# Preface

In this book, I would like to share my research experiences in the field of earthquake seismology; in particular, using seismic tomography to study seismotectonics, volcanism, and the interior structure and dynamics of the Earth and Moon. To date, I have been fortunate to have studied and worked at eight universities in China, Japan, and the USA, and so I have had opportunities to become acquainted with many outstanding scientists working in various fields of the Earth sciences, and to collaborate with some of them in studying seismic structure and geodynamics of many different regions and tectonic settings.

As an undergraduate student, I studied in the Department of Geological Sciences, Peking University, from 1980 to 1984, where I acquired a basic knowledge of Earth sciences and participated in the 2–8 week field geology course every year in northern China. This helped me realize that geological structures and processes are very complicated and can hardly be described precisely using mathematical and physical methods. Between November 1984 and September 1985, I joined an intensive course for learning Japanese at the Dalian University of Foreign Languages, where I met 99 students from different universities in China, selected from various fields including natural sciences, social sciences, engineering, agriculture, and medical sciences. From these classmates, I learned the main concepts, issues, and research approaches of their respective fields. In October 1985, we 100 Chinese students went to study at the Japanese national universities. Five years later, most obtained a Ph.D. degree in Japan, and now many of them are distinguished experts in their fields.

In the period April 1986 to March 1991, I was a graduate student in the Department of Geophysics, Tohoku University, and my advisors were Profs. Akio Takagi, Akira Hasegawa, and Shigeki Horiuchi, who introduced me to the field of earthquake seismology. With their kind and helpful guidance, I studied the Conrad and Moho discontinuities beneath NE Japan (Tohoku) for my Master's thesis, and worked on the seismic tomography of the Japan subduction zone for my Ph.D. thesis. From April 1991, I spent one year in the Geophysical Institute (GI), University of Alaska Fairbanks as a post-doctoral fellow, and I worked with Prof. Douglas Christensen on the tomographic imaging of the Alaska subduction zone. I was impressed by the then GI director Prof. Syun-Ichi Akasofu's aurora study. During May 1992 to

April 1995, I was a Texaco post-doc fellow at the Seismological Laboratory of the California Institute of Technology (Caltech), and Prof. Hiroo Kanamori was my advisor. I learned the basic facts of earthquake source studies from Prof. Kanamori, and I worked with him on the high-resolution tomographic imaging of the source zones of large crustal earthquakes, including the 1992 Landers (M 7.3), the 1994 Northridge (M 6.7). and the 1995 Kobe (M 7.2) earthquakes. I was impressed by Prof. Kanamori's earthquake source studies, Prof. Don Anderson's global seismology, and Prof. Don Helmberger's waveform modeling studies. In my first year at Caltech, I was supported by a fellowship from the Southern California Earthquake Center (SCEC), and so I had opportunities to report my works to the then SCEC director Prof. Keiiti Aki, who was at the University of Southern California. Prof. Aki kindly gave me thoughtful comments and suggestions on my tomographic studies.

During May 1995 to June 1997, I worked in the Department of Earth and Planetary Sciences, Washington University in St. Louis, as a research scientist, where I worked with Prof. Douglas Wiens on the tomographic imaging of the Tonga subduction zone. At the weekly seminars, I was impressed by Prof. Julie Morris's geochemical study of arc magmatism and Prof. Michael Wysession's study of the deep Earth structure. In St. Louis, I also worked on the stress tensor inversion for the 1994 Northridge earthquake area. In July 1997, I moved to the Department of Earth Sciences, University of Southern California (USC), as a research scientist, where I continued my study of local and regional tomography. At USC, I was impressed by the fault-zone trapped-wave study by Dr. Yong-Gang Li and Prof. K. Aki.

Beginning in February 1998, I spent nine years at Ehime University, Japan, as an associate professor, and then as a full professor from January 2003. I established my laboratory where I worked with my graduate students, post-docs, and visiting scholars to make extensive studies of multiscale seismic tomography. I started my study of global seismic tomography in 1999 and used global tomography to study hotspots, mantle plumes, and deep subducting slabs. I also invited many able researchers and students from India, China, the USA, Spain, Egypt, Taiwan, Korea, and South Africa to study in my lab, and we collaborated to study the 3-D crustal and mantle structure, seismotectonics, and volcanism in different regions and tectonic settings. We developed the off-network tomography method to study the 3-D velocity structure beneath oceanic regions. We proposed the big mantle wedge (BMW) model to explain the intraplate magmatism and mantle dynamics in East Asia. I had the idea to study seismic tomography of the Moon and we obtained a good result.

In April 2007, I moved back to my alma mater, Tohoku University, as a professor of geophysics. I worked with my colleagues and students on the global tomography, the East Asia mantle tomography, and the detailed structure of the Japan subduction zone. We presented tomographic images of the source area of the great 2011 Tohoku-oki earthquake (Mw 9.0) soon after its occurrence. We also worked on P-wave anisotropy tomography, and applied the new method to study the seismic anisotropy and structural heterogeneity of many subduction zones and continental regions. Recently, we worked on the 3-D attenuation (Qp and Qs) structure of the Japan subduction zone.

