The First International Pressure Calibration Workshop was held at Misasa, Japan on August 22-23, 1997. Sixty seven scientists, representing the diamond anvil and multianvil communities from six countries, attended. Thirty seven papers were presented in three oral sessions titled, "Equations of state and the absolute pressure scale", "Multianvil calibration", and "Diamond anvil and other studies" and eight papers were presented as posters. In a final discussion period, it was decided to publish a multi-authored paper describing the Preliminary International Pressure Scale (PIPS-97). It was decided that this scale should contain consensus pressure calibration phase transitions at room temperature, equations for well-characterized phase transitions at high temperatures and pressures, and the equations of state for NaCl, Au, and MgO.

On August 22-23, 1997, 67 scientists from Australia, Germany, Japan, the Republic of China, the United Kingdom, and the United States met at Misasa, Japan to attend the First International Pressure Calibration Workshop (IPCW). The meeting was co-sponsored by the Institute for Study of the Earth's Interior, Okayama University, Japan; by The University of Texas at Dallas, USA; and by the Center for High Pressure Research, a USA consortium involving the State University of New York at Stony Brook, Princeton University, and the Geophysical Laboratory, Carnegie Institution of Washington.

The most recent previous effort to produce international agreement on a pressure scale is the 2nd AIRAPT IPPS Task Group Report [1]. For pressure measurements below 1.4 GPa, they recommended that a primary standard piston gauge should be used. In the absence of such a gauge, they suggested use of the mercury melting curve [2] as a secondary standard. At pressures above 1.4 GPa, they recommended that pressures be referenced to the ruby fluorescence method [3-7] and the equation of state for NaCl [8-10]. Also, they listed preferred values at room temperature for seven fixed-point transitions at pressures ranging from 2.55 to 13.4 GPa.

In the 11 years since the 2nd AIRAPT report [1] was published, two developments have occurred. First, a very large amount of phase equilibrium data has been published at high temperatures and pressures relevant to the deep interiors of the planets. These studies are commonly carried to about 25 GPa using multianvil presses and to a few hundred GPa using diamond anvil devices, far beyond the range of the room temperature fixed points recommended by the 2nd AIRAPT Task Group. Second, although the theoretical basis for a primary pressure scale has been understood for 43 years [11], several groups have only recently begun experimental programs to establish such a scale. The purpose of the First IPCW was to build on and extend previous efforts by the 1st and 2nd AIRAPT Task Groups. To accomplish this task, the multianvil and diamond anvil communities were brought together to work toward the establishment of a primary pressure scale extending to extreme pressures and covering a wide range of temperatures. The Workshop was called the First IPCW to distinguish it from the Second IPCW that is currently being planned.

Thirty seven oral papers and eight poster papers were presented. The Workshop started with a morning session on "Equations of state and the absolute pressure scale". In the initial paper by A. Yoneda and H. Spetzler, an explanation of the complete thermodynamic equation of state was presented and applications were explained for determination of the complete travel time equation of state at simultaneous high pressure and temperature, the absolute pressure scale, and complete thermodynamic analysis on Hugoniot. This theoretical discussion was followed by several papers describing experimental efforts to develop an absolute pressure scale. In the first of these papers, W. A. Bassett, A. Yineda, H. Spetzler, R. J. Angel, H.-J. Reichmann, G. Chen, and A. H. Shen described the design of a new diamond anvil cell that allows simultaneous ultrasonic interferometry and X-ray diffraction study of single crystals at high temperatures and pressures. Then, C.-S. Zha, T. S. Duffy, R. T. Downs, H.-K. Mao, and R. J. Hemley explained how they have used a diamond anvil device to make simultaneous X-ray diffraction and Brillouin scattering measurements up to 32 GPa on a single crystal of San Carlos olivine. From these data, they determined the equation of state of the olivine and found the pressure indicated by the Brillouin scattering pressure measurement to deviate by 0.3% from the ruby fluorescence scale. Next, R. C. Liebermann, G. Chen, B. Li, J. Chen, M. T. Vaughan, and D. J. Weidner explained their use of a DIA-type cubic-anvil press (Sam 85) installed on the Brookhaven synchrotron to make simultaneous X-ray and ultrasonic measurements on alumina, Mg2SiO4 (olivine and wadsleyite), and MgSiO3 garnet at 9 GPa and 1500 K. M. Manghnani and J.-A. Xu then described their plans to conduct simultaneous Brillouin scattering and X-ray diffraction measurements in a diamond anvil cell. On the basis of simultaneous single crystal X-ray diffraction on
fluorite and quartz, R. Miletich, R.J. Angel, and L. W. Finger reported that the Decker equation of state and the ruby fluorescence scale are accurate to <0.3% at pressures <9 GPa. Other papers in this session discussed misalignment of X-ray diffraction optics caused by deformation during application of pressure (Y. Zhao, R. B. Von Dreelle, D. J. Weidner, and S. M. Stishov); use of the P-V-T equation of state of CaO, as determined by molecular dynamics simulation, as an internal pressure calibration standard (M. Matsui); constraints on equations of state based on Hugoniot compression curves (T. Mashimo, M. Uchino, Y. Syono, and D. E. Grady); use of the hexagonal-BCC phase transition of Zr at 33 GPa as a pressure calibration point (Y. Akahama and H. Kawamura), and a review of various candidates for fixed points (A. Onodera, A. Ohtani, O. Shimomura, and Takemura).

