THE CONTINENTAL DRIFT CONTROVERSY

Volume II: Paleomagnetism and Confirmation of Drift

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.

Beginning in the early 1950s, continental drift found new life from an unexpected source, paleomagnetism, which records the Earth's magnetic field in rocks and how its direction and intensity has changed over time. This second volume provides the first extensive account of the growing paleomagnetic case for continental drift and the development of apparent polar wander paths that showed how the continents had changed their positions relative to one another – more or less as Wegener had proposed. Paleomagnetism offered the first physical measure that continental drift had occurred, and helped determine the changing latitudes of the continents through geologic time.

Other volumes in *The Continental Drift Controversy*:
Volume I – Wegener and the Early Debate
Volume III – Introduction of Seafloor Spreading
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, 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 Johanna

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Foreword

This is the story of the formative years – the decade of the 1950s – of paleomagnetism as a scientific discipline in conjunction with a focus on the big questions of the day – the origin of the geomagnetic field, polar wander, continental mobility. The exposition is meticulously documented with referral to primary published literature and enlivened by extensive referral to real-time correspondence and retrospective views based on the author's interviews and written exchanges with many of the principals dating back to the early 1980s. Some of the themes that emerge from the account are the ever-importance of serendipidity and the ability of top scientists to identify tractable aspects of a big problem, adjust the scope and direction of the research as needed, and recognize applications to seemingly oblique problems. Paleomagnetism involved some of the major figures in physics of the post World War II era, including the Nobel laureate Blackett (who studied under Rutherford, another Nobelist), who spins up the story with an ingenious experiment to test whether the geomagnetic field is a fundamental property of a rotating body. The results were famously negative yet the theory and experiment had several notable positive outcomes, namely capturing the interest of his Ph.D. student, Keith Runcorn, to test the fundamental theory versus the competing dynamo theory by making measurements of the geomagnetic field in mine shafts, and the deployment of the sensitive magnetometer developed for the experiment for paleomagnetic research on rocks. Runcorn went on to assemble what became the leading group in paleomagnetism research (started at Cambridge but soon moved to Newcastle), whose students would emerge in the vanguard of the subject's most influential practitioners. The enterprise was graced with luck right at the outset with the arrival in late 1949 at Cambridge of Hospers, a student from Holland who came with his own scholarship and wanted to sample young lavas in Iceland hoping to correlate them by their intensity of magnetization. In the process, Hospers produced evidence for a global correlation tool, polarity reversal stratigraphy; for the exquisitely simple geometry for charting polar motions or continental mobility, the field of a geocentric axial dipole; and providing data that motivated the development of statistical methods on a sphere, Fisher statistics. These are pillars of paleomagnetism and they were basically established by 1953. Soon after Hospers arrived, Runcorn recruited Irving with his background in geology to look for evidence of geomagnetic secular variation in the Torridonian, thick sedimentary beds of Precambrian age. This was a wildly optimistic effort that nevertheless developed modern techniques and produced the first magnetic polarity reversal stratigraphy in sediments and oblique directions that indicated magnetic stability, which pointed to such fine-grained redbeds as key sampling targets for studies of the ancient geomagnetic field. The range of research expanded and was conducted at an exhilarating pace in a global network of information flow with sharp attention to publication priority. Creer, Runcorn's second student in paleomagnetism, built a sensitive astatic magnetometer at Cambridge after the design of Blackett's machine and only managed to start sampling and measuring a series of rock units half-way through his three-year fellowship; nevertheless, by 1954 he constructed an apparent polar wander path for Britain in 1954, the first such path and the conceptual basis for testing continental drift. Irving leaves for Australia in 1954, builds a lab from scratch with a new student, Green, and they had new results on Mesozoic dolerites in press within 2 years. And so forth.

