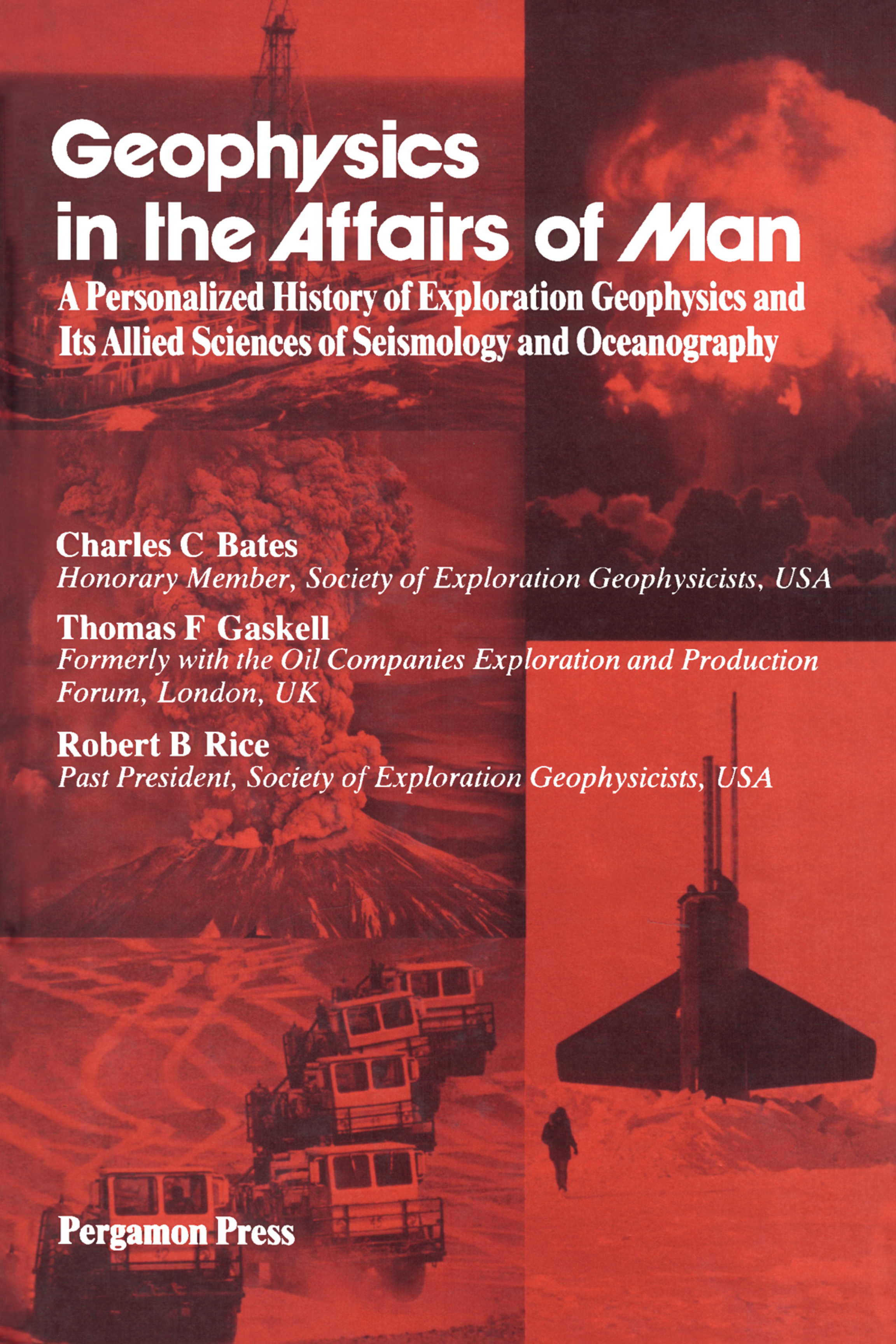

Geophysics in the *Affairs* of *Man*

A Personalized History of Exploration Geophysics and Its Allied Sciences of Seismology and Oceanography

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Approximate Conversion Factors

Monetary Units (8 October 1981)

One British pound (£) equals 1.87 U.S. dollars ($) or 2.24 Canadian dollars (C$). One Canadian dollar (C$) equals 0.83 U.S. dollar ($) or 0.44 British pound (£). One U.S. dollar ($) equals 0.53 British pound (£) or 1.20 Canadian dollars (C$).

