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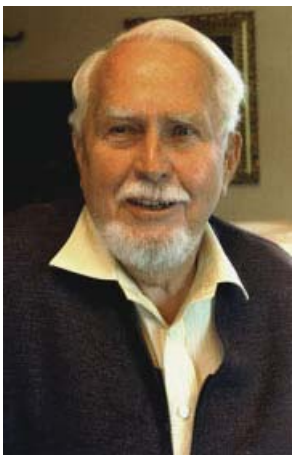
OBITUARY



OLGIERD C. ZIENKIEWICZ
(18 May 1921–2 January 2009)

1. INTRODUCTION

Olgierd C. Zienkiewicz has died at age 87 in Swansea, Wales after a brief illness. He was known affectionately to his friends worldwide as 'Olek' and will be greatly missed by all. At the time of his death, Olek was Professor Emeritus and Director of the Institute for Numerical Methods in Engineering at Swansea University, and held the UNESCO Chair of Numerical Methods in Engineering at the Universitat Politècnica de Catalunya in Barcelona, Spain. During his long career he was a great engineer in the construction of hydro-electric projects, author of many books and technical articles, co-founder of this Journal (with the late Richard H. Gallagher*), and a leader in the founding of the International Association of Computational Mechanics. He was also an avid sailor, enjoyed snorkeling, and an adventurous gourmet.

2. EARLY YEARS IN POLAND

Olek was born on 21 May 1921 in Caterham, Surrey in England, the son of a Polish father, Kasimierz, and an English mother, Edith. At the age of two his family relocated to Poland. During

*See: In Memoriam to a Great Engineering Scientist and Educator, *International Journal of Numerical Methods in Engineering* 2000; **47**:3–7.

the next few years the family moved several times, which often interrupted his studies. Thus, at an early age he developed the ability to learn new subjects from reading and personal tutors. Olek had a phenomenal memory and could in late life clearly recall poems of the Iliad learned from his Latin tutor, sing the Polish songs of Wladyslaw Szpilman and recall salient points from any of his publications. In the early 1930s the family settled in Katowice where his father had attained a position as a judge in the regional court. To prepare for university, Olek was sent to a boarding school in Rydzyna where he studied science subjects, literature and learned the art of boat building. However, in the second year of his studies he had health problems starting with a septic finger and then an injury suffered while playing the Polish game 'Palant'. During the game Olek was struck in the area of his hip by a thrown ball. This resulted in a serious infection in his hip joint, Osteomyelitis eventually fusing the joint. In June 1939, after a long recovery in which he was in and out of hospitals, Olek managed to complete his high school studies in the field of mathematics, descriptive geometry and physics. In addition he was required to learn a foreign language. He wanted to use English as by this time he was conversant in this language as well as Polish. His mother, however, had other ideas and thus he chose German. During the summer of 1939, he was able to build a sail boat he had started in Rydzyna and learned the art of sailing. His love of sailing instilled a desire to study naval architecture at university. However, none of the three polytechnic universities in Poland offered the subject. Thus, he chose civil engineering and was in Warsaw preparing for entrance exams to the university when the Second World War began.

3. WAR YEARS

In September 1939 Olek, his sister and mother were all in Warsaw, where they remained for the first 2 months of the war. During the first month, Olek participated in the building of barricades and digging trenches for the defense of the city. After the first 2 months, times became more difficult and food became scarce. Because of his hip problem he was not called into the army—a fact that may have saved his life. At the end of October, his father was able to get permission for the family to return to Katowice where preparations to leave Poland were started. His father, being well connected with authorities, was eventually able to obtain visas for the family to go to Italy. In early December they locked their home and traveled by train through Czechoslovakia and Austria to Italy. On the way Olek recalled being a tourist in Vienna, Venice and Rome. Because the family had very little money, they often stayed in monasteries where food was plentiful for their under nourished bodies. By the middle of January 1940, the family had secured official visas to France where the Polish Government in exile was situated in Angers. Here the family rented a house and Olek learned French from the son of the landlord in exchange for teaching him German. He also studied from a four volume set of physics books he had been able to bring with him from Poland. In May, however, the war again caught up with them in Angers and they moved south to Bayonne. They eventually were able to leave France on the Polish ship, Batory, embarking from St. Jean de Luz and arriving in Plymouth, England 3 days later.

