THE CONTINENTAL DRIFT CONTROVERSY

Volume III: Introduction of Seafloor Spreading

Resolution of the sixty-year debate over continental drift, culminating in the triumph of plate tectonics, changed the very fabric of Earth science. Plate tectonics can be considered alongside the theories of evolution in the life sciences and of quantum mechanics in physics in terms of its fundamental importance to our scientific understanding of the world. This four-volume treatise on *The Continental Drift Controversy* is the first complete history of the origin, debate, and gradual acceptance of this revolutionary explanation of the structure and motion of the Earth's outer surface. Based on extensive interviews, archival papers, and original works, Frankel weaves together the lives and work of the scientists involved, producing an accessible narrative for scientists and non-scientists alike.

This third volume describes the expansion of the land-based paleomagnetic case for drifting continents and recounts the golden age of marine geology and geophysics. Fuelled by the Cold War, US and British workers led the way in making discoveries and forming new hypotheses, especially about the origin of oceanic ridges. When first proposed, seafloor spreading was just one of several competing hypotheses about the evolution of ocean basins, and every hypothesis left unexplained the newly discovered and wholly unexpected magnetic anomalies associated with mid-ocean ridges and in the Pacific Basin off the western coast of the United States.

Other volumes in *The Continental Drift Controversy*:
Volume I – Wegener and the Early Debate
Volume II – Paleomagnetism and Confirmation of Drift
Volume IV – Evolution into Plate Tectonics

HENRY R. FRANKEL was awarded a Ph.D. from Ohio State University in 1974 and then took a position at the University of Missouri–Kansas City where he became Professor of Philosophy and Chair of the Philosophy Department (1999–2004). His interest in the continental drift controversy and the plate tectonics revolution began while teaching a course on conceptual issues in science during the late 1970s. The controversy provided him with an example of a recent and major scientific revolution to test philosophical accounts of scientific growth and change. Over the next thirty years, and with the support of the United States National Science Foundation, the National Endowment for the Humanities, the American Philosophical Society, and his home institution, Professor Frankel's research went on to yield new and fascinating insights into the evolution of the most important theory in the Earth sciences.

To Nora

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Volume III: Introduction of Seafloor Spreading

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Foreword

Henry Frankel has a fine eye, and ear, for the interlocking aspects of the emergence, recognized evolution, and acceptance of that flowering of a worldwide phenomenon, continental displacement. I see the enlightening process as a scaled-up relay in which – by mid-1950s to early 1960s – the baton was being passed from terrestrial paleomagnetists to sea-smart marine geologist–seismologists and their shoreside arbiters. In retrospect, the number of participants is not great; Frankel has identified them plainly and rather fairly, in my view.

In the early 1950s still-young Earth science-trained graduates of several US, British, and European universities joined wartime agency-fostered academic installations, acquired institutional use of platforms capable of open-sea operations, taught themselves to carry out (to publication) fruitful exploratory reconnaissances and also magnified experiments at sea, viz., topographic–geological–geophysical collaborations even in the most remote and deepest parts of the oceans. Given the opportunities for actual *discovery*, and perhaps collegial renown, competition was vigorous but arguably constructive. We knew of, and could admire and apply, each other's accumulating refinements to the submarine macro-jigsaw puzzle.

Stemming from undergraduate exposure to ideas of Gutenberg, Vening Meinesz, and Benioff, I undertook to clarify and determine reliably the characteristics – bathymetry, crustal structure, geological processes and petrology – of several Pacific trenches. By late 1954–early 1958 we at Scripps Institution of Oceanography (Scripps) had demonstrated off Central America and Peru/Chile the "creeping crustal layers," igneous oceanic crust above the Moho passing diagonally beneath the trenches' inshore slope and continental shelf, presumably even farther (from Benioff–Wadati seismicity analysis).

But at just the same time an ultimately much more significant program – identification of seafloor magnetics – was being initiated by London University's Ronald Mason and his engineer Arthur Raff at Scripps. (Early incidents in a revolution can be, and should be, remembered.) People at Scripps had learned that the US Coast and Geodetic Survey's vessel *Pioneer* would undertake a multi-year electronically navigated, closely spaced, E–W track bathymetric survey for several hundred kilometers

off the West Coast, from the Mexican to the Canadian border. Sensing a windfall opportunity, Mason and Raff got approval to provide and monitor a flux-gate magnetometer towed throughout those mid-1950s surveys. They, with their contoured magnetic anomaly plots, were the *discoverers* of the parallel-lineated seafloor magnetic field pattern associated with the world-girdling active igneous ridge systems, "stripes" found and dated in all the oceans, the key element via the Vine–Matthews hypothesis of Hess's "seafloor spreading," which he first proposed in a December 1960 preprint sent to many of us in marine geology and geophysics.

Until the mid-1960s other towering figures, well brought to us in this volume and by their own published recollections, built upon the cascading observations and implications, interpreted very often, and most convincingly, by Mycrofts ashore. The result: the mobilistically compelling "plate tectonics."