Rate of Inflation

Year	U.S. Consumer Price Index	British Wholesale Price Index
1600	–	54
1700	–	83
1800	51	130
1900	25	75
1940	42	100
1950	72	350
1960	89	420
1970	116	530
1980	260	1200 plus
(1981)	(275)	(1350 plus)

References: U.S. Bureau of the Census, *Historical Statistics of the United States,* 1975, page 211.
Jastram, R., *The Golden Constant,* John Wiley & Sons, 1981.

Weights, Measures and Speed

From Metric (SI) to British units

Symbol	When you know	Multiply by	To find	Symbol
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	0.55	fathoms	fm
km	kilometers	0.6	miles (statute)	mi
km	kilometers	0.54	miles (nautical)	nm
km^2	square kilometers	0.4	square miles	mi^2
m/s	meters/second	1.9	knots	kt
m/s	meters/second	2.2	miles per hour	mph

Note: 1 metric tonne of crude oil is roughly equivalent to 7.6 barrels or 308.8 gallons (U.S.) depending upon the type of crude oil.

From British to Metric (SI) units

lb	pounds	0.45	kilograms	kg
in	inches	2.54	centimeters	cm
ft	feet	0.30	meters	m
fm	fathoms	1.8	meters	m
mi	miles (statute)	1.6	kilometers	km
nm	miles (nautical)	1.85	kilometers	km
mi^2	square miles	2.6	square kilometers	km^2
mph	miles per hour	0.45	meters/second	m/s
kt	knots	0.5	meters/second	m/s

Frequency

cps	cycle per second	1.0	hertz	hz

Prologue

Every aspect of human life is directly affected by the earth on which we live. The air we breathe, the water we drink, the food we eat, the shelter we construct, the energy we consume, and the elements through which we travel are all directly related to man's optimal use and improved understanding of the planet Earth. "Geophysics" is that part of observational and experimental physics which pertains to this same planet, particularly its atmosphere, hydrosphere, crust, mantle, and core. As a consequence, geophysics is an intriguing scientific and technical field of endeavor full of sharp contrasts, and it provides an unusual blend of the theoretical and the practical, the laboratory and the field, the non-profit effort and the profit-making venture, the keeping of peace and the conduct of war.

This book describes many of the key and intriguing developments which took place within several major fields of geophysics. The authors' main emphasis is placed on describing the geophysical enterprise as an interplay of technical, social, and economic factors, for even the purest science cannot prosper when divorced from the human world around it. Yet this is not a book written by science historians. Instead, it is written by members of the profession who were reasonably well acquainted with many of the key actions and players during the time that the major events took place. All three authors have engaged in the commercial search for oil and natural gas, and all have actively carried out and fostered basic research. Bates and Gaskell first met, however, while engaged in a different mode of geophysics – that of geophysical warfare. This took place on a cold February day in 1944 in a frigid, sunny office just off London's Whitehall where Gaskell was serving as Deputy Science Advisor to General Laycock of Combined Operations, and Bates, as a U.S. Army weather officer posted to the British Admiralty, was looking for assistance in the acquisition of reliable wave data from the English Channel.

Our training was acquired when neither the individual nor his community believed that "London", "Ottawa" or "Washington" could –

or should – solve all types of local problems, whether they be schooling, physical or mental health, energy supply and pricing, or optimal land use. Instead, our youthful goals were to wrest an ever better standard of living from the earth's resources for the betterment of mankind. As a result, we view with dismay the opinion held by many of our younger political leaders that the objectives of business and government are basically inimical, that a prime role of "big government" is to protect its constituents from the "spoilers of the national patrimony", and that more emphasis should be placed on the redistribution of wealth than on its creation.

