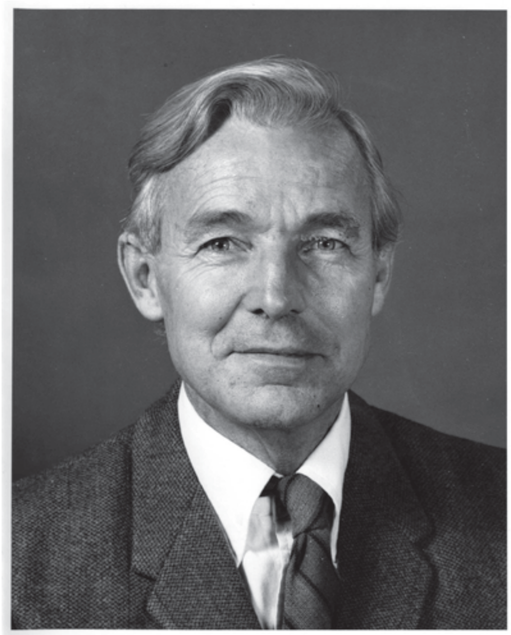
Biographical Memoir, Edward (Ted) Irving, FRS, FRSC, CM

May 27, 1927 – 24 February 2014

Roy Hyndman FRSC ***April 7, 2015***



Dr. Edward Irving, FRS

Summary

Dr. Edward Irving, one of Canada's most respected geoscientists died 24 February, 2014, in Saanichton B.C. Canada at age 86, leaving his wife Sheila and children Katie, Susan, Martin and George. Following his early work as a student at Cambridge in Britain, he moved first to Australia and then to Canada. Over more than 60 years his scientific career was devoted mainly to the use of magnetic remanence recorded in ancient rocks to address fundamental geological questions. This seemingly simple technology proved to have remarkably many applications. Through his measurements and analyses of rock samples that recorded the magnetic field at the time of their formation, Ted was in the forefront of demonstrating that continental drift was real, at a time when the theory was out of favour. His meticulous work on rocks from many areas of the world was instrumental in showing how continents have been constantly moving, breaking up, and colliding to make new larger continents and then breaking up again. He published over 200 articles in international scientific journals. His reference text *Paleomagnetism and its Applications to Geological and Geophysical Problems* is still widely used. Applying remanent magnetism to study the motion of continents, and to other important geological problems, required careful analyses and interpretations. These included showing that the secular change in the earth's magnetic field direction averaged over time aligns with its rotation pole; that the earth's magnetic field has reversed its polarity at irregular intervals of a few million years, and that overprinting by re-magnetizations of rocks at different geological times can be separated by special laboratory techniques. Other contributions included important research in ancient climates, continental glaciations, the origin of mountain systems, and the relative displacements of parts of continents (terranes), especially the inferred large northward movement of parts of western North America, a conclusion that remains controversial. His most important results depended critically on his developing and using the best field sampling methods, laboratory instrumentation and procedures, and data analyses methods. During his career he established world-class paleomagnetic laboratories in Cambridge, England, in Canberra Australia, and in Ottawa and in Victoria in Canada. Ted Irving had broad interests and knowledge. He was a serious gardener and horticulturalist and wrote several scholarly articles on plants, especially on the biogeography of rhododendrons and magnolias. He received numerous awards, medals, and recognition, including Fellow of the Royal Society of London, Fellow of the Royal Society of Canada, Fellow of the American Geophysical Union, Honorary Fellow of the Geological Society of London, and Foreign Associate of the US National Academy of Sciences. He also received many awards and medals from professional geological

societies. Ted Irving received Honorary Doctorates from two universities, and the Order of Canada, in recognition of his outstanding scientific contributions.

TED IRVING`S LIFE AND CAREER

Early Life Colne, England, 1927-1945

Edward (Ted) Irving was born in 1927 in Colne, Lancashire, in northern England. The primary industry of the town was the weaving mills where his father worked. He was the first one in his family that attended university, and the only one in his generation. He attended the local Lord Street Council School from age five to nine, and then won a scholarship to the Colne Grammar School. He was a year younger than most of his classmates. He played rugby and cricket, was Boulsworth House captain and later Head Boy. On completion of the Colne School with a Higher School Certificate he obtained a Lancashire County Major Scholarship to continue at university. He had a place at University College London to read Geography, but military service intervened. In his early years he learned his love of the outdoors from extended walking trips with his father. During his later school years through his undergraduate and graduate years he took many trips across Britain and in Europe, often alone, as he described, looking at scenery, paintings, and buildings and listening to music. Ted felt very much his transition from a working class family to a broader world. He wrote: “My earlier life was down-to-earth and gritty, firmly placed in the settled but as we now know dying traditions of the Lancashire working class.... I became increasingly detached from my social surroundings, as my educational and cultural horizons broadened.... I was being torn loose from the secure social scheme into which I was born.”