The afternoon session was devoted to multianvil calibrations. The first three papers discussed various aspects of calibration of the Walker-style MA-8 apparatus (D. Tinker, G. M. Baxter, and C. E. Lesher; C. B. Agee; S. W. Parman, A. D. Holheid, and T. L. Grove.). This was followed by a discussion of temperature-pressure precision of multianvil experiments at pressures less than 7 GPa (D. C. Pressnall), a test of individual and group precision (M. J. Walter, E. Ito, M. Kanzaki, T. Katsura, and S. Ono), a proposal to use phase relations in the system CaO-Mgo-SiO$_2$ as a calibration grid (T. Gasparik), a discussion of uncertainties in phase transitions due to volume changes and metastability (D. C. Rubie), a discussion of phase boundaries between various hydrous phases in the system Mg$_2$SiO$_4$-Fe$_2$SiO$_4$-H$_2$O (T. Inoue, J. Chen, D. J. Weidner, and H. Yurimoto), and pressure calibration using sintered diamond anvils at pressures greater than 30 GPa (E. Ito and T. Katsura). Y. Wang et al. described a new multianvil (MA-8 or 6/8) press designed for in-situ X-ray diffraction studies that is being installed at the GeoSoilEnviroCARS sector at the Advanced Photon Source, USA. This facility will permit in situ X-ray diffraction studies over the entire range of pressures and temperatures accessible to the MA-8 apparatus (about 2500°C at 25 GPa), a capability that will significantly improve pressure calibration for this type of apparatus. The session concluded with four additional papers on the melting curve of gold to 20 GPa (N. Nishiyama, T. Irfune, and S. Urakawa); the breakdown of diopside (CaMgSi$_2$O$_6$) to CaSiO$_3$ and MgSiO$_3$ (T. Irfune, M. Miyashita, K. Kuroda, and T. Uchida); and a redetermination of the β-γ transition in MgSiO$_3$ and the ilmenite-perovskite transition in MgSiO$_3$, and suggested use of these transitions as pressure calibration points at high temperatures (T. Kato, E. Ohatani, H. Morishima, T. Kubo, A. Suzuki, T. Kikegawa, and O. Shimomura).

The morning of the second day was devoted to diamond anvil and other studies. Six papers concerned diamond anvil studies and five papers described a variety of other studies using multianvil presses. Two of the diamond anvil papers discussed pressure determinations using the ruby scale (J. M. Brown, E. Abramson, L. J. Slutsky, and S. Wiryana; E. Huang and J.-A. Xu). The other four described uncertainties in pressure determinations as estimated by in situ X-ray diffraction studies (G. Shen and Y. Wang), the effect of stress on X-ray determinations of molar volume and pressure determination (T. Yagi, T. Uchida, and N. Funamori), the effect of stress on the transition pressures of ZnS, GaP, and Zr (T. Uchida, T. Yagi, K. Oguri, and N. Funamori), and procedures for improved pressure and temperature measurements (R. Boehler and G. Serghio). The final five papers of the Workshop discussed statistical methods for treating phase equilibrium experiments (A. Kavner, T. Speed, and R. Jeanloz); the temperature dependence of pressure measurement in a multianvil apparatus (I. Aoki and E. Takahashi); phase equilibrium data for the potential pressure calibrants, ZnTe and CdTe (K. Kusaba, Y. Syono, T. Kikegawa, and O. Shimomura); and a discussion of experimental procedures for a large-volume belt-type apparatus in the 10 GPa region (M. Akaishi, S. Yamaoka, and H. Yamada).


A final open discussion on the afternoon of the second day addressed two main issues; (1) the immediate need for a set of consensus calibration curves at high temperatures (1000°-2000°C) and pressures (up to 25 GPa) that would allow a more orderly comparison of multianvil data from different laboratories, and (2) the best way to tie reference pressures for phase transitions to the absolute pressure scale. It was decided to publish a multi-authored paper describing the Preliminary International Pressure Scale (PIPS-97), which will consist of consensus values for fixed point transitions at room temperature, equations for preliminary reference transition curves up to about 25 GPa at high temperatures, and the equations of state for NaCl, Au, and MgO. Because the recommended transition curves have not yet been tied to the absolute pressure scale, PIPS-97 must be considered to be only temporarily useful. Nevertheless, it was agreed that it is important to publish such a reference scale so that data from different laboratories can be compiled in a more orderly manner. Even though the scale will certainly be shown by future work to contain errors, perhaps even serious errors, the widespread use of a common scale will allow better
comparisons of studies from different laboratories. It was decided that authorship should consist of all those who wished to participate. The authors will be listed alphabetically at the end of the paper, and an acronym will be used for the authorship of the paper. The acronym will reference the alphabetical listing at the end of the paper. A web site will be established at The University of Texas at Dallas that will serve as an electronic source for all the data for PIPS-97, and this web site will be referenced in the published version of PIPS-97.

The second issue concerning the need to tie secondary standard phase transitions at high temperatures and pressures to the emerging absolute pressure scale was also discussed. A problem is that precise determination of the absolute pressure scale is needed by multianvil users at temperatures up to 2000°C; but externally-heated diamond anvil devices, which have good temperature control and which can therefore be used for equation of state studies, are not capable of reaching these high temperatures. It is not yet clear that laser-heated diamond anvil devices, which have more robust temperature capabilities, can determine temperature with sufficient accuracy for reliable determinations of equations of state. However, R. Boehler presented an interesting paper suggesting that this may be possible. As an alternative, it was emphasized during the discussion that the recent development of MA-8 presses capable of studies involving in situ X-ray diffraction will significantly improve the precision and accuracy of the secondary standard calibration curves.

At the Second IPCW, tentatively planned for 1999, it is anticipated that the absolute pressure scale will have been developed to a more mature level both by multianvil and by diamond anvil studies, and that some of the reference transitions for PIPS-97 will have been tied to this scale. This should allow publication of a revised PIPS.


References