By 1958, there were published results from young lavas from four continents in support of a geocentric axial dipole and the reality of polarity reversals, full results from the Deccan of India by the Blackett group, data from Australia by Irving's lab in Canberra, from South America by Creer, and paleoclimate evidence from proxies like Opdyke's analysis of wind directions in full support of the paleomagnetic assumptions: the evidence from the British schools (and from others like Gough in Africa and the brave Khramov in the Soviet Union) was decisively in favor of crustal mobility. In contrast, Graham at the Department of Terrestrial Magnetism at the Carnegie Institute came to very different conclusions. Graham actually had a head start with the availability of a sensitive spinner magnetometer at the Carnegie that allowed him to publish in 1949 a paleomagnetic survey of sedimentary formations from throughout North America and to develop seminal reliability tools like the fold test. Unfortunately, Graham was unable or unwilling to counter what the author describes as the prevailing fixist and anti-field reversal orthodoxy of the American community, and called upon cryptic strain effects and self-reversal (given credence by theoretical work of Nobel laureate Louis Néel, followed shortly thereafter by the chance discovery by Nagata's group in Japan of a self-reversing rock, now known to be an exceedingly rare occurrence) to explain otherwise straightforward evidence for crustal and/or polar mobility.

By 1959, the author points out that every major paleomagnetist with the notable exception of the American Graham (and Cox and Doell) favored crustal mobility, but despite this level of success, the paleomagnetists who advocated continental mobility were a beleaguered group. For one, the U.S. effort simply lacked a charismatic leader like Blackett to counter the negativism of the geologic community. And to cap this desultory period in the paleomagnetic case for crustal mobility, a lengthy critical review by Cox and Doell that appeared in the GSA Bulletin in 1960 reserved judgment, an opinion that tended to conform with general disbelief in crustal mobility expressed by the pillars of the American geological community (e.g., Bucher, Gilluly) as well as some of the high priests of theoretical geophysics (e.g., expressed in Jeffreys' *The Earth* and in Munk and MacDonald's *The Rotation of the Earth*). A great irony is that despite what is appropriately described as one of the greatest flukes in the history of testing continental drift (ranking right up there with the self-reversing rock from Japan) – Cox's report in 1957 of the aberrant direction from the Eocene Siletz volcanics from Oregon falling close to the Deccan pole from India with continents in the present position and ascribed to rapidly varying geomagnetic fields, which turned out to be due to local tectonic rotation of the Siletz – Cox's misjudgements were basically forgotten and his (with Doell's) reputation rested on their subsequent work on the timescale of polarity reversals (motivated in part by the self-reversing fluke), which was the basis of the Vine and Matthews hypothesis. The decade-long effort to make the case for continental mobility with land-based paleomagnetism was not in vain. It not only helped prepare the community to accept plate tectonics (the topic of the author's next volume), it eventually provided the natural paleogeographic reference frame.

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Abbreviations

AAPG	American Association of Petroleum Geologists
AF	Alternating fields
AG	*Advances in Geophysics*
AGU	American Geophysical Union
APW	Apparent polar wander
ANU	Australian National University
BMR	Australian Bureau of Mineral Resources
BAAS	British Association for the Advancement of Science
FRS	Fellow of the Royal Society (London)
GAD	Geocentric axial dipole
GSA	Geological Society of America
IGY	International Geophysical Year
IUGG	International Union of Geodesy and Geophysics
JGG	*Journal of Geomagnetism and Geoelectricity*
JGR	*Journal of Geophysical Research*
Lamont	Lamont Geological Observatory
Ma	Million years
NRM	Natural remanent magnetization
NSF	National Science Foundation (USA)
ORS	Old Red Sandstone
RAS	Royal Astronomical Society
RS1	Research Strategy 1
RS2	Research Strategy 2
RS3	Research Strategy 3
SEPM	Society of Economic Paleontologists and Mineralogists
Scripps	Scripps Institution of Oceanography
UCLA	University of California, Los Angeles
USGS	United States Geological Survey
IUGG	International Union of Geodesy and Geophysics
VRM	Viscous remanent magnetization

Introduction

By the late 1940s and early 1950s, mobilism was at a low ebb, perhaps its lowest ever. Volume I has shown that regionalism, isthmian links, the failure to find a generally acceptable mechanism and a host of special objections had left mobilism in tatters. Fixism ruled. Globally, mobilism had few advocates and there was no sign that their numbers were increasing. The fixism/mobilism debate was moribund and something entirely new was needed, something astounding, to breathe new life into it, and break the impasse. In timely fashion during the early 1950s, the fortunes of mobilism were revived by the work begun by two British research groups studying the natural remanent magnetization of rocks, paleomagnetism.

