tion (254-1) is reported explicitly at least in two other places in the text with no cross-references. The book gives throughout the text some of the key mathematical formulas involved in the phenomena. The level of mathematical sophistication needed is that of an upper division or even graduate physics or engineering student at a good North American university. For example, partial differential equations are used with the expectation that the reader is familiar with their manipulation.

A complementary approach to studying natural hazards is the more empirical one of emphasizing significant observations in selected case histories. The present book, however, gives few field reports and little general discussion of the phenomena from a historical or phenomenological point of view. There are, however, references to published papers and accounts throughout the text.

The section on earthquakes in the book consists of 38 pages out of 253 pages. The author deals briefly with the causes of earthquakes, earthquake intensity, spectra of strong ground motion, seismicity distributions, magnitude relations, and a little on seismological risk and zoning. Recent work on earthquake prediction in time is also treated briefly and the author optimistically remarks, "Success may not be very far off."

The treatment of most topics in this chapter is probably too brief to make it stand alone as a text on seismic hazard questions. The subject of earthquake hazards is as hard as anything in seismology, and if it is to be treated at the level of much of the rest of the book, then the analysis must be deeper than that given. One comment ought to be made about Figure 6. It is hard to know exactly what this small drawing of world seismicity means. There are many fine maps available now displaying global earthquake distribution as a function of time, magnitude and depth; it is a pity to see a display that represents the more limited knowledge of decades ago.

BRUCE A. BOLT

SEISMOGRAPHIC STATION
UNIVERSITY OF CALIFORNIA
BERKELEY

The Earth's Density by K. E. Bullen, Chapman and Hall, London, 1975, xiii +420 pp.

Bullen's name is associated with many of the early developments in seismology including the Jeffreys-Bullen travel-time tables and the Bullen density models. His interest in the methodology of scientific inference has always been evident in his papers and continues in this monograph. *The Earth's Density* is a superb account of the history of a science, starting from ancient determinations of the size and the mass of the Earth up to the modern age of computer inversion.

The first two brief chapters are historical and deal with early astronomical and gravity investigations. Subsequent chapters develop the theories of spherical harmonics, gravitational attraction, figure and moment of inertia of the Earth, elasticity and seismic-wave transmission. Early models of the Earth's radial density variation and rigidity, including the Legendre-Laplace density law and the Williamson-Adams equation, are discussed in Chapter 6.

Several chapters deal with the seismic evidence for the structure of the mantle and core. Among the most interesting sections are those that give an historical account of the development of the Bullen Earth models of types A and B.

The author is a mathematician and naturally stresses the mathematical aspects of the subject. The reader will be disappointed, however, if he expects a complete treatment of the modern inversion methods which have been important in the recent advances in this field. It is only with these newer techniques that uniqueness, resolving power, and trade-offs can be understood. Emphasis throughout is on radially symmetric Earth models. The Earth's density distribution is important for discussions of tectonics and composition but these are outside the scope of the book. Supplementary data from laboratory studies in the fields of equations of state and experimental petrology are important in interpreting the Earth's density, but the reader must look elsewhere for this material.

Bullen ends his discussion on the density of the Earth by addressing the problem of standard and optimal Earth models. He states that there has long been a demand for a well-chosen internationally agreed-upon standard or reference Earth model. He stresses that this standard model should be "simple." The purpose of such a model, according to Bullen, is to provide a reference base against which new data and results can be tidily presented and uses as an analogy the presentation of travel-time data as residuals against the J-B tables. This is a poor analogy. Tabulating data residuals has served to focus attention on the needed corrections to the tables and on regions that are anomalous. There is a need for such a set of standard tables in order that earthquakes be located uniformly by all observatories. No simplicity condition exists for such tables—they should be as accurate as possible; optimal tables are the same as standard tables—no purpose is served by simplicity *per se*; smoothing is done to eliminate gross errors but not to the extent that known data is violated.

The "demand" for a standard Earth model resulted in an international standard Earth model committee being set up in 1971 at the instigation of the International Association of Geodesy; "The task of the committee has proved to be more complex than had been anticipated, partly for the reason that prima donnas performing simultaneously on different keys are slow to produce harmony, partly because of widespread failure to appreciate the difference between a standard and an optimum model." The present reviewer admits that he also fails to appreciate the difference. An Earth model either fits the data or it doesn't and there is no virtue in a simple standard Earth model that does not fit the available data. "A cardinal requirement of a standard model is simplicity;" but what is simple? A constant velocity model is certainly simple but is not very useful. A model having a uniform mantle and core is also simple but is hardly a useful standard against which to compare other models. A model having linear gradients in the mantle and core is still relatively simple but no more physically realistic than the simpler models. A smooth model has no particular virtue if the data, or the physics, demands discontinuous variations in parameters.

It seems to the present reviewer that the establishment of a standard data set should precede the adoption of a standard Earth model. Furthermore, ground rules should be established, in advance, on the relative weights of various data sets. It is misleading to compare models that differ greatly in their selection of data to be fit or in their goodness-of-fit to the overall data set.

In the final chapter Bullen applies the equations of state for particular internal zones of the Earth to other planets. He deliberately stays away from the geochemical theories of planetary structure and therefore the only observational constraint is the mean density. In order to apply terrestrial data to the other planets one must make an assumption about the composition of the Earth's core. Bullen clearly prefers the phase-change hypothesis over the iron-core theory and his treatment of the terrestrial planets reflects this preference. He believes that the arguments against the idea of uniform composition of the mantle and core are not conclusive. He discusses at great length the idea that the cores of the terrestrial planets are Fe_2O, rather than iron-nickel, with the goal of showing that Mars, Earth and Venus can have the same chemical composition. This chapter is mainly of historical interest since it is based on old data and the older theories of planetary formation. He refers to, but does not discuss, some of the geochemical constraints.

The book will be useful in an introductory course on the Earth's interior.

Don L. Anderson

Seismological Laboratory
California Institute of Technology
Pasadena, California 91125