Army, 1945-48

At age eighteen in November 1945, just after the end of the war, Ted was conscripted into the British Army and started military training. He served mainly in north and east Africa until 1948. The war was just over, but Britain had world-wide imperial responsibilities and there were mandates and occupied territories to police. He went through 6 weeks of boot camp general training which he described as terribly “regimented and brutish”. At the end of the year he was sent for intensive training, identified as “officer material”. However, in the selection he was deemed “too young” and he subsequently volunteered for overseas draft. He was sent to northern Palestine near Hadera, Afula, and Haifa. He became a lance-corporal. International pressure was building for unlimited Jewish immigration out of the horrors of Hitler’s Europe and his battalion was engaged in anti-terrorist activities for the Jewish agricultural settlements. He was a member of a royal guard-of-honour for King Abdullah. In early 1947 he was sent to Asmara as part of the military presence in Eritrea, the old Italian colony which had been occupied by British troops. There he had his 20th birthday.

Cambridge Undergraduate

At the end of his military service in 1948, Ted applied to a number of colleges at Oxford and Cambridge and was finally accepted in Natural Sciences at Fitzwilliam College, Cambridge, specializing Part I in geology, mineralogy, and zoology, and Part II in geology and paleontology. He graduated in 1951 with geology as a special subject. As he noted, there was no course in geophysics or in tectonics, subjects that subsequently played such an important role in geosciences, and later he described the department as a relic of the great days of Cambridge geology in the early part of the century. Although there were several great lecturers, Ted described the department as lacking the vigorous interactions of staff, the hallmark of a great department. As he said, it is not surprising that the important discoveries in the Earth Sciences at Cambridge in the 1950's and 60's were made in the Department of Geodesy and Geophysics, not the Department of Geology. He was most impressed by supervisions with Gertie Elles who was about 80 and long retired. She recommended that he read original papers where he could appreciate the real difficulties and uncertainties of science, rather than subsequent books that gave ordered summarized results. He had read Wegener's 1924 work and the theory of continental drift that played such a large role in his subsequent career, although at the time it was generally not favoured. He noted that the two excellent scientists Brian Harland and Maurice Black discussed continental drift favorably.

Wartime regulations allowed graduation in two years, so Ted's undergraduate training was short. However, he described it as an intense social and cultural education, for which he was not well prepared. In Cambridge at the time there was an intimate mixing of different social levels and highly diverse cultural and intellectual interests. He described his early post-war class as self-confident and able, and that most did well subsequently. During vacation periods Ted travelled extensively in Europe, the start of his long interest in travel.

Cambridge Graduate Research

In 1951 after graduation Ted applied for numerous jobs. The applications were generally unsuccessful except one in South America that he did not take because of what he described as political uncertainty. In June he received a letter from S.K. Runcorn (FRS) a new Cambridge Research Fellow about a summer job. Runcorn wanted someone to accompany him on a rock-collecting trip for magnetic measurements of the paleosecular geomagnetic variation to be made at Manchester University. This proved to be the start of Ted's life-long involvement in paleomagnetism, the record of the past geomagnetic field preserved in ancient rocks. Ted met Runcorn in Kendal on the edge of the Lake District and over lunch and drinks outlined his plans for the study, and hopes of developing a rock magnetic laboratory at Cambridge. This was a turning point in Ted's career. Runcorn treated him as a colleague. Runcorn knew no geology and Ted provided the essential geological knowledge. Ted knew little physics. Ted described Runcorn as giving him his first lesson on how research happened, in this instance by two people with disparate backgrounds sharing information and questioning each other; one way to learn quickly.

Thesis Work

Just before Ted became involved, an important development was the building of a high-sensitivity magnetometer by PMS Blackett for another application. It proved to be very suitable for measuring the magnetization of rocks. Especially important work was by Jan Hospers who did magnetic measurements on Iceland lavas. The direction of the magnetic field is frozen into such lavas at the time they cool. The Iceland data showed geomagnetic reversals and the approximate long-term geocentric axial dipolar nature of the geomagnetic field. The latter, support for the Geocentric Axial Dipole Hypothesis (GAD), was critical to subsequent paleomagnetic studies. The results were published in a paper in Nature in 1951. A crucial collaboration was with R.A. Fisher (FRS), Professor of Genetics at Cambridge, who developed the essential spherical statistics used in most subsequent studies of paleomagnetism.

Ted, working with Runcorn made the first measurements of weakly magnetized sedimentary rocks. Magnetic sediment grains rotate into the direction of the magnetic field as they settle to the bottom, preserving the direction of the field at the time of deposition. It was this study and work by fellow graduate student Ken Creer that led eventually to the discovery of apparent polar wander (APW, the motion of all continents relative to the earth's rotation axis) and the first physical test of continental drift. Soon more efficient magnetometers for rock magnetic work were developed in Cambridge (1953), Newcastle upon-Tyne (1955), Manchester and Imperial College (1952-53), and the Australian National University (1955), the latter leading to Ted's subsequent work there. At the same time there was considerable effort on rock magnetism in the USA, especially at the Carnegie Institution. Unfortunately that work was soon largely terminated. In the UK there was a willingness to consider continental drift compared to general rejection in the US. At Cambridge a large group of students were formally and informally associated with Runcorn and rock magnetic work in the very creative period 1951-1954, including R. Hide (FRS), P. Roberts (FRS), F. Lowes, H Hughes, A. Moore, D.W. Collinson, P.M. Du Bois, J. Belshe, J. Parry and especially Jan Hospers and K.M. Creer. The scientific discipline of continental paleomagnetism as we now know it was created during this period.