These paleomagnetists found that the directions of magnetization in rocks that were less than about twenty million years old were not along the present geomagnetic field but were, on average, along the field of a dipole situated at the center of the Earth and directed along the axis of rotation, the geocentric axial dipole (GAD). The time average field, its average over several thousand years, had this simple form. Making paleomagnetic surveys in Britain, they found that rocks older than about twenty million years, rocks (and this was of crucial importance) that could be shown to be magnetically stable, had magnetizations that were systematically oblique to the present geocentric axial field, sometimes very strongly oblique, differing from it by as much as 90°! It was as if Britain had moved many thousands of kilometers relative to Earth's present axis of rotation and rotated many tens of degrees relative to the present meridian. A survey in peninsular India suggested that during the past sixty-five million years it had drifted 5000 kilometers northward and rotated almost 30° counterclockwise relative to the present meridian. Certain results were also obtained by a third, older paleomagnetic group, from the United States of America, some of which could have been interpreted in terms of comparable motions of North America but were not. Over the next half-dozen years, from research carried out in Europe, India, Australia, the Soviet Union, southern Africa, South America, and Antarctica, systematically varying, oblique magnetizations were observed to be grossly inconsistent from continent to continent; inconsistent in much the same way as expected from the paleoclimatic evidence and from the reconstructed movements of continents relative to each other and to the paleogeographic pole as proposed on entirely different grounds by

Wegener (I, §2.7, §2.8, §2.15, §3.2, §3.10, §3.13, §3.15), Köppen (I, §3.15), and du Toit (I, §6.5–§6.7). These astonishing paleomagnetic results obtained between mid-1951 and 1959 provided the first solid physical evidence for continental drift and reversed the downward trend of mobilism's fortunes. Collectively they confirmed that continental drift had happened, and almost every paleomagnetist accepted them as evidence of drift. However, a few from the United States saw otherwise. Most fixists outside paleomagnetism also rejected the results as evidence of drift, while old-time mobilists welcomed them. Some opponents raised difficulties, often the same ones repeatedly, which pro-drift paleomagnetists showed to be either phantom difficulties or ones that had already been disposed of. How all this came about is the subject of this volume in which certain other topics of much concern at the time will also be addressed.

As in Volume I, 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; the 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 that gave it a decided advantage over its competitors.

The development of paleomagnetism's case for mobilism is a story of how a small, disparate, often quarrelsome band of researchers working in Britain in the early 1950s took a backwater discipline in the Earth sciences and made it of central importance; how they found a way to measure, quantitatively, past movements of continents relative to the paleogeographic pole, and, less directly, to each other. Besides reviving the fortunes of mobilism, the work described in this volume has had a long-lasting and likely permanent legacy: the provision of a geographical frame of reference for mapping Earth's major features in the remote geological past, a frame of latitudes and longitudes analogous to that we have for the present world. This work began in the early 1970s with a synthesis between rock magnetization directions transformed into paleomagnetic poles and plate tectonics, which began in the early 1970s beyond the time frame of this book.[1]

Note

1 It was Smith, Briden, and Drury (1973) who initiated this synthesis in a general way with their atlas of paleogeographic maps. A short history of the formative stages of this synthesis has been given by Irving (2005). Later developments, which became possible as data accumulated, have involved the construction of "composite" apparent polar wander paths (also variously called "world" or "synthetic" APW paths) in which all continental paleomagnetic data are combined into a single path (Phillips and Forsyth, 1972; Besse and Courtillot, 2002; Kent and Irving, 2010). At present, this synthesis can be made only for Late Triassic and later times, because there are no oceans, on which plate tectonic methods depend, older than this.