WHEN RUBBLE PILES ATTACK: THE MENAGERIE OF MICROSCOPIC METEORITE DEBRIS IN PICA IMPACT GLASS.

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Introduction: The recent images from OSIRIS-Rex illustrating the littered surface of asteroid Bennu serve to remind impact petrologists that asteroids and comets can be anything but monolithic, homogenous projectiles. As these images arrived, we serendipitously were documenting the mineralogy and geochemistry of Pica glasses, which we argue were most likely produced when surface sediments melted during a late Pleistocene airburst over the northern Atacama Desert [1-3]. One might imagine that volatile-rich, fragmental rubble piles are the most likely candidates to catastrophically detonate in the atmosphere before having the opportunity to excavate craters. And indeed, the amount and variety of meteoritical debris entrained in the Pica glasses is demonstrative of just such a body.

The effort to record and correlate each microscopic meteoritical grain to a specific impactor type has become somewhat staggering as they appear to represent a wide range of materials. The data may yet converge to a single identifiable parent body, but at this point the debris are a menagerie of disparate lithologies. However, it is important to recognize that they do form a well-defined suite of contaminants, occurring in Pica glasses formed at different locations (separated by many tens of kilometers) by melting of different local target sediments, but during the same temporal event. In other words, they are not easily explained as a random bunch of meteoritical debris distributed across the Atacama sands. Preliminary analyses of the pre-impact sediments also do not support that scenario.

In addition to just being a treasure-trove of exotic mineralogy, the Pica glasses provide a useful case study to investigate how well, or how poorly, bulk geochemical techniques perform when applied to the ejecta from impact events involving heterogeneous rubble piles. And relatedly, the glasses are proving to give important insights into how moderately volatile meteoritic components, such as nickel and copper, fractionate and are transported during turbulent, ultra-high temperature heating events. Ironically, not predicting the end results of those processes may have been responsible for previous researchers [4] overlooking the presence of the geochemical signatures they admitted would have convinced them that the glasses were not formed by terrestrial processes.

Methods and Results: Thus far, more than seventy thin and thick sections have been analyzed using backscattered electron microscopy on a Hitachi SU-3500 VP-SEM at Fernbank Science Center. Chemical compositions of selected phases were determined using an EDAX Element EDS detector.

The easiest meteoritical clasts to identify in the Pica glasses, and perhaps the most abundant, are clasts of Ni-bearing to Ni-free troilite, Ni-free pyrrhotite, and Cu-rich iron pentlandite (Fig. 1). They typically are found lining the walls of vesicles and may occur in assemblages of euhedral grains or in a variety of shapes corresponding to the degree of partial melting. Those that exhibit nearly any melting never retain detectable nickel, and those that approach being spherules or subrounded nuggets do not contain copper.

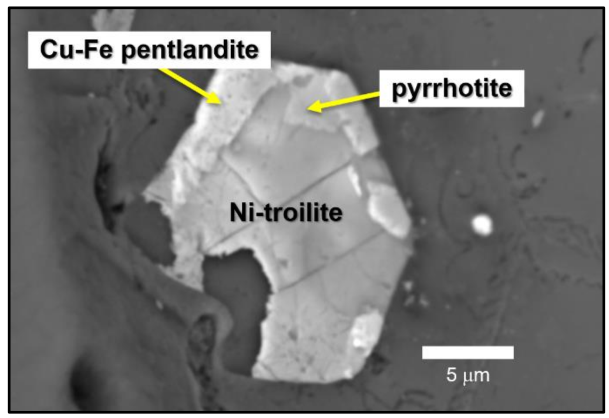

Figure 1. Electron backscattered (BSE) photomicrograph of a typical unmelted assemblage of Fe±Ni sulfides that commonly occur on the walls of vesicles in Pica glass.

The ultimate fate of some nickel and copper appears to be complete volatilization followed by rare re-condensation with other highly to moderately volatile elements into "bronze" spherules (Fig 2.)

