commodating Plowshare-type projects under the provisions of a comprehensive test ban, however.

In addition, there is at present no proposal for peaceful applications for U.S. purposes that appears attractive. The Rio Blanco gas stimulation experiment (p. 189) seems to have been a failure as far as commercial development is concerned. The American excavation projects that have been proposed all involve environmental hazards that appear to be unacceptable, if not illegal. The control of earthquakes by relieving tectonic strain with explosion-generated motion (p. 209) should no longer be considered as a serious suggestion in view of the great uncertainties of the interaction of the dynamic stress field from the explosion with the ambient stress field and geologic structures. Fluid injection and withdrawal offer a much more promising approach, based on principles we understand better. It seems unfair to suggest (as the author does on p. 246) that some proponents of an extended treaty want to end Plowshare programs. Another interpretation is that they see these as incompatible with a test ban and choose to forgo them in the interest of achieving an end to nuclear weapons development.

The text is almost free of editorial and technical errors, and the few I noticed will be of concern more to the seismologist than to the general reader. More information on Soviet seismic arrays is available, in a RAND report published in June 1975, than the author suggests on p. 146. The problem of determining the depth of a shallow seismic source, discussed briefly on p. 151, is more difficult than the author implies, and recent results using techniques not discussed are promising. The statement, on p. 170, that "shallow-focus earthquakes are always followed by a sequence of aftershocks" is not true, as seismologists who have worked with earthquakes in the central United States are well aware.

The publication of this book is especially timely in view of the treaty between the United States and the Soviet Union limiting underground tests to yields smaller than 150 kilotons that was to have gone into effect on 31 March and that is being honored even though the negotiations are incomplete. The background provided by this book will be most useful to the reader who wants to consider the problems of test bans on the basis of the facts.

CARL KISSLINGER

Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder

Forecasting

Earthquake Prediction. TSUNEJI RIKITAKE. Elsevier, New York, 1976. xvi, 358 pp., illus. $37.95. Developments in Solid Earth Geophysics, 9.

Twenty years ago one would have kept a book on earthquake prediction on the same shelf with texts on astrology, ESP, and dowsing. Because of limited and sketchy data, lack of good understanding of earthquake mechanics, and relatively poor detection equipment, scientific prediction of earthquakes was impossible. All that has drastically changed. The seismic and other geophysical data available today are voluminous and quite accurate, the equipment to obtain the data is versatile and sensitive, and the mechanics of faults is much better understood.

The near accomplishment of earthquake prediction raises new challenges. It is now necessary to specify more precisely what is required of an earthquake prediction. If we characterize an earthquake by its location, time, and magnitude, it is necessary to predict all three with a certain accuracy. If uncertainties in predicted time, location, or magnitude are large, the significance of prediction is greatly reduced. The prospect of earthquake prediction raises also social, political, and economic questions. How can and how should society respond to an earthquake warning? How can we deal with the uncertainties of prediction? What degree of prediction accuracy is necessary to justify the evacuation of an area at risk?

Rikitake's book is therefore timely. It opens with a brief collection of legends about harbingers of earthquakes, a resume of historical developments in earthquake research, and a description of the Japanese, Soviet, U.S., and other national programs. These are followed by an extensive collection of examples of crustal motion and deformation, seismic activity, and geomagnetic and electrical variations detected in association with earthquakes. Special attention is paid to variations in seismic wave velocity preceding earthquakes and to their possible relation to dilatancy and fluid flow in the earth's crust. It is interesting to point out here that the work that led to the development of the dilatancy-diffusion hypothesis was international. In the 1920's, Bridgman at Harvard University discovered that the elastic moduli of rocks increase significantly with pressure, owing to crack closure. In 1948 M. Hayakawa in Japan suggested that the change of stress in the earth's crust should cause small changes in wave velocities, which he observed. Fifteen years later a Russian team repeatedly detected velocity changes preceding local earthquakes. This was followed by similar observations in the United States. At the same time laboratory studies of velocities in rocks and dilatancy at the Massachusetts Institute of Technology provided the basis for the explanation for the velocity changes.

The dilatancy-diffusion hypothesis highlights the otherwise empirical approach that has been taken to earthquake prediction. The final section of the book contains a prediction theory developed by the author that is almost entirely statistical in nature and makes no use of physical models for earthquakes or their precursors. In fact, the lack of physical models is probably the greatest weakness of the book. Reid's notion of elastic rebound, which opened the way in 1906 to an understanding of strain accumulation and release, is mentioned only once. There is no mention of work on faulting mechanics, such as that by Burridge, Walsh, Haskell, and many others. Friction, which is probably the most important physical quantity in earthquake faulting, is not even listed in the index. The lack of concern with these aspects of earthquakes is also reflected by inaccuracies in references to original work on, for example, velocities in dry and saturated rock.

The book falls short of putting earthquake prediction into a strong scientific framework with working hypotheses. It is, however, an invaluable collection and summary of past and current work on the prediction of earthquakes around the world. As such, it will be an important reference for earthquake students.

AMOS NUR

Department of Geophysics, Stanford University, Stanford, California

Experimental Petrology

Composition and Petrology of the Earth's Mantle. A. E. RINGWOOD. McGraw-Hill, New York, 1975. xviii, 618 pp., illus. $29.95. McGraw-Hill International Series in the Earth and Planetary Sciences.