The family was taken to London where they were placed in temporary housing as refugees. His father was able to contact former business associates from his earlier days in England who provided housing for them in the north of London at Highgate. By the summer of 1940 the family was settled and Olek attained a scholarship as a Polish student to attend Imperial College. Here he resumed his studies of chemistry, physics and mathematics and did so well during his first year that he was awarded an additional 3 years scholarship. During this period he had teachers who would

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become his longtime friends. Professor Fred Bickley taught him mathematics and later provided tutoring during his research studies and Professor A. J. S. Pippard taught structures. During the evenings, Olek was a fire-watcher and a warden. He received his Bachelor of Science degree in 1943. Olek considered technical work for the armed forces but was persuaded by Professor Pippard to undertake postgraduate studies. This he accepted and was awarded an additional 2 years scholarship. The opportunity arose for Olek to work with Professor Richard Southwell (later Sir Richard) performing research with 'relaxation methods'. Here, during 1944–1945 he worked as a 'computer' with Derek Allen and Jillian Vasey. Working with Professors Pippard and Southwell, Olek performed a finite difference stress analysis of the Aswan Dam to understand potential uplift forces at the base. By mid-1945 Olek had completed his analysis and upon submission of his doctoral thesis was awarded his PhD, as well as a Diploma of Imperial College.

Having completed his doctoral studies on dams, Olek was interested in pursuing work connected with their construction. In August 1945 he secured employment with the firm of Sir William Halcrows and Partners as an engineer in charge of a survey party on the design of hydroelectric schemes in Scotland. In this capacity he was required to drive a car, which he had never done before. In the 3 weeks prior to starting actual work he enrolled in a class and gained sufficient knowledge, although no driving test was required to secure his provisional license. In September he arrived in Scotland and for the next few years worked on the design and construction of the hydro-electric schemes at Glen Afric and Mullardoch. During the second year, his first published paper on stress distribution in gravity dams appeared in the *Journal of the Institute of Civil Engineers*. It was here also that he met Eammon (Eddie) Dillon who was the engineer for the contractor. Typical of Olek they became close friends and during the construction period Olek encouraged and tutored Dillon in research for his doctoral thesis. This experience motivated Olek to re-enter academia and in 1949 he accepted an appointment as Lecturer at Edinburgh University. Dillon completed his thesis in 1950 to become the first of 70 (see Table I) to complete a doctorate under Olek's supervision.

4. LECTURESHIP AT EDINBURGH

During his period in Edinburgh, he continued to work on problems related to hydraulic and structural problems encountered in hydro-electric projects. His studies were both experimental and analytical in nature, but he found that academic life also allowed time for other activities. He now had time for climbing and walking in the mountains around Edinburgh for pure enjoyment. It was also here in 1951 that he met Helen Flemming at a dance they were both attending. Helen had come to Scotland as a visiting Canadian to work in the chemistry department. After a 1 year courtship, they were married in December 1952 and for the next 5 years lived in a house that Olek had divided into three apartments. His parents occupied another of the apartments and his sister was also living in Edinburgh—so his family was once more close together. In the second year of their marriage Olek and Helen welcomed their first son, Andrew. A second son, David, was born in 1955.

In the summer of 1953, Olek returned to France on a Carnegie Scholarship to visit Electricité de France in Grenoble and to visit dams throughout the Alpine region. He made the trip with Helen and Andrew in their first car—a station wagon that allowed them to carry large amounts of luggage so that they could camp during the entire trip. It was on this excursion that Olek first learned to snorkel—a sport he enjoyed for the remainder of his life.

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Table I. Doctoral theses supervised by O. C. Zienkiewicz.