Upon reviewing the literature describing the evolution of geophysics over the past six decades, it appeared to us that none of the existing books adequately described the extensive and valuable interplay between academia, industry and government that has so characterized this particular area of science and technology. For example, excellent textbooks by such authors as Sverdrup, Johnson, and Fleming (1942), Byerly (1942), Dobrin (1976), Richter (1958), and Sheriff (1980) paid scant attention to the human and economic sides of geophysics. Intriguing books by wives and daughters of sea-going scientists, such as those by Raitt and Moulton (1967), Schlee (1973), Shor (1978), and Deacon (1971) also tended to emphasize activities of classical, rather than applied, geophysicists. To be sure, recent books by practicing geophysicists and engineers, such as Wenk (1972), Bolt (1976), Petty (1976), and Sweet (1978), filled in parts of this gap in the literature but still addressed only certain aspects of the profession. A fourth approach has been that by skilled science writers, such as in *Continents In Motion* by Walter Sullivan (1974) of the *New York Times,* in *The Politics of Pure Science* by Daniel Greenberg (1967), publisher, *Washington Science News Report,* and in the ongoing historical monograph series of the American Meteorological Society. The fifth approach to documenting the actions and hopes of geophysicists has also become quite common – that of the "special pleading" study generated by the non-profit community and targeted at the need to spend more taxpayer's money on a specific field of interest. Excellent products of this school of thought can be found in the National Research Council's reports such as *Polar Research – A Survey* (1970) and *Trends and Opportunities in Seismology* (1977), the National Academy of Engineering's *Toward Fulfillment of a National Ocean Commitment* (1972), and the National Academy of Science's *Directions for Naval Oceanography* (1976).

But if none of these approaches totally portray the broad scope of how geophysics has affected the affairs of man, what is it that we hope to achieve? Our approach is to address, in a personalized history format, the discipline of exploration geophysics and its closely allied sciences of seismology and oceanography. This means the intentional omission of other important facts of modern geophysics—meteorology, hydrology, glaciology, volcanology, aeronomy, and magnetospheric physics – even though these, too, are incorporated within the International Union of Geodesy and Geophysics's realm of interest. Space limitations have also required the saga to be primarily limited to those activities undertaken by the citizens of Canada, Great Britain, and the United States of America, with emphasis on the latter, for that is where the largest number of people have found it appropriate to call themselves "geophysicists".

Because this chronicle stresses challenge and change, the overview is bracketed by two major flex points in Western civilization – the initial waging of deadly global war (1914–1918) and the onset of skyrocketing energy costs that leaves the world's economies and politicians in disarray (1973 on). To be sure, there have been about 100 successive lifetimes since the Sumerians first invented writing. Yet it has been our particular fortune to spend nearly one cent of civilized time within a period of enormous and catastrophic change. Thus, our generation has lived simultaneously in the "Nuclear Age", the "Age of Velocities (or Jet Engines)", the "Age of Electronics and Computers", the "Age of Mass Communications", and the "Age of Population Explosion". Perhaps the most worrisome facet of this change, besides the rapid growth in population and the potential for nuclear war, is the reappearance of appalling monetary inflation rates and the associated turmoil and uncertainty in human and property values. Before 1940, prices had been so stable over the previous century that a "nickel beer" was a "nickel beer" from the times of Presidents Thomas Jefferson to Woodrow Wilson, and a "three-penny beer" the same from the times of the Duke of Marlborough to David Lloyd George.[1] Today, unfortunately, the consumer price index stands at more than six times that existing at the start of World War II. The reader is cautioned, therefore, to make appropriate price adjustments as he goes along because monetary values expressed here are in the values of the moment (see listing of conversion factors).

