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Mervyn Silas Paterson 1925–2020

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Mervyn Paterson exploited a background in metallurgical engineering and the physics of metals as the basis for a long and influential career in earth sciences, mainly at the Australian National University. Recognising the need for specialized equipment for experimental rock deformation, Mervyn made a highly distinctive contribution through his design and construction of a series of machines of progressively increasing sophistication for laboratory studies of the mechanical behaviour of rocks under conditions of high pressure and temperature. The new insights thus obtained in the laboratory have found widespread application in understanding the behaviour of the Earth's crust and underlying mantle, notably within the disciplines of structural geology and geodynamics.

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Origins: early childhood on the family farm

Mervyn Silas Paterson (Fig. 1) was born on 7 March 1925 in Booleroo Centre 300 km north of Adelaide into a longstanding South Australian farming family. His forebears were amongst the earliest settlers in the South Australian colony, having arrived from Britain during the period between the foundation of the colony in 1836 and the 1850s, and taken up farming land in the Booleroo district when it first became available during the 1870s. His parents Charles and Edith May Paterson (née Michael) had both been born in Booleroo Centre in 1896, and were respectively, the eldest of five, and the fourth of eight siblings. Soon after their marriage in March 1924, Charles and Edith moved into a five-room stone house 'Ellimatta' newly constructed on their farm of one square mile (640 acre) area, immediately south of the Paterson family's Ballery Park farm which had been acquired by Mervyn's great-grandfather Philip Paterson in 1875. Incidentally, Philip Paterson, born probably in Glasgow in 1822, had come to Australia to work for John Angas with his Angas cattle. The Paterson's farm was situated in a region of relatively low and unreliable rainfall near the famed Goyder line, defined in 1865 by the transition from dominant mallee scrub vegetation to saltbush, as the northern boundary of land suited to agriculture. Wheat-growing was the primary activity on the family farm, alongside the raising of a few sheep, mainly for salted mutton, cows for milk, cream, and butter, and 'chooks' for eggs and meat on special occasions.

Mervyn was the eldest of four siblings, being followed by Lorna (1928), Glenn (1930), and Fay (1937) who was born after the family's move south to Prospect Hill. The 1930s were challenging years as the farming community faced the combined effects of depression, severe drought and frequent dust storms, and finally the devastating bushfires of January 1939. As fuel for farm machinery became prohibitively expensive, the family's McCormick-Deering tractor was sold, and by 1934, their 1925 Chevrolet was put up on blocks. Accordingly, farming reverted to the practices of a bygone era with a team of eight brumbies broken in for farm work, and a horse and buggy used for transport between farm and town.

In 'Mervyn Paterson Family History',[1] Mervyn recalled that his parents, between them, had had only one year of high-schooling—mother Edith being 'the parent with the higher education'. Edith was 'a very conscientious wife and mother, making do with the frugal means of life at the time .... [O]n the farm she tended to be the one who milked the cows, and fed the fowls, made butter if need be, did the clothes washing and ironing, cleaning the house and cooking the meals'. Mervyn described his father Charles as being 'of limited

