

David Vernon Boger (1939–2019)[†]

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ABSTRACT

David Boger was born in Pennsylvania and earned a Bachelor's degree in Chemical Engineering at Bucknell University. After receiving his PhD from the University of Illinois (1965), he migrated to Australia and became a citizen there. He became an outstanding rheologist at Monash University. He is especially noted for his development of the vane method for determining yield stress in particulate materials, and for the development of Boger fluids that enabled clarification of some puzzles in the study of viscoelastic liquids. He eventually became Laureate Professor at the University of Melbourne. There, he made many contributions to the problem of waste disposal in the mining industry, especially the solution of the red mud problem arising from the aluminium industry. After retirement from Melbourne, he returned to Monash University and also spent time at the University of Florida. He received many honours for his work, and he is survived by three children and six grandchildren.

Keywords: Boger fluids, elasticity, environment, mining, non-Newtonian, rheology, tailings, viscosity.

Early life

David Vernon Boger (Fig. 1) was born in Kutztown in south-eastern Pennsylvania. Kutztown is a small borough with about 4000 inhabitants in Berks County. His forebears came to the district from southern Germany in the early 1700s and settled there. Nearly 200 years later, David's father Charles David Boger (1911–1985) was born in Kutztown and became a member of the local Trinity Lutheran Church. He was the Secretary of Maxatawny Township, which surrounds Kutztown, from 1966 until 1978. He worked as a self-employed painter and paper-hanger for twenty years, and then he became a postal employee in the Kutztown Post Office until his retirement in 1981. His granddaughter Samantha Leggett told us that 'Charlie was a joker, liked to play games; we all played lots of Checkers (Draughts) with him and he was always smiling'. She also said that they only saw him in the USA and he never travelled to Australia.

David's mother Edna Geneva Boger (1917–2010, née George) was also born in Kutztown and belonged to the Lutheran Church. She was a graduate of the Kutztown Area High School (class of 1935) and the Lankenau School of Nursing (1938). She rose to be Director of Nursing at the nearby Topton Lutheran Home, practised there for many years, and finally was Director of Nursing at the Hamburg State School. According to Samantha, she visited Australia quite often, and we were told, 'Edna was always taking us (grandchildren) places, for swims, to the waterpark, for walks, to the movies, to community members' houses for cake. She knew many people and was a central part of her local community as a local nurse for many years, and the head Matron of the local hospital. She was kind, hard-working, driven, very proud of Dad and cooked delicious corn on the cob'.

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Fig. 1. This portrait photograph of David Boger was taken in 2007 by the Prudence Cuming Associates and is © The Royal Society.

David, their only child, grew up in the semi-rural area and developed a strong affinity for the natural environment. He liked to fish and this passion lasted all his life. He attended a one-room school (1945–6), and then a school that was an offshoot of Kutztown Teachers College (1946–54). There he was highly influenced by John Silan, the basketball and baseball coach. From 1954 to 1957 he attended Kutztown Area High School and became a basketball star. We can see something of his high school experience in the notes from an interview conducted for the Society of Rheology (McKinley 2019). David said,

I went to Kutztown High School. I was only interested in sport ... Wasn't a bad student, but wasn't a good student. I was captain of the basketball team and captain of the soccer team, and played baseball ... I had no idea of what I was going to do ... Someone said to me, 'You're pretty good at chemistry, maybe you should become a chemical engineer'.

His parents were keen for him to have a university education, but with a mediocre high school record, he received few offers of places. Finally he settled on Bucknell University. Bucknell is a private liberal arts university near Lewisburg, Pennsylvania, about 140 km (88 miles) from Kutztown. He had no scholarship, so his mother paid the fees. At present Bucknell has about 3800 undergraduates and a very small postgraduate enrolment. It has a College of Engineering and that is where David got his Bachelor's degree in Chemical Engineering in 1961, the first member of his family to receive a university degree. Besides being a good student (elected to the Engineering Honour Society Tau Beta Phi and given an Omicron Delta Kappa Achievement Award), he also achieved Varsity Colors for Soccer

