**Community Large Multi-Anvil Press Facility (LMAPF) at ASU through COMPRES**

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We proposed to build a National Multi-Anvil Facility by combining a new 5000-ton press together with existing two 1000-ton presses, two 300-ton presses, and other high-pressure equipment at Arizona State University. The facility will serve the COMPRES community by supporting users in conducting experiments and synthesis of large quantity, high-quality samples at deep mantle pressure-temperature conditions in a large multi-anvil press facility (LMAPF).

**Introduction**

The 6-8 style multi-anvil press has played a vital role in advancing our understanding of processes in the deep interior of Earth and other planets over the past forty-six years since the first report on the technology by Kawai et al. (1970). Over the years, a diverse array of approaches and techniques based on this design have been developed at labs around the world. The standard method uses eight tungsten carbide blocks to press on a ceramic octahedral pressure medium. The size of the blocks was originally 32 mm and the pressure attainable is limited by the deformation or indentation of the steel wedges behind the carbide blocks at the limit of force, or by the size of the press. This configuration can be employed to sample pressures up to about 25 GPa at high temperature (~2000 C). At these conditions sample sizes are only about 1 mm3 (a few mg in mass), limiting our capability to study important physical and chemical processes in Earth and planetary interiors.

The pressure barrier and the sample volume limitation have been recently overcome by using larger presses (hereafter referred to as the large multi-anvil press, LMAP) combined with larger carbide cubes (second stage anvils) at Bayreuth and Ehime. The larger carbide cubes are necessary in order not to exceed the yield strength of the steel first-stage anvils that are permanent parts of the press. In the ‘Botchan’ 6000-ton multi anvil device at Ehime University in Japan (Figure 1), a sample of up to 1 cm3 can be created at pressures up to 18 GPa and temperatures near 2000 K. In this press, polycrystalline nanodiamonds have been created and then used as anvils to achieve the pressure-temperature conditions of the lower mantle (up to 50 GPa thus far) to study important processes such as element partitioning and the deep transport of water (Irifune et al. 2010; Nishi et al., 2014). At the Bavarian Geoscience Institute (BGI), a 5000-ton press has produced many breakthrough results in Earth sciences, including redox conditions and water and carbon cycles (Frost et al., 2004; Stagno et al., 2013). In the BGI press, bridgmanite samples can be made at 25 GPa with dimensions of up to 3-4 mm diameter (Mosenfelder, pers. comm).

Figure 1. LMAP at Ehime, Japan

These capabilities are currently lacking in the US. In June 2015, Dan Shim convened a special COMPRES workshop on community needs for a LMAP. Thirty-five scientists came together to discuss the needs and potential of such a system. The results of the workshop indicated community needs and desires for several types of high pressure systems, including the system proposed here. Such capabilities would also have a profound impact on other communities in the US, such as physics, chemistry, materials science, and engineering. This proposal is an outgrowth of that workshop.

**Plan for a community-serving facility**

We propose to acquire a 5000-ton press to achieve higher pressure-temperature conditions for large volume samples than currently possible in the US. We do not aim to copy the existing capabilities in Ehime and BGI. Our plan is optimized for achieving the broadest possible impacts on the US high pressure community by taking full advantage of ASU’s experiences in managing multi-anvil user facilities and developing standardized and special purpose multi-anvil cell assemblies for the community for more than 20 years. The approach we propose is to take advantage of the openness and diversity of the US community to excel in the development of this critical technology for which the US community is at least a decade behind the Japanese and European communities. We propose to have two programs in the facility.