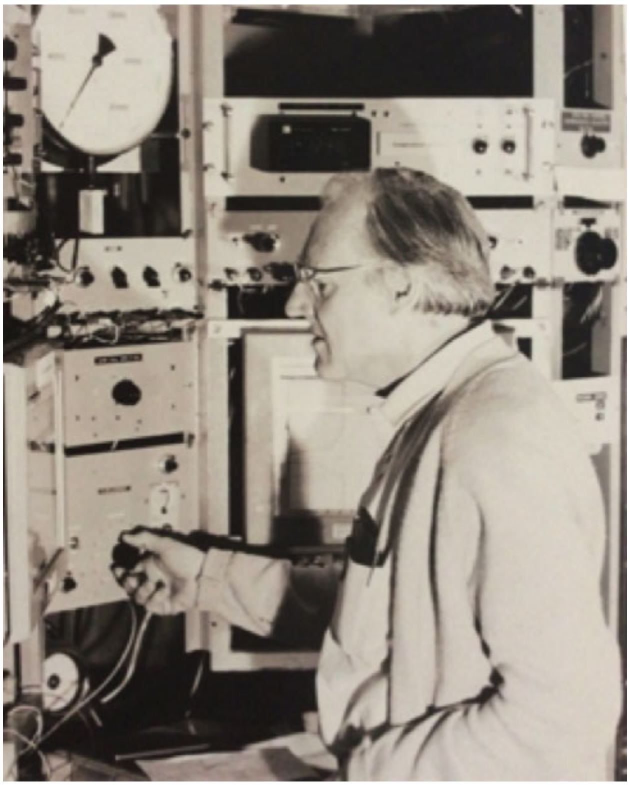

Fig. 1. Mervyn Paterson at the controls of one of his machines for experimental rock deformation under conditions of high pressure and temperature. Published with permission of the Research School of Earth Sciences, ANU.

[1] Paterson (2010).

schooling' but having 'a considerable intellectual interest, largely self-taught.' For example, he was an active Freemason who ultimately became Grand Master of the Melrose Lodge, and was a committed lay-preacher in the Methodist Church. The family strenuously avoided partaking of alcohol, and Sunday mornings were invariably spent at church and Sunday school.

Another prominent recollection from Mervyn's childhood was the somewhat monotonous diet based around salted mutton, homemade sour-dough bread, a few staple vegetables, and desserts based on tasteless pie melons. Food was kept fresh in a 'Coolgardie safe', which was a small cupboard with walls of damp bagging for evaporative cooling, like the canvas water bags also then in widespread use. There were weekly trips to Booleroo Centre for shopping and worship, visits to the nearby annual Melrose Show, and (pre-1934) occasional trips by car over mainly unsealed roads to Adelaide to visit relatives, and even on one occasion as far as Mt Gambier.

Schooling and undergraduate education

Mervyn recalled his schooling at various one-teacher schools in the Booleroo district (initially at Booleroo Whim, and Hundred of Wollowie, and later Mount View), involving travelling the three to ten kilometres to school either on horseback or on foot. At the Mount View school, newly re-opened in late 1932, fourteen students mainly of German descent, and spanning seven grades, were taught simultaneously within the one room usually by a young female teacher straight out of teachers' college—later described by Mervyn as a 'good educational experience'.

By late 1936, the economic situation for Mervyn's family in the Booleroo district had become so parlous, that they sold their farm and moved to Prospect Hill near Meadows, 50 km from Adelaide in the Southern Adelaide Hills. There Mervyn completed his primary schooling in another tiny one-teacher school—under the influence of an inspirational teacher, Max Wiadrowski. At Prospect Hill, Mervyn's extra-curricular activities included milking cows before and after school, and helping his father to clear land and trap rabbits—then (pre-myxomatosis) present in plague numbers, and valued both for food and their skins. The family subsequently moved to a larger property near Birdwood ~50 km NE of Adelaide during one of the worst bushfires in South Australian history in January 1939. In 1942, they moved to a market garden property in Netley, now part of Adelaide airport—thereby concluding a century of family farming.

With encouragement from his parents, Mervyn gained entry into the selective Adelaide Technical High School (ATHS) associated with the South Australian School of Mines and Industries. His attendance, from 1938, was made possible by boarding in Adelaide during the week with his paternal grandmother and two of his father's sisters. The technical stream at ATHS was designed to prepare students for careers in the trades or engineering technology. Accordingly, instruction in English, mathematics, physics, and chemistry, was complemented by training in woodwork, sheet metal work, fitting and turning, and technical drawing. Politely deferring an invitation to join his father in a new pastoral venture in south-eastern South Australia, Mervyn continued with his high schooling beyond the Intermediate Certificate.

On completion of the Leaving Year in 1940, Mervyn, yet to turn 16, was awarded one of only twelve State Scholarships to the University of Adelaide that was to pay his tuition fees and a living-away-from-home allowance of £40 a year. With a growing interest in chemistry, and his perception that science with a practical application was more likely to lead to employment opportunities in a depression era, Mervyn decided on extraction metallurgy. So, in March 1941, he enrolled in engineering with a specialisation in extraction metallurgy—then mainly ore dressing and smelting, along with basic mathematics, physics, chemistry, and engineering subjects. Due to the wartime emergency, an abbreviated engineering degree termed 'Interim BSc (Eng)' was taught across four rather than three terms a year. After graduating in December 1943 (into a reserved occupation), Mervyn was able to pursue additional coursework during 1944, in parallel with a half-time tutorship in mathematics. The further coursework along with the subsequent required practical experience led ultimately to conferral of the substantive BE degree in December 1945.

