Shocks and Rocks—Seismology in the Plate Tectonics Revolution

Jack Oliver
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The American Geophysical Union's history committee continues to play a vital role in documenting the growth of geophysics. In this attractive, largely autobiographical book, Volume 6 of the *History of Geophysics* Series, Jack Oliver presents the story of seismology's contributions to the takeover of plate tectonics as the evolutionary descriptor in geology and geophysics. Although his emphasis is the decade of the 1960s, when he made his own valuable contributions, the book has three preliminary chapters on the pre- and three on the post-plate tectonics era. The preface sets out the various aims of the book. The first is an outline of the role of seismology in the construction of plate tectonics. The second is "not to add glory to the revolution and its participants but rather to describe just how science works when things are going well." Another goal is to "sketch and trace certain streams of seismological efforts and other activities of related nature through an interval of history much longer than that of the decade of the sixties." Finally, Jack Oliver hopes to "stimulate rising young scientists of today to think and reason in ways that will help them avoid...missteps in the future."

The book glows with enthusiasm, generous references to colleagues, and personal anecdotes and events. Oliver makes clear that he does not intend a scholarly tome with the completeness of library research and citations, but instead a book based on his personal perspective that may give "a subjective and somewhat biased view of historical events." His audience is not only seismologists and scientists in related disciplines, but also non-scientific readers with a general interest in seismic shocks and rocks. The upshot is a fascinating read.

At the outset, about the only drawback of the book should be noted. For a general reader with little or no geological (particularly seismological) background, this difficulty arises from the almost completely essay form. A few key figures on the structure of the Earth and an up-to-date geomorphic map of the tectonic plates would have greatly aided comprehension. As it is, readers are fortunate that they can turn to figures in the famous 1968 paper "Seismology and the New Global Tectonics" by Isaacs, Oliver and Sykes, which is reprinted as an appendix. In any reprinting of this work, I would strongly recommend adding at least some cross-references to these figures.

The breadth of the frontal assault on pre-plate theories of Earth dynamics, notably contraction of the Earth, has been well documented elsewhere. Oliver has decided largely to exclude the crucial contributions of geomagnetism, although he does make clear the central role played by oceanography in the plate tectonics revolution. Those of us whose geophysics careers encompassed the 1960s remember that the battle for dominance of the old and new theories was accompanied by all sorts of flanking movements and skirmishes. The reader might concentrate on two key questions: "Did seismology play a crucial role?" and "In what way is plate tectonics a truly predictive theory of geological questions?"

As a major participant on the seismological side and a key witness to much that went on, Jack Oliver is well placed to provide answers to these questions. Especially he was, at a most propitious time, a senior academic at (then) Lamont Geological Observatory of Columbia University. Oliver writes about its founder and director, Maurice Ewing, in generous terms. An irony emphasized by other historians is that Ewing, until very late, differed in his explanations of many of his findings at sea from those provided by "the new global tectonics." The remarkable fact is that many basic seismological aspects of the new thinking emerged at a research institute whose director was not sympathetic to mobility notions, but nevertheless contributed mightily to the foundation evidence of the new theory.

The first three chapters of the book, particularly the second, lay a basis for an understanding for the non-specialist reader of what seismologists do, particularly those who work in earthquake observatories. Oliver's account properly stresses the successive improvements in earthquake recording since seismology's inception at the end of the last century. In my view, and I think Oliver's, there cannot be enough acknowledgment given to the operators of seismological observatories who, day after day, maintain surveillance of earthquakes around the world, with all the routine that entails. By 1960, as Oliver stresses, along with this observational upgrade came high-speed digital computers. Truly, seismologists were "in the right place at the right time." Essentially, three basic seismological contributions to the mobile lithosphere arguments became available: more reliable earthquake locations globally, more dependable fault-plane solutions of source mechanisms, and more consistent measures of earthquake magnitudes. (Although the last turned out to have much more to do with the attempt being carried on at the same time to discriminate between earthquakes and underground nuclear explosions.)

