

Introduction

Laboratory measurements of the sound velocities and elastic properties of minerals are indispensable for understanding the deep Earth and other planetary bodies. Although direct samples of the Earth's mantle are available, for example as diamond-bearing xenoliths, such samples are relatively rare, may not be representative of the mantle as a whole, and the conditions under which they formed are still a matter of debate. In contrast, seismological investigations of Earth's velocity structure provides global information on the in-situ properties of the interior at depth. Tomographic studies are providing detailed 3-D images of fast and slow regions which relate not only to our notions of the current compositional state of the mantle, but to convective flow and mixing over time (e.g., Forte et al., 1995). We can now "see" the penetration of some slabs into the lower mantle (Grand et al., 1997), the stagnation of other slabs in the transition zone (e.g., Widiyantoro et al., 1999), and broad differences in velocity structure beneath continents and oceans (Forte et al., 1995). In other studies of reflected and converted seismic phases, subtle undulation in the depths of seismic discontinuities are being mapped and related to the properties of phase transformations which likely cause them (Castle and Creager, 1998; Flanagan and Shearer 1998; Gu et al., 1998; Helffrich, 2000). At the core-mantle boundary, we see astonishing degrees of heterogeneity and complex velocity structure which may be related to chemical reactions between the mantle and core, and/or the recycling of subducted material in a slab graveyard (e.g., Garnero et al. 1998). It is now clear that the mantle and core are not as simple as previously thought. The role of average 1-D models such as PREM and IASP-91 is being reevaluated as the heterogeneity due to subduction and upwelling plumes is being documented. As new seismological initiatives come on line, such as the US Array component of Earthscope, mantle structure will be imaged with yet greater resolution and with broader global coverage. It is not, however, a simple matter to connect the fast or slow velocities in tomographic images with actual mantle temperatures or composition, and it is here that mineral physics plays a crucial role. Laboratory measurements of velocities and elastic properties allow the raw information provided by seismology to be interpreted in terms of physically meaningful quantities such as chemistry and temperature. In effect, these lab-based measurements are the language that allows seismic results to be translated into other quantities of interest. Without accurate information on the variation of mineral velocities with temperature, pressure, and composition, it is not possible to form a realistic picture of Earth's interior.

With this Grand Challenge, we have attempted to assemble groups of mineral physicists from around the country who are working to measure acoustic velocities of Earth materials at high pressure. By working together we have a unique opportunity to move towards our goals. We propose a highly coordinated program involving a number of complementary techniques with the aim of accurately determining the sound velocities of minerals at P-T conditions encompassing those in Earth's lower mantle and approaching those at the core-mantle boundary. Our approach will be:

- 1 To exploit the current level of technology with a coordinated attack on measuring and modeling elastic properties. High-pressure synthesis of samples is essential and will be led by Zhang (Stony Brook). We will begin with olivine and its polymorphs and progress through community consensus. We will also make a major effort to characterize ‘standard materials’ that can be used as pressure calibrants. These acoustic techniques have the possibility of defining absolute pressure scales. We will continually compare results between experimental techniques and between experiment and theory and will attempt to rationalize the differences. A yearly workshop will be held for this purpose, and to set future priorities.
- 2 To push the technological frontier. All of the experimental techniques that are available have developed enormously over the last decade, and some are still in their infancy. None of these techniques are yet capable of providing the ultimate type of data. The use of the synchrotron is particularly youthful and full of future potential.
- 3 To broaden community access to highly specialized techniques which have, to this point, been limited to a few highly trained specialists. Broader community access will bring broader community input and faster progress in both the technological and scientific domains.

We contend that our goals have the highest probability of being fulfilled through a collaborative approach involving several institutions and experimental techniques. The institutions and individuals included in this collaboration are: University of Illinois Urbana-Champaign (J. Bass), SUNY at Stony Brook (D.J. Weidner, J. Parise, B. Li, J. Zhang), Carnegie Institution of Washington (R. Hemley, H-k Mao), University of Colorado (H. Spetzler), University of Washington (J.M. Brown), University of Minnesota (R. Wentzcovitch), University of Michigan (L. Stixrude), and Delaware State University (G. Gwanmesia).