CSIR Division of Aeronautics

Late in 1944, Professor Gartrell of the Department of Mining and Metallurgy at the University of Adelaide identified a possible job for Mervyn at Mt Lyell in Tasmania to work on flotation of their copper ore. Although such work was closely matched with Mervyn's interest in the physical chemistry of flotation, the idea of a life spent in a remote mining town was not very appealing. Instead, Mervyn (Fig. 2) successfully applied for a position as Assistant Research Officer in the CSIR Division of Aeronautics at Fishermans Bend, Port Melbourne (CSIR being the predecessor of CSIRO). His travel by train to Melbourne was delayed several weeks until February 1945 by the wartime need for a permit for interstate travel. Mervyn later recalled that he was somewhat underprepared for research in physical metallurgy, having 'had very little on secondary metallurgy in our Adelaide course, just one course in metallography … which did not even mention crystal structure'. However, he had bought a copy of C. S. Barrett's *Structure of Metals*[2] during his last year in Adelaide and 'this was an absolute revelation to me on crystal structure and mechanical properties'.[3]

At CSIR, Mervyn quickly became immersed in research projects involving both experimental studies and theoretical analysis of various aspects of the mechanical behaviour of metals. These included failure by fatigue, the damping capacity of metals subject to oscillatory stress, and investigation of Lüders bands—bands of inhomogeneous deformation in steel. Reports of this early work included an oral presentation at a conference on 'The Failure of Metals by Fatigue' held at the University of Melbourne in December 1946, and a paper with John Cowley in *Nature* in 1947, reporting on X-ray diffraction studies of yielding in mild steel.[4]

[2] Barrett (1943).
[3] Paterson (2008).
[4] Cowley and Paterson (1947).

Fig. 2. The youthful Mervyn Paterson (~1945, photo courtesy of the Paterson family).

Postgraduate study at the University of Cambridge

By mid-1946, exposure to research at CSIR had evidently whetted Mervyn's appetite for further study—overseas, as PhD courses in Australian universities were new and not widely available. In June 1946, Mervyn submitted a thesis entitled 'Damping Capacity Measurement and Relation to Cold-work in Mild Steel' to Adelaide university in support of an application for the prestigious Angas Engineering Scholarship that had been established in 1888 by the Honourable John Howard Angas MLC to pay for fees and overseas travel associated with professional development for engineering scholars. Mervyn's travel to England, supported by the Angas Engineering Scholarship and a CSIR Overseas Scholarship, thus closed the loop opened by his great-grandfather Philip Paterson's migration to South Australia a century earlier to work for the Angas family. Mervyn successfully applied for admission to the University of Cambridge (and Clare College) to work towards a PhD in the Cavendish Laboratory under the supervision of Egon Orowan.[5] Orowan, a Hungarian-born Jewish refugee from pre-war Europe, was already well known for his contribution to the seminal idea that dislocations might be responsible for the plastic deformation of metals. Mervyn arrived in Cambridge in March 1947 after a sea voyage of more than four weeks' duration.

After some discussion with Orowan, it was decided that Mervyn would pursue a project involving the influence of low-temperature deformation on X-ray line broadening in copper. The project required the development of experimental arrangements for both deformation and X-ray diffraction at liquid-nitrogen temperature. Mervyn was personally responsible for maintaining and operating a Metrovick X-ray generator with a continuously pumped X-ray tube, making his own X-ray targets, measuring the line broadening on film, and applying corrections for instrumental broadening. Although the PhD degree was duly conferred in June 1949, full publication of this work was delayed by 'difficulty getting Orowan's involvement'[6] until 1954.[7]

Postdoctoral experience at the University of Chicago

In July 1949, while on board ship returning to Australia and the Aeronautical Research Laboratories (ARL) at Fishermans Bend, Mervyn received a cable offering him a postdoctoral position in the Institute of Metals at the University of Chicago, for which he had apparently been recommended by Orowan. Mervyn was able to negotiate a further year's leave from ARL to take up the postdoctoral position working with C. S. Barrett whose textbook had already helped shape Mervyn's career. The main research outcome from Mervyn's year in Chicago was his work on the theory of X-ray diffraction from crystals with crystallographic faulting resulting from plastic deformation. His paper on the theory for face-centred cubic metals was destined to become an ISI citation classic.[8]

Significantly, it was at International House of the University of Chicago, that Mervyn met his future wife Katalin Schmidt/Sarosy,[9] a brave young woman who had fled her native Hungary following the communist takeover, and completed undergraduate studies in Paris, before moving to Chicago for postgraduate study.