One of the most intriguing sections of the book is the description of the exciting days at Lamont, particularly its program on earthquake seismology. I was privileged to spend a year at Lamont on sabbatical leave from the University of Sydney in 1960. My stimulation was unbounded, not only in seeing Ewing's program from the inside, but also working alongside seismologists caught up in detailed analysis of seismograms coming from the new Standard Seismological Stations (WWSSN) around the world. These heady days are recounted by Oliver, who goes on to emphasize the contributions of L. Sykes on fault-plane mechanisms and J. Dorman on global maps of epicenter locations. His own research leadership at that time was obvious, particularly his stress on reading and explaining the wiggles on the seismograms. I was able to make some small contribution by leaving behind a statistical program that enabled hypocenters of earthquakes to be revised rapidly and uniformly. The second most important seismological input was inferring faulting mechanism. Many have wondered why the fault-plane solution method had not been used earlier to develop crucial hypotheses on global deformation. Oliver points out that although the seminal work in this field for teleseisms was done by P. Byerly, J. Hodgson, W. Stauder, and others, it was the WWSSN observations after 1960 that yielded the needed precision and consistency of first motions. Of course, it also helped to have a definite tectonic hypothesis to test, such as the transform fault model of J.T. Wilson. This was done convincingly at the hands of Sykes.

As mentioned already, Oliver aims, beyond an historical account, to present a generic analysis of seismology's contributions. In any such attempt, a burden is that older readers will also have been there at the time; indeed, some of them before the contributions at Lamont. All these readers know how the coming of plate tectonics was for them. What excited me at the time was the realization that seismology provided a more-or-less quantitative model for plate kinematics along structural boundaries, under the oceans and in remote continental regions already mapped by bathymetry and topography. On the matter of predictive power, I was particularly intrigued by Jack Oliver's reminiscence of a trip with Clarence Allen in the early 1970s during which they observed the direction of slip along the great Philippine fault. "The fault moved...in a left-lateral sense, just as the global theory predicted!" It could be argued, however, that the directions of principal slip, and even stress, were forecast decades before plate tectonics by seismological fault-plane solution methods; these very results were the evidence for the theory. Byerly recalled to me how his procedure was for a long time not received with much favor at other U.S. seismological centers until, at last, a predicted motion of fault slip, using remotely recorded P polarities, was verified in the field.

A valuable aspect of the book is Jack Oliver's interest in discussing questions of scientific method related to the accomplishments of the 1960s. He argues that plate tectonics should be put on the same level of trust as Darwin's theory of biological evolution and Newton's theory of mechanics. This stand is not to say that, in both these classical cases, certain adjustments, some quite significant, have not been made in the ensuing years. In an analogous way, he sees plate tectonics as a theory that has been, and is, subject to non-fatal adjustments. The usual description of scientific method in textbooks incorporates the testing of hypotheses by crucial experiments, such as the bending of light around the sun in Einstein's relativity theory. Sykes's use of fault-plane solutions of earthquakes along the zig-zag pattern of mid-oceanic ridges is a fine example of this procedure. Oliver goes on to discuss the role of chance in science. His main example of this paradigm is the work of Brian Isaacs and others on the seismicity of the Tonga and Fiji trenches, following their installation of modern seismographic equipment on those islands. He remembers, "I had the hunch that the deep earthquakes were occurring where they did because the material of that part of the Earth was somehow anomalous and unlike the mantle at comparable depths, but the project was not begun with such speculation as the basis. That guess was off the mark." What the group discovered was that high frequency S waves were propagated much more efficiently through the lithospheric subduction slab than around it. Their inference, that underthrusting of crustal and upper mantle material was occurring on a large scale, is recalled by Oliver as "a Eureka phenomenon." The serendipitous nature of these discoveries should not be pushed too far. Experiment and theory are never completely separate. It is clear in this milestone illustration that chance in the ordinary sense was not involved; while the authors did not know the outcome of their Pacific excursion, they had been stimulated by the thinking of the time. This background was enough to fund and undertake the field work.

The last type of scientific theory related to the decade of the 1960s in Chapter 8 is entitled "Science by Synthesis." Oliver means the drawing together of diverse studies, works, and conclusions on a scientific question and then their integration as a body of evidence to support a well-articulated conclusion. In his case, such a synthesis occurred, in collaboration with his students Isaacs and Sykes, in the paper referred to above, "Seismology and the New Global Tectonics." Oliver's discussion of the interactions that led to this widely-read work alone makes the book worthwhile for students of scientific activity. Oliver says that this synthesis is his proudest achievement, although at Cornell he moved on to other valuable research referred to only in passing in this book.

Bruce Bolt
University of California, Berkeley
Seismographic Station
493 McCone Hall
Berkeley, CA 94720