Runcorn's plan was to determine the secular magnetic variation (variation with time) in ancient varved (annual layering) sedimentary rocks by sampling bed by bed. The secular variation of the geomagnetic field over the previous several hundred years was known to some degree because of the need to know the variation in magnetic north as used in ocean navigation. It was at this time that Ted and Runcorn first worked on the mechanisms by which rocks could be magnetized, and started a study of the magnetization of different rock types to determine which were best suited to record the ancient magnetic field. Ted discovered that one especially suitable rock was a type of fine grained red sandstone, and he later commented that there were only two types of rocks, the "red" ones, i.e., the paleomagnetically useful, and the rest. It was mainly this type of rock that allowed the first magnetic polar wander paths to be determined and the definition of the paleofield in ~1000 Ma rocks from Scotland to represent more than 60 degrees latitude from its present position. This was the first clear physically measurable evidence of continental drift. Ted and Runcorn also established that there usually was preserved a combination of an ancient field and a modern overprint in the direction of the present magnetic field.

It was at this time, 1951, that Ted had the idea that he could determine if India had moved to the north by a large distance before it collided with Asia, as suggested by several earlier geological reconstructions. In 1952 he was able to obtain samples from India using contacts through Sir Ronald Fisher in Cambridge to M.S. Krishnan, Director of the Geological Survey of India. The samples from the Deccan Traps volcanic rocks (65 Ma age) indicated a northerly movement, "drift", of 55 degrees latitude or 6,000 km. Subsequent larger collections by the Imperial College group confirmed this result. This independent confirmation of a specific drift relative motion was Ted's first truly original and significant result.

Ted commented that his detailed work on the paleomagnetic magnetometer and the work on the numerous required corrections gave him confidence in "guessing" and then testing the

Ted Irving at University House, the graduate residence and college, Australian National University

guess experimentally. He said “I was never again afraid of physicists or allowed them to terrorize me”. Ted also learned from P.M.S. Blackett that “he should carry out projects first, talk about them afterwards”, “that science was a competitive business. It was not just having fun”. Ted registered as a PhD research student in 1952.

Runcorn arranged to be built a wooden non-magnetic thermally insulated hut behind the Geodesy and Geophysics Bullard laboratories. They also built Helmholz coils to balance the current earth’s magnetic field and give a zero field measurement space. The necessary careful specimen preparation methods were developed and they compiled lists of correction factors required in the calculations. In this period Ted made much of the operational differences between the Cambridge (Runcorn group), and Imperial College (Blackett group) in paleomagnetic work. Runcorn provided very little supervision, resulting in an apparently chaotic but ultimately highly productive atmosphere, whereas Blackett’s was a very controlled organized top-down management, with John Clegg serving as the daily operations officer. The one negative that Ted felt at this time was that the publication of his work and that of the other students seemingly was delayed by Runcorn because he wanted to be credited with the discoveries himself.

In 1952-53 Ted carried out a study of the billion-year-old Torridonian, red argillaceous sedimentary rocks, which occur extensively in the northwest Highlands of Scotland and established that such rocks could hold a magnetic record for long geological times, and that geomagnetic field reversals occurred in the Precambrian. He and fellow student Ken Creer found that all the pre-Miocene rocks (about 23 Ma) that they studied which had preserved magnetic directions were strongly oblique to the present field. They realized that their results opened the way to a physical test of continental drift by obtaining and comparing the APW paths from different continents. The also realized that their results were roughly consistent with Wegener’s reconstruction of continental movements.

Ted wrote his thesis in a very intense period from July to early September 1954. He was already late for the job he had taken at the Australian National University (ANU) and his Cambridge support grant had ended. He had applied in February in response to an advertisement in the Cambridge Reporter and received an offer in April 1954. Keith Runcorn was absent for most of the later work included in Ted’s thesis, often in the USA, and was not much involved. Ted worked closely with Ken Creer, who finished at nearly the same time. Ted appreciated that Australia offered the opportunity for “his own show” and an unlimited opportunity for the continental drift test. He met Professor John Jaeger the head of the then new ANU department who was on study leave and visited Cambridge. They did initial planning for his paleomagnetic work in Canberra, including the non-magnetic hut and the initial low-sensitivity magnetometer. He sailed for Australia in November 1954.

Australia, 1954-1964

Ted went by sea to Australia in late 1954 to work at the new Australian National University in Canberra, under the Head of the Geophysics Department, Professor J.C. Jaeger who was appointed in 1952. Upon his arrival, Ted learned that this thesis *Palaeomagnetism of the Torridonian sandstone series of NW Scotland*, submitted to the University of Cambridge was rejected for the degree of PhD. He was awarded a default MSc. The exact reasons are not clear. The examiners may not have understood the methods of paleomagnetism and they may have found the results and conclusions, including his paleomagnetic evidence for the northerly motion of India, were unacceptably radical. Following his subsequent ground breaking publications, this error in assessment was in part redressed by the university awarding him the degree of ScD in 1965. The significance of his work was recognized by his election in 1979 as a Fellow of The Royal Society of London for his contributions to the science of paleomagnetism.