The Australian National University: the early years

Following his return from Chicago in July 1951, Mervyn initially rejoined the Aeronautical Research Laboratories. There he resumed his research on metal fatigue, now focussed on experimental studies of reversed deformation at relatively large strain amplitudes, requiring design and construction of a new apparatus.

However, only a year later, Mervyn was approached by Professor John Jaeger, the foundation Professor of Geophysics in the Research School of Physical Sciences (RSPhysS) at the newly established Australian National University (ANU). Experimental rock deformation had been identified as a possible research direction for Jaeger's fledgling department following a workshop at ANU involving prominent Canadian geophysicist J. Tuzo Wilson. Professor Mark Oliphant, director of the ANU RSPhys, had known Orowan in Birmingham, where he first worked after fleeing Europe, with Rudolf Peierls. Jaeger duly contacted Orowan on Oliphant's suggestion and Mervyn was identified as a potential ANU recruit.

Following discussions with Jaeger, Mervyn applied for and was duly appointed to an advertised position, taking up his new appointment as a senior research fellow in June 1953. Part of the appeal of deformation studies on minerals and rocks was the usefulness of transmission light microscopy in understanding the deformation of transparent specimens—as demonstrated by John Nye, Mervyn's fellow student at the Cavendish Laboratory. However, studies in rock deformation were to require high-pressure techniques. Significantly, Mervyn confided in Jaeger at the time of his ANU

[5] An obituary for Egon Orowan was published by Nabarro and Argon (1995).
[6] Paterson (2008).
[7] Paterson (1954).
[8] Paterson (1952).
[9] Katalin's family name Schmidt was changed during World War 2 to Sarosy.

application 'I can't make any elaborate claims of engineering prowess to bring to bear on the design of high pressure equipment but expect that I could cope with what would be necessary in this direction'.[10] Mervyn's quiet confidence was to be amply justified by his design of equipment of steadily increasing sophistication for experimental rock deformation during the decades to follow.

During his first year-and-a-half at ANU, Mervyn conducted reversed deformation experiments on single-crystal copper with the machine that he had built at ARL and been able to transfer to ANU. During this time, he was also busy setting up an X-ray diffraction laboratory and building some simple facilities for experimental rock deformation. By early 1955, Mervyn was able to make a start on the deformation of calcite crystals and fine-grained (Solnhofen) limestone using his newly constructed simple piston-in-cylinder devices. This equipment, in which he employed O-ring seals for the first time, rather than the gaskets in common use, allowed compressive deformation under essentially constant confining pressure. The next step, from mid-1956, was to commission a triaxial deformation apparatus (Fig. 3) that Jaeger had had constructed before Mervyn's arrival—to a design from the US Bureau of Reclamation in Denver.[11]

Significantly, its notional capability for deformation at room temperature under confining pressure to 100 MPa, was realised only with redesigned seals incorporating O-rings (Fig. 3). Early tests on granites for Jaeger's consultancy with the Snowy Mountains Hydroelectric Scheme were followed by seminal work on a coarse-grained (Wombeyan) marble, establishing the brittle-ductile transition in this material at room temperature.[12] Fig. 4 depicting the transition with increasing confining pressure from brittle failure to ductile (plastic) behaviour has been reproduced in many textbooks of structural geology. Mervyn considered his work on Wombeyan marble to represent his 'serious *entrée* into experimental rock deformation'.[13]