Experimental petrology addresses problems related to the origin of magmas and the evolution of the crust and upper mantle. High pressure petrology is a subdiscipline that concerns itself with phase assemblages that occur deeper in the mantle. Geologists and geophysicists

need experimental petrology to interpret field and seismic observations and to unravel the history of the earth's outer layers. Petrology is also relevant to the origin of the solar system. This book demonstrates the importance of a specialized field to a broad spectrum of earth and planetary sciences. The author takes us from detailed geological studies of the surface to speculations on the composition of the deep interior of the earth, the origin of the moon, and the early evolution of the solar system.

Such speculations require input from almost every branch of science: astrophysics, cosmology, geology, physics, chemistry, geochronology, petrology, thermodynamics, crystal field theory, and Newtonian mechanics. Anyone attempting a synthesis of knowledge of the origin of the solar system, the earth, or the earth-moon system must understand constraints imposed by fields other than his own. It is virtually impossible for any individual to be conversant with all the physical and chemical constraints. It is difficult to design a completely consistent scenario for the origin and evolution of even such a well-studied body as the earth. Any attempt to synthesize available data and theories inevitably reflects the biases and specialty of the synthesizer. This book is one of the more Herculean attempts to bring a large amount of the available information to bear on the subject of the composition of the earth's interior and the implications of that composition for a theory of its origin.

The author's original purpose in writing the book was to review recent petrological research and its bearing on knowledge of the composition and constitution of the mantle. Ringwood and his colleagues have developed many techniques of high pressure petrology and have discovered many high pressure phases. They have also made substantial contributions to the subject of magma genesis and the synthesis of petrological and other data bearing on the evolution of the earth. Experimental petrology is becoming more specialized, and it is often difficult for workers in other fields to make full use of the results of this powerful tool. Ringwood attempts to provide a synthesis that will be intelligible to a wide spectrum of earth scientists. A large part of the book is based on Ringwood's own research. Work from other laboratories is also reviewed, but, as Ringwood admits, he found it hard to be objective. Petrologists will consider this a decidedly one-sided view, but few of them have attempted such a broad synthesis of their field. Even a one-sided view is useful from a mind as fertile as Ringwood's.

Part 1 covers the composition of the crust and upper mantle, the gabbro-eclogite transformation, the Mohorovicic discontinuity, the origin of magmas, and the role of water in petrogenesis. Part 2 covers the geophysical and petrological evidence on the composition of and phase assemblages in the deeper mantle, including high pressure transitions in olivines, pyroxenes, and garnets.

The concluding chapter, "Mantle composition and the earth's origin" is a heroic attempt to reconcile the author's earlier work with later developments and information from other fields. Although Ringwood was forced to drop the idea that silicon was the light alloying element in the core, he still believes that the volatiles were initially near the center of the earth, that the core was originally at the surface, and that the moon condensed from material vaporized at the surface of the earth. The inconsistencies with earlier chapters and the biases of the author are painfully obvious.

This is more a monograph than a textbook. It is mainly a collection and distillation of the author's monumental contributions to the petrology of the earth and the moon and his evaluation of the contributions of his competitors. Advanced graduate students in geological and planetary science will profit greatly from reading it. They need not be forewarned of the biases of the author, since they come through clearly. On the whole, the strong imprint of the author's personality is more a plus than a minus. The book is certainly more enjoyable to read than most petrology texts, even though it may infuriate the many earth scientists Ringwood has controversies with.

DON L. ANDERSON
Seismological Laboratory, California Institute of Technology, Pasadena

Seventeenth-Century Studies

Newton as Chymist

The Foundations of Newton's Alchemy. Or "The Hunting of the Greene Lyon." BETTY JO TEETER DOBBS. Cambridge University Press, New York, 1976. xvi, 300 pp., illus. $22.50.

. . . at spring and fall of the leaf . . . he used to employ about six weeks in his elaboratory, the fire scarcely going out either night or day. . . . What his aim might be I was not able to penetrate into, but his pains, his diligence at these set times made me think he aimed at something beyond the reach of human art and industry.

Thus Humphrey Newton, who assisted Isaac Newton in experiments from 1685 to 1690. His suggestion that metallic transmutation was Newton's "chief design" has often infuriated historians who have studied Newton's chemical work. But why then did Newton scribble at least 650,000 words on alchemical topics, mostly as notes from alchemical authors?

Dobbs has attempted to provide an answer by a careful and intensive study of manuscripts she assigns by painstaking handwriting analysis to the period 1668–1675 (constituting about 10 percent of the total). She has chosen to examine Newton's chemical notebook in close conjunction with the alchemical manuscripts for the light each can throw on the other.

Dobbs quickly disposes of the view that Newton was searching through alchemical authors for nuggets of useful information. He selected the most mysterious and esoteric passages. He then drew on his knowledge of other alchemical writings, chemical operations, mythology, and anything else that could help unravel the meaning. Finally he tested out the resulting hypotheses in laboratory operations. Underlying the interpretative techniques was the conviction of a secret "wisdom of the ancients" hidden in myth as in alchemical enigmas. As an adherent of the mechanical worldview, he was led to restate alchemical ideas in mechanical and particulate terms.

Newton's first experiments aimed at recovering the "mercury of metals," which was supposed to give metals their specific characteristics. One method was to heat various metals with the volatile sublimate of mercury. Since the mercury released in the substitute reaction was