at Bucknell after he played on the team for three years (1958–60). As an amateur, he also played college baseball, he was a good swimmer, and acted as a lifeguard at the Kutztown outdoor pool in summer. He did not play basketball at Bucknell; although he was not short, he said he was not tall enough. He was grateful to his adviser Professor R. Slonaker and to Professor Ju Wa Chen who urged him to go on to graduate study. He was accepted for postgraduate study at the University of Illinois at Champaign-Urbana, where he was awarded an MS (1963) and then continued on to a PhD in Chemical Engineering in 1965. His thesis, under the supervision of Professor James W. Westwater, involved the study of the effect of buoyancy on melting and freezing in heat transfer (Boger and Westwater 1967). This paper has been quite well cited. After the PhD he was offered seventeen jobs, mainly in industry, but he felt he would like to teach. He met some Australians, caught the travel bug and then decided to take up a lecturer position in Chemical Engineering at Monash University, which lies in an outer suburb of Melbourne, Australia.

Monash and marriage

Monash University began admitting students in 1961 and was therefore in its infancy when David arrived. The Department of Chemical Engineering at that time had a single professor (Owen Potter), who was head of school. It was run on fairly autocratic lines and David was encouraged by the Head of School not to work on heat transfer, but to take up the study of rheology instead. David knew nothing about rheology, but the Department had bought a Weissenberg rheogoniometer and he was urged to do something on non-Newtonian fluids with it, and that is how he became a rheologist. As it turned out, it was a good move for him.

Although the initial appointment at Monash was only for three years, David decided to stay in Australia. He became an Australian citizen and never returned permanently to the USA. He began as a lecturer and was promoted to senior lecturer, and then to reader.

He married Elizabeth (Liz) Anne Mannix, who was the departmental secretary at Monash, on 7 October 1967, and they had two daughters and a son. David and Liz set up house in Harkaway, Victoria, 39 km south-east of the Melbourne business district. Harkaway is a small community of about 1000, and it is a 24 km drive to the Monash Campus at Clayton. The area suited the Bogers' taste for rural living.

The University of Melbourne

In 1982 he was appointed as Professor of Chemical Engineering at the University of Melbourne. The travel from

Harkaway to Melbourne University was more demanding than he was used to, but joining Melbourne was a good career move. He and his team at the prestigious Australian Research Council Advanced Mineral Products Centre, and then at the Particulate Fluids Processing Centre, made a string of pioneering discoveries in non-Newtonian fluid mechanics. He served, somewhat reluctantly, as head of department (1997–9), as associate dean for research in engineering (1990–2), and as deputy dean (1988–1990). He was appointed Laureate Professor in 2000, one of only three in the University.

He was also an honorary Professor at Nanyang University in Singapore (2002–05), and spent a month or two there each year. When he was offered two jobs as Dean (one at Monash), he was talked out of them by the Melbourne Vice-Chancellor and so he stayed—with an increase in salary (McKinley 2019).

Elizabeth died in 2000 and David married Reba Angstadt, also a Kutztown High School graduate, in September 2003.

After winning the Prime Minister's Prize for Science in 2005, which included a \$A300,000 reward, David bought a farm near Buchan in East Gippsland, Victoria. The farm is isolated—the nearby village of Buchan has a population of about 200. It is about 320 km from Harkaway to the 300 acre (122 ha) property, which was to David's taste. A new comfortable house was built on the site, and a manager oversaw the raising of beef cattle.

One of David's life-long passions was fly-fishing, and he fished not just locally, but world-wide (Figs 2 and 3). He made excursions into Florida and Alaska in the USA, to the Northern Territory of Australia, and many other venues, often with friends.

Retirement

David retired from the University of Melbourne in 2007, and returned to resume life at Harkaway and Monash University as adjunct professor (2010–15). He split his time between Monash and Florida. He was a visiting professor at the University of Florida after retirement where a collaborator commented, 'David was a supportive peer, and a true friend, always willing to share his vast knowledge without pretension. Despite David's outstanding scientific and technological achievements, and international acclaim, he remained extraordinarily humble'.