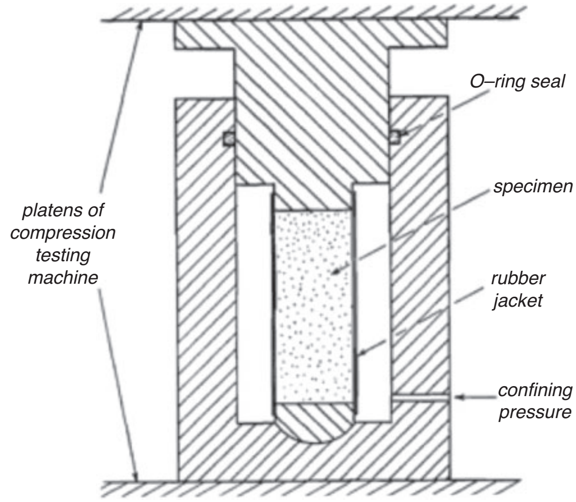

Fig. 3. Sketch of the simple 'Bureau of Reclamation' apparatus commissioned by Mervyn Paterson for triaxial rock deformation (reproduced with permission from Paterson (1958)).

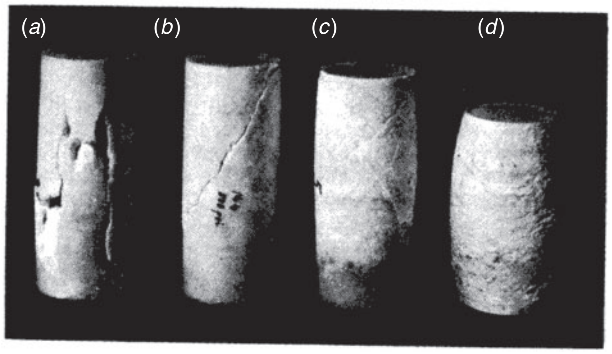

Fig. 4. Illustration of the impact of confining pressure on the competition between brittle failure and ductile deformation. The confining pressure increases in stages from 0.1 MPa (atmospheric pressure) to 100 MPa from left to right (reproduced with permission from Paterson (1978)).

Specialised equipment for experimental rock deformation

Next came a more ambitious project: the design and in-house construction of a free-standing rig with its own loading system and independent pressure generation—intended for triaxial deformation over a much wider range of well controlled pressure (to 1000 MPa). Following Griggs,[14] Mervyn's approach to deformation under high confining pressure was to employ a pair of pistons yoked together so that the loading piston moved into the pressure vessel from one end while the other piston moved out of the other end, thereby maintaining constant confining pressure during deformation. The differential loading applied to the piston had to overcome the frictional resistance to the advance of the piston, and deform the specimen, but importantly didn't need to work against the confining pressure. This most sophisticated of Paterson's apparatuses for deformation at room temperature was used in a wide variety of experiments from the late 1950s to the mid-1960s and beyond. For pressures reaching 1000 MPa, reliable sealing was achieved with O-rings, fabricated from appropriate polymeric material and supported by anti-extrusion (mitre) rings, rather than gaskets. Notable applications of this apparatus were in studies of the glass transition in rubbers,[15] of folding and kinking in foliated metamorphic rocks,[16] and in investigation of volume changes associated with deformation.[17]

[10] Paterson (2008).
[11] Involving, in principle, independent control of all three principal stresses, but in practice only the confining pressure and the superimposed axial load.
[12] Paterson (1958).
[13] Paterson (2008).
[14] Griggs (1936).
[15] Paterson (1964).
[16] Paterson and Weiss (1966).
[17] Edmond and Paterson (1972).

However, it was becoming clear, especially through Mervyn's contact with the Griggs laboratory at the University of California Los Angeles, that high temperature was essential for broadly meaningful high-pressure rock deformation studies. So, by early 1961, Mervyn had started work on an entirely new apparatus capable of deformation at low strain rates under conditions of simultaneous high temperature (order of 1000°C) and high pressure (1000 MPa), along with controlled pore-fluid pressure. The new machine again used the Griggs arrangement of a pair of yoked pistons, with differential loading through the yoke to one of the pistons. Innovations included the use of H13 Cr-Mo-V steel hardened to HRC50–51 for the pressure vessel, and the use of argon as pressure medium, delivered by a three-stage pumping system involving oil-driven pumps and intensifier, and the installation of a two-winding internal furnace. Following initial pressure tests to 1000 MPa at room temperature in July 1963, conditions of 1000°C at 800 MPa were realised in December 1964, and an internal load cell was introduced in Jan 1965. This apparatus (Fig. 5) was later described in detail.[18]