But on a poignant note: one morning in the mid-1960s, while climbing the stairs to a Scripps seminar, visitor Ron Mason turned to me and said, "Bob, if only we'd carried it one step farther. . ." Ron's enduring misfortune: only in their surveys' latest traverses, the Juan de Fuca Ridge sector off Washington State, is the East Pacific Rise's magnetic anomaly plot bi-laterally symmetrical, age-wise. In nearly all other areas, and most historically the Carlsberg Ridge, such patterns are mirrored, as demonstrated so fruitfully by Cambridge's Drum Matthews (aboard HMS *Owen* in the Somali Basin, 1961–2) with Fred Vine in their attic nook at Madingley Rise.

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Abbreviations

AAPG	American Association of Petroleum Geologists
AGU	American Geophysical Union
AMSOC	American Miscellaneous Society
ANU	Australian National University
APW	Apparent polar wander
Caltech	California Institute of Technology
CRM	Chemical remanent magnetization
GAD	Geocentric axial dipole
GSA	Geological Society of America
IGY	International Geophysical Year
IUGG	International Union of Geodesy and Geophysics
JGR	*Journal of Geophysical Research*
Lamont	Lamont Geophysical Observatory
Ma	Million years
NAS	National Academy of Sciences (USA)
NEL	US Navy Electronics Laboratory
NRM	Natural remanent magnetization
NSF	National Science Foundation (USA)
ONR	Office of Naval Research (USA)
RAS	Royal Astronomical Society (UK)
RS1	Research Strategy 1
RS2	Research Strategy 2
RS3	Research Strategy 3
Scripps	Scripps Institution of Oceanography
UCLA	University of California, Los Angeles
UCRN	University College of Rhodesia and Nyasaland
USCGS	United States Coast and Geodetic Survey
USGS	United States Geological Survey
VRM	Viscous remanent magnetization
WHOI	Woods Hole Oceanographic Institute

Introduction

Volume II described the development of the paleomagnetic case for mobilism based on observations from continents. It explained how, in the second half of the 1950s, a few researchers took a small field of enquiry and transformed it into an important field, and used it to show that continental drift had occurred. Volume III describes how, during the first half of the 1960s, paleomagnetists further expanded the land-based paleomagnetic case for mobilism. My treatment of their case ends by describing how six notable participants in the controversy responded to it.

Leaving behind land-based paleomagnetism, the remainder of this volume describes the first half – late 1940s through the early 1960s – of the golden age of marine geology and geophysics, when a small group of Earth scientists, supported by governmental funding based on defense concerns during the Cold War, crisscrossed oceans, better familiarizing themselves with known features of the ocean floor and discovering entirely new ones. Prompted by these new discoveries, especially new information about mid-ocean ridges, four hypotheses were proposed. There was seafloor spreading by Hess and Dietz, followed by Menard's hypothesis of seafloor thinning; both were motivated by mantle convection and both had much in common with Holmes' 1928 theory of mantle convection. Then there was rapid Earth expansion by Heezen. Finally, Maurice Ewing proposed that the ocean ridges were produced by mantle convection but without continental drift.

During this decade, most Earth scientists did not acknowledge that continental drift had been shown to occur by paleomagnetists; their descriptions of their land-based evidence of drift fell mainly on deaf ears. Drift did, however, find support among a few marine geologists. Hess became a mobilist because of it, and took drifting continents as a constraint on his speculations about seafloor evolution. Dietz too accepted drift's paleomagnetic support. Menard appealed to it when proposing and defending seafloor thinning but, as we shall see in Volume IV (Chapter 3), ceased to do so when he rejected seafloor thinning and instead proposed a fixist hypothesis of seafloor evolution. Heezen eagerly endorsed mobilism's land-based paleomagnetic support until it became inconsistent with rapid Earth expansion. For Heezen and Menard, appeal to drift's paleomagnetic support

was a luxury, jettisoned once it became an embarrassment. Ewing, an inflexible fixist, at this time paid no attention to paleomagnetism.

As in Volumes I and II, I shall describe how researchers acted in accordance with what I have identified as three standard research strategies (I, §1.13). Workers did not recognize or say that they acted in this way; these three research strategies are my retrospective description of how they went about their tasks, how they addressed their problems. Research Strategy 1 (hereafter, RS1) was used by researchers to expand the problem-solving effectiveness of solutions and theories. Research Strategy 2 (hereafter, RS2) was used by them to diminish the effectiveness of competing solutions and theories; RS2 was an attacking strategy used to raise difficulties against opposing solutions, and to place all possible obstacles in their way. Workers used Research Strategy 3 (hereafter, RS3) to compare the effectiveness of competing solutions and theories, and to emphasize those aspects of a solution or theory which gave it a decided advantage over its competitors.

Like the small group of researchers who turned paleomagnetism from a backwater discipline into one of central importance in the Earth sciences, this small group of marine geologists and geophysicists took another little-known field of enquiry and turned it into one of central importance in Earth history. It is a story about how these surveyors of the deep used new technologies to uncover the basic structure of seventy percent of the Earth's surface, about how these new discoveries fostered speculation about seafloor evolution, and about how this speculation later led to the further confirmation of continental drift.