Jaeger had set up an unusual department, mainly geophysics, but without the usual geophysics disciplines of seismology, classical geomagnetism, and gravity. He wanted new fields with less competition, that were not too expensive, and where major breakthroughs might be made. Ted reported that Jaeger said to him “...you are just a temporary fellow, ...if you don’t find anything interesting, I can fire you after three years and you will not have cost me very much”. Jaeger himself did not have a PhD and was not concerned by the rejection of Ted’s PhD thesis, advising him to have a beer and move on. Ted appeared to have been happy with Jaeger’s high expectation. After five years of graduate research with no publications, he began in 1956 to publish frequently. He soon made contacts with a number of Australian geologists and geoscientists with relevant expertise and knowledge and met the department scientists staff and began to work with the excellent technical staff who subsequently played an important role in his instrumentation facilities.

Immediately on his arrival, Ted undertook the job of constructing a new paleomagnetic laboratory. He found a location with minimum potential magnetic disturbance on the university grounds. The ‘mag hut’ design was similar to but an improvement on the one built in 1952 that he had used in Cambridge. It was constructed of non-magnetic wood with copper nails, to minimize spurious magnetic fields. The non-magnetic lab housed low and high sensitivity magnetometers for measurements on high magnetization igneous and low magnetization sedimentary rocks. These instruments were used on a wide collection of rocks. Ted also developed a rock demagnetization facility that was important for the removal of the more recent ‘soft’ magnetizations acquired since the rock’s original emplacement. In 1955 Ronald Green arrived from the Bureau of Mineral Resources to the ANU as a research student and began to work with Ted. He was a physics graduate with field work and observatory experience. He was an excellent complement to Ted who had geological training. Green was responsible for a second astatic magnetometer, more sensitive than the first for measurement of weakly magnetized rocks, and for important improvements to the statistical treatment of data. A new feature was the use of a newly available ferroxdur material for the magnets in the astatic sensing system. These magnets were magnetized transversely rather than longitudinally, giving an astatic system that was stable and efficient with a reduced response time. Green was later followed by Ted’s second student Peter Stott who made important additions to the paleomagnetic laboratory. Unfortunately Peter was unable to finish his PhD. A third student was Bill Robertson who was a geology graduate of Queens University Belfast. A critical development for the paleomagnetic studies was the establishment of age dating facilities at the ANU, and the work of Evernden, Richards, and McDougall.

Initially, they measured rocks from the Older (Eocene) and Newer (Pliocene to Recent) Volcanics of Victoria. The Older Volcanics gave a pole position significantly different from the present geographic pole position, whereas the Newer Volcanics gave a pole that agreed with the present geographic pole. With earlier results from Tasmania, an initial polar wander path for Australia was clearly different than that for Europe. That the Newer Volcanics results agreed with the present geographic pole position gave support to the geocentric axial dipole field model. This was the first southern hemisphere Geocentric Axial Dipole (GAD) Hypothesis result, i.e. that the paleomagnetic field averaged over sufficient time is equivalent to that expected from a dipole centered on the earth's rotation axis. They also found reversed magnetizations, which at that time were still unexplained.

In early 1955, Ted wrote a paper which he thought his most creative. It compared polar wander paths for Europe and North America, with the India pole from his thesis work and his newly obtained Tasmania pole. The manuscript included analyses of global climates by Köppen and Wegener, which he had begun discussing in this PhD thesis, and latitudes using the new paleomagnetic methods. He was the first to draw separate polar wander paths for Europe and North America, and showed that results from both continents differed substantially from those he had obtained from India and Tasmania. He furthered this argument for continental drift as opposed to polar wander alone, by showing that paleoclimatic results for each continent were consistent with paleomagnetic results. If only polar wandering is invoked, paleomagnetic and paleoclimate latitudes are inconsistent. He also argued that consistency between paleomagnetic and paleoclimate data gave further support to the GAD hypothesis. The paper was rejected by the *Journal of the Geological Society of Australia*, but subsequently published by *Geofisica Pura e Applicata* in 1956 through Jaeger's intervention. The importance of this article has been recognized by the recent article by Henry R. Frankel that included a reproduction of the original paper (Frankel, 2014).

This work was followed by the production of a full APW path for Australia, from the Late Precambrian to the Present, which allowed Australia to be added to the global paleomagnetic test of continental drift. An important turning point in the international community taking the paleomagnetic support for continental drift seriously was the presentation by Ted at the Toronto, Canada, meeting of the International Union of Geodesy and Geophysics (IUGG) in 1957. He showed the huge difference in APW between Australia compared to Europe and North America. Ted was particularly pleased that the prominent Cambridge geophysicist Edward Bullard complimented him on his spirited defense to critical questions from the audience after his presentation. A paper on the Australian results was submitted to the American *Journal of Geophysical Research* in 1957. It was rejected, a result which Ted interpreted as a demonstration of the opposition to continental drift in the USA. The paper was then submitted with the encouragement of one of the editors, Alan Cook, to the new British publication, *Geophysical Journal of the Royal Astronomical Society*, where it was accepted and published.