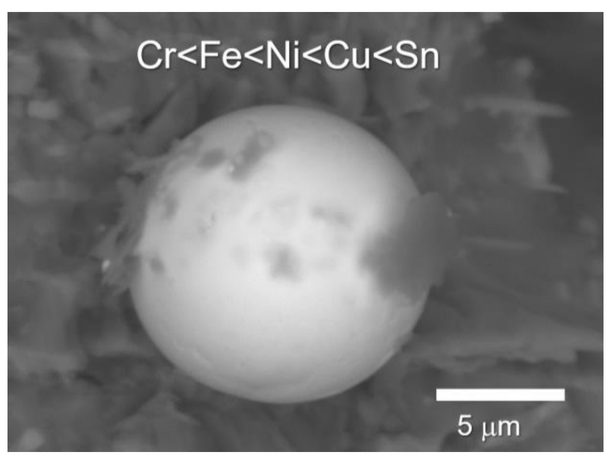

Figure 2. Electron backscattered (BSE) photomicrograph of a bronze-like spherule in Pica glass.

The Fe±Ni sulfides may occur near or in direct contact with chlorine-rich apatite, buchwaldite ($NaCaPO_4$) (Fig. 3), and Si-bearing calcium phosphates. These associations are similar to those observed in troilite nodules from iron meteorites [5]. But other clasts lead to very different conclusions.

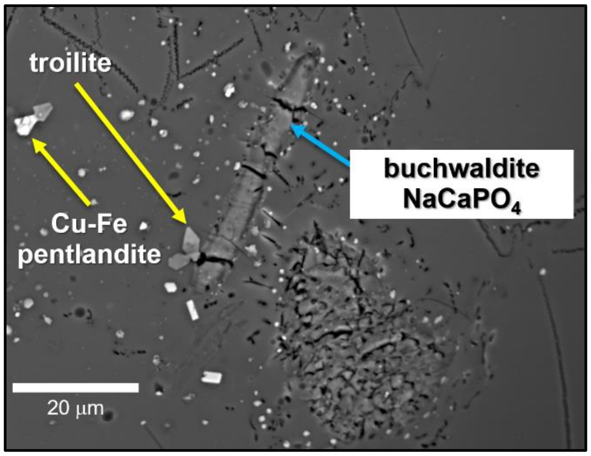

Figure 3. Electron backscattered (BSE) photomicrograph of acicular buchwaldite that typically occurs with Fe±Ni sulfides in Pica glasses.

Some Pica glasses contain melilite-rich microscopic rock fragments occurring as coronas around troilite and fine-grained "dusty" clasts rich in calcium, aluminum, and titanium, which have the appearance of CAIs. The same samples contain chlorine-rich albite chondrule-like objects in association with troilite, phosphate, and silica (Fig. 4). Some samples contain abundant enstatite grains with troilite inclusions while others trade enstatite for diopside, jadeite, or even serpentine. Carbonaceous chondrite? Enstatite chondrite? Or all of the above in a fragmental regolith disintegrating as it collides with Earth? We present the compendium of petrologic characterizations to-date and the implications for the Pica bolide.

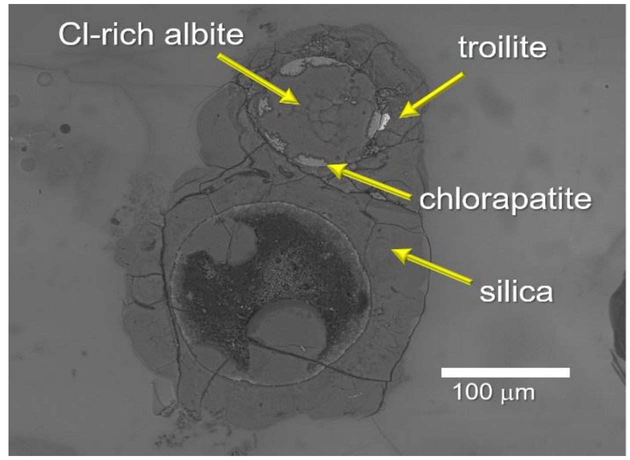

Figure 4. Electron backscattered (BSE) photomicrograph of Cl-rich albite spherules in association with troilite, phosphate, and silica

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