Petrography in 3D: Why isn't everybody doing it?

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Aims

An early critique of X-ray CT for geological applications was that it only produced "pretty pictures," and subsequently great effort has been expended developing computational tools to extract quantitative data from voxel data sets. However, within those "pretty pictures" lie underexplored opportunities for changing the way we do geoscience by helping us to think in new ways. This talk will discuss two examples of the power of high-resolution X-ray CT for amplifying geological intuition, for understanding asteroid surface processes and deciphering the origin of carbonado diamonds.

The meteorite CM Murchison is a classic "carbonaceous chondrite," with organic molecules that could be building blocks for life. Murchison is also a regolith breccia, basically consolidated rubble from the surface of an asteroid, and is known to have undergone some degree of hydrous alteration while still on its parent body.

Carbonado is a polycrystalline variety of diamond found only in Brazil and the Central African Republic. Its unique structure, of 10-100 μm diamonds sintered together by ~1 μm diamonds, making it the hardest substance in nature. Carbonado has a number of other unique and enigmatic features, including a fully connected pore network, light carbon isotopes suggesting an organic source, and inclusions rich in uranium and rare earth elements and reflective of crustal rather than mantle pressure and temperature conditions.

Method

Several specimens of carbonado diamond were CT scanned – a 27-carat specimen, and several 5-10 carat specimens. Scans were taken from 40-140 kV, and dual-energy scanning was used to locate the high-Z components within the volume and distinguish them from iron-rich ones. Volumes of interest identified during lower-resolution scout scans (10-30 μm) were re-imaged at 2-6 μm to examine inclusions and pore structures in greater detail.

A single specimen of the Murchison meteorite was acquired on loan from the Smithsonian Institution. The entire volume was imaged, and close-in scans were taken of specimen corners for greater resolution. CT images were used to select regions for sectioning for subsequent petrographic, chemical and crystallographic analysis.

For both projects, visualization was done using Avizo software, and 3D measurements of individual objects and bulk fabrics were taken using Blob3D[1] and Quant3D[2].

Results

Initial scans of the Murchison sample revealed a subtle flattening fabric in its chondrules that had not been previously quantified. In sum, particle shapes exhibited flattening with a preferred orientation within the flattening plane. Estimates of bulk strain under end-member assumptions of compressible and incompressible chondrules resulted in an estimate of 31-59% porosity loss in the matrix due to compression, providing a partial explanation for the phenomenon of meteorites found on Earth tending to be considerably less porous than their parent bodies. Follow-up micro-analysis indicates multiple episodes of fracturing and hydrous

mineralization, and few indications of plastic deformation, indicating that most deformation was brittle and was likely the result of repeated impacts.[3]

Additional work has concentrated on the fine-grained rims of the chondrules, whose origin remains debated between the solar nebula and local processes on the asteroid surface. Careful analysis of the rim shapes and volumes reveal that they conform closely to predictions based on a model of moderate turbulence in the solar nebula, while other analyses compositional comparison of rims to various core types appear to rule out alteration on the asteroid surface as a reasonable mechanism.

The 27-carat carbonado scan revealed many never-before-seen textural clues, such as dodecahedral pseudomorphs after an original but now-absent phase, and grading and preferred orientation of irregular pores suggesting vapor- or fluid-filled bubbles deformed during a deformation event likely associated with crystallization of the 1-µm diamond phase[4]. Subsequent scans of additional specimens show the strong preferred orientation of pores to be a pervasive feature of carbonados, and additional pseudomorphs that appear to have diamond ingrowths may document a second original phase that may have started resorbing prior to the end of the diamond crystallization event.

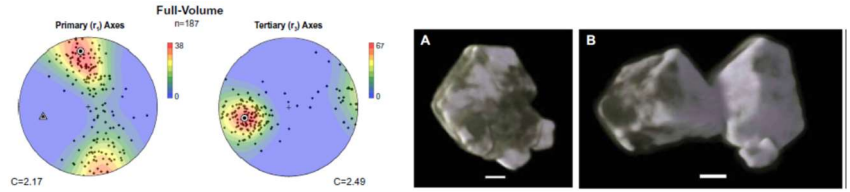

Figure 1: (left) Chondrule orientations in meteorite Murchison CM. (right) Pseudomorphs in carbonado diamond; scale bars are 50 µm.

None of the original results of these studies were anticipated before scanning began. In both cases the original scans were exploratory, and only during extensive follow-up visualization and contemplation did meaningful patterns become apparent, which in turn led to further scanning and quantitative analysis. In both cases, study continues to this day.

Conclusion

These examples of the power of 3D observation combined with simple geological insight and imagination point to the tremendous potential for scientific discovery with more widespread dissemination and utilization of CT data, and the importance of lowering the technical, educational, and financial barriers to it.

References:

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