He continued to attend and enliven conferences, and Roger Tanner recalls having dinner with him and other friends at the Society of Rheology Meeting in Tampa Bay, Florida in February 2018. After that, he suffered a long decline in health and mobility, and by December 2023 he needed a wheelchair to get around, but his mind was still fully active. He died in July 2025, and his second

wife Reba Angstadt died in Florida in May 2026. He is survived by his son Steven (PhD in earth sciences), two daughters, Samantha (artist and mathematics teacher) and Brooke (sports administrator), and six grandchildren.

Non-Newtonian fluid mechanics and rheology

Most materials encountered in everyday life lie between the two classical extremes of a Hookean elastic solid and a Newtonian (constant viscosity) liquid. Examples of everyday soft materials are multigrade oils, polymer melts, polymer solutions, suspensions, emulsions, gels, paints, food materials, and body fluids. The subject of rheology treats the flow and deformation of such materials. Some materials are essentially solid until a sufficient stress (the yield stress) is applied; for larger stresses the materials behave like a liquid. Materials without a yield stress are called non-Newtonian fluids, and may or may not possess a memory of past deformation. Those which do are called viscoelastic liquids, and are endowed with both viscous and elastic properties.

The measurement of the mechanical properties of such materials forms the subject of rheometry. In simple shearing, and generally in viscometric flows, the components of the stress tensor lead to three viscometric functions (Lodge 1964; Tanner 2000) that play important roles in the rheology of incompressible liquids. These three independent functions of the stress tensor are the viscosity, and the first and second normal stress differences. In (steady) simple shear, all three are functions of the rate of shear. Most, but not all, non-Newtonian fluids are shear-thinning, that is, the viscosity is a monotonically decreasing function of shear rate. Constant viscosity, or shear-thickening behaviour is rare in these soft materials. In extensional flows there is no shearing and the two stress differences can be functions of the strain, and/or rate of strain.

Measurement of the viscometric functions, especially the shear viscosity, provides valuable information for characterising a material and in applications to engineering. Additional measurements are needed, however, to characterise a material's memory, which governs its response to a time-varying applied stress or applied strain. In the limit of small strain or strain-rate, memory effects emerge within the context of linear viscoelasticity, wherein a linear change in stress induces a linear change in strain, and vice-versa. Experimentally, a sudden change in strain (step-strain) yields the relaxation modulus of the material, while an applied oscillatory shear identifies a complex dynamic viscosity, both of which are directly related to the memory function of the material, and to the spectrum of relaxation

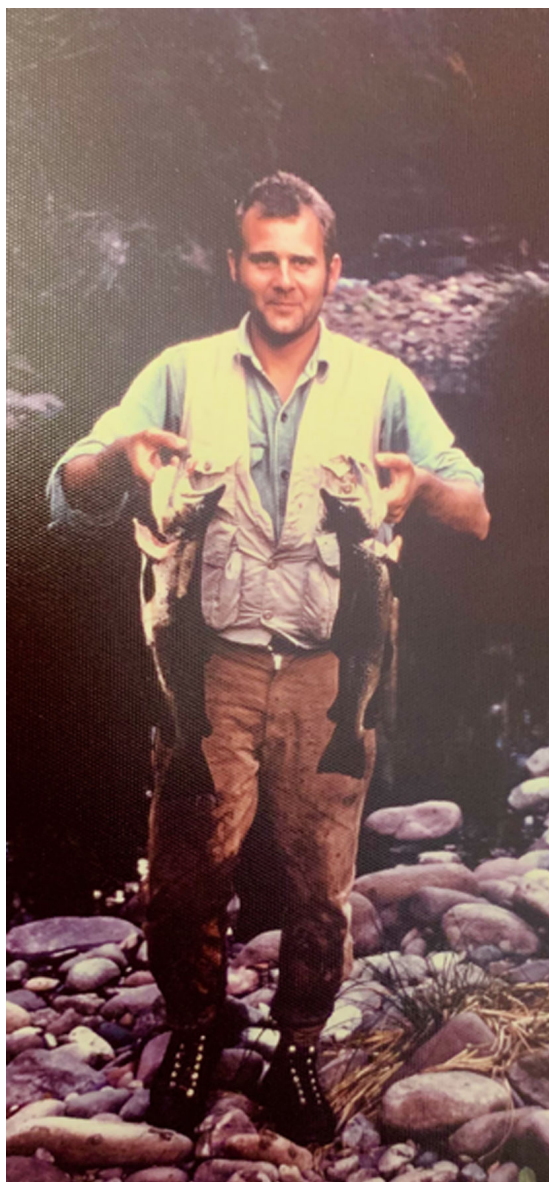


Fig. 2. Young David with fish (From the Boger family collection).

times (relaxation spectrum) that characterise its molecular relaxation processes.