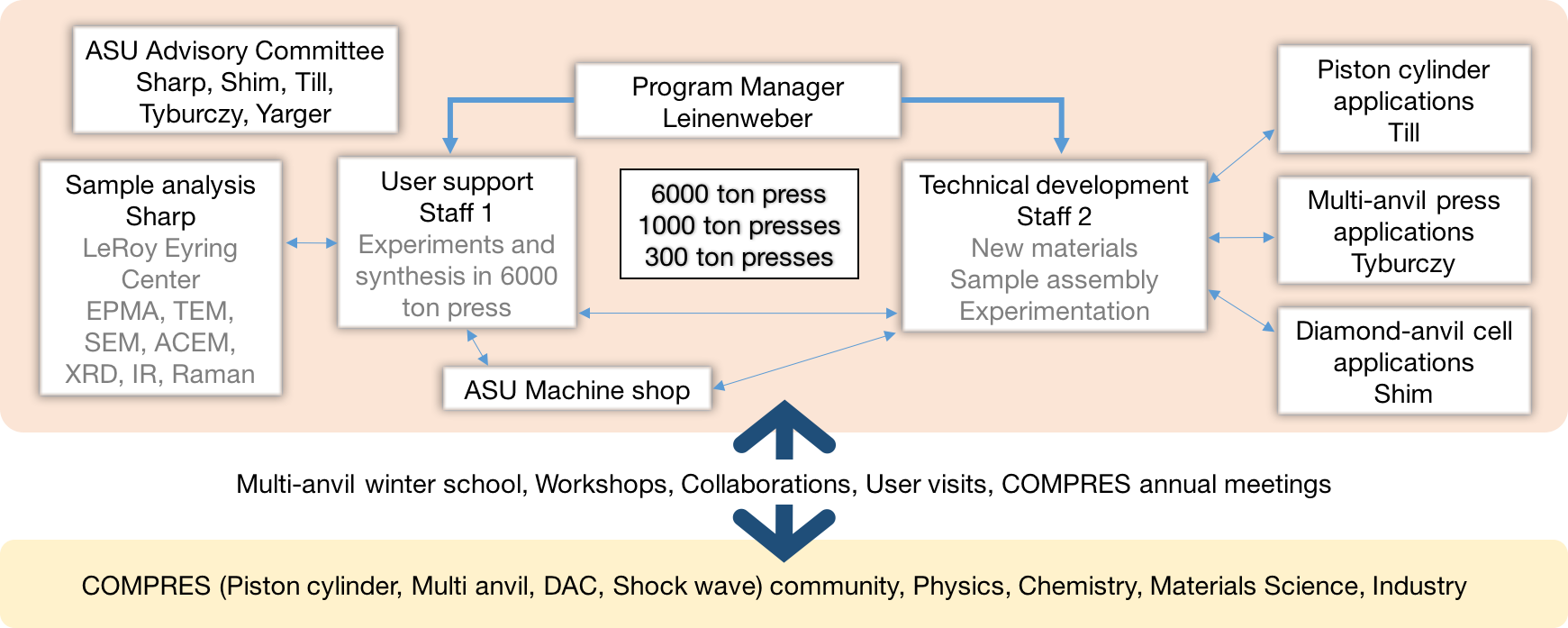


Figure 2. Structure of the proposed ASU multi-anvil press facility and community involvement program.

User program: The large-volume multi-anvil press, LMAP, will be installed alongside currently existing equipment in the ASU high pressure facility consisting of two 1100-ton multi-anvil presses, 3 non-end-loaded piston cylinders, several gas-pressure vessels, a 1-atm gas mixing furnace, 1 atmosphere furnaces, and a laser welder. Sample preparation facilities, saws and other tools also exist in the laboratory. All of these tools will be available to visiting users. A staff member will train and assist the users. The staff will also work with the machine shop at ASU for maintenance of the 5000-ton press and other equipment. We plan to enable users of the facility to conduct the required analysis during their visits, thereby enhancing the success rate of visits. Thus the staff will also coordinate sample analysis with the various analytical instruments available on the ASU campus (EPMA, TEM, SEM, ACEM, XRD, Raman, IR, and FIB, in the LeRoy Eyring Center for Solid State Science, as well as the NMR and NSF-sponsored SIMS and Nano-SIMS facility at ASU) for visiting users.

Development program: The 5000-ton press can make large volumes of high-pressure materials, which opens up the possibility to use these materials as components for high pressure experiments, such as anvils, gaskets, heaters, and electrodes, in the multi-anvil press and diamond-anvil cell. For example, the Ehime group has demonstrated that the LMAP can be used for developing nanocrystalline diamond aggregates that can be used as anvil materials. Also the Misasa group in Japan has developed B-doped diamond synthesized at high pressure in the LMAP, which can be used as effective x-ray translucent heating components for multi-anvil presses and possibly diamond-anvil cells at extreme pressure conditions (Shatskiy et al., 2009). Although such materials have been synthesized using the LMAP in Japan, they have never been openly available to other groups for high-pressure experiments, due mainly to the fact that the programs in Japan are mostly supported by industry and therefore patented (e.g., Sumitomo). By building a community-supported development program at ASU, we will not be bound by such issues and can share new techniques with the whole COMPRES community for the largest possible impact. Such developments will be available for users visiting the facility and will be shared widely with the COMPRES community. This program will also include other experimental technique developments, such as oxygen fugacity control and ultrasound measurements.