The narrative style is semi-technical in order that the text may prove interesting to others besides practicing geophysicists. Much that is contained herein should actually appeal to those family associ-

1. In fact, English wholesale prices remained relatively stable for two centuries beginning in 1717 when the physicist, Sir Isaac Newton, then Master of the Mint, placed the pound on a gold standard (Jastram, 1981). Because gold is too scarce to be debased, this worked well until it became necessary to finance World War I during 1914. Even today, the annual production rate for gold is only about two percent of estimated above-ground supplies.

ates who wondered why their favorite geophysicist found it necessary to be away for weeks to months at a time. Certain events, if not well described elsewhere and personally known to us, are narrated in extra detail. The overall and quite complex story is portrayed in a discursive manner, for there are no short-cuts within the "time machine". To accomplish this, the book treats seven geophysical epochs, roughly broken into decades. This time sequence is then supplemented by a major chapter describing the business side of geophysics, for it is one of the most rapidly growing industries on the international scene. Finally, because there is such a strong intermingling of science, technology, and human endeavor within geophysics, the closing chapter is written by the profession itself. This feat is accomplished by having nearly two score noted geophysicists delineate what they consider the most outstanding actions they were ever involved in, and then supplementing that material by six vignettes written in the first person that clearly portray the uniqueness of the profession.

After having carefully reviewed and contemplated the accomplishments of geophysicists during the past century, we continue in the firm belief that the best process for understanding and optimally using the physics of the earth is the continued fostering of a strong partnership between academia, industry, labor, and government in which all readily participate and none forcibly dominates the others. Today's trend towards dealing with social and economic problems of high geophysical content by manipulating public opinion via slanted "public hearings", noisy public demonstrations and biased media presentations, rather than through careful consideration of finite physical facts, distresses us. Even the art of "grantsmanship" appears to lean too far towards use of the scary "Chicken Little sky-is-falling" syndrome or towards that trusty alternative, the claim that "The Russians are coming!" To you of the coming generation who will apply the tools and techniques of geophysics in solving many of the world's key problems, we cite Herman Wouk's dedication (in Hebrew) of the book, *The Winds of War*, to his two young sons. His thought therein was but one simple word of guidance – REMEMBER!

CHAPTER 1

Some Antecedents to the Modern-day Profession of Geophysics Through World War I

The roads you travel so briskly lead out of dim antiquity, and you study the past chiefly because of its bearing on the living present and its promise for the future.

Lieutenant General James G. Harbord, U.S. Army (Retired) (1866–1947)

Diffusing Geophysical Knowledge

Scientists have long been trained to build on the successes or failures of their predecessors, their teachers, and their fellows largely through scientific associations and their publications. Such societies range from small, local ones to huge organizations with membership drawn from over 100 countries. The oldest and most prestigious for geophysicists is the Royal Society, given both its name and charter by Britain's King Charles back in 1660. The Royal Astronomical Society chartered in 1820 has also had a marked interest in geophysical matters, even to the extent of publishing a *Geophysical Journal,* because the earth is very much a part of the planetary system. Within the United States, the prestigious *N*ational *A*cademy of *S*ciences (NAS) was started as an ally of government at the initiative of President Abraham Lincoln who asked the scientific community in 1863 for technical assistance with the war effort.[1] Geophysical societies *per se* did not appear until the early 1900s. As a result of the great San Francisco earthquake of that year, the *S*eismological *S*ociety of *A*merica (SSA) was formed in 1906. The *I*nternational *U*nion of *G*eodesy and *G*eophysics (IUGG) came into being during 1911, while its U.S. interface, the *A*merican *G*eophysical *U*nion (AGU), was finally

1. In 1916, the NAS further expanded its capabilities for meeting the wartime and civil needs of government for scientific and engineering advice by creating the *N*ational *R*esearch *C*ouncil (NRC) which could draw on far more than the 150 members of the Academy. By 1979, the NRC had 800 boards, committees, panels, and *ad hoc* study groups.

organized in 1919.[2,3] The field of exploration geophysics lagged even further, with the Society of Exploration Geophysicists not being incorporated until 1930. In Canada, achieving a critical mass for independent societies outside of such major groupings as the Royal Society of Canada was difficult to achieve, and Canadian geophysicists tended to orient themselves toward the appropriate "American" grouping based in the United States.