Rationale for an Elasticity Consortium: It is an opportune time to undertake the proposed collaborative research due to advances in experimental techniques and sample synthesis capability. Over the past 15 years, enormous progress has been made in our ability to both measure and calculate the velocities of high-pressure mantle silicates and oxides. Two decades ago, it was a major achievement to measure the elastic moduli of a germanate, titanate, or other chemical analog of an actual mantle silicate to a few kilobars and/or several hundreds of degrees. In contrast, it is now possible to measure the single-crystal elastic properties of high pressure silicate phases such as wadsleyite (Zha, 1997) or ringwoodite (Sinogeikin et al., 2001) to pressures at or near those in the transition zone. Single-crystal sound velocity measurements have also been carried out to temperatures of ~1500C (Sinogeikin et al., 2000). Our ability to perform accurate velocity and elastic modulus measurements on actual mantle silicates has come about through a long sequence of technological breakthroughs. The development of spectroscopic techniques such as Brillouin scattering (see section by Bass below) and impulsively stimulated scattering (section by Brown below) allowed elasticity studies on microscopic sized samples, and in particular on synthetic crystals of dense mantle silicates. After years of refining these techniques for work with progressively smaller samples, they were adapted for accurate measurements in diamond cells using 10-15 μm -thick slivers of material (Duffy, 1995; Sinogeikin and Bass, 2000). Polycrystalline samples of high-pressure silicates can now be produced with nearly theoretical density and several mm^3 in volume for ultrasonic velocity measurements at high P&T in a multi-

anvil apparatus (Gwanmesia 2000, Rigden, 1991). Gigahertz ultrasonic velocity measurements can now be performed for both P and S waves in a diamond anvil cell (section by Hemley et al. below). Formidable technical hurdles in the areas of instrument development, data collection methodology, data reduction, sample synthesis, and sample preparation have been overcome for all of these techniques. Most of the methods listed here have matured to the point that clear strategies are now in place for significantly advancing the accessible P-T range.

The availability of samples often limits the scope of an experimental research agenda. Synthesizing samples of high-pressure silicates is difficult and time-consuming, especially high-quality single crystals or polycrystals. One must often rely on informal relationships to acquire samples, and it is difficult to persuade a colleague to dedicate resources toward a major synthesis effort. Therefore, this collaborative effort will include provisions for sample synthesis. Over the last 10 years, the Center for High Pressure Research (CHiPR, an NSF Science and Technology Center) has gained enormous experience in synthesizing samples, both polycrystals for ultrasonic measurements and single-crystals for x-ray diffraction and other measurements. To undertake a coordinated study of the most important mantle minerals, a source of high quality specimens is required, and we will use the synthesis facilities of Stony Brook to obtain samples for our elasticity work. Stony Brook's facilities and especially their experience in fabricating high quality specimens will be indispensable for the success of this proposal.

We will as a group make an effort to measure the elastic properties of Fe-bearing olivine, its high pressure polymorphs β and β' ($\text{Mg,Fe})_2\text{SiO}_4$, and silicate perovskites $(\text{Mg,Fe})\text{SiO}_3$ (both with and without minor aluminum). These phases are basic reference points for our understanding of mantle chemistry and dynamics, but thus far their elastic properties are unmeasured at the P-T conditions of the transition zone. Moreover, most of the measurements that have been performed to date were done using pure Mg end-members, and not on Fe-bearing compositions most directly applicable to the Earth's mantle. Stony Brook will be responsible for synthesizing both single crystal and polycrystalline samples of the needed silicate phases. Our other primary targets are materials which are useful as high-pressure and high P-T calibration standards, such as NaCl, Au, Pt, and MgO. The importance of these standard materials cannot be overemphasized. For example, it is currently not known whether the β/β' perovskite transformation in Mg_2SiO_4 occurs at a pressure corresponding to the 660 km discontinuity, or much shallower (Irifune et al., 1998). This question comes about because of uncertainties in pressure calibration. Characterizing standards is a first-order problem that is best approached through a community effort.

As we make progress towards characterizing the properties of our primary target materials under transition zone P-T conditions, the members of this collaboration will collectively decide upon where to focus our future efforts. These decisions will be made at workshops for participants in this Grand Challenge collaboration.