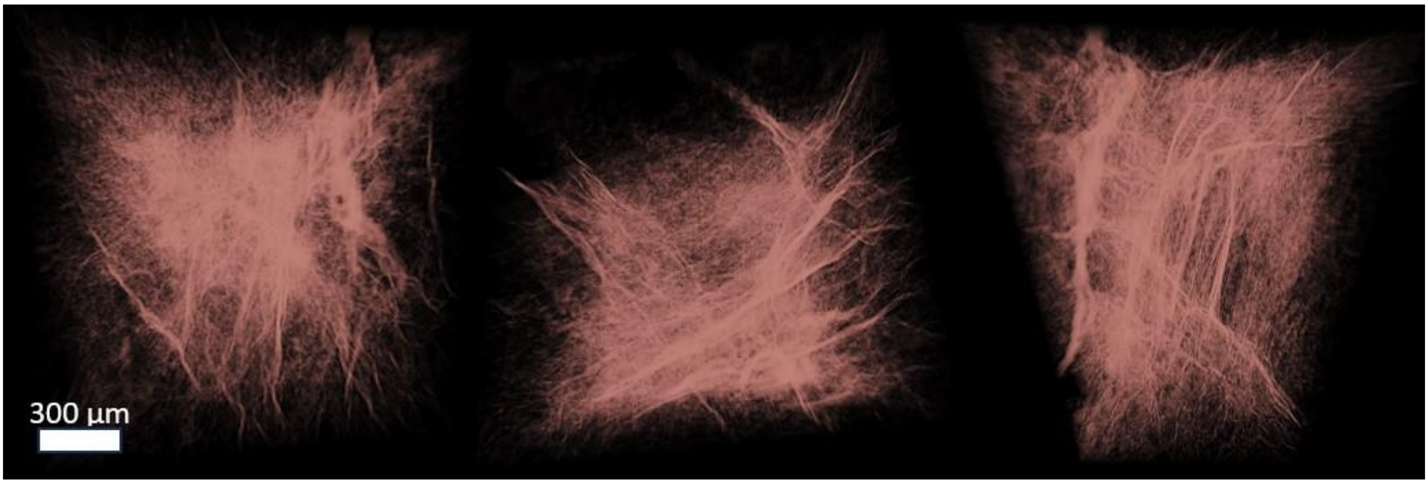

Figure 2. Example of the largest porosity component in a sub-volume of ordinary chondrite Jelica (LL6) imaged at high-resolution. The porosity of the sub-volume is 17.7 vol% of which the largest component comprises 95.5 vol%. The bulk porosity of the entire sample of Jelica measured using a gas pycnometer is 16.5 vol%.

This continuous network of porosity has a significant effect on thermal properties in meteorites and their parent bodies as it blocks thermal paths. On the other hand, continuous porosity provides paths for shock propagation and thus influences shock effects in meteorites and their parent bodies. Pore shapes are related to the interconnectivity and tortuosity of the pore spaces and thus permeability. The results of this experiment add to the limited experimental data that exist on three-dimensional pore shapes of meteorites.

The imaging data and quantified results of this experiment are useful in exploring the origin and evolution of the chondrites, but they can also be used in many studies utilizing thermal and porosity properties of meteorites, such as orbit determinations, asteroid probing, and sample return missions. Linking meteorite physical properties to currently determined asteroid physical properties gives deeper insight into the structure of the early forming solar system.

References

[1] Friedrich J. M., Macke R. J., Wignarajah D. P., Rivers M. L., Britt D. T., and Ebel D. S. 2008. *Planetary and Space Science*. *56*(7):895–900.
[2] Sasso M. R., Macke R. J., Boesenberg J. S., Britt D. T., Rivers M. L., Ebel D. S., and Friedrich J. M. 2009. *Meteoritics & planetary science*. *44*(11):1743–1753.
[3] Friedrich J. M. and Rivers M. L. 2013. *Geochimica et Cosmochimica Acta*. *116*: 63–70.
[4] Soini A. -J., Kukkonen I. T., Kohout T., and Luttinen A. 2020. *Meteoritics & Planetary Science*. doi: 10.1111/maps.13441.