In February 1967, an experiment being conducted at room temperature and 500 MPa was abruptly terminated by rupture of the pressure vessel. This incident, in which Rob Coe and Mervyn Paterson at the controls were unhurt thanks to the protective barrier, was attributed to a combination of corrosion of the bore and excessive hardness of the steel. Accordingly, in order to achieve enhanced ductility, a lower hardness of HRC48 was specified for subsequent vessels, all made of vacuum-melted H13 steel, including the replacement installed in June 1967 which came to be known by later users as 'Rig #1'. Moreover, operating procedures were modified to minimise the risk of condensation of water vapour within the pressure vessel.

This high-temperature, high-pressure capability allowed a wide range of experiments during the 1960s—notably those involving the dehydration of serpentinite,[19] the synthesis and deformation of aggregates of platy minerals,[20] the α-beta transition in quartz,[21] and the deformation of biotite.[22] Rig # 1 was also used for important studies of the link between porosity and permeability,[23] and much later was upgraded with the addition of a laser interferometer to provide highly time-resolved information concerning slip during brittle failure.[24]

A second apparatus ('Rig #2') of similar design was fully commissioned by 1973 with enhanced furnace capability to 1200–1300°C. Highlights of the experimental work on plastic deformation included studies of the deformation of quartz and quartzites,[25] and the rheology of fine- and coarse-grained carbonate rocks,[26] partially molten granite,[27] and olivine crystals and dunites—both natural and synthetic.[28]

Mervyn's involvement in design and development of equipment for the mechanical testing of rocks continued during the late 1970s

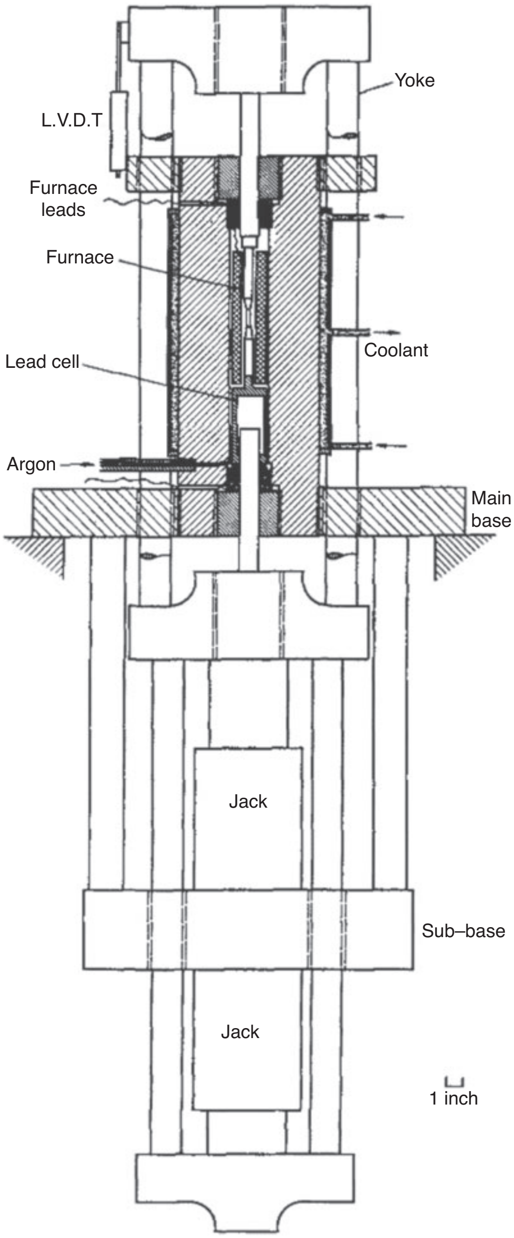

Fig. 5. General arrangement of apparatus for experimental deformation of rock specimens under conditions of high pressure and temperature (reproduced with permission from Paterson (1970)).