Some Geophysical Forbearers Prior to the 19th Century

However, long before the advent of scientific societies, perceptive men had been contending with the physical forces of nature. In fact, Aristotle (384–322 B.C.) compiled the first known geophysical treatise, the *Meteorologica*, less than half of which pertained to weather matters, thereby allowing the remainder to deal with oceanography, astronomy, and "meteors" (also called shooting stars). Formal seismic instrumentation appeared as early as A.D. 132 when Chang Heng set up a seismoscope in China that not only indicated that an earthquake had occurred but also the direction of the first motion. However, man's formal knowledge of the physics of the earth did not change much from the time of Aristotle until late in the European Renaissance, when the fertile mind of Leonardo da Vinci (1452–1519) initiated new thinking on this subject, as he did in so many others. Early in the 16th century, he studied, for example, the tides of the Euxine (Black) and Caspian Seas, as well as the mechanics and inherent dangers of rock slippage along a geological fault near Florence, Italy. He also deduced that Alpine rocks were at one time submerged for he found embedded sea shell fossils. He observed that the speed of a falling body increases with time, but did not derive the exact relation. This amazing man also had some practical knowledge of hydrodynamics, including wave propagation on the water's surface. Studying light and sound, he recognized that reflection of an optical image is like a sound echo, and that the angle of reflection is equal to the angle of incidence. Thus, five centuries ago, Leonardo demon-

2. As of 1981, the IUGG was funded at the rate of $236,000 annually. The United States provided the largest annual donation ($24,000), followed by Great Britain, the Federal Republic of Germany, and France ($16,000). The next lower category included the Soviet Union and Japan ($12,000). Thirty-three countries, alphabetically ranging from Algeria to Zimbabwe, contributed $800 annually. The IUGG's President was Dr. George D. Garland of the University of Toronto, while its Secrétaire Général was Dr. P. Melchior based at the Royal Observatory, Brussels, Belgium.

3. The AGU, as a standing committee of the NRC, had as its objectives: "... to promote the study of problems concerned with the figure and physics of the earth, to initiate and coordinate researches which depend upon international and national cooperation, and to provide for their scientific discussion and publication".

strated an elementary knowledge of geology, the earth's gravity field, and wave propagation and reflection, all of which are an integral part of modern geophysics.

Modern-day exploration geophysics is based on four important earth properties: (1) density, typically measured as the local force of gravity; (2) magnetization, expressed in terms of local magnetic force; (3) electrochemical, variously measured by surface or down-hole electrodes, Geiger-type counters, aerial antennae, or gas-samplers; and (4) acoustical response, measured in terms of voltages derived from seismometers or hydrophones. How scientists and engineers learned to measure these properties from the time of Leonardo to the present has been described in extensive detail in the various editions of the *Encyclopaedia Britannica* and in numerous technical publications issued over the years. Suffice it to say that many of the early "geophysicists", whose notable actions are encapsulated in Table 1.1, remain world famous and their basic concepts are utilized even today.[4]

A Brief Overview of Earth Physics During the Period 1800–1919

Although today's geophysical forbearers were able to stake out and explain specific physical phenomena of the earth, they also faced the difficult problem of having their particular segment of the total system, as was every other one of the component parts, subject and responding to a complex set of forces, each of which involved a large number of variables. Even more confusing to these early workers was that many of the observable variables changed with time and physical position. To make sense out of such confusion, the researcher is heavily dependent on four allied and supporting technologies — instrumentation, transportation, communication, and computation. Thus, despite the unique skills and great talent of the early "geophysicists", major advances in this field that would truly benefit mankind on a large scale were not possible until after the invention of the telegraph in 1840, the radio in 1900, and the vacuum tube amplifier in 1905.

As a consequence, the development of the geophysical profession during the 1800s was a very slow one and largely academic in nature.

4. The term, "geophysics", first appeared in 1853 when a German lexicon used it as a substitute for the term "earth physics".

