Physics and Chemistry of the Earth's Interior

Crust, Mantle and Core

Edited by

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Indian National Science Academy
A Platinum Jubilee Special Issue

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**Gupta & Dasgupta: Physics and Chemistry of the Earth's Interior
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Professor Kenzo Yagi (1915 – 2008)

This volume is dedicated to Professor Kenzo Yagi, for his remarkable achievements and contributions to the field of experimental mineralogy and petrology, particularly with reference to the genesis of alkaline rocks and volcanology.

Editors

Foreword

The Indian National Science Academy was established in January 1935 with the objective of promoting science in India and harnessing scientific knowledge for the cause of humanity and national welfare. In 1968 it was designated as the adhering organisation in India to the International Council for Scientific Union (ICSU) on behalf of the Government of India. Over the years, the Academy has published a number of journals, volumes, biographical memoirs, etc.

The year 2009–2010 will be specially celebrated to mark the Platinum Jubilee of the Academy. Many programmes are planned in different centres in India on this occasion. In addition, the Academy has decided to publish a number of special volumes on different subjects ranging from earth sciences to life sciences. This volume is on Physics and Chemistry of the Earth's Interior.

One of the main objectives of geophysicists is to establish the internal structure of the earth as revealed by seismic tomography. It is also their primary goal to correlate geophysical data to reveal thermal and chemical state of the crust, mantle and core of the earth. In order to interpret seismic velocities and associated density and elastic properties in terms of mineralogical and petrological models of the earth's interior, thermodynamic and high-pressure temperature data from mineral physics are essential. With the advent of different types of multi-anvil and laser-heated diamond anvil equipment, it is now possible to simulate conditions prevalent even in the lower mantle and core of the earth.

With high P-T experimental studies on essential mineral phases during the past three decades, it is now possible for mineral physicists to develop a clear picture about the earth's interior and dynamic processes associated with it. Seismological studies provide additional constraints on these models.

Leading national and international scientists have contributed to this special issue and I sincerely hope that this volume will throw further insight into our quest to understand how the earth works.

M. Vijayan

President, Indian National Science Academy, India

Preface

During the past three decades, considerable amount of geophysical studies have been done towards establishing various seismological discontinuities from the surface to the core-mantle boundary of the earth. Two major discontinuities, one at 35–45 km below the continents (10–15 km below the oceans) and the other 2850 km below the surface, divide the earth into 1) crust, 2) mantle and 3) core. In most cases these discontinuities are associated with increase in density of the earth materials associated with velocity jumps as a function of depth. In some cases there is a sudden drop in the seismic velocity because of the presence of melt or occurrence of low-density materials subducted underneath.

Development of multi-anvil and laser-heated diamond anvil high-pressure equipment in recent years, have helped mineral physicists to establish different phase transformations of mantle minerals, which are associated with changes in the rheological properties, increase in density or variation in elastic constants of the earth materials.

The present volume encompasses several papers related to Physics and Chemistry of the crust, their metamorphic history as a function of pressure and temperature, mode of melt generation in the crust and their migration. There are also experiments related to the causes of orogenic events associated with plate tectonic processes in the upper part of the mantle. Another group of authors discusses about phase transformation of mantle minerals and their correlation with respect to various seismic discontinuities, the thermal state of the mantle and genesis of convective cycles.

Conservation of mass during metamorphic reactions is emphasised by *Sengupta* and *Dasgupta (Chapter 2)*, who use the singular value decomposition method to balance metamorphic reactions. Texturally-constrained metamorphic reactions from the Chilka Lake anorthosite complex are balanced to evaluate the nature of mobile elements during metamorphic reconstitutions. In the process they characterise the Pan-African thermal overprint in the Eastern Ghats Belt, India. The result has important implications on Indo-Antarctic correlation during Neoproterozoic.

Mandal et al. discuss geodynamic models pertaining to the development of large-scale fold belts (*Chapter 3*). In this paper they review some of the important models in context of the Himalayan-Tibetan system, which is believed to be the most spectacular collision type orogenic belt. The authors deal with theoretical and experimental models that address large-scale phenomena in orogens. Over the past two decades, geoscientists and geophysicists have extensively used wedge tectonic models to explain several tectonic processes in mountain chains, such as sequential thrusting, folding and rock upliftments. The wedge models pivot principally on two considerations: 1) choice of boundary conditions and 2) rheology of the crust.

Brown and *Korhonen (Chapter 4)* review the processes of melt generation during various types of metamorphism ranging from ultra-high-pressure to ultra-high temperature terranes. They discuss the source of heat to account for very high temperatures in the crust. Partially molten rocks invariably lose melt, but the nature of the melt escape channels varies with the volume of the melt produced. Bulk of the melt in the crustal rocks is produced by dehydration–melting. Melting and effect of melt loss are evaluated through quantitative phase equilibria modelling of two common crustal rock types, viz. pelites and aluminous greywackes.

Ganguly and *Tirone (Chapter 5)* address a fundamental problem related to retrieval of cooling history of rocks from mean closure temperature versus cooling age data of multiple geochronological systems. They discuss and review recent developments between the cooling age and cooling rate relations and show how cooling rate can be retrieved without knowledge of mean closure temperature. Further, mean closure temperature for a specific system, grain size and geometry can be retrieved from inferred cooling rate.

Estimation of pressure-temperature conditions of metamorphism remains a prime target for metamorphic petrologists. However, *Essene (Chapter 6)* argues that many of the geo-thermo-barometers suffer from severe inadequacies. This is particularly true for empirical thermo-barometers, and he cites several instances through a careful re-evaluation. He considers that the newly developed thermo-barometers in the system, Ca-Zr-Ti-Q, could be potentially usable, provided proper pressure corrections are employed for thermometers and activity of TiO_2 is correctly estimated.

Santosh (Chapter 7) argues that magmatic, metamorphic and metasomatic fluids play a pivotal role in the geochemical and tectonic evolution of the earth. The nature of fluids varies with tectonic settings. The fluid budget in the earth is controlled by various processes operative in the crust and mantle, and there could be significant crust-mantle interactions through fluid transport.

Rai, Suryaprakasam and *Gaur (Chapter 9)* discuss mantle discontinuities beneath India from the south Indian Archean cratons to the Himalayan subduction zone. Their results show presence of Lehmann discontinuity at a depth of 220–250 km beneath southern part of India. The 410 km discontinuity is sharp and at its normal depth beneath the Precambrian terrains and is elevated by 10–15 km in the Ganges basin and the Himalayas. They suggest that there was progressive cooling or thickening of the Indian lithosphere towards its northern margin. They also observe a 660 km discontinuity with a broad double peak beneath the Himalayas and southern India. They interpret this to be due to the presence of non-olivine component in the deep mantle. Apart from the above-mentioned global discontinuities, a velocity interphase is mapped at 475 km depth beneath Ladakh. The transition zone in the mantle show 10 km thickening beneath the Ganges basin, suggestive of the presence of relatively cold material within. The elevated 410 km discontinuity beneath the Ganges basin and the Himalaya is interpreted as the signature of north-east subducting the Indian slab and perhaps part of the Tethyan oceanic lithosphere in front of it.

Singh (Chapter 10) concludes that the present thermal structure of the crust can be constructed using the available heat flow and radiogenic heat data with steady state heat conduction models, which are temperature-dependent; and require thermal conductivity and depth-dependent radiogenic heat data. Thermal models are also needed to study the influences of heat, effect of additional materials to the crust, reordering of heat sources, temperature flux in the mantle, uplift and erosion-related events and fluid transport in the Indian crust. He summarises several thermal models useful in constraining above processes and emphasises that geological events leave behind signatures, which are embedded in the Indian crust.

Manglik (Chapter 11) thinks that solid state convection is the main heat transport mechanism in the earth's mantle because of significant temperature difference between the base of lithosphere and the core-mantle boundary. Mode of convective circulations in the mantle, induced by thermal heating, can be described using the fluid dynamical modelling approach. Initially some analytical models were developed to understand the process of convection in the mantle. However, the complexity of the structure, dependence of rock properties on pressure and temperature, grain-size effects, distribution of plate boundaries, presence of heterogeneous boundary layers, etc. have led to the development of numerical techniques to understand the dynamics of the mantle, plume-lithosphere interaction, flood basalt volcanism and ridge and subduction-related processes. Ever-increasing computing power has helped us in the development of more realistic models of the mantle dynamics. A brief overview of mathematical formulation and some of the applications of mantle convection modelling has been presented in this chapter.

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