EXPLORING THE LARGEST MASS FRACTION OF THE SOLAR SYSTEM: THE CASE FOR PLANETARY INTERIORS.

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Why explore planetary interiors: The typical image that comes to mind for planetary science is that of a planet surface. And while surface data drive our exploration of evolved geologic processes, it is the interiors of planets that hold the key to planetary origins via accretionary and early differentiation processes. It is that initial setting of the bulk planet composition that sets the stage for all geologic processes that follow. But nearly all of the mass of planets is inaccessible to direct examination, making experimentation an absolute necessity for full planetary exploration.

Facility in development: Our vision is to establish a 5000 ton press open user facility that will serve the planetary science community as well as the greater scientific community as a whole. The Community Extreme Tonnage User Service (CETUS) will be responsive to current user needs, and adapt to carry out missions that benefit the greater research community. Instrument time and facility resources will be specifically dedicated for innovation and pilot studies. Projects that are community driven, such as the establishment of a standard synthesis library for distribution will be an ongoing priority for CETUS.

Current challenges in high pressure experimental petrology: Larger sample volumes will allow better control of the sample environment and complex mixtures of starting materials to be studied in greater detail, expanding the types of conductivity, diffusivity, and phase equilibria studies possible. This larger volume relative to the capsule interior area reduces or eliminates concerns about surface interactions between the sample and capsule, which can swamp experiments at the highest pressures in a capsule of $<1 mm^3$ volume (compare to 1 cm^3 of a large press at the same pressure conditions). Controlling the oxidation state of the sample by adding solid media buffers would be feasible up to higher pressures.

Potential benefits to exploration community: The large press will allow experimenters to reach higher pressures (above 30 GPa) and larger sample volumes than is currently achievable with existing presses. Pressures corresponding to the central pressure of Mars (fig. 1) and deeper into planetary mantles will be attainable. The large press could also contribute to a greater understanding of physical properties of planetary interiors (e.g., thermal conductivity), rheology, paleomagnetism, all of which are linked by complex early planetary dynamics. This new capability even opens experimental opportunities for studies of the evolution and mantle-core compositions of exoplanets such as super-earths.

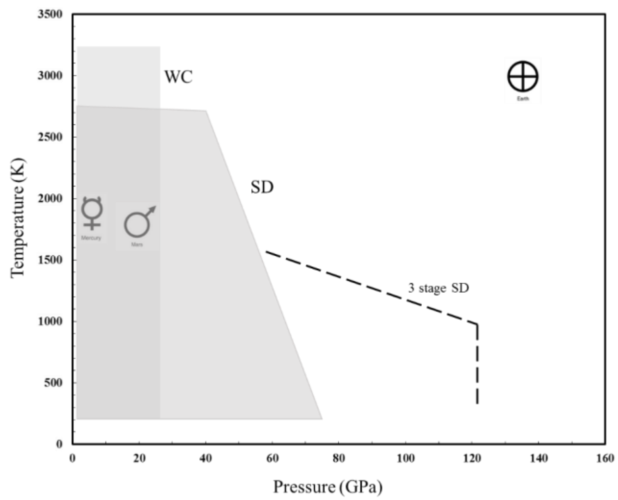

Figure 1. Schematic of achievable pressure-temperature space of multi anvil experiments with various second anvils, modified after [1]. Shaded block labeled "WC" (tungsten carbide) is the current pressure temperature regime of multi-anvil apparatuses in the United States. "SD" is sintered diamonds, which require modifications to the pressure module normally used for WC anvils. Even higher pressures have been achieved by use of a 3 stage assembly with additional nano-polycrystalline diamonds, [2]. Symbols for Mercury, Earth, and Mars approximate the core-mantle boundary conditions.

The potential for studies of volatiles in planetary evolution would be enhanced, with the expanded experimental assembly volume able to contain comparatively sizeable amounts of volatile-rich material within noble metal capsules. This ability opens up more direct simulations of the interiors of the outer planets.

