Through the Methodist connection he had met Marjorie Jacoba de Villiers Carter, ‘on the steps of the parsonage on a Saturday evening in January 1931’.[9] Of Afrikaans-speaking background, but with mainly English education, she was studying at the Cape Town Teacher’s College. They corresponded sporadically while he was in Cambridge and met again when he returned to South Africa for the 1932 summer vacation because, he said, ‘I lived at home which cost a great deal less than living in England and the fare was only £30 return’. When Anton returned and moved to Johannesburg in 1933, he and Marjorie managed to meet infrequently—involving epic car journeys over several days in his recently acquired new Willys 77. They were married in January 1936.

a e a d a d B 1933/40

Anton was appointed to the University of Witswatersrand (Wits) as junior lecturer in pure mathematics. He completed his PhD in 1936 (from UCT),[10] based on the work he had started in Cambridge. Graduation involved another epic journey with rain-swollen rivers and a cracked differential casing and parts for his now not-so-new Willys that had to be sent by train from Cape Town. Anton wrote that academic gowns were expensive for a junior lecturer on £300 a year so he made one himself, against the advice of his mother and his wife! If his workmanship was anything like the way he periodically fixed his spectacles in later life, with safety pins and elastic bands, it must have been a quite remarkable garment.[11] At Wits he progressed rapidly to senior lecturer, moving to the Department of Applied Mathematics in 1938 in the process.

At Wits he wrote three papers on geophysical convection that also made up the core of his thesis: in the atmosphere, in geysers, and in the solid Earth.

Falls and Transvaal Power Company (that supplied much of the electrical power to the Johannesburg gold mines) and with a substantial grant from the Carnegie Institution in Washington.[23] A specific requirement by Price was that Schonland be appointed to head it as professor at Wits. Schonland's research at the time was directed at lightning including the associated electrical disturbances in the atmosphere and their effect on radiowave propagation, work that became of great importance a few years later in the development of wireless direction finding.[24] Price's motives in establishing BPI were partly altruistic but also, 'that his company would certainly benefit from whatever lightning protection measures might spring from the institute's work.'[25] The intent was that BPI would become self-supporting within a ten-year period and that this would require support from South Africa's mining industry. This would have been an important consideration in the appointment of Hales to BPI in 1937—as an honorary senior research associate while keeping his appointment as senior lecturer in the Department of Applied Mathematics at Wits—to work on the causes of small earth tremors that occurred frequently in central Johannesburg and to establish whether they were 'natural' or triggered by mining activity. This was part of Schonland's strategy; that South Africa's largest industry might one day come to appreciate more the value of science.[26]

This marked the start of Anton's work in seismology, a field to which he would contribute greatly in his later years at Dallas, Texas, and at ANU. It also marked his first departures from purely theoretical work. With P. Gane, deputy director at BPI and a geophysicist but also skilled in electronics, and J. A. Keiller, a talented instrument maker, they built a network of six recorders, their own seismometers (inverted pendulums of the Weichert type), recording (on smoked paper) and timing (daily recording of time signals transmitted by local radio) systems. They also had to develop their own analysis methods (using a graphical location board) to locate the positions of the tremors that took into consideration that the location and timing of the sources, as well as the velocities of the compressional and shear waves, were unknown. The first records were obtained and analysed by Gane and Hales and the network was declared operational by the time war was declared in 1939, locating 'the events with considerably greater accuracy than any other network of the time, other than those studies using timed explosions at known locations'.[27] The first scientific papers did not appear until 1946.[28] These demonstrated convincingly that the sources of the tremors occurred close to the areas of mining and 'that it was legitimate to assume that the tremors resulted from the weakening of the structure resulting from mining operations.'[29] But more important perhaps was that they led to the development of methodologies for determining the local and regional seismic structure that led to the detection of an 'intermediate layer' in the crust.[30]

