NEUTRON TOMOGRAPHY AS A TOOL FOR PIN-POINTING METEORITIC COMPONENTS IN IMPACTITES

J. Martell[1], C. Alwmark[1], S. Holm-Alwmark[1,2,3], S. Hall[4, 5], J. Hektor[6], R. Woracek[7], L. Helfen[8], A. Tengattini[8].
Dept. of Geology, Lund University, Sölvegatan 12, 22362 Lund, Sweden (josefin.martell@geol.lu.se), [2]Niels Bohr Institute, Copenhagen, Denmark, [3]Natural History Museum Denmark, Copenhagen, Denmark, [4]Department of Solid Mechanics, Lund University, Lund, Sweden, [5] Lund Institute of Advanced Neutron and X-ray Science, Lund, Sweden, [6]LUNARC, Lund University, Lund, Sweden, [7]European Spallation Source, Lund, Sweden, [8]Institut Laue Langevin, Grenoble, France.

Introduction: Fragments from a projectile rarely survive a hypervelocity impact event due to extreme pressure and temperature conditions occurring during impact [1]. Projectile contamination of impactites can however be pin-pointed by resolving distinct chemical and/or isotopic signatures, in some cases even allowing determination of the type of impactor (e.g., [1, 2]). The extraterrestrial component will be heavily diluted when it mixes with significantly greater volumes of vaporized, melted, and fragmented target rocks, resulting in actual amounts of extraterrestrial components in impactites of typically <1 wt.% [2]. Generally, chondrites and iron-meteorites have considerably higher concentrations of platinum group elements (PGEs) and siderophile elements than typical terrestrial crustal rocks [3]. Enrichments of such elements (e.g., Ir, Rh, Cr, Co) can be used to establish impact origin, e.g., K-Pg boundary [4].

It is not clear whether meteoritic material is preferentially distributed in certain types of, or parts of, specific impactites [2]. To gain better understanding of the mixing and distribution of extraterrestrial matter in impactites and to identify possible "hot-spots" where PGEs are especially abundant, we have employed a combined neutron- and X-ray tomography, which provide outstanding potential to non-destructively study projectile material in three dimensions.

X-ray attenuation increase monotonically with the atomic number of an element, whereas neutron attenuation does not. This means that many metals interact weakly with neutrons, while some light elements, such as H, are clearly visible. This allows a differentiation between elements that are close to one another in the periodic system, and makes it possible to locate phases that are not visible using only X-rays [e.g., 5, 6]. To date, the world's most powerful neutron source is located at the Institut Laue Langevin (ILL) in Grenoble, France, and, dependent on sample dimensions and material composition, the NeXT instrument can collect tomograms with a voxel size in the range of a few micrometers. This can be combined with simultaneous high-resolution X-ray tomography on the same beamline, offering a powerful characterization capability due the complementary contrast mechanism, which is especially useful for pin-pointing of a wide range of mineral phases.

Specifically, the focus of this study is to localize Ir, which is detectable even in small amounts with neutron imaging due to its high neutron absorption cross section [6]. Other elements of interest (with relatively high neutron attenuation coefficients) are Rh and Co. The high atomic number of these elements means that they also will appear strongly in the X-ray tomographies.

Samples: In this pilot study we have chosen an impactite from the Lockne impact structure in Sweden. Lockne is a marine structure formed 455 Ma ([7] and references therein), and the sample is part of the resurge deposit that formed when water rushed in into the newly excavated crater. The sample consists of a mixture of fragments of limestone and shale, and pieces of crystalline target rock with high abundances of Fe and Cr [8].

Impactites from the Lockne impact structure are already known to contain physical material from the impactor, in the form of chromite [9], which is a common accessory mineral in meteorites. The samples are also strongly enriched in Ir [8]. This makes Lockne impactites the ideal sample for testing the potential of complementary neutron- and X-ray techniques as a way of locating PGEs.

Methodology: A sample of Lockne impactite was cut to an approximately $1 \times 1 \times 1$ cm^3 sized piece, mounted in a sample holder, and scanned over 360° rotation at the NeXT instrument at ILL. A setup with a pinhole size of 15 mm and 1792 projections allowed a voxel size of 7 μm. In order to enable voxel-wise 3D alignment between the two volumes, the software SPAM [10] was used for registration. Visualization was made in Fiji [11].

