NONDESTRUCTIVE MAPPING OF DISTINCTIVE FEATURES IN A LIKELY THERMALLY ALTERED INTERPLANETARY DUST PARTICLE. Z. W. Hu[1] and R. Winarski[2], [1]XNano Sciences Inc., P. O. Box 12852, Huntsville, AL 35815, USA (zwhu@xnano.org). [2]Center for Nanoscale Materials, Argonne national Laboratory, Argonne, IL 60439, USA.

Introduction: Interplanetary dust particles (IDPs) collected from the stratosphere, likely fragments of asteroids and comets, are an important resource for the study of the origin and early evolution of planetary bodies. Typical IDPs are delicately bound aggregates of small solar nebular and presolar components, with complicated pore structure and rich textures. Unlocking the nanoscale three-dimensional (3D) structures of such aggregate IDPs and the relationships between different components and/or features is likely to provide important information to better constrain the sources of IDPs and the formation and evolution of IDPs and their parent bodies. Yet, IDPs experience varying degrees of pulse heating during atmospheric entry, it is important to distinguish indigenous properties from thermal alteration products.

A number of approaches have been used to investigate thermal alteration effects [1-5], and secondary alteration features or products have been observed in thin microtome sections of larger, strongly heated particles, including vesicular carbon [1] and magnetite rims [4]. Such secondary thermal alteration products add an extra challenge to dealing with issues concerning original properties and processes, including the origin of pore structure in IDPs. Following the initial success of nondestructive 3D mapping of small pore structure in IDPs with X-ray phase contrast nanotomography [6-7], we have been taking steps further to noninvasively examine atmospheric entry heating effects on IDPs morphologically and microstructurally in 3D nanoscale detail and develop a viable way to distinguish indigenous structures from secondary thermal alteration products, aimed at providing new information complementary to data obtainable from other analytical tools to help better understand the origin and early evolution of the solar system.

Methods: High resolution and high sensitivity of X-ray phase contrast nanotomography was exploited to assess atmospheric entry heating effects on relatively larger cluster IDPs. As described previously [6], the sample was mounted on the top of a tungsten pin in such a manner that the entire volume of a particle could be tomographically scanned and subsequently analyzed in 3D nanoscale detail. For nanotomography, transmission images were aligned for drift correction prior to being reconstructed.

Results & Discussions: A cluster IDP of ~ 12 μm in length, W7069-D-1, was selected for this investigation and further developing the effectiveness of the new noninvasive nanoscale imaging technique in distinguishing small or subtle features that may otherwise be masked by carbonaceous matrix. The particle appears, on the submicron level, to be composed of irregular but often flake-like carbon-rich components, with a high proportion of "void spaces" present between the components throughout the particle. But its porosity tends to be higher in the outer regions than the inner (Fig. 1), which is consistent with stronger pulse heating and stronger alteration effects normally occurring on the outer layers of dust particles during atmospheric entry.

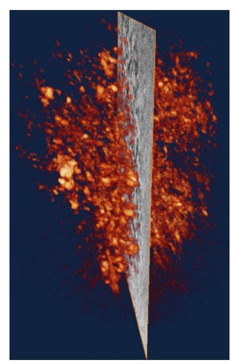

Fig. 1. 3D rendered view of an IDP combined with a 2D cross-section image.

What is more interesting is a wealth of 3D structural and textural information revealed on the nanoscale. These flake-like carbon-rich components are richly textured, with rugged surfaces and jagged or porous edges as well as with an abundance of vesicles ranging, say, from ~ 10 nm to submicrons in size (Fig. 2), consistent with vesicular carbon observed in thin microtome sections of strongly heated IDPs [1]. The "void spaces" between the larger carbon-rich components have turned out not to be really empty, but instead containing numerous scattered but interconnected small "skeletons" (usually < 100 nm in size). Such morphological, textural and microstructural features provide evidence that the particle experienced strong secondary thermal alteration during atmospheric entry. In addition, small crystals of ~ 10-20 nm in size are also observed on the surfaces of components (Fig. 2). Detailed analysis is underway to see whether such small grains exist only on surfaces, forming rim-like structure e.g., or are embedded throughout carbonaceous material.

Our preliminary 3D image data analysis indicates that the degrees of heating experienced by particles vary during atmospheric entry and even thermal alteration effects vary from one region to another in a given strongly heated IDP. While this may not be surprising at all, the variations revealed in 3D detail may well provide a real opportunity to distinguish between indigenous structures and secondary thermal alteration features. In two-dimensional (2D) images (e.g., Fig. 1), vesicular spaces, particularly larger ones, are also discernable. But it would be hard to appreciate their 3D structure and spatial distributions, and their nature (without morphological, textural, and microstructural details in context).

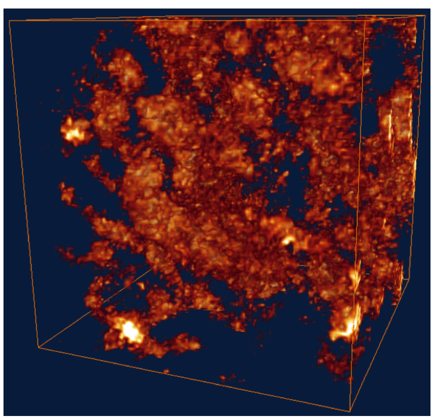

Fig. 2 A close-up of a region with the rendered volume of 1.5×1.5×1.5 μm^3.

Summary: It is important to learn more about thermal alteration effects and features in order to uncover more puzzle pieces to tell the full, intriguing story of IDPs. Our initial analysis has shown that X-ray phase contrast nanotomography is capable of non-invasively mapping thermal alteration related features in a detailed manner otherwise impossible. In the case study presented here, we have observed distinctive morphological, textural, and microstructural 3D features that formed more likely as a result of pulse heating during atmospheric entry. The revealed 3D-nanoscale-detail-in-context information agrees with previous TEM studies but also yields new insight into the origin of a specific type of vesicular structure present in IDPs, opening a new way to distinguish properties indigenous to IDPs and the parent bodies from secondary features induced by pulse heating during atmospheric entry. New data will likely help better constrain the sources of IDPs and establish a better connection between laboratory study of extraterrestrial materials and space mission measurements. Such work will also likely benefit Stardust mission sample investigation as uncovering small indigenous components and unmasking thermally altered ones in the returned samples become key to maximizing the scientific return from the Stardust samples.

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