We believe that this plan will enable us to achieve the broadest possible impact from a single 5000-ton press, which has not been done by any other LMAPs in other countries. We also believe that our technical developments using the 5000-ton press will enable the COMPRES community to aim for acquiring more specialized LMAPs (large deformation and/or highly aligned multi-axis presses) in other institutions and large user facilities (synchrotron and neutron sources) in the near future.

The plan will also engage the whole COMPRES community in the technical developments through user visits, workshops, and ASU technical experts (Till for PC, Shim for DAC, and Tyburczy for multi anvil press), thereby invigorating research activities in high pressure science that will produce breakthroughs and advance our knowledge in Earth and planetary science, materials physics and chemistry, and engineering. The Center for Solid State Science and SIMS facilities run very successful Winter Schools at ASU every year, and we propose to organize a similar school for high pressure techniques, perhaps coordinating with the other Winter Schools.

**Examples for scientific and technical impacts**

1. Preparation of large (up to ~1 cm3) samples of transition zone and lower-mantle minerals for high-quality property measurements, such as deformation, elasticity, calorimetry, diffusion, rheology, and electrical conductivity, etc. We note that some of these measurements have been impossible due to the sample size limitation in the multi-anvil press.
2. Use of large sample assemblies to control oxygen fugacity and other thermodynamic properties of mantle transition zone and lower-mantle minerals and, importantly, complex multi-mineral phase equilibria.
3. In situ experimentation on large samples of mantle minerals – for example ultrasonic and elastic properties (seismic velocity), diffusion, electrical conductivity, rheology, etc. The ability to perform such measurements is limited by the volume. The device discussed here will facilitate dramatic advances in *in-situ* measurements at high pressures and temperatures.
4. Single crystal growth. Single crystals are uniquely suitable for measurements of any property that depends on direction in the crystal (velocities, structural properties, diffusivities etc).
5. Novel materials to enable higher pressure experimentation. We will pursue experiments that will enable synthesis of polycrystalline nanodiamond for use by the high-pressure community in the US. This material has the potential to greatly expand the pressure range of multi-anvil devices and diamond-anvil cells. This work will also lead to invention and synthesis of other novel materials and has potential for industrial collaborations.
6. Preparation of relatively large volumes of materials to enable sharing of samples between multiple groups for interlaboratory comparisons and calibrations. This work can greatly improve reliability and reproducibility of difficult measurements.

**Why ASU?**

Since the beginning of COMPRES in 2002, ASU has a long history of community-based development of materials and technologies for multi-anvil cell assemblies. Through the long-term efforts of Leinenweber with advice and assistance from Sharp and Tyburczy, and now others in the Advisory Committee, ASU is extremely well-regarded in its reputation for multi anvil capability combined with community service and communication. The ‘COMPRES Multi Anvil Cell Development’ project is the longest-running non-beamline project supported by COMPRES. Materials produced by ASU have been (and currently are being) used by scientists all over the world owing to their reliability, reproducibility, and traceable calibrations (see Leinenweber et al., 2012). Till and Shim are now heavy users of the expertise and capabilities of the ASU Multi Anvil facility, and the facility also hosts users from outside Universities on a regular basis. This spirit of supporting the needs of the broader community sets ASU multi-anvil efforts ahead of most facilities. This range of capabilities is also attractive to industrial users who need exploratory high-pressure work, additional expertise, or more accurate pressure-temperature determinations to assist with their industrial processes. The ASU multi-anvil lab already has ongoing research projects with Sandvik Hyperion in Ohio, for example.

ASU also offers a wide array of supporting facilities – those currently in most frequent use for high-pressure research are powder and single-crystal x-ray diffraction, Raman and IR spectroscopy, electron probe microanalysis, NMR, scanning electron microscopy and transmission electron microscopy. However, there are also many other techniques available and users would be able to potentially break new ground with facilities that have not been highly utilized for high-pressure studies (such as SIMS and Nano-SIMS). In addition, there is a state of the art DAC lab (Shim) and end-loaded piston-cylinder lab (Till) that could be accessed through collaboration (these are PI-operated laboratories and not user facilities). Their role is expected to be vital for the development program proposed here as they will be connections for the broader diamond-anvil cell and piston cylinder high pressure communities.