Year	Student	Year	Student	Year	Student
1950	E. C. Dillon	1976	C. Humpheson	1986	J. Peraire
1953	P. Hawkins		G. M. A. Jones		W. C. Zhang
1956	J. Sandover		R. E. Ricketts	1987	J. Z. Zhu
1959	T.-J. Wang		C. Hupeheson		R. Fejzo
1960	R. W. Gerstner		J. F. Lyness		A. Shakharami
1961	R. D. Kersten		D. Shantaram		J. Beynham
1964	Y. K. Cheung		T. K. Hellen	1988	A. H. C. Chan
	B. Nath		P. C. Jain		F. Q. Shen
1968	J. G. Ergatoudis	1977	G. N. Pande	1989	J. Szmelter
	S. Valliappan	1978	E. Oñate		G. C. Huang
1969	S. Ahmad		N. Bicanic		J. P. Vilotte
1970	C. J. Parekh	1979	C.-T. Chang	1990	D. Lefebvre
1971	P. W. France	1980	G. G. W. Mustoe		Y. M. Xie
	G. C. Nayak		V. Norris	1991	L. Bottura
	J. M. Too		I. Austin		X. K. Li
1972	D. V. Phillips	1982	H. Abdel-Rahman	1992	J. Wu
	A. Razzaque		G. D. Tong	1994	A. Teixeira
1973	R. D. Wood		J. P. de S. R. Gago	1995	M. Huang
	A. S. Mawenya		S. Nakazawa		
	C. R. Dullage		D. K. Paul		
	M. F. Yeo		W. S. Abdullah		
1974	P. N. Godbole	1983	M. Akiyama		
	G. Al-Mashidani		T. Shiomi		
1975	R. Delpak	1984	R. Löhner		
	J. S. Campbell	1985	Y. C. Liu		
	D. J. Naylor		S. Toyoshima		

On returning to Edinburgh, Olek's research publications became more numerous and exhibited the intensity that was to characterize the remainder of his career. He also graduated several doctoral students during this period. In 1956, Olek received two offers for employment, one as a chief engineer for a hydroelectric project on Victoria Island in Canada and the second as a professor at the Northwestern University in Evanston, Illinois. He decided to remain in academia and desired only to accept a visiting appointment at Northwestern. Unfortunately, he learned that leave for one full year from Edinburgh could not be granted. He decided to accept the risk and resigned his tenured post at Edinburgh to accept a tenure track position at Northwestern.

5. NORTHWESTERN UNIVERSITY

Olek, Helen and family arrived at Northwestern in January 1958. It was a busy time of settling into a new country and also welcoming the arrival of their daughter, Krysia, in March. At the same time Olek was learning to adjust to the American philosophy of 'publish or perish'. This he did well and within a year and a half was promoted to full professor. His research at Northwestern focused on structural problems, many still addressed to the behavior of dams. He continued to apply relaxation solution methods to finite difference equations throughout this period. During this period, however, he also heard of a technique that was to become known as the Finite Element

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Method from Professor Ray Clough of the University of California, Berkeley. Olek had earlier met Ray at a conference and later, when he visited Berkeley, they had a chance to discuss the subject more thoroughly. At this time, Olek believed that finite difference methods could solve all elasticity problems equally as well as finite element methods. However, finite element methods offered a way to solve shell problems associated with arch dams if appropriate bending elements could be developed. This he set out to accomplish but did not succeed until later.

In late 1959 Olek acquired an unfinished house and once again devoted much work to restore this to a finished condition. The family lived in the completed house less than a year before Olek was offered the Chair of Civil Engineering at Swansea. This required a personal interview in London during March 1961—unfortunately on a date when no international flights were leaving Chicago due to a snow storm. Olek, with typical tenacity, did manage to obtain a flight to Pittsburgh and then on to New York for the international flight to arrive on time in London, where he successfully obtained the appointment in which he was to acquire international fame. In August 1961 the family crossed the Atlantic by ship arriving in the U.K. in early September.

6. THE SWANSEA YEARS

In 1961 Civil Engineering was a Division of the School of Engineering at Swansea and consisted of five faculty members. During the next few years, the size grew adding staff who would later become well known also (e.g. E. Hinton, B. M. Irons, R. W. Lewis, K. Morgan, D. R. J. Owen, C. Taylor). His first research student at Swansea was Kai Cheung and together they started research on finite element methods. By 1962 they had succeeded in formulating finite element approaches using virtual work, writing computer programs and using the Atlas Computer at Harwell to solve some problems. With Cheung, Olek was successful in devising a thin plate element of rectangular form in which continuity existed only at nodes—but converged for known plate solutions.