As we continue to expand and extend our human exploration of the solar system, new materials and technologies will be needed. Ultrahard materials may be useful for shielding and durable tools, for example, and optically transparent ultrahard materials may have additional applications in instrumentation and space vehicles (fig. 2).

Figure 2. High-quality polycrystalline garnet synthesized at 15 GPa and at 1,400 °C, with a diameter of ~4 mm and thickness of ~2 mm; grossular with 2 mol% $Ca_3Cr_2Si_3O_{12}$ uvarovite (green), pure grossular (colorless, hardness of ~14Hk) and $Mg_3Al_2Si_3O_{12}$ pyrope with 5 mol% knorringite $Mg_3Cr_2Si_3O_{12}$ (purple). After [3].

Milestones and direction: A number of milestones have already been reached in 2016 for implementing the CETUS facility:

1) A Planetary Major Equipment proposal was submitted to the NASA Emerging Worlds solicitation for the full cost of the press and partial FTE for development team members. (6/3/16)

2) A full sub-award proposal was submitted to COMPRES for 2 FTE research and technical staff to run the CETUS facility. (8/15/16)

3) A sub-award was submitted to COMPRES for experimental cell assembly development. (8/15/16)

4) One development team member attended the European High Pressure Research Group International Meeting on High Pressure Science and Technology, Bayreuth, Germany, 9/5/16-9/9/16, and conducted a site visits to Bayreuth Geoinstitut and the Voggenreiter factory (fig. 3), which is the preferred vendor for the 5000 ton press.

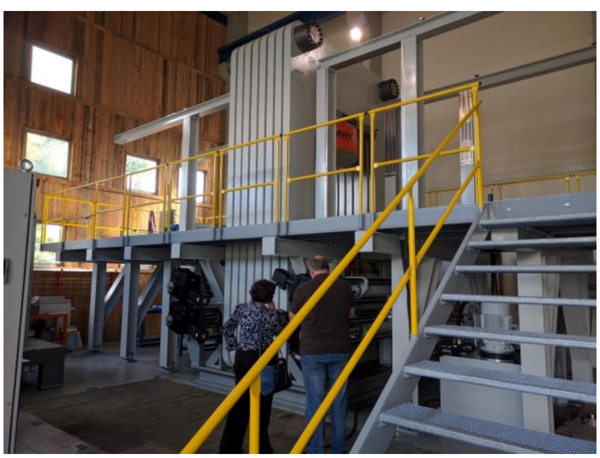

Figure 3. The two module frame of the 5000 ton press at the Voggenreiter factory in Mainleus, Germany. Lisa Danielson and Michael Petri, Head of Development in foreground.

5) A development working group meeting that will address a number of programmatic issues and outline a plan of action for CETUS development for 2017 was funded by COMPRES, and will be hosted by the Lunar and Planetary Institute January 23-24, 2017.

Our current timeline goal is to open CETUS for general use in 2021. The useful lifetime of CETUS should extend to 2050 and potentially beyond with our dedication to constantly evolving technology.

Team members of Experiments in Extreme Environments Laboratories, spring 2016, from center-front clockwise: Lisa Danielson[1]; Kellye Pando[1]; Loan Le[1]; Roland Montes[1]; Jenny Rapp[1]; Mark Cintala[2]; Dave Draper[2]; Frank Cardenas[1]; Frances McCubbin[2]; Poorna Srinivasan[3]; Kathleen Van der Kaaden[3]; Mya Habermann[1,3]; Kevin Righter[2]; Ian Szumila[1,3]. [1]JETS Contract; [2]NASA civil servant; [3]graduate student. Not shown: Fred Horz[1], emeritus; John Jones[2], Etienne Medard, visiting scientist, LPI; Asmaa Boujibar, NPP postdoc.

References: [1] Liebermann, R. C. (2011). *High Pressure Research, 31(4), 493-532.* [2] Kunimoto, T. et al. (2008) *High Press. Res. 28(3), 237–244.* [3] Irifune T. et al. (2016) *Nature Communications, 7, 13753.*