Ted`s work in Australia involved detailed measurements and studies that consolidated the evidence that continental drift was real, the first quantitative global test of drift. He set out a number of main tasks, (1) He augmented and strengthened the APW path, especially for Australia to see if it had moved with respect to Europe. (2) He started the important work of correlating paleomagnetic data with paleoclimate data that he followed to much success in his subsequent career. Paleomagnetic data proved to be remarkably consistent with the by then quite extensive paleoclimate data, i.e., glacial deposits near the equator, and tropical and desert sedimentary deposits at high latitudes. He correctly viewed comparison of paleomagnetic and paleoclimate data as one of his most important contributions.

In Australia, Ted and colleagues were among the first to recognize that magnetic reversals provided a new tool for rock chronology, once the reversal history had been established. This reversal chronology proved to be instrumental in understanding the seafloor magnetic anomaly stripes, normal and reversed magnetizations, that were critical for establishing seafloor spreading.

Some of Ted`s important collaborators at the ANU were Fulbright Fellow Neil Opdyke, Colin Bull, Frank Stacey, David Brown and PhD student Don Tarling and Jim Briden.

An important part of Ted`s work in Australia was the completion of his book, *Paleomagnetism and Its Application to Geological and Geophysical Problems* (Irving, 1964), that still remains a primary reference for the field. It was published in 1964 just after he left Australia and moved to Ottawa. An important component of the book was a compilation that Ted made of all available paleomagnetic data.

During this period Ted met and was greatly impressed by the Austrian-British philosopher of science Karl Popper. He realized that the scientific framework of falsifiable hypotheses was very suited to presenting the paleomagnetic proof of continental drift.

Some other important contributions in Australia

The full global paleomagntic test and general acceptance of continental drift took more than a dozen years from 1951 to the mid to late 1960s. The evidence for seafloor spreading from magnetic anomaly stripes and the evidence for subduction underthrusting of ocean crust at trenches in the mid-1960's provided the missing process element for drift. The continents moved with the oceans not through them. Ted often discussed why it took so long for the evidence for drift to be accepted, why the majority of geoscientists were fixists and the minority mobilists. He was then surprised that the continental drift debate was over so suddenly, with the advent of the new marine data and interpretations.

Ted carried out the first paleomagnetic confirmation of S. Carey`s reconstruction of Pangea including both the northern and southern hemispheres. (Pangea, supercontinent that formed approximately 300 million years ago and began to break apart after about 100 million years). Much of the land mass was in the Southern Hemisphere. Ted found an indication of what he called a huge intra-Pangean shear cutting the super continent that was not in the Wegenerian reconstruction. This shear is still being debated.

Latitude and past climate, paleogeography

An important contribution by Ted was comparison of paleomagnetic latitude with latitudes inferred from geological indicators of paleoclimate, ranging from warm tropical conditions that could be explained by equatorial locations, compared to cold sometimes glaciated conditions, interpreted to be polar. There proved to be remarkable agreement between the paleomagnetic and paleoclimate data, and strong disagreement of past inferred latitudes with current latitudes for areas of many continents. It also became evident that there has been relative

Ted Irving rock sampling in the Canadian Arctic for a film documentary

movement between areas within individual continents. The boundaries were associated with strongly deformed orogenic belts. Ted also studied the latitudes of important global oilfields and found that the vast majority had accumulated in very low paleolatitudes. This very important practical application work has been widely used by the petroleum industry.

Lists of Paleomagnetic Results

Important work that Ted commenced in Australia was compiling and publishing lists of paleomagnetic results, a service that he continued until 1965 at which time M.W. McElhinny who followed him at ANU took them over. He was concerned that too many authors discredited continent motion and presented other conclusions using limited data, ignoring critical paleomagnetic data that was available but sometimes not readily available. These lists proved to be an invaluable aid for Ted and many others in global interpretations of polar wander and continental drift. The first was published in the first volume of the *Geophysical Journal of the Royal Astronomical Society* in 1959.

Ottawa Canada, Dominion Observatory, Earth Physics Branch

During his 1957 visit to the Toronto IUGG, Ted visited the Dominion Observatory in Ottawa and was impressed by the fine high sensitivity magnetometer that had been built by Jean Roy at an isolated location at the Experimental Farm just outside the city. He also visited the Geological Survey of Canada rock magnetic laboratory. In 1963 and 1964 Ted found there were a number of reasons to move on from the ANU. He was forced to move and build again the paleomagnetic laboratory to an isolated location several kilometers from the main department, when he had just completed but not yet used a major new wing with facilities for low magnetization sediments. This took very considerable time and effort. Secondly, he found that the centre of gravity of the department had moved to geochemistry, such that his influence was much reduced. Third, he found very appealing that surface outcrops in Canada had been scoured clean by glacial action in contrast to the deeply weathered and paleomagnetically difficult rocks of Australia. Finally, he and his wife Sheila with 4 small children needed larger accommodation. They recognized the quality of the Canadian educational system for their children. Sheila's father and her step mother P.K. Page were then living in Ottawa. Sheila also had a considerable family in Canada, which was of benefit with Ted often away on fieldwork. Sheila's father had recently retired from the Canadian Foreign Affairs and subsequently became publisher of the Victoria Times in BC. In early 1964 Ted accepted the job of Scientific Officer in the Geomagnetic Division of the Dominion Observatory of Canada in Ottawa. With 4 young children, the youngest two 16 months old, they sailed for Canada via UK in May 1964.