When strains and strain-rates are no longer small, one enters the realm of nonlinear viscoelasticity. Unlike Newtonian fluid mechanics, where the motion of all fluids can be described by the Navier-Stokes equations, in non-Newtonian fluid mechanics there is no single mathematical model that can be applied under any flow condition. We now consider David Boger's contributions to the subject.

Measuring yield stresses

The measurement of the yield stress is arguably the best known part of David Boger's scientific work. He seems to



Fig. 3. The mature fisherman (From the Boger family collection).

have become interested in the subject around 1980, when he discovered that red mud (see Section below) had a measurable yield stress (Boger and others 1980). In 1983 he began to work with the vane technique for measuring yield stress (Dzuy and Boger 1983). The vane test was not new, but was adapted from its use in soil mechanics. The vane test uses a four-bladed rotor, which when rotated slowly in the specimen, cuts a cylindrical portion of the material. The torque needed to start the vane rotating is measured and a simple analysis is used to estimate the yield stress; later numerical work showed the simple analysis is quite accurate (Keentok and others 1985). The paper is one of David's highest cited papers (Dzuy and Boger 1983). An important papershowed in 1985 that the vane method could be used to estimate the yield stress of red mud (Nguyen and Boger 1985), and the bases of the method were explored by Dzuy and Boger in 1985 (Dzuy and Boger 1985). In 1992 he and Q. D. Nguyen published a review that is David's most-cited article (Nguyen and Boger 1992). It is an excellent and extensive survey of the advantages and disadvantages of various methods of finding the yield stress, and also discusses the definitions of yield stress that are found in the literature. A 1992 follow-up article contains much information on the correct use of the vane method (Liddell and Boger 1996).

This work established the use of the vane method in rheology, especially for the minerals processing industry. Then David's work turned towards the use of the slump test to estimate yield (Pashias and others 1996; Clayton and others 2003). The slump test, following a similar test used in concrete testing, is suitable for on-site work. In this case it is only necessary to measure the decline (slump) of the height of a standard lump of material due to gravity. Instead of the usual conical specimen used in concrete testing (ASTM International 1998), the Melbourne team used a cylindrical specimen (Pashias and others 1996; Clayton and others 2003). The analysis leading

to the yield stress value is somewhat simpler than that for the ASTM cone specimen. The measurement of the height of the sample after deformation under its own weight enables the yield stress to be calculated. It was found that there was good agreement with the vane method (Clayton and others 2003).

This body of work brought science to the minerals processing industry and is one of David's most significant contributions. Besides application in minerals processing, the vane method was also used to determine the properties of waxy crude oils (Wardhaugh and Boger 1991; Chang and others 1998).

Flow visualisation and Boger fluids

David was first and foremost an experimenter, and many of his papers include excellent photos of experimental flow patterns. Initial work in rheology by David was on flow properties of polymer solutions. The motivation for this work was to understand polymer processing operations and how these were influenced by the properties of the molten polymer. A common geometry in all these operations was that of a fluid flowing from a large reservoir into a smaller tube, such as found in the extrusion of tubes or formation of fibres. These geometries then became the prototype flows to gain a basic understanding of the intricate interactions between the flow properties of the fluid and the geometry. To simplify experiments and enable measurements to be made at room temperature, the molten polymer was replaced by a polymer solution whose properties could be varied and measured. Using transparent materials such as glass walls, and seeding the solution with tracer particles containing mica-coated titanium particles, allowed the fluid flow to be visualised by photography. Furthermore, multiple exposure would permit the measurement of point velocities in the flowing field. These comprehensive data sets were laborious to obtain, but could be invaluable to verify emerging theoretical models of the fluid mechanics of the process.