The war years

South Africa entered the war a few days after Britain declared war on Germany, and the resources of BPI were directed to the war effort, 'for research work of a special nature',[31] with no further elaboration but which was later declared to be designing and building radar for the protection of South Africa's coastline.[32] Because of the now-classified nature of the institutions work, seismology was to continue until complete outside of BPI at Wits and without Ganes and Keiller. Hales was asked to take responsibility for the project and complete the report to the Chamber of Mines. For this he still had to have access to the BPI dark room, which required him to sign the Official Secrets Act in the event that he saw the highly prized glass slides containing the British secrets of radar, obtained by Schonland from the New Zealander Ernest Marsden.[33]

When the report had been submitted, Hales volunteered to join the 42nd (Geological Survey) Section of the South African Engineering Corps that he joined in East Africa in early 1941 as 2nd lieutenant (physicist).[34] The specific objective of this unit was prospecting for groundwater in East Africa, Somalia and Ethiopia using geophysical means, primarily resistivity but also magnetometer surveys, in support of the northward advance of the South African army against Italian forces.[35] But the advances were generally too rapid to make effective use of the experiments that he conducted, experiments that were plagued by instrumental failures resulting from the rough transport conditions. This was to be Anton's introduction to geophysical field work in remote and harsh conditions, work that he was to continue years later in the western USA, Central and South America and later still in Australia. He learned to improvise, for example, so that the galvanometers used in his resistivity experiments could be repaired using the balance springs from watches. He returned to South Africa briefly in July 1942 to obtain spares for his instruments but by the time these arrived in Cairo the packages had been pilfered. In Egypt, his unit

[23] Allibone (1973).
[24] Austin (2001).
[25] Austin (2001) p. 140.
[26] Austin (2001) p. 159.
[27] Hales notes e.1, 'The Bernard Price Institute of Geophysical Research Years 1937–1962', undated other than post 1988 and possibly an early draft of a shorter paper published that year, 1988 (Hales 1988).
[28] Gane and others (1946).
[29] The quote is from a later paper of Hales (1960).
[30] Willmore and others (1952).
[31] Austin (2001) p. 170. The secret work turned out to be the design and construction of radar.
[32] Allibone (1973)

spent most of its time between the Nile and the Red Sea, exploring and drilling for water in support of a port construction on the Red

improved underground measurements and found that the horizontal component increased with depth, consistent with the core origin.[48]

n e n f Ca e T , 1949/54

In 1949, Hales was appointed to the chair of applied mathematics at UCT. The appointment did not provide many opportunities for his new-found interests in experimental geophysics and so he retained his link with the BPI by spending the summer months in Johannesburg on the projects started in earlier years. He did become involved in university politics, something he had avoided at Wits, but otherwise was mainly involved with teaching first year students in both pure and applied mathematics. The problem he faced was that the majority of the students in pure mathematics saw it as a tool and not an end in itself and he devoted his inaugural lecture in 1950 to 'Mathematics: end or tool?' An important indirect aspect of the appointment was that UCT received more international visitors than did Wits, and of these his meeting, on the evening of his inaugural lecture, with Harry Hess (professor of geology at Princeton) and Tuzo Wilson (professor of geophysics at Toronto) was important. Hess and Wilson were to make fundamental observations upon which the plate tectonics hypothesis was built some fifteen years later but Anton recalls that on that evening 'Not one of us believed in continental drift'. Another important visitor during this time at UCT was J. C. Jaeger, the Foundation Professor of Geophysics at ANU, and I return to this below. In 1952, Hales took sabbatical leave for a term, spending the greater part of the time in Cambridge with Marjorie and their first (newly born) son, James. There he worked mainly on the theory of thermal contraction of the Earth.[49] More important was that this visit introduced him to S. K. Runcorn and his students[50] working on palaeomagnetism, work that led to the detection of the drift of the magnetic pole across Earth's surface through geological time and ultimately to the recognition that the continents themselves had changed their relative positions through time.[51] Anton was, however, still not ready to shift from his earlier position, it being 'impossible' (for physicists) 'to think of the stiff ocean floor permitting movement of the continents'.

n ec f B 1954/62[52]