**Funding/Budget/Operation Plan**

The facility and associated staff will be supervised by Leinenweber in a manner similar to how the current multi-anvil facility is run. We request two staff members for our proposed facility and development program.

We have been accepting outside users into the current high pressure facility at ASU on an open basis – in fact, equal treatment of users is a requirement of the Research Technical Services (RTS) office that supervises ASU facilities. This policy will continue with the renovated facility and the Large-Volume Multi-Anvil Press. Visitors will receive full training in multi-anvil techniques, and advice on sample analysis and help accessing the other facilities at ASU.

Cell assembly materials would be provided to users for the particular experiments they wish to perform. The goal will be to have the full array of cell assemblies for the pressure, temperature and volume ranges needed by the users. What user fees are applied to the experiments, and how to treat COMPRES member users versus other outside users, will be carefully worked out to encourage usage while at the same time allowing the facility to continue operating on a financially stable and sustainable basis.

The development portion of the facility will also be supervised by Leinenweber with input from the local experts (Till for PC, Shim for DAC, and Tyburczy for multi-anvil press). The local ASU experts will also play as liaison to distribute the new technology developed in our program to different high-pressure communities and also to collect feedback from the communities. The COMPRES community and other high-pressure communities will be consulted throughout development including 1) seeking input on the highest priority materials to synthesize, 2) sharing the results of initial development projects and finally 3) in having access to any materials developed through workshops and user trainings.

**Budget**

The budget for the new facility and the sources of funding are outlined here. The press itself will be sought through an MRI proposal to be submitted through Arizona State University. The MRI has been submitted for the 2017 internal competition and we are awaiting word on whether it will be chosen for submission to NSF. The budget listed in the internal submission is $2.9 M and is based on a quotation for a 5000 ton press from Voggenreiter, and includes 2 years of a staff scientist and materials and supplies money for developing and testing the equipment. This would allow a working press to arrive and be fully installed on the floor of the laboratory and working. A space on ground level, with a solid concrete pad floor and a high bay door to allow the press to be moved in, will have to be created by renovations to an existing space and we have a suitable space identified at ASU. The cost of renovations is estimated to be $0.75 M and funding would be sought through other channels.

Staff for the facility would require two positions. One senior scientific research staff member would oversee the installation and use of the press; their salary will be requested through COMPRES. A technician would also be needed, and that technician would be funded through the MRI proposal followed by individual NSF proposals.

The budget for materials and supplies is based on the materials needed for large-volume multi-anvil experiments at an anticipated frequency of 100 experiments per year. Large carbide anvils are available from Fujilloy and possibly other manufacturers – sizes such as 52 mm, 65 mm, and 72 mm are available (compared to the “normal” cube sizes of 26 mm or 32 mm used in 1000-ton presses). The Ehime press, for example, is designed to exchange between these sizes depending on need. Prices per cube range from $1000 for the 52 mm cubes to $2000 for the 65 mm ones.

Cube breakage needs to be kept to a minimum, but it can be expected that users will need to go to high tonnages to achieve their research goals. Thus a realistic rate of cube breakage needs to be taken into account. For 100 runs per year, we can expect a breakage of about 100 cubes (estimated one broken cube per experiment). That, combined with the expendables for cell assemblies, leads to the estimated operating costs of $250 K per year (not including personnel). These costs would be sought from COMPRES (for development and testing only), and from the research budgets of grants that are involved in the research goals of each experiment.

Request to COMPRES first year budget summary (also see attached spreadsheet in NSF format):

Senior staff position (starts at 80 K per year): $341,080 for 3 years, including fringe benefits.

Operations, including tungsten carbide cubes, ceramics, precious metals (Materials and Supplies) and machining (Facility Use Fees): $60,000.

Indirect costs: $231,738

TOTALS: Year 1: $206,606. Year 2: $213,830. Year 3: $221,381.

Sum total for years 1-3: $641,818.

MRI budget summary

5000-ton hydraulic press (Voggenreiter): $1,066,122

Staff scientist (2 years): $152,250 plus fringe and overhead

Materials and supplies: $400,000

Indirect costs: 357,369

TOTAL: 2,930,824

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