Fig. 4 shows a typical example from the work of David with P. J. Cable (Cable and Boger 1978; Cable and Boger 1979). It was found that the entry flow is stable at low and moderate flow rates, but at higher flow rates, the entry flow of sufficiently elastic fluids can be disturbed by several instabilities, which are not seen for purely viscous fluids. The stable laminar entry flow is characterised by the development of large vortex flow patterns upstream of the small tube entrance, due to the nonlinear viscous fluid properties, as well as the elastic properties of the fluid. These instabilities can also manifest as extrudate distortions and affect the properties of the ultimate product. To speed up the process and allow higher production rates, these instabilities needed to be understood and if possible, eliminated or delayed.

It was this complex interaction between the fluid flow and the fluid properties that fascinated rheologists, and

was to occupy David's interest. Some of these photos were later incorporated into a book (co-authored by Ken Walters FRS), entitled *Rheological Phenomena in Focus* (Boger and Walters 1993). During the late 1970s and 1980s, David had great fun at conferences. He would tease and taunt the numerical and theory specialists by showing some beautiful photos of flow patterns, often with vortices, and then ask why no one could predict the flows. In a 1992 paper he wrote,

Research in non-Newtonian fluid mechanics has been characterized by the theoretical types (the left wing) who make predictions that cannot be observed and by the experimental types (the right wing) on the other hand, who make observations that no one can predict (Boger and Yeow 1992).

He had a point, because at that time there were severe convergence problems with the computations and the fluid models were not optimal. In any case, he certainly livened up rheology meetings.

Another very well-known paper, from 1977, describes the properties of fluids with a constant viscosity but which also show elastic as well as viscous properties (Boger 1977). Ultimately these fluids became known as 'Boger fluids', and they helped clarify the separate effects of elasticity and variable viscosity on flow of such fluids. David also took part in the making of a film entitled *Boger Fluids*, which was part of a series of films about rheology created by the Walters group at Aberystwyth. A review with the title, 'Boger Fluids', was written by James (2009).

Polymer solutions were characterised by two basic properties – a viscosity that decreased with increasing shear rate and a small first normal stress difference that was quadratic in shear rate (at small shear rates). Early research was focussed on separating the effects of inertia, shear thinning, and elasticity. To reduce inertia experiments were required to be conducted at low shear rates (low flow rates). Under such conditions the elastic effects were insignificant. These contradictory requirements did slow progress.

To increase elastic effects, early fluids used to mimic the molten polymer were an aqueous solution of polyacrylamide with corn syrup being used to elevate the viscosity. Using corn syrup increased the solution viscosity, while also increasing the first normal stress difference. In steady shearing flow, the shear stress, at a given shear rate, of these solutions, was two to three orders of magnitude lower. The first normal stress difference was similarly lower for the fluids. The ratio of these two defined a characteristic time constant which was of similar magnitude thus providing a justification for the use of these fluids. In elongation (Sridhar and others 1986) these fluids behave in a very elastic manner (Fig. 5).