In 1954, Schonland had joined the Atomic Energy Research Establishment at Harwell as Deputy Director and Hales had been sounded out about whether he would accept the post of Director of the BPI if it were offered to him.[53]

position in that its deputy director was the seismologist Phillip Gane and so Anton decided that he would leave this field to him.[60] The program Hales developed focused on some of the then fundamental questions being asked about the structure and evolution of Earth but framed in terms of more immediate objectives but ‘always we hope that by solving the immediate problem we shall contribute a new piece of information bearing on the major problems of earth history’.[61]

a ae a e h

Paleomagnetism at BPI had begun in the early fifties, before Hales was appointed Director, by an initiative of Gane who, on sabbatical

What led to Hales' decision to leave South Africa at this time, having earlier rejected the Princeton offer? He did note later that' 'it was an appropriate time to hand over the BPI to new leadership.'[91] I can only speculate that he saw opportunities within a like-minded group at Dallas to build his own programs, rather than the more sheltered life offered by a well-established traditional university such as Princeton. Undoubtedly, the resources available at Dallas and the vitality of the research environment that he had witnessed when he travelled across the USA in 1960 helped. Yet another must have been the darkening political situation in South Africa that affected both him and Denise: He had been called up, at the age of fifty, for reserve officer duties, and the recognition that Denise's support for the work

of the crustal structure across the zone of transition from oceanic to continental crust.[99] Another major involvement was his participation in the Early Rise project that involved thirty-eight five-ton chemical explosions fired in Lake Superior (in July 1966) and the recording of the reverberations along profiles radiating out across North America. This led to the discovery of what became known as the 'Hales discontinuity', a rapid increase in P-wave velocity at a depth of 60–100 km, which they interpreted as the mineralogical phase transition from spinel to garnet that had been observed in laboratory experiments in rocks of pyrolite composition at upper mantle temperatures and pressures.[100] Subsequent programs in the western USA and in South America, using explosives as controlled energy sources, prepared the ground for Hales' subsequent work in Australia and possibly also to his first public notice in Canberra.[101] The result was a substantial body of research output on the propagation of seismic waves from crust to inner core in which he identified many of the radial and lateral variations in wave velocities and attenuation that were to find their way into the later global three-dimensional models.

Denise describes the Dallas years as 'an exciting time'. Anton apparently did not believe in holidays and Denise can only account for three short breaks in some forty-five years of marriage that were not work related. But she did participate in many of the field trips around the USA and conferences,[102] accompanied by the four boys. She was there for the Early Rise field work where he celebrated her birthday with a gift of clean nappies for six-week-old Mark but then flooded the cottage basement because he forgot to turn off the tap while talking to his colleagues. Other years the gifts would consist of useful things for the garden, like bags of manure or cement for a pathway. Apparently there was little formal social life around the new centre in Dallas and in consequence most entertainment focused on the Hales residence and their visitor book, recording those who stayed a night or more, families included, is a virtual who's who of geoscience at that time.[103] Visitors included K. E. Bullen, J. C. Jaeger, H. Jeffreys, E. Teller,[104] and a host of visitors, staff and students to SCAS in need of short—and not always so short—term accommodation. James noted that his father saw 'his fellow scientists as extended family.' At this time Anton's own father, in his late eighties and with dementia, had also joined them in Dallas adding to the household confusion. Helsley's description is apt:

> we often met at Anton's home and poured ourselves a scotch and retired to the den for a lively and intense discussion of the latest problem—much to Denise's chagrin. Eventually, she would win and we would emerge and join our wives for dinner and socializing. Even then, most discussions were about work![105]

Early connection with ANU and Australia[106]

