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Introduction

New Developments in High Pressure Mineral Physics and Applications to the Earth's Interior

Geophysical measurements, such as the lateral variations in seismic wave velocities that are imaged by seismic tomography, provide the strongest constraints on the structure of the Earth's deep interior. However, in order to interpret seismic velocities and the associated density and elastic property estimates in terms of mineralogical/compositional models of the Earth's interior, data from mineral physics are essential. Consequently, considerable effort has been made over the last 30 years to determine the physical and chemical properties of Earth materials (minerals, rocks and melts) under the relevant conditions of high temperatures and pressures. Thermodynamic properties, phase equilibria, crystal chemistry and crystallography at high pressure are examples of areas in which major contributions have been made. Many experimental measurements have been made possible only by a range of technical developments in the quest to achieve high pressures and temperatures in the laboratory. At the same time, analytical methods, including X-ray diffraction, a variety of spectroscopic techniques, electron microscopy, ultrasonic interferometry, and methods for rheological investigations have been developed and greatly improved. In recent years, major progress has been made also in the field of computational mineralogy whereby ab initio simulations are used to investigate the structural and dynamical properties of condensed matter at an atomistic level. These numerical techniques provide an important tool for understanding the fundamental physics behind experimental observations and for probing mineral properties at pressure and temperature conditions not currently accessible by experimental techniques.

Early developments in the field of high-pressure research in Earth Sciences took place mainly in USA and Japan. In the period 1976–1996, scientists in these countries organised and participated in a series of small meetings entitled "US–Japan Seminars on High Pressure–Temperature Research" approximately once every 5 years. The participants (normally around 60) originated almost exclusively from Japan and USA. A notable result of these small meetings was the publication of a series of high quality volumes that beautifully summarized the scientific and technical developments of high-pressure research in mineral physics. Today, these volumes still represent indispensable reference sources. The last three of these volumes were published by the American Geophysical Union, in 1987, 1992 and 1998, as Geophysical Monographs (volumes 39, 67 and 101, respectively).

In the last 15 years, high-pressure research has become more international and leading institutes are now also located in countries such as France, Germany and UK. Because the field is still developing rapidly, both technically and scientifically, a new series of small international meetings has now been established that replace the old "US–Japan" meetings. The new meetings are called "High Pressure Mineral Physics Seminars" (HPMPS) and the first of these, HPMPS-6, took place in Verbania (Northern Italy) on August 26-31, 2002 (following on from the five earlier US–Japan Seminars). More than 90 scientists attended and the number of scientific contributions (talks and posters) was also about 90. This volume has arisen largely from this meeting but also includes a number of contributions from scientists who did not participate.

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The aim of this volume is to present an overview of recent developments in high-pressure mineral physics. As can be seen from the contents, the contributions cover a broad range of topics. Although we have attempted to group the 49 papers according to topic, many contributions actually cover two or more aspects.

The first eight papers deal with studies of the elastic properties of mantle minerals—which, as mentioned above, are essential for deriving mineralogical and compositional models of the Earth's mantle from seismic data. As detailed in the various papers (and also in the section on technical developments), elastic properties can now be measured at high pressures using a variety of different techniques, including X-ray diffraction, inelastic X-ray scattering, ultrasonic interferometry at GHz and MHz frequencies, and Brillouin spectroscopy.

In the following section on phase equilibria, contributions deal with mantle mineralogy in realistically complex chemical systems—the results of which are required for developing improved elastic models of the Earth's interior and for interpreting the causes of seismic discontinuities. The effects of oxygen fugacity on mantle mineralogy are discussed as well as mineralogy and crystal chemistry in FeO-bearing systems. It is still challenging to study phase equilibria under conditions of the deep lower mantle and this section includes several state of the art contributions in this research area.

The section on fluids and volatiles in the Earth is the outcome of the realization, which has developed over the past 15 years, that many mantle minerals can accommodate significant quantities of water into their structures. Consequently, water (and other volatiles such as CO_2) are cycled readily between the surface (hydrosphere and atmosphere) and the Earth's deep interior through processes such as subduction and volcanism. At any given time, an enormous volume of water can be stored potentially in the Earth's mantle. Because dissolved water has profound effects on mineral and rock properties (e.g. rheology, diffusion and electrical conductivity), melting processes and the thickness of seismic discontinuities, attempts are made to identify water-rich regions in the mantle, for example using seismic tomography. For this purpose, it is essential to know how dissolved volatiles affect the structure and elastic properties of minerals—which are the topics of several papers in this volume.

In the area of transport properties and rheology, important advances have been made in the last few years, as documented in the five papers of this section. These include measuring heat transport properties (thermal conductivity) in situ at deep mantle conditions and innovative methods for studying the rheology and deformation behavior of mantle materials at high pressures and temperatures. Rheological data are urgently required for understanding the cause of deep earthquakes and modeling mantle convection. Recent progress in this field has been impressive, although the determination of steady-state flow laws during high strain deformation at low strain rates under deep mantle conditions is still elusive.

The volume continues with a set of contributions on melting relations and element partitioning at high pressure. The aim of such studies is to constrain not only melting temperatures deep in terrestrial planets but also to understand the early differentiation of the Earth. Early geochemical evolution during the early accretional history of the Earth and other planets likely involved the crystallisation of deep magma oceans as a consequence of giant impacts.

The properties of iron, particularly with reference to understanding planetary cores, are the subject of several papers. Experiments at conditions of the Earth's core are still extremely challenging and important topics addressed include the crystal structure at ultrahigh pressures, theoretical study of magnetism in iron, and the density and structure of non-crystalline iron. In the case of Mars, equations of state of core forming iron alloys also provide important constraints on the internal structure of the planet.

The final section is concerned with recent technical developments. These papers include reports on new types of multianvil apparatus, the measurement of high pressures and temperatures in multianvil and diamond anvil cell experiments, measurement of elastic properties, recent developments of new diamond-based materials that are potentially valuable for use as anvils in generating high pressures, and some new spectroscopic tools for probing material structures at the atomistic level.

Finally, we would like to thank all the authors for contributing to this volume and especially to the numerous referees who have dedicated their valuable time and assistance in providing detailed and constructive reviews.

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