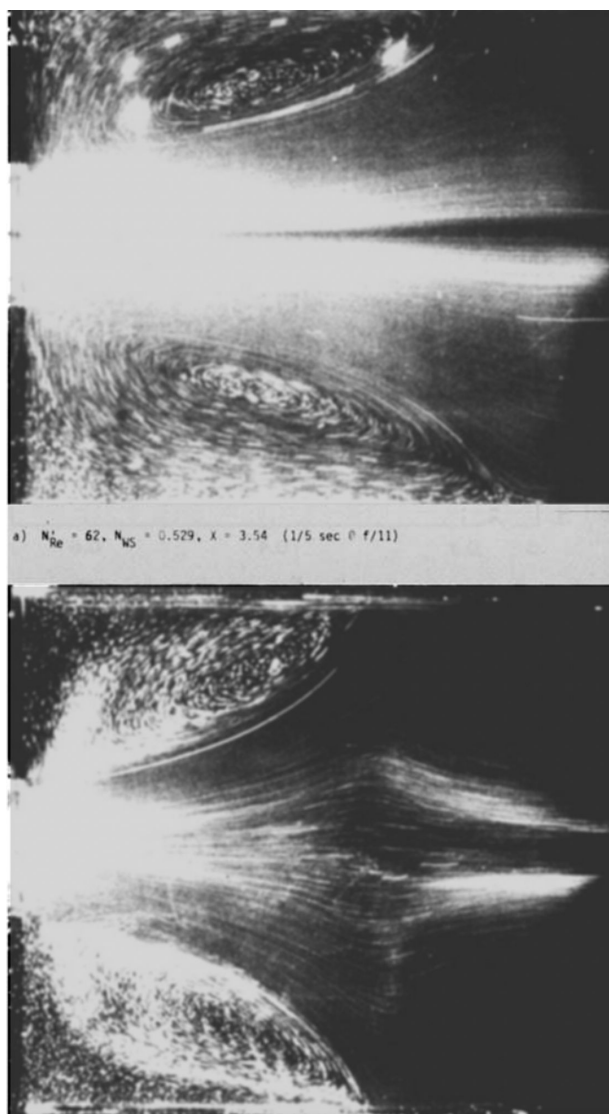


Fig. 4. Flow visualization in entry flows. Flow is from right to left. At low flow rates (top) one sees stable entry flow with a growing vortex (Cable and Boger 1978). The bottom figure indicates a swirling unstable flow along the centreline. From Cable and Boger (1979), used with permission from John Wiley and Sons.

These early results led to great excitement in the rheological community and such fluids were called ‘Boger fluids’. They were widely adopted to study several flow problems. Most of the early work was analysed using a single mode Maxwell model. This model predicts that the first normal stress coefficient (the normal stress difference divided by the square of the shear rate) was identical to the storage modulus divided by the square of the frequency. (The storage modulus is the ratio of the in-phase or elastic part of the shear stress magnitude divided by the sinusoidally oscillating strain magnitude). However, experimental results in low amplitude sinusoidal deformation gave an intriguing result. It showed that the Boger fluids

exhibited elasticity in steady shear, but were nearly inelastic in imposed periodic sinusoidal strain. These results were explained using an Oldroyd B model, and showed that Boger fluids naturally emerge whenever a small amount of polymer is introduced into a highly viscous solvent (Prilutski and others 1983). This vastly expanded the recipe for producing such constant viscosity Boger fluids, and expanded the arsenal at the hands of experimentalists.

Environmental rheology and mining

David Boger spent a great deal of time and effort on environmental problems arising from the mining industry (Jones and Boger 2012; Boger 2013; Pullum and others 2018), and his last (2018) publication recorded on the Web of Science is a review of mining waste disposal (Pullum and others 2018). His first significant contact with these problems came from an approach by the Alcoa company in Western Australia in 1974. The company was producing 15,000 tonnes of red mud daily. Red mud is a waste product from aluminium production from bauxite, and traditionally it was stored as a suspension of about 25% solids in open ponds with earthen dams to contain it. The mud is extremely caustic with a pH of around 13, and is therefore dangerous and constitutes a severe environmental problem. An escape of red mud in Hungary from a small pond due to failure of the dam in 2011 led to a 2 m high mud wave, which killed eight people and injured more than 120 others. The company was fined heavily (Jones and Boger 2012); hence, a solution was needed.

In the early 1980s, as mentioned above, he adapted the yield stress measurement test from geomechanics and soil science for use with mineral tailings (waste) suspensions. At the time, these suspensions were disposed at low solids content because at higher solids content, they showed a yield stress, and minerals companies were reluctant to pump such material. He taught the minerals industry how to deal with these non-Newtonian yield stress fluids, and developed the vane yield stress technique to help with operational control of higher solids disposal. The vane technique has become the industry standard for characterisation of the propensity of tailings suspensions to be pumped and to flow in tailings placement facilities.

He also developed the slump test colloquially known as the ‘fifty-cent rheometer’. This test allows practitioners to get a measure of the yield stress in an operational setting, without the need for a laboratory or sophisticated equipment. Once again, it is now an industry standard. The team alleviated the problem of the high pH of red mud by adding vinegar (an acid), and the big step forward was the idea of dewatering, thereby raising the solids content so that the residue became a paste. It was then shown that one was able to convert the waste into a solid that could be cut and stacked – it was also possible to grow grass on it.