TABLE 1.1

Some Notable Geophysical Findings in the 16th through the 18th Centuries

Scientist	Accomplishments of geophysical interest
William Gilbert (1540–1603)	While Court Physician to Queen Elizabeth, founded the sciences of magnetism and electricity; observed that north-pointing tip of magnet dipped at angle dependent on latitude.
Viscount Francis Bacon (1561–1626)	Besides serving as Lord Chancellor (1618), expounded on nature of gravitational and magnetic forces and stressed need for physical experiments. Suggested southern tips of South America and Africa would prove to be homologous.
Galileo Galilei (1564–1642)	Developed correct formulae for motion of a pendulum (basic term for force of gravity now termed a "gal"); invented primitive thermometer (1593).
René Descartes (1596–1650)	Founded analytic geometry; published 10-part discourse, *Meteorology*, on winds, clouds, and precipitation (1637); measured index of refraction to explain rainbow.
Unknown	Used magnetic compass to search for Swedish iron ore deposits (*circa* 1640).
Evangelista Torricelli (1608–1647)	Invented mercury barometer to demonstrate presence of atmospheric pressure (1643).
Christian Huygens (1629–1695)	*Traité de la Lumière* explains refraction and behavior of wave impinging on an interface, as well as diffraction (1693).
Sir Isaac Newton (1642–1727)	Discovered (independently from Baron von Leibniz) concept of the calculus (1669); stated basic laws of motion and explained true cause of ocean tides in his *Principia*.
Pierre Bouguer (1698–1758)	Compared regional mass of earth with local mass of mountain via pendulum measurements (1740). (Correction of gravity measurements for elevation above a datum is now termed the "Bouguer correction".)
Benjamin Franklin (1706–1790)	Studied lightning and recommended use of lightning rods (1749); elected member of Royal Society from America (1750); published comprehensive chart of Gulf Stream based on current and temperature measurements (1770); postulated continental drift (1780); attempted to track storms over North America.
Reverend John Michell (1724–1793)	As Woodwardian Professor of Geology at Cambridge University, published important first paper on cause of earthquakes (1760); described method for measuring gravitation field by a "torsion balance" (1777). (Charles Coulomb also built similar device to study magnetic and electrical attraction in 1777 as well.)
Captain James Cook, RN (1728–1779)	First global navigator to apply scientific method to geographic exploration, including initial extensive use of chronometer to determine longitude rapidly during three long cruises to the Pacific Ocean region between 1768 and 1779. (His chief scientist was Sir Joseph Banks.)
Count Pierre Laplace (1749–1827)	Paper on tidal theory written in 1778 uses equations similar to those in 1835 when Coriolis explained why gases and fluids, such as air and water, tend to flow along, rather than across, lines of equal pressure (isobars) on a rotating sphere, such as earth.

To be sure, in 1845 the Irish engineer, Robert Mallet (1810–1881), began some pioneering work on the use of "artificial earthquakes" to measure the velocity of seismic waves through differing surface materials. His approach consisted of detonating buried gunpowder charges and timing, by an electrical chronometer, the disturbance of a spot of light falling on the surface of a bowl of mercury. This effort was well conceived, but the glitter method still failed because it did not show the early weak arrivals of the all-important "compressional wave" typically used for purposes of seismic exploration.

The second major geophysical advance of the 1800s was that of mapping and interpreting the earth's gravity field. Much of this advance was due to the efforts of Baron Roland von Eötvös (1848–1919), a Professor in Experimental Physics at the University of Budapest. By 1890, von Eötvös had completed his first single-beam torsion balance as a sizeable improvement over those built by Coulomb and Michell more than a century before. Then, after making extensive field surveys in Hungary with his single-beam device, von Eötvös invented during 1902 the double-beam torsion balance, essentially the instrument of today, and used it to delineate the subsurface extension of the Jura Mountains in France. The chief competitive method for measuring gravity – using a "gravity meter" to measure the displacement of a weight on a spring – had been suggested back in 1833 by Sir John Herschel (1792–1871), but never developed further during that century to provide accuracies comparable to those obtained by measuring the beats of a pendulum.