[18] Paterson (1970).
[19] Raleigh and Paterson (1965).
[20] Means and Paterson (1966).
[21] Coe and Paterson (1969).
[22] Etheridge and others (1973).
[23] Fischer and Paterson (1992), Zhang and others (1994).
[24] Hayward and others (2016).
[25] Hobbs and others (1972), Morrison-Smith and others (1976), Kekulawala and others (1978), Mainprice and Paterson (1984), Paterson and Luan (1990).
[26] Schmid and others (1977, 1980).
[27] van der Molen and Paterson (1979).
[28] Mackwell and others (1985), Chopra and Paterson (1981, 1984), Karato and others (1986).

Fig. 6. Mervyn Paterson in middle age (~1975, photo courtesy of the Paterson family).

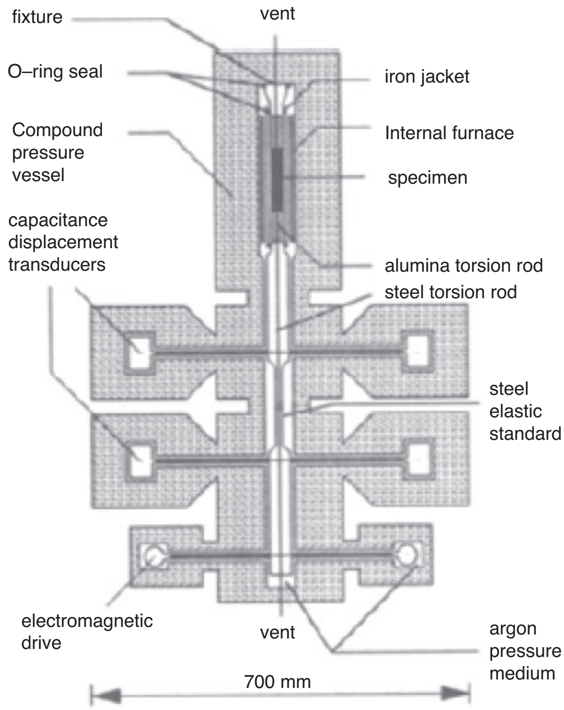

Fig. 7. Arrangement for studies of anelastic relaxation by torsional forced oscillation under conditions of high pressure and temperature (reproduced with permission from Jackson and Paterson (1993)).

and 1980s (Fig. 6) in collaboration with Ian Jackson on an attenuation apparatus for experimental studies of anelastic relaxation through torsional forced oscillation (Fig. 7). Another major project of the 1980s was Mervyn's design and construction of a further gas-medium deformation apparatus, the servo-creep (or 'green') machine that became the prototype for his commercial high-pressure-temperature testing machine.

Commercialisation of the 'HPT' machine

As early as 1978, Mervyn's experience of his students and collaborators successfully using the deformation machines in his ANU laboratory, suggested that it might be possible to develop a version of his high-pressure-temperature (HPT) mechanical testing machine for the commercial market. Accordingly, the 'green' machine was developed during the mid-late 1980s as a stand-alone apparatus housed within its own custom-designed barricade, thereby eliminating the need for a dedicated isolated bay. In a significant innovation, the pair of yoked pistons was replaced by a more compact arrangement in which a 'compensating' piston was connected in series with the loading piston. Suitable loading of the compensating piston by the confining pressure within an auxiliary chamber neutralises the load associated with the confining pressure acting on the loading piston. All previous experimentation had involved constant piston displacement rate provided by a hydraulically driven actuator. Incorporation in the new machine of an electro-mechanical actuator (initially supplied by Instron®) provided the opportunity to servo-control the advance of the piston to either a specified displacement rate or load. The latter possibility allowed, for the first time, the conduct of a creep test at essentially constant stress. This machine, assembled and commissioned during the period 1985–1990 with the assistance of technical officer Graeme Horwood and research assistant Jan Bitmead, has been extensively used since Mervyn's retirement from ANU in 1990, both for hot-isostatic pressing—particularly of synthetic dunite materials[29]—and for creep tests on fully synthetic dunites within both the diffusional and dislocation creep regimes.[30]

During the early 1980s, Mervyn had conducted a thorough search for a possible commercial partner leading ultimately to negotiation with ANU's ANUTECH Pty Ltd. The result was a partnership—Paterson Instruments Pty Ltd—registered in January 1989, in which Mervyn and his wife Katalin held 70% of the shares and ANUTECH 30%. Mervyn's apparatus had by then become the instrument of choice for precise measurements of rock deformation in research laboratories worldwide and thirteen such apparatuses were manufactured and sold during the next two decades. Mervyn's HPT testing machines were sold to laboratories in the UK, France, USA, Germany, Switzerland, and China—initially by Paterson Instruments and later by its successor company Australian Scientific Instruments Pty Ltd.