Ted's new office was in the old chief astronomer's large house which was located on Observatory Hill on the experimental farm along with two other geophysical buildings. The Earth Physics Branch had just been formed by dividing the old Dominion Observatory organization into astronomy and the geophysical observatories. The Earth Physics Branch included the national magnetic observatory network to monitor secular magnetic variation as needed for compass navigation and short time variations and magnetic storms for correcting mining prospecting and other magnetic surveys. It also included the national seismograph network for locating, measuring and characterizing earthquakes and the national gravity survey. Jean Roy had, in 1955, built an excellent astatic magnetometer similar to the Cambridge and Canberra instruments on the experimental farm. It was used extensively by Geological Survey of Canada (GSC) Geophysical Division workers.

Ted found the new Earth Physics Branch was well funded, had good workshops and technical support and with rapidly expanding world class facilities for geophysical surveys and studies. Funds were assigned to build a new national geomagnetic facility including instrument development for the magnetic observatories and new paleomagnetic laboratories at a quiet 100 acre site in the green belt near Ottawa. There were some organizational difficulties because the GSC that also had a paleomagnetic program was a separate Branch in the government. The work included measuring the magnetic properties of rocks to assist in the interpretation of magnetic anomalies in survey data, and other geologically useful studies. Ted needed the geological knowledge of the GSC scientists to find appropriate well dated rocks for paleomagnetic study and for logistical support. In an early talk at the GSC Ted's presentation was on paleontology and paleomagnetism, including how both provided latitude and other paleogeography data for rock formations. However, the two paleomagnetic groups generally worked separately. Ted's early work from Ottawa included assisting Jean Roy and Bill Black sampling in Prince Edward Island and with Neil Opdyke at the Lamont Geological Observatory in New York on some Appalachian rocks for which thermal demagnetization was important and where oroclinal crustal bending (in a horizontal plane) may have been important.

Leeds University

In the fall of 1965 Ted received a letter from Leeds University offering the position of Professor of Geophysics. The university had embarked on an ambitious program involving the Department of Geology becoming the department of Earth Sciences. Robert Shackelton was Professor of Geology. The Irvings soon moved and purchased a house in Menston near Leeds. One of the programs was working with Sandy Steward on the Torridonian which had received much earlier magnetic and geological study. It was a short stay of a little more than a year. Despite being closer to his parents and extended family, it appears to have been a disappointing period for his career, of which Ted spoke little. Ted and family returned to Ottawa sailing from Liverpool to Montreal in the summer of 1967. He was cordially welcomed back in Ottawa. They purchased a new house in the Alta Vista suburb. Ted returned to his old office that had remained unoccupied.

New Work in Ottawa

Ted's return to Ottawa was at the time 1967-68 when the key elements of Plate Tectonics was being developed. This was a major geoscience revolution, consisting of seafloor spreading producing new crust and ocean crust being consumed at subduction zone trenches. This concept removed the continental drift problem of continents ploughing through the oceans, for which there was no evidence. However, plate tectonics and seafloor magnetic anomalies provided evidence for drift only for about the past 100 m.y., the maximum age of significant remaining seafloor, whereas paleomagnetism provided evidence for very much longer. The important question that directed much of the lab work then became: what could systematic paleomagnetic studies of older rocks of which Canada was largely composed tell us about plate-like motions in earlier times? How far back in geological time did plate tectonics go? Dealing with older rocks involved many technical problems. An important effort was on the Precambrian sedimentary basins of the western Canadian Shield with Alan Donaldson and John McGlynn. This was part of a larger effort on Precambrian paleoclimate and paleogeography. This work developed in part into studies of tectonics and of magnetic overprinting. Overprinting magnetizations subsequent to the initial formation of rocks became a major issue.

One of his most cited publication was his 1982 compilation of Global Apparent Polar Wander Paths, in which he produced age-windowed averages. It was the first use of absolute ages, and added a new level of precision to continental reconstructions.

Ted became involved for a time on the magnetic properties of Mid-Atlantic Ridge rocks to try to understand the origin of the seafloor parallel magnetic anomalies mapped thorough ship-towed magnetometer surveys. They were becoming recognized as due to seafloor spreading. At this time Ray Yole then chairman of the Geology Department at Carleton University suggested that Ted become involved in the western Cordillera of Canada, starting with rocks from Vancouver Island. Initial work was carried out in Ottawa.

Victoria Canada, Pacific Geoscience Centre (PGC)

In 1982 Ted requested a move to the Canadian west coast to be part of the new Federal Pacific Geoscience Centre (PGC). The Centre was part of the Institute of Ocean Sciences that had just been completed adjacent to the Victoria airport on Saanich Inlet. The Institute included PGC and ocean science parts of the Department of Fisheries and Oceans (DFO). They were administratively separate but shared library and many other facilities. The PGC marine programs shared the ships and other marine facilities with the DFO ocean science. PGC initially consisted mainly of a unit of the Earth Physics Branch but included a marine geology group from the Geological Survey of Canada. Later the two groups were merged, both becoming part of the Geological Survey of Canada. There he set up a new paleomagnetic laboratory. An important new technical development, the fluxgate spinner magnetometer, allowed magnetic measurements of all but the most weakly magnetized rocks in a normal laboratory space of the PGC building. A non-magnetic building in a magnetically quiet area was no longer very necessary.

