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Inside the Subduction Factory

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Cover:
Low-oblique aerial photograph of erupting Fukutoku-oka-no-ba and extinct Minami Iwo Jima volcanoes in the central Izu-Bonin-Mariana arc (24°16'N, 141°29'E). The picture was taken from a airplane of the Hydrographic and Oceanographic Department of Japan on the morning of Jan. 21, 1986, looking south. Courtesy of the Hydrographic and Oceanographic Department of Japan.

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PREFACE

Subduction zones helped nucleate and grow the continents, they fertilize and lubricate the earth's interior, they are the site of most subaerial volcanism and many major earthquakes, and they yield a large fraction of the earth's precious metals. They are obvious targets for study—almost anything you learn is likely to impact important problems—yet arriving at a general understanding is notoriously difficult: Each subduction zone is distinct, differing in some important aspect from other subduction zones; fundamental aspects of their mechanics and igneous processes differ from those in other, relatively well-understood parts of the earth; and there are few direct samples of some of their most important metamorphic and metasomatic processes. As a result, even first-order features of subduction zones have generated conflict and apparent paradox. A central question about convergent margins, for instance—how vigorous magmatism can occur where plates sink and the mantle cools—has a host of mutually inconsistent answers: Early suggestions that magmatism resulted from melting subducted crust have been emphatically disproved and recently just as emphatically revived; the idea that melting is fluxed by fluid released from subducted crust is widely held but cannot explain the temperatures and volatile contents of many arc magmas; generations of kinematic and dynamic models have told us the mantle sinks at convergent margins, yet strong evidence suggests that melting there is often driven by upwelling. In contrast, our understanding of why volcanoes appear at ocean ridges and "hotspots"—although still presenting their own chestnuts—are fundamentally solved problems.

Over the last several years, the "subduction problem" has changed in response to advances in several sub-disciplines that collectively redefine, and are likely soon to solve, some of our most deeply entrenched debates. Data on the mineral physics and melting properties of hydrous silicate rocks have improved to the point that one can use them as detailed constraints on models of convection and magmatism; geophysical data have directly imaged details of subduction zones that were previously inferred; numerical models are beginning to capture key, in some cases counter-intuitive, kinematic behaviors and their dynamical forcings; geochemical data have proliferated and their general features abstracted in ways analogous to our long-standing, relatively deep understanding of volcanism at mid-ocean ridges. The emerging picture is different from what we held just a few years ago. The present volume articulates this new picture and points the way toward the next set of challenges faced by scientists interested in subduction zones.

It is common for volumes of this type to divide themselves into two types of papers: those that broadly summarize a field, much as a text book or review paper might, and those that present recent scientific results, much as an article contributed to a journal. We have done something different. The papers in this volume can be sub-divided by the region or discipline they consider (more on this below) and contain pedagogical "coverage" of the background to their subjects. At the same time, contributing authors advance new ideas that consider recent discoveries or advances in observational or experimental method while focusing on fundamental questions in subduction zone research: How does the earth's mantle move near subducting plates; what does this movement mean for the thermal evolution of subducting slabs; what, in turn, does this thermal evolution imply about the metamorphism of, and phases escaping from, the slab; and what, in detail, are the consequences (rheological, magmatic, and chemical) of delivering those escaping phases to the overlying mantle?

We have organized the volume so that the papers will build upon one another in a logical way. At the same time, the authors have not slavishly conformed to such a structure, and you will find several major themes developed in detail throughout the book. The introduction briefly summarizes the last century of scientific thought about what we now recognize as subduction zones, providing a context for readers with little background in the field. Section I initiates the discussion with a set of three papers on the subducted slab: Chapter 1 discusses the thermal structure of slabs, in particular their upper surface; Chapter 2 analyzes the geochemistry of slabs, in particular the compositions of fluids and melts that might be released from them due to heating; and Chapter 3 reviews geophysical methods for interrogating shallow subduction-zone structure, including the electromagnetic methods.

In section II, we focus on the mantle wedge—that part of the mantle between the down-going slab and the over-riding plate. The dynamics and melting behavior of the mantle wedge is arguably the centerpiece of current debates about subduction zones, so this section contains the largest number and most mechanistically detailed papers in the volume. We start, in Chapter 4, with geophysical constraints on the structure and kinematics of the mantle wedge, followed by a discussion of experimental and observational constraints on the rheology of upper mantle rocks in Chapter 5—a specialized problem but one that underlies some of the most important issues facing subduction zone research. Then, in Chapter 6, we discuss experimental constraints on the way in which the mantle wedge melts in response to the introduction of slab-derived hydrous phases and end this section with Chapter 7—a particularly forward-looking proposition for a means of geophysically mapping hydrogen concentration (arguably the controlling parameter for rheology and melting properties) in the upper mantle, including the mantle wedge.

Section III brings together a set of papers on another side of subduction zone research: the need to come to grips with historical and geographic idiosyncrasies of individual subduction zones. These papers explore the geology, geophysics, and geochemistry of three subduction zones that are the focus of much recent research, including two that are 'focus areas' identified by the Margins program of the National Science Foundation. These are the Central American arc, the Izu-Bonin-Mariana subduction zone system in the western Pacific, and the Aleutian island arc—Chapters 8, 9, and 10, respectively. It is important to note that these papers develop arguments that are certain to prompt future research on subduction zones generally and are not simply reviews of prior work.

The book concludes with two papers in section IV that advance focused arguments with broad implications for the behavior of subduction zones, based on syntheses of much of the material discussed in more detail throughout the rest of the volume. These include a proposal for the processes that control the location of subduction zone volcanoes—a problem worth re-visiting whenever our understanding of convergent margins advances—and a radical suggestion, backed by evidence from igneous and metamorphic petrology and thermal models, that subducted slabs are often, if not always, heated above their melting points. This is an idea that was deeply held thirty years ago, discarded almost entirely for most of the last twenty years, and is apparently ready to be revived for a new and more sophisticated look.

This volume derives from a conference, "The Subduction Factory," held in Eugene, Oregon in late summer of 2000. The conference was an inspiration to many of those who attended because it brought together key players in the study of subduction zones at a special time of discovery and conceptual advances in their respective fields. A majority of speakers and a few particularly active attendees were asked to contribute chapters to this volume, reporting on the key results they presented, summarizing the contextual background of their relevant sub-disciplines and, perhaps most importantly, reflecting on relationships between their advances and what they learned from others at the meeting. In the two years that have passed since this meeting, the ideas it generated have retained much of their immediacy and matured as authors reflected on one another's work.

We thank, first and foremost, the authors who contributed to this volume, both for the thought and work they put into their own contributions and for their patience with the collective effort. We are also grateful to the many reviewers who helped improve these chapters—particularly those asked to deal with the longer and more technically detailed contributions and those who had to work under a demanding deadline. Similarly, we thank Allan Graubard, our acquisitions editor, Bethany Matsko, our production editor, and the rest of the AGU book production staff, who provided much needed guidance and repeatedly demonstrated the patience of saints. Finally, we thank the organizers of the "Subduction Factory" conference and the administrators and staff in NSF's Margins program that supported both that meeting and this volume.

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