Fig. 5. Rod (R.J.) Binnington demonstrating the extraordinary extensional behaviour of a 2.2% polyacrylamide solution in glycerine/water. Rod was a very gifted experimenter who worked with David Boger at Monash and Melbourne. The photograph was taken at a Science Festival in Melbourne, 1993. (Copyright unknown.).

It also led to a smaller volume of waste and saved water. It was a wonderful solution to a severe environmental problem.

A more general approach to waste management by water reduction was made at the University of Melbourne through the Particulate Fluids Processing Centre, and its predecessor, the Advanced Minerals Processing Centre. David became a crusader trying to get the mining industry to improve its environmental record. At the Australian Academy of Science he was awarded the prestigious Matthew Flinders Medal and Lecture in 2000, and he gave his views in a typical forthright manner using some words not often heard at the Academy! Some were shocked, but the message was clear: the mining industry should take better care of its waste products.

No doubt his environmental work contributed greatly to the many honours he received. The list is long and is included in Supplementary material, but we note especially the Pol Eureka Prize for Environmental Research (1993), the Prime Minister's Prize for Science (2005), the Fellowship

of the Royal Society of London (2007), election to the U.S. National Academy of Engineering (NAE) in (2017), and the Companion of the Order of Australia Award (AC) in 2024. There were only four recipients of the AC award in 2024; it is the top civilian honour in Australia. Clearly the work with the mining industry led to world-wide contacts for consulting work and the launching of a consulting firm that continues under the guidance of Dr. Peter Scales.

Consulting and community service

David, with two others, formed Rheological Consulting Services in 2003. It is a company supplying deep technical and research-based services either as laboratory measurements, technology assessment, or advice. Part of the advice involved being a key advisor to BHP on tailings dam safety and dry disposal implementation over many years. It continues to this day, and has over 200 industries on its list of clients. The consulting work, especially for the BHP Company, took David around the world; he consulted for more than 90 companies. The farthest consulting trip was to go from Melbourne to the middle of the Atacama Desert in northern Chile. He was critical of the minerals industry and gave many addresses on how to improve the disposal of waste from mining. Basically, many of the dangers of disposal could be avoided by dewatering the tailings to form a paste, which ensured that no escape of the tailings could happen. He continued to consult after retirement from academic life.

He served as President of the Australian Society of Rheology and organized the editing and publication of the four volumes of the *Proceedings of the 10th International Congress on Rheology in Sydney* (1988), which was a heroic effort. He was also a prime mover in setting up close collaboration with South Korea in rheology, having edited the *Korea Australia Journal of Rheology* (now published by Springer) for several years, and initiated, with a Korean colleague, the sequence of biennial Korea-Australia Rheology Conferences. He served the Australian Academy of Science as a council member, 1999–2001.

Closing remarks

A celebration of David's life was organised on the Monash University campus on the afternoon of 25 July 2025. A large gathering of family, fishing companions, faculty colleagues, former students, and friends came from all over Australia and abroad for the celebration. As noted above, he was passionate about the environment and took it upon himself to find the most remote of streams, lakes and rivers, and just loved spending time outdoors. Australia, where he lived, proved to be ideal for this quest and as an accomplished fly fisherman, his belief that the most remote

rivers had the best fish led to a lifelong recreation. Indeed, his passion for fishing saw him cast a line in nearly every one of the very large number of countries he visited. His weekends and holidays were spent on his remote farm at Buchan, in eastern Victoria, Australia. His farm adjoined the lower reaches of the Snowy River, which he fished regularly. He farmed cattle and it was quite often easier to have an extended conversation about his cows as distinct from non-Newtonian fluid mechanics. He did really great science and engineering, as we have shown above, but never left his love of the land and the natural environment behind.

A complete bibliography of David Boger's published work is included in the Supplementary material that accompanies their biographical memoir.

Supplementary material

Supplementary material can be accessed from the article page online.

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