During 1962, Olek with the assistance of a member of his staff, G. S. Holister, organized a conference at which experts in various numerical approaches for solving structural problems were invited. The conference was held in January 1963. The participants included Ray Clough, who was visiting Cambridge on sabbatical leave, C. E. Massonet and B. F. de Veubeke from Belgium, and J. R. H. Otter from London. The conference was a great success and resulted in the volume *Stress Analysis* published by John Wiley & Sons in 1965.

It was during this time that Olek also met Bruce Irons who was an engineer at Rolls-Royce and was also interested in finite element methods. Working jointly, they produced a triangular plate bending element that was fully conforming and which appeared in a paper at the first conference on Matrix Methods in Structural Mechanics in Dayton, Ohio. This paper became famous for also introducing the concept of the *patch test* to prove convergence of non-conforming elements.

It was in 1965 that Olek and Cheung showed that finite element methods could be applied to any problem formulated by a differential equation. The paper was a short one entitled ‘Finite elements in the solution of field problems’ appearing in ‘*The Engineer*’. Also, about this time Olek was successful in attracting Bruce Irons to Swansea as a Lecturer. This was a fortuitous appointment as Bruce was aware of much work being performed in the aeronautics industry—an example being the research of Ian Taig on the direct construction of quadrilateral elements. At Swansea this evolved into the family of *isoparametric elements,* which was successful in generalizing element forms for use in two- and three-dimensional problem of elasticity and other subjects based on second-order differential equations. The introduction of isoparametric elements also facilitated the

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development of *shape function modules* that, in combination with quadrature, greatly simplified the development of elements.

Olek devoted a significant portion of his activities to the solution of real engineering problems. One of the first dams he analyzed was the Clywedog Dam in Wales—this was the first time that finite elements had been used as a part of the design of a new dam. He also traveled extensively attending conferences and giving lectures at universities and industries. Through these efforts, he was quickly becoming known as the 'Ambassador of Finite Elements'!

By 1966, the subject of finite elements had evolved to where Olek considered a book was needed. He wrote the book during the latter part of the year and this was published in 1967 by McGraw-Hill, consisting of some 250 pages and a short chapter by Kai Cheung on programming the method. The book was an immediate success and firmly established Olek worldwide as a leader in finite element theory and practice.

During the late 1960s, Olek and his students Valliappan and Nayak developed and applied finite element methods to the solution of plasticity problems. Many of the applications were to soil and rock problems associated with dam foundations. At the same time, isoparametric element formulations were being extended to higher-order interpolation and found application in the modelling of arch dams and their foundations. The use of isoparametric curved elements suggested to Olek the possibility of using them to solve thin shell problems. With Bruce Irons, Olek and their student, S. Ahmad, presented the solution to axisymmetric shell problems at the Second Conference on Matrix Methods in Structural Mechanics in 1968. They discovered, however, that when applied to very thin shells the solution diverged or 'locked'. This was eventually solved using reduced quadrature in the work by Olek with J. M. Too and R. L. Taylor.

By the late 1960s Olek realized that publication of numerical finite element research required a new outlet, since the available journals in mechanics were more interested in theory than in solution methods. Together with Professor Richard H. Gallagher as co-editor he established the *International Journal of Numerical Methods in Engineering*, which was first published by John Wiley & Sons in 1969. The Journal first appeared as four issues per year but, due to the rapid growth of finite element and other numerical-based methods, gradually grew to the present 52 issues per year. In the early 70s the second author of this obituary became involved in the administration and running of the Journal. It was an exciting time and strong friendships were forged between the three editors, which lasted the remaining years of both Dick and Olek's lives.

During the first 20 years, Olek had been in quite robust health and was able to enjoy physical activities such as mountain climbing, snorkeling and sailing, which he had again pursued upon his return to Swansea. By the middle of 1969, however, he was experiencing some difficulty in walking due to misalignment of his hip. He underwent surgery in October, which greatly curtailed his travel and allowed a close friendship to develop with the first author of this paper.

By 1970 the activities at Swansea were producing work related to widely disparate subjects. Computers were also of sufficient power to allow for fully three-dimensional problems to be tackled and solved. In addition to the solution of increasingly complex inelastic structural problems, examples of non-structural applications included solution of the Helmholtz equation, coupled vibration of submerged structures, natural modes in harbor oscillations and transient-free surface flow—to name just a few. The topics Olek addressed during the next 25 years are too numerous to fully summarize here—the reader can consult Olek's total list of publications in the Appendix. However, some of the more important ones will be referred to.