Although he officially retired in 1992, Ted continued to be very active as an Emeritus Scientist. He extended his work on mobility within the Canadian Cordillera (the Baja BC controversy) and Canadian Shield mobility. He also moved into mineralization dating with Kurt Kyser at Queens University. He continued his work on the motion of the continents during and prior to the formation of Pangea, including “Pangea B”, the last mega continent that broke up to form the modern continents. He also worked on models for the previous supercontinent, and plate tectonics of Archean cratons back to 2.0 Ga. He continued work on the correspondence of paleoclimate and paleomagnetic conclusions. Both provide indicators of latitude. Paleoclimate indicators such as the fossil remains of tropical plants found in the arctic and glacial deposits now at equatorial latitudes, agreed well with the paleomagnetic latitudes at those times. At PGC Ted began a long collaboration with Rene Barendregt on magnetostratigraphy of glacial deposits in western Canada, and accurately dating the magnetic reversal time scale which could be used

Ted Irving rock sampling on Vancouver Island, Canada

as a dating tool. Ted undertook work on large scale remagnetization events in the Appalachians and in the Cordillera. This work was continued extensively by Randy Enkin for western Canada; the “big flush, chemically resetting paleomagnetic directions over large areas by regional hydrothermal processes.

Pangea A and B

Never one to shy away from controversies and willing to go where data took him, Ted continued what remains a controversy over when and how Wegener’s supercontinent Pangea formed and then broke up. Laurasia and Gondwana were the northern and southern parts of the Pangaea supercontinent about 300 to 200 m.y. ago. They separated 200 to 180 m.y. ago in the late Triassic period during the breakup of Pangaea toward the modern continents, Laurasia drifting further north after the split.

Irving first noticed a discrepancy in Gondwana and Laurasia paleomagnetic pole positions in 1957 when testing Carey’s last pre-drift reconstruction of the continents. There was a noticeable latitudinal gap, labeled the Inter-Pangea paleomagnetic anomaly, between the two supercontinents. Irving had returned to the problem in the late 1970s. To remove the anomaly and overlaps, he proposed that Wegener’s Pangea, he called Pangea A, did not form until the early Jurassic or late Triassic, a reconstruction closer to du Toit’s than Wegener’s. He proposed that a super-continent, Pangea B, began to form in the middle Carboniferous, and morphed into Pangea A as Laurasia moved along a right-lateral transform fault relative to Gondwana. G. Muttoni and D. Kent, more recently with new data, concluded that Irivng’s Pangea B indeed existed and transformed into Pangea A during the Permian. However, the large lateral transform fault shear between Gondwana and Laurasia is not clear in geological data and the controversy over the nature and development of Pangea continues. Ted saw similarities between this controversy and the earlier one over continental drift. Calling those who continued to favor Wegener’s single stable Pangea that broke up into the modern continents, neo-fixists, he argued that they, like those who had favored continental fixism, resort to non-falsifiable hypotheses such as non-dipole fields to dismiss the paleomagnetic data.

Movement of Cordilleran Terranes

Although started earlier, it was here that Ted initiated serious work on the movement of terranes or coherent parts of the Cordillera of North America relative to the old cratonic core of central Canada, and such relative motions within other continents. He notably developed the model of “Baja British Columbia”, that western BC had moved long distances north along the margin (also the geologically defined “Cordillera Ribbon Continent” or “SAYBIA”). The motion was viewed in a similar way to the present northward motion of Baja California which is attached to the Pacific Plate, and is moving northward along with the westernmost part of

California west of the San Andeas Fault relative to the main North America. He concluded that there had been motion of the western terranes of at least 1,500 and as much as 3,000 km to the north. A large part of British Columbia and southern Alaska was at the latitude of Baja California, Mexico, at 85 to 95 Ma in early Late Cretaceous time, reaching its current position by the mid-Eocene, ~50 Ma. The paleomagnetic data also suggested that there may have been a prior motion to the south. The geological difficultly is that, although some fault displacement in the expected directions had been mapped, it was difficult to identify the faults or shear zones along which the large motions occurred. The Coast Shear Zone is prominent on the west side of the Coast Mountains but paleomagnetic data indicated large northward motion of rocks further to the east in the Intermontane and Insular belts. There appear to have been several independent terranes with progressively greater northward motion from east to west, that have amalgamated. Such motions of large parts of continents subsequent to their initial amalgamation is of fundamental importance to the understanding of continental geology globally.

Much of his technical and scientific support at PGC was provided by Jane Wynne and Judith Baker, and after his retirement he had collaboration with paleomagnetist Randy Enkin who was hired at the Pacific Geoscience Centre as his replacement.