The most significant global initiative of the period was the establishing and interpretation of earth physics data from observational networks. At the urging of the famed German geographer and climatologist, Baron Friedrich von Humboldt (1769–1859), magnetic stations were set up in many places on the globe during the 1830s. One of the key contributors was Professor Karl F. Gauss (1777–1855) who, as director of the University of Göttingen's observatory between 1807 and 1855, invented the bi-filar magnetometer and began the Magnetischer Verein (Society for Magnetic Research) which started making accurate, simultaneous magnetic measurements throughout Europe between 1836 and 1841.[5]

Seismic networks lagged magnetic networks by more than a half century. The first accurate earth displacement meter (or seismometer) was not constructed until 1880 by a team of British workers, Gray, Ewing, and Milne, at the Imperial College of Engineering in Tokyo.

5. The standard unit of magnetic intensity is termed the "gauss", while the curve generated by plotting observational error is known as a "gaussian curve".

Their approach was to support a heavy mass within a horizontal bracket pendulum such that the mass had a free restoring period of 12 seconds, or about six times that of the vertical pendulum in a "grandfather clock". With great inertia and a relatively independent suspension, the seismometer's undamped, slow-moving mass would lag sharply behind the earth's movement during an earthquake and, when linked to a stylus, trace out the differential motion between the pendulum and the earth during a seismic event. Mechanical linkages for multiplying this motion – true "Rube Goldberg" devices – were used even long after the Russian, Prince B. B. Galitizin, developed electromagnetic seismographs as early as 1906 that drove mirrored galvanometers which deflected beams of light over photographic paper. Thus, as late as 1922, de Querrain and Piccard built the "Universal seismograph" at Zurich, Switzerland, which used a mass of 21 tons. In this instance, the vertical sensor had a one-second period and a static magnification of 1,500, while the two horizontal components had three-second periods and a static magnification of 1,300.

The first seismographs in California were installed at Berkeley and the Lick Observatory during 1887 by the University of California's Department of Astronomy. In 1895, Professor John Milne (1850–1913) finally returned to London's Royal School of Mines and by 1897 was able to have the British Association for the Advancement of Science propose that a world-wide network of seismic stations be established. The concept was well received by directors of meteorological and astronomical observatories, and in 1899, a coordinated network of 27 stations was operating on all continents (Herbert-Gustar and Nott, 1980). The Association then began publishing a list of global seismic events, and the International Seismological Association was formed in 1903, with ultimate headquarters at the Institut de Globe, Strasbourg, France, to facilitate data exchange.[6] With so much raw seismic data available, it was necessary that the results be interpreted, and in 1901 the first, of many, "Institute of Geophysics" was started by Professor Emil Wiechert at the University of Göttingen.

Almost immediately, analysis indicated that earthquakes recorded from the same distant area looked amazingly alike on seismograms obtained at a given site. As the detectors improved, it was also apparent that the large waves in the most conspicuous part of the record would be preceded by as much as a half hour by smaller, shorter-period wavelets which could be further split into primary and secondary

6. The British listing of seismic events continues even today at the International Seismological Centre near Newbury, Berkshire.

tremors (see Fig. 1.1). To sort this all out, seismologists agreed on an international nomenclature based on Latin. The initial wave, which was compressional-rarefactive, was labeled "P", the immediately following transverse (or shear) waves, "S", and the later, large, long-period wave train was labeled as consisting of "L", "M", and "C" waves. Study soon showed that the "P" and "S" waves traveled directly through the earth and thereby arrived at distant stations from below, while the larger waves were primarily surface waves, including some of the type originally predicted by John William Strutt (Lord Rayleigh) and expanded upon in 1911 by Augustus E. H. Love.[7]

Because of the multiplicity of wave paths between the seismic event and the seismic recorder, sorting out which phase was arriving at a given time could become a complex endeavor. In fact, a common saying soon arose that "two (seismic) shocks are the last refuge of a seismologist", as two near-simultaneous shocks from different epicenters could explain almost any series of recorded phases.