In 1952, Professor J. C. (John) Jaeger had been appointed Professor of Geophysics in the Research School of Physical Sciences (RSPhysS) at ANU.[107] Jaeger was, like Hales, an applied mathematician with a special interest in application to earth physics problems and, again like Hales, recognized the opportunities offered by the technological advances wrought by the war, and had set about developing a department that addressed key questions in the earth sciences. This growing department would be quickly recognized as a world player. In October 1953, Jaeger as Professor of Geophysics made the first of his many trips around the world to visit geophysics laboratories and his first stop was South Africa during which he visited Hales in Cape Town. Hales recalled: 'Jaeger and I talked over dinner. We discussed the BPI program, Jaeger remarking that he would not put as much effort into seismology as was the case at the BPI.' From this time onward a long-term correspondence and friendship developed that served both institutions well. Jaeger was to change his mind on the question of seismology at ANU and in 1954 had written to Hales about the possibility of recruiting Phillip Gane, then at BPI, to develop a seismology program at ANU.[108] In 1956, Jaeger was able to borrow seismometers and recording equipment from BPI to record seismic signals generated across the Nullarbor by the Maralinga explosions. A few years later Jaeger again visited South Africa and became aware of the experiment initiated by Hales to monitor earthquakes generated during and after the filling of the Kariba dam in Rhodesia. In this case Jaeger was able to return the earlier favour through a loan of ANU seismometers to BPI, thereby turning an inadequately funded project into a successful one. In 1955, Jaeger had sought support to solve a problem that had arisen at ANU when Cambridge University

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[99] Hales and others (1968). Helsley captured Anton well in his letter to Denise in December 2006: 'a chain-smoking individual dressed in a dark suit and wearing a tie, even when he was digging a hole for a seismometer.'

[100] Green and Hales (1968). Green and Ringwood (1967–1968).

[101] When he left Texas his students presented him with a photographic record of his field experiments, including made-up newspaper headlines about running explosives across the US-Mexico border. Later in Canberra this record was left on his car roof and was only returned after it had been handed in to the *Ca be a T h e* and made its own headlines! Whether this was via the Federal Police was not established.

[102] On one occasion in California, Denise had been introduced to Harold Jeffreys who was not known for his small talk. In desperation she asked him what he did to which he replied 'I taught your husband everything he knows' to which Lady Jeffreys corrected him with 'Rather, Anton was exposed to everything my husband knows'. After that, Denise never attended a social event without Anton first telling her who everybody was.

[103] Visitor Book kept by Denise Hales.

[104] Edward Teller, controversial physicist involved in development of the atomic and hydrogen bombs, ostracized by the scientific community for betraying his colleague J. Robert Oppenheimer, perhaps better known today for his 'freedom through defense' views. Because of furore surrounding his visit to the UTD campus in 1965 he stayed with the Hales' rather than in a hotel (Denise Hales notes). Of interest is that he was one of the early voices warning against the dangers of burning fossil fuel when in 1959, as president of the Sun Oil Company and as a director of the American Petroleum Institute he spelled out to the US oil industry the impact of uncontrolled growth of carbon dioxide emission (Guardian Weekly, 1 January 2018).

[105] Email from C. E. Helsley to Denise Hales, 16 December 2006.

[106] The quotes in this section are mostly from the Hales Notes E.1, *e ac h h' J' Jae*, undated but post 1982.

[107] Paterson (1982).

[108]

submissions as he deems necessary.’[116]

to provide funds for the development.' He arrived in June 1973, having left Denise behind in Dallas—with two small boys, Mark, born in March 1963 and Colin in November 1964; the two older boys, James and Peter from the earlier marriage, having decided to stay in the USA—to pack and sell the house. She arrived in Canberra in late October of that year.[126]

opportunity offered by the first Maralinga nuclear explosion in 1956 for a large-scale controlled source seismology study of the deep crust of Australia; and a request from the UK in 1965 to establish a seismic facility for monitoring underground explosions.[135] The last, the Warramunga seismic array (WRA) outside of Tennant Creek—in addition to its monitoring function—had been seen as an attractive option for the scientific exploration of the mantle beneath the Australian continent using the earthquakes to the north and east of Australia as energy sources.