Results: Corresponding slices from the neutron- and X-ray volumes are shown in Figure 1. The grayscale reflects the attenuation of different minerals to neutrons and X-rays, respectively. The boxes mark examples of mineral phases that are discernible either in both volumes (box 1, 2) or in just one of the volumes (box 3).

Discussion: Phases that are bright in both volumes are areas of particular interest, as these might represent PGEs and Cr; these are elements that have previously been detected in the Lockne samples [8, 9]. Phases that only show up in the X-ray volume might represent Fe-

rich phases, and phases that are highly attenuating only in the neutron volumes might be rich in, for example, H or Co. Comparative studies of this sort can provide guidance when targeting areas for further analysis, and when confirmed (e.g., via extraction), their spatial distribution can be studied in greater detail non-destructively.

The PGEs are believed to form micrometer-sized nuggets [12], and the lower resolution of neutron tomography compared to X-ray tomography might be a limiting factor for their detection. In this study, the setup that gave the best signal-to-noise ratio yielded a voxel size of 7 µm.

In summary, the preliminary work is promising for further studies, where the material will be extracted and analyzed for classification. If successful, bimodal tomography could be used as a guide to obtain material with a high concentration of projectile material. Thus, it would be possible to circumvent problems associated with the currently employed whole-rock techniques of determining projectile contamination of impactites.

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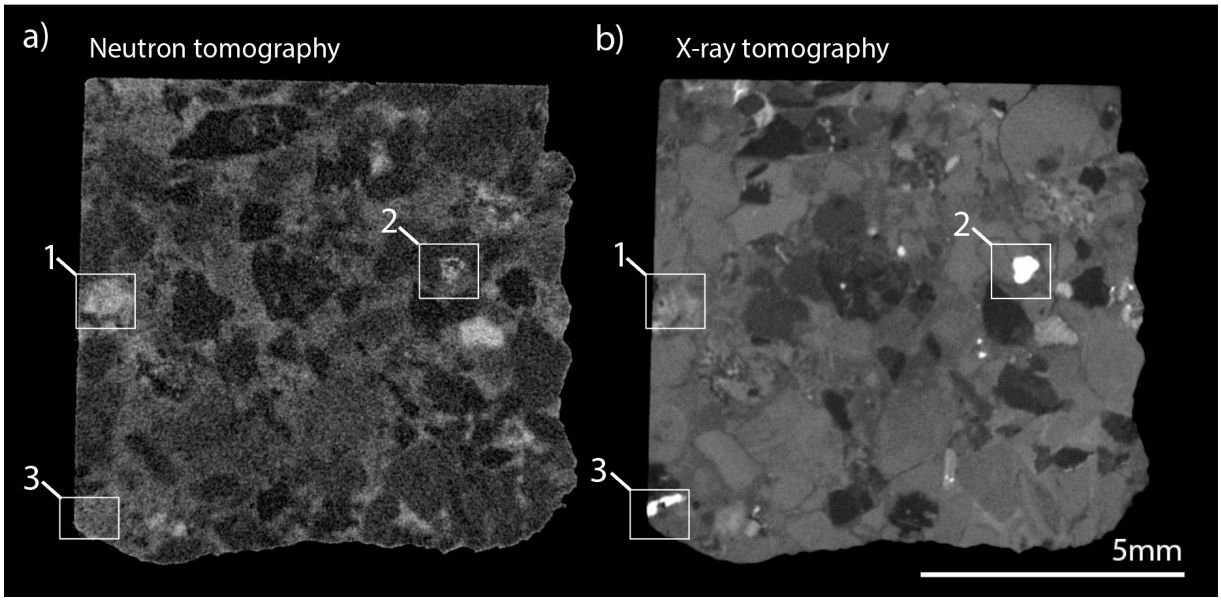

Figure 1 Corresponding slices from the a) neutron volume, and the b) X-ray volume. The volumes have a voxel size of 7 µm. The boxes mark examples of areas of different contrast: (1) mineral phase that is clearly visible in the neutron volume, and only vaguley discernible in the X-ray volume, (2) mineral phase that is vaguley visible in the neutron volume, and very bright in the X-ray volume, (3) mineral phase that is only visible in the X-ray volume.