The topic of finite elements had greatly expanded during the 3 years since his first book appeared. In 1971 the second edition appeared, which was nearly twice the size of the previous edition

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and remained the only book on the subject available at that time. Subsequently, the third edition appeared in 1977, followed by the fourth edition expanded to two volumes in 1989 and 1991, which was co-authored with R. L. Taylor. The fifth and sixth editions were largely written in Spain and published by Butterworth–Heinemann/Elsevier in 2000 and 2005, respectively. These editions had further expanded to three volumes and were devoted to linear problems, non-linear solids and structural problems and also to fluid dynamics.

In the mid-1970s Olek's attention had turned to the solution of fluid dynamics problems, a topic that occupied his interest for the remainder of his life. Early applications used viscous fluid flow formulations to solve forming problems. The issue of incompressibility was addressed using a penalty method and this also was used to solve other classes of problems with internal constraints—including electro-magnetics, plastic behavior and contact problems. Working with A. R. Mitchell from Dundee, Olek applied 'upwind' forms to develop weight functions for a Petrov–Galerkin formulation to problems with high advection. The early solution of the Navier–Stokes equations were formulated with J. C. Heinrich using these 'upwind' functions in isoparametric formulations. In collaboration with his student, E. Oñate, and Heinrich, they used flow formulations to solve plastic deformation of metals for both thermal extrusion and thin sheet forming. By the mid-1980s the solution to both compressible and incompressible flow problems were being regularly solved by Olek and his students. The methods also permitted solution of shallow water equations and one application was a full analysis of the tidal flow in the Bristol Channel. Starting in the late 1980s Olek searched for a scheme that could solve all classes of problems with a single algorithm. This he achieved with a method he called 'Characteristic-Based Split (CBS) algorithm' in collaboration with colleagues from Swansea and Barcelona, Spain.

Fluid dynamics solutions require adaptive mesh refinement in order to achieve practical and efficient answers. This necessitates use of an error estimator and here Olek, together with J. Z. Zhu, devised an efficient and accurate procedure they called 'superconvergent patch recovery'. Today the method is known simply as the ZZ-error estimator. The method is based on the use of points in elements that have higher-order convergence rates. By making a local polynomial approximation through these points, Olek and Zhu showed that the amount of error in a solution could be reliably estimated and used with automatic mesh generators to achieve a desired solution accuracy. This elegant and practical scheme is now widely used, not only for estimators, but also to produce contour plots of element variables.

A third major research was the modelling of geotechnical materials. In these area of studies he devised models based on the theory of plasticity, viscoplasticity and generalized plasticity to model the behavior of soils and rocks. The effect of pore water was included in order to permit an assessment of consolidation and liquefaction under transient seismic loading. The results of the research was included in the book *Computational Geomechanics: With Special Reference to Earthquake Engineering* that Olek co-authored with A. H. C. Chan, M. Pastor, B. A. Schrefler and T. Shiomi and published with John Wiley & Sons in 1999.

The last major research mentioned is that of plate analysis by finite element methods. This is the topic that was the initial impetus for Olek to undertake research in finite element methods. He continued to explore newer methods to solve the problem throughout his time at Swansea. After initial efforts to solve thin plate theory he turned his attention to solving thick plate forms based on Reissner–Mindlin theory. Using this approach he was successful in developing a number of element forms capable of solving both thick and thin plate applications. The main problem was enforcing the transverse shear behavior without over-constraining or 'locking' the bending response. Initial success was achieved using 'reduced integration' as mentioned previously. However, by using

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mixed approaches he was able to show why 'reduced integration' was successful and, hence, the problem was fully solved.

In recognition of his achievements, Olek was elected as a Fellow of the Royal Society of London and a Fellow of the Royal Academy of Engineering in 1979. Through his travels around the world, Olek recognized a need for an international organization devoted to numerical methods. Through his efforts, the International Association of Computational Mechanics was founded in 1986 and he served 4 years as its first President. During the mid 1980s, he also was co-chairman for the International Advisory Panel of the World Bank Chinese University Project. Under this programme he sent experts to the Peoples Republic of China in order to increase technical interactions in that area of Asia.