When Hales arrived in Canberra, the seismology group was small, consisting of J. R. Cleary and K. J. Muirhead with Australian-data sources collected from WRA and a number of field recording systems built by Muirhead with encouragement from Jaeger. Hales found an array that operated at less than half efficiency because of a combination of climate conditions, lightning and termites,[136] and with limited computer capability for data analysis. While there was another seismic array outside Alice Springs, operated by the USA Air Force, data from which was not generally available for scientific research, Anton thought that it be desirable that 'some country other than the US' should be involved. No doubt motivated by the recognition that the array could reveal finer details of the velocity distributions within the mantle, new arrangements with the UK were set up in late 1973, and updated in 1976.[137] RSES took a more proactive role in this upgrade to ensure reliable access to the records for scientific purposes, leading to improved transmission of the seismic signals from the individual instruments to the central recording system, installation of a computer for partial on-site data processing, changing from analog to digital recording, new

international profiles, as well as by his international roles at critical junctions. The influence of his personal leadership in institution building as well as the impact of his direct and indirect input into the development of modern geophysics in areas beyond his immediate personal research interests, have not often been matched. As a mentor, he influenced his peers and shaped following generations, generous to the end in helping others in their scientific journeys. One of his strength was to get the best out of the technical staff. As James Hales has noted, 'My Dad loved to build physical things himself but I think he realized that there were others better at that sort of thing than himself'. As a husband, this assessment is best left to Denise, but I would sum it up by 'he was fortunate to have enjoyed two very loyal women in his life who did not abandon him when he abandoned them on his long field and overseas excursions or his long nights in the lab.' As a father, James notes 'he pretty well left us to our own devices without pressure of any sort… Notwithstanding a light-handed approach to parenting he came through when required with various projects: science fairs, cub-scout projects, costumes for fancy dress parties and the like. But for the most part he left things up to you'.

Anton Linder Hales died on 11 December 2006 in Queanbeyan. He is survived by Denise Lynne Hales (née Adcock); his sons, James Andrew, Peter John, and Colin Adcock; and his grandchildren Peter, Michael, Megan, Brendan, James, Oscar, and Hayley. His fourth son, Mark Anton Hales, died in May 2004.

Conflicts of interest

The author declares no conflicts of interest.

Referencing of Hales' notes

Professor Hales started writing these notes after he returned from Dallas in 1982 and primarily after about 1990. The majority are undated but an approximate chronology can be established from the declining hand writing. As a result, there is considerable overlap and repetition that I have not, at this stage, edited. These notes, together with copies of correspondence or other non-readily available material to which I have made reference, will be held in the Australian Academy of Science archives, as will be the five 'Pen Carbon' books (cross referenced to as IA, IB etc.) that cover the period December 1959 to January 1961, a near as possible complete bibliography of his published papers, and the notes I received from Denise Hales. The provisional referencing that I have used for his notes is the following:

A. Early and family

a.1 Answers to (grandson) Peter's questions (15 October 1990). (Includes notes on his undergraduate days at UCT and the war years)
a.2 Letter to James and Peter (sons). (Notes on their mother)
a.3 Family history (February 1999). Covers the period up to about 1921
a.4 More Family history (2) (undated but probably post a.3). (Covers similar ground to a.3 but extends to his undergraduate years at CTU, his Cambridge years, and early appointments at Witts and CTU up to the time of his BPI appointment.)
a.5 Family History (mainly up to 1923)
a.6 Family History 1954–1962 (but including notes on his move to Dallas and ANU appointment).

B. The early years 1933/40
C. The war years 1940/5
D. The Canberra years 1949/54
E. The BPI years 1937/62

e.1 The Bernard Price Institute of geophysical Research Years
e.2 Curriculum Vita (Background Materials 1927–62)
e.3 A glimpse into the fifties—Selwyn Sacks' PhD project
f.1 Interaction with John Jaeger
f.2 The campaign for a Research School of Earth Sciences

G. Early academic years

f.1 Part I
f.2 Part II

H. The Canberra years

g.1 Part 1
g.2 Part II

I. Miscellaneous

h.1 Additional note on time at UTC 1929–30
h.2 Additional notes on time in England in 1931–3
h.3 Additional note on early link with Jaeger and ANU
h.4 File note of 24 amily

Anton and Denise for as long as I have, and H. McQueen have carefully read the manuscript and modified at least some of my grammatical constructs. I thank them all for their inputs. Finally, Denise and James have read the final manuscript and picked up, what I hope, are any final inaccuracies.

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