Interest in the history of Earth Science

As well as his paleomagnetic work, Ted took up an interest in the history of tectonics from 1950s through the 1970s when continental drift, after years of controversy, became widely accepted. He began to work very closely with the Hank Frankel, University of Missouri-Kansas City, who studied the history and philosophy of science. Frankel was completing an encyclopedic study of the history and philosophy of 20th century geological tectonics. Ted worked with him over many years while he wrote his four volume work, *The Continental Drift Controversy*, serving as an invaluable aid and guide. Ted served as Frankel's unofficial editor, helped him understand the foundations and techniques of paleomagnetism, and encouraged him to keep trying to figure out how the drift controversy evolved. He encouraged Frankel to be authentic, and to be fair and thorough not only with Ted's own work, but with the work of others, be they paleomagnetists or earth scientists in other fields. At the same time, however, Irving did not press his own views on Frankel.

In Victoria, Ted also wrote on the origin and evolution of rhododendrons and of magnolias with Richard Hebda, at the Royal British Columbia Museum.

Family

In 1955 Ted met Sheila Irwin, his life-long partner. She was a Canadian and her father was Canadian High Commissioner in Canberra. He apparently introduced himself by the ANU University House reflecting pool; they met often before she left in August for London where she worked for a year. They met again in 1957 at the IUGG scientific meeting in Toronto. They were married at Hart House Chapel, University of Toronto in September 1957. This exceptionally happy union resulted in four children and continued until Ted's death. Jaeger was at the IUGG meeting and met and apparently approved of Sheila. He also evidently was pleased with Ted`s work and recognized his need for financial stability. Shortly after, he set up Ted's promotion to Fellow at the ANU, a permanent post. After visits to Ted`s family in Colone and visits to Imperial College they sailed 5 weeks back to Australia arriving in February 1958.

Dr. Edward Irving at the ceremony for Honorary Doctorate, Memorial University, Newfoundland

Sheila became pregnant and University housing was not available for married research fellows, so they purchased what Ted described as one of the smallest houses in Canberra. But, it had a large property that Ted gardened with much enthusiasm. Katie was born in November 1958 and Susan in March 1960. Martin and George were born on Christmas Eve in 1962.

Ted and Sheila's first Ottawa rental house was in the new Parkwood Hills subdivision of Ottawa not far from the Observatory, where they stayed for two years. In the summer of 1966 they left Ottawa for Leeds where they bought a house in nearby Menston. On return from Leeds they purchased a new house on Billings Avenue in Alta Vista, an inner suburb of Ottawa. Upon moving to the Canadian west coast, the children had left home and Ted and Sheila built a beautiful west coast cedar house with extensive gardens in the Victoria semi-rural suburb of North Saanich near the Institute, where he lived until his death. The garden with an extensive collection of rhododendrons was much his love along with his continuing scientific work. Ted and his family were regular church attendants. As Ted wrote: "Christianity is one of the bases of our civilization and it was important that children know something about it. We did not want our children later to feel they had been deprived of it". His funeral service with an overflow congregation, was held at the beautiful Holy Trinity Anglican Church facing Saanich Inlet, one of the oldest churches in the Victoria area, founded in 1885.

Honors

Considering his subsequent exceptional scientific contributions, it is surprising that in 1954 Ted's PhD thesis was rejected by Cambridge University. However, in 1965, with the recognition of his scientifically important publications, Cambridge University granted him his Sc.D.

Irving was a Fellow of the Royal Society of London (1979), Fellow of the Royal Society of Canada (1973), Fellow of the American Geophysical Union (1967), Honorary Fellow of the Geological Society of London (1979), and Foreign Associate of the US National Academy of Sciences (1998). He also received numerous awards and medals from professional geological societies. They included: the Gondwanaland Gold Medal of the Mining, Geological, and Metallurgical Society of India (1962), the Logan Medal of the Geological Association of Canada (1975), Bucher Medal of the American Geophysical Union (1979), the Tuzo Wilson Medal of the Canadian Geophysical Union (1984), the Wegener Medal of the European Geophysical Union (1995), the Day Medal of the Geological Society of America (1997) and the Wollaston Medal of the Geological Society of London (2005).

Ted Irving received Honorary Doctorates from Memorial University (1986), and the University of Victoria (1999), and was made a member of the Order of Canada, CM (2003) in recognition of his outstanding scientific contributions.

Acknowledgements

Ted Irving left detailed notes on his work until his move to Victoria B.C. Much of this summary comes from those notes. Later information comes from his annual report of activities as an Emeritus Scientist, to the Director of the Pacific Geoscience Centre. An important source, especially on Ted's role in the continental drift controversy came from Henry R. Frankel's four volumes *The Continental Drift Controversy* (Frankel, 2012). Additions and editing by Frankel were especially appreciated. Dr Randy Enkin, Ted's replacement at the Pacific Geoscience Centre and ongoing collaborator, provided much important information and kindly carefully edited this text. A number of others provided important information on Ted's scientific work. Ted's son, Martin Irving, provided information and editing.

References cited:

Irving, E., 1964, Paleomagnetism and Its Application to Geological and Geophysical Problems, John Wiley and Sons, Ltd., New York, 399 p.

Frankel, H.R., 2012, The Continental Drift Controversy, 4 volumes, Cambridge University Press.

Frankel, H.R., 2014, Edward Irving's palaeomagnetic evidence for continental drift (1956), Episodes, 37, 59-70.