In 1909, the Jugoslav, A. Mohorovičić, in studying seismograms from an earthquake which occurred not far from Zagreb, observed

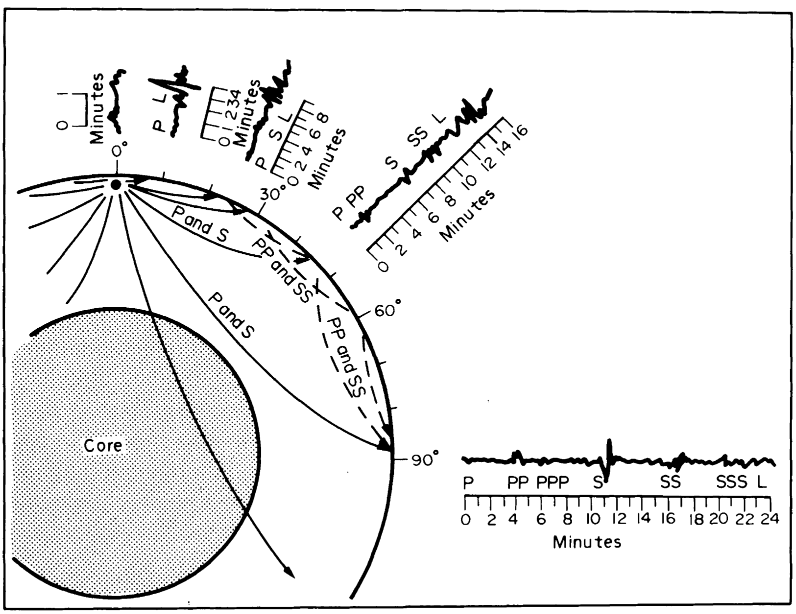

FIG. 1.1. Schematic diagram showing increase in complexity and duration of seismic wave train with distance from epicenter.

7. Two of the dominant surface phases are now called "Rayleigh" and "Love" waves.

that if the records were taken within 150 km of the source, the initial waves were sharp, followed by a lesser motion, and possessed a velocity of about 5 km/sec. Farther out, however, initial arrivals started with a comparatively small, long-period motion (now called P_n waves), followed by at least one larger, sharper wave train of shorter period, and possessed a velocity of about 8.0 km/sec. His calculations soon showed that the faster waves came in first at the greater distances because they traveled deeper and through rock with much higher velocities than that which existed near the surface. This interface between slower and faster rocks was explained by there being a marked difference between "crustal" and "mantle" rocks. As a consequence, the interface was labeled the "Mohorovičić discontinuity" (or "Moho" for short) and has since been found to exist at depths of as little as 5 km below the ocean floor and to more than 60 km under certain mountain roots. In 1912, 23-year-old Dr. Beno Gutenberg (soon to be a meteorologist in the German Army) found, while working at the Strasbourg center, that something was blocking reception of P_n wavelets at distances of 108° to 143° of latitude from earthquake epicenters.[8] Such a blockage, he calculated, could be created by an "earth core" slightly larger than the Planet Mars starting at a depth of 2,900 km. This important finding, of course, verified the earlier claims of Emil Wiechert (1896) and Richard D. Oldham (1897) that the earth consisted of two major components, rather than just one vast homogeneous sphere (Brush, 1980). Thus, just 13 years after the start-up of the first global seismological network, geophysicists were able to point out that the earth consisted of three important elements – a core, a mantle, and a crust.

Despite the frequent occurrence of damaging earthquakes within the United States, local chambers of commerce and state legislators were not anxious to see the issue publicized. Hence, when the Seismological Society of America caused a bill to be introduced into the Congress during 1910 which would establish a "Bureau of Seismology" within the Smithsonian Institution, the concept was rejected even though it would have cost but $20,000 per year. As a consequence, the U.S. Weather Bureau, as part of the Department of Agriculture, operated just a few seismographs at selected weather stations until 1925, when the function was finally transferred to the *C*oast and *G*eodetic *S*urvey (C&GS) within the Department of Com-

8. P_n waves are compressional-rarefactive in nature and analogous to sound waves. Associated with them, but traveling at about 0.6 their velocity, are S_n waves, which are transverse (or shear-like) to the direction of wavefront advance, as in the transverse vibration of a string.