Following his retirement from ANU in 1990, Mervyn was heavily engaged in further design, construction, installation, and commissioning of the HPT machines around the world. There was substantial further innovation, most notably in the development of the capability for testing rock specimens to large strains in torsion as well as compression (Fig. 8).[31]

[29] For example, Jackson and others (2002).
[30] Faul and Jackson (2007), Faul and others (2011).
[31] Paterson and Olgaard (2000).

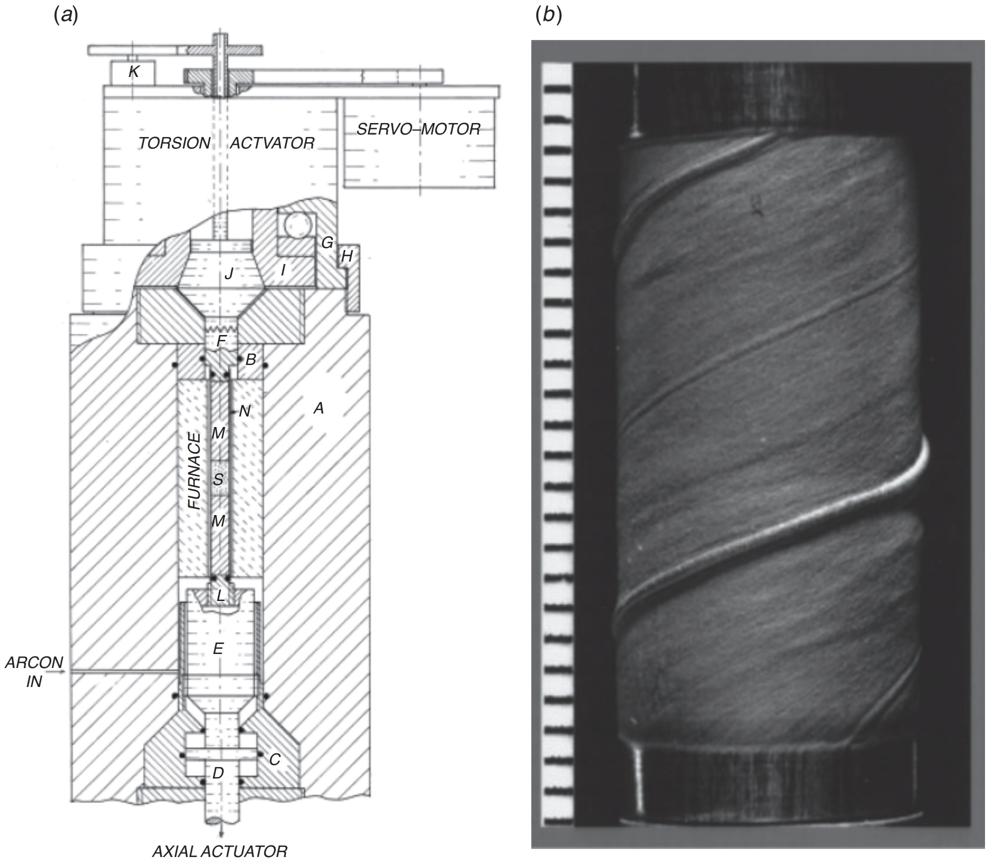

Fig. 8. (*a*) Schematic of module for deformation in torsion; (*b*) Photo of jacketed Carrara marble specimen following deformation to a maximum shear strain of 2.1 at the cylindrical surface of the specimen (reproduced with permission from Paterson and Olgaard (2000)).

Professional career—summary

During his long career at ANU, Mervyn Paterson exploited his flair for designing innovative high-pressure equipment constructed by skilled machinists in the well-equipped ANU engineering workshops, ably led in RSES during the 1970s and 1980s by Frank Burden and Bob Waterford. Mervyn thus became an international leader in the field of experimental rock deformation. Appointed Senior Research Fellow in 1953, he was