After a career spanning five decades, Olek retired as Head of Civil Engineering at Swansea in 1988. Later, the Zienkiewicz Library was established in the Department as a lasting memorial to his contributions. Although, formally retired, he continued to make contributions in both the technical and professional areas for the next 20 years.

7. THE RETIREMENT YEARS

Following his retirement in 1988, Olek served as Director of the Institute for Numerical Methods in Engineering at Swansea and continued his research and supervision of doctoral students. Shortly after his retirement he was awarded the title of Commander of the British Empire by Queen Elizabeth II in recognition of his lifetime accomplishments.

During the next several years, Olek held a visiting professorship at several major international universities. In 1989 he held the Joe C. Walters Chair at The University of Texas in Austin. He was the Jubilee Visiting Professor at Chalmers University of Technology in Goteborg, Sweden in 1990 and 1992. In 1991 he was the Royal Society Kan Tong Po Visiting Professor at the University of Hong Kong where he renewed collaboration with his first doctoral student, Kai Cheung. From 1989 to the time of his death, he was a visiting professor in the International Center for Numerical Methods in Engineering (CIMNE) at the Universitat Politècnica de Catalunya in Barcelona, Spain. On his annual visits to Spain he had opportunities of collaborating with many CIMNE scholars, including his former student Eugenio Oñate. In 1989 Olek was appointed as the UNESCO Chair of Numerical Methods in Engineering at UPC. This was the very first UNESCO chair in the world and arose from interactions with Geoff Holister who was working at UNESCO in developing support for technology and engineering. The concept of such a position arose from an idea in the book *Small World* by David Lodge. In the book, professors of literature imagined an UNESCO Chair that would allow them to retire into a world of continuous travel with no lecture obligations and an extravagant salary! The award to Olek attracted considerable interest by others and today there exist some three-hundred UNESCO Chairs worldwide.

8. HONORS AND AWARDS

Through his research and associations with scholars throughout the world, Olek achieved an international reputation as the leader in the development of finite element methods. This led to his election as foreign member in the Academia Nazionale Dei Lincei, Rome, the Chinese Academy of Science, the Polish Academy of Science and the U.S. National Academy of Engineering.

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He has also received many honors in addition to those cited above. He received the James Alfred Ewing Medal of the Institute Civil Engineers for distinguished contributions to research, The Nathan Newmark Medal of the American Society of Civil Engineers for outstanding contributions to Structural and Soil Mechanics, the Worcester Warner Reid Medal and the Timoshenko Medal of the American Society of Mechanical Engineers for important contributions to engineering, The Royal Medal by the Royal Society for pioneering research and development of the finite element method, The Newton–Gauss Medal of the International Association of Computational Mechanics, the Gold Medal of the Fiftieth Anniversary of Krakow University, and the Leonardo da Vinci Medal by the European Society for Engineering Education for outstanding contributions to engineering education. In 2005, Olek received the prestigious Prince Philip Medal of the Royal Academy of Engineering.

Olek has received 28 honorary doctoral degrees from universities throughout the world, including those in Argentina, Austria, Belgium, China, England, France, Greece, Hong Kong, Hungary, Ireland, Italy, Norway, Poland, Portugal, Scotland, Spain, Sweden, U.S.A. and Wales.

9. LEGACY

The adage that 'behind every great man is a great woman' was especially true for Olek and Helen. Helen was his team mate who was hostess to many students, colleagues and friends who regularly visited their home. During the last 25 years she also accompanied him on his travels and appointments in the various locations cited above. She was a loyal partner throughout all of his activities.

In addition to his scholarly activities and world travels, Olek was adventurous in the food he ate—ranging from very rare steaks, plates of escargot, tapas heavy on the garlic to oysters. Olek and Helen also roamed over south Wales searching for fungi, berries, samphire or anything else they deemed to be edible! Accompanying him on a drive was another type of adventure, as Olek enjoyed many diversions to see new sights. Often travelling over roads that were nearly impassable, he would at the same time discuss his latest works or current interests!

Olek leaves a legacy in the form of his books and writings as well as in many students and collaborators who benefited from his advice and tutoring. He was indeed a distinguished scholar and good friend to many. He will be greatly missed but not forgotten.

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