The main results of these multiscale tomographic studies are summarized in the present book, especially the results obtained during the past decade. To date, several nice books on seismic tomography have been published. The first one, *Seismic Tomography: With Applications in Global Seismology and Exploration Geophysics,* edited by Nolet (1987) and written by 17 authors, summarized the early theoretical developments of seismic tomography and its applications in exploration geophysics and global seismology. The second book is *Seismic Tomography: Theory and Practice,* which was edited by Iyer and Hirahara (1993) with contributions by 49 authors. Except for a few chapters which focused on the technical aspects of seismic tomography, most of the chapters in Iyer and Hirahara (1993) introduced applications of seismic tomography to various regions and tectonic settings, from local to global scales. The third book, *A Breviary of Seismic Tomography: Imaging the Interior of the Earth and Sun,* written by Nolet (2008), focused on the theoretical aspects of seismic tomography and contained many mathematical equations. The present book describes the state-of-the-art in seismic tomography, with an emphasis on the tomographic results, rather than on the methods. All the tomographic images are shown in color in this book, which are clearly visible and easy to understand. In contrast, no color figures were included in the previous three books.

As mentioned above, I have become acquainted with many researchers working in various fields of the Earth sciences. My experiences have taught me that seismology is an important, but small, field in the Earth sciences. Most non-seismologists have no interest in the technical details of seismological studies; instead they are much more interested in the seismological results and need seismologists to provide them with useful information and constraints on the geological phenomena they are working on, such as earthquake fault zones, active volcanoes, basins, mountain building, subduction zones, hotspots, mantle plumes, large igneous provinces, etc. Some seismologists enjoy developing new and mathematically sophisticated techniques, which may look advanced and profound and so may frighten most geoscientists who are generally not good at advanced mathematics. Concerning methods for solving the very complicated geoscience problems, I like the Chinese proverb, *Dadao Zhijian*, which means “the simplest way is the best way!” Occam’s razor expresses the same principle for solving problems. A sophisticated new technique is certainly fine, but it must produce better results which can better explain the geological, geophysical, and geochemical observations. I think that body-wave travel-time tomography based on ray theory is the most straightforward, robust, and mature tool that has produced many more credible and geologically reasonable results than any other tomographic methods, and now it is time to summarize these reliable and nice results obtained with travel-time tomography in a monograph. As Prof. Peter Shearer (2009) argued in his book *Introduction to Seismology*, a large fraction of current seismological research continues to rely on travel times, and ray theory is still good enough for most seismological applications. Therefore, in this book I have perhaps included more results from ray theory based travel-time tomography and less on surface waves, normal modes, and other methods than a truly balanced book would require. Any book, to some extent, reflects the prejudices of its author (Shearer, 2009). Hence, this book is not written for professional seismologists but for undergraduate and graduate students, researchers, and professionals in the broad fields of Earth and planetary sciences, who need to broaden their horizons about the crustal and upper mantle structure beneath various geological features and tectonic settings, seismotectonics, volcanism, and the deep structure and dynamics of the Earth and Moon. I hope this book may help to foster more communications among seismologists, geologists, geochemists, mineral physicists, and planetary scientists.

I have tried to keep each chapter concise but not economize on references which provide more detail. However, it is a huge job to review all related publications, and I confess that a complete review of seismic tomography was not possible. For example, when I began to write Chap. 3, "Subduction Zone Tomography", I tried to review the related publications region to region. However, after a few months of hard work, I found it was impossible to do it that way, because there are thousands of related publications, which require a grand tome to summarize. Hence, I had to change my mind and to summarize the subduction-zone tomographic studies according to the three seismic-structural parameters: seismic velocity, attenuation, and anisotropy. Thus, in the text I had to introduce only some representative publications for every subduction zone, and had to give up many other important papers which are worth mentioning, although I have tried to include them in the list of references as much as possible. Now I know there are so many diligent tomographers working on subduction zones! Similarly, in the whole book, I have cited publications in English, Chinese, and Japanese but had to omit related publications in other languages which I cannot read. This is unfortunate, and I apologize for this to the authors of those papers.

Springer Japan asked me to write each chapter independently with a complete list of references. Although this has resulted in some references appearing in different chapters, every chapter has become self-consistent and independent, and so the reader may feel free to pick up any chapter to read without having to refer to the other chapters. The mathematical equations are kept to a minimum in all chapters except for Chap. 2 on the tomographic methodology, so that the non-seismologists can read and understand them easily. Even in Chap. 2, simpler equations and formulas are adopted, so that undergraduate students will also understand them. Those readers who are interested in the technical details of tomographic methods are referred to Nolet (1987, 2008).

In this book, each chapter focuses on the tomographic studies of one type of tectonic setting. However, not all tectonic settings are covered by this book. For example, an important tectonic setting, the mid-ocean ridges, is not reviewed by this book, simply because the author has not worked on this topic and is not very familiar with it. The interested reader may refer to a nice review article written by R. Dunn and D. Forsyth (2007), "Crust and Lithospheric Structure—Seismic Structure of Mid-Ocean Ridges", Vol. 1.12 in *Treatise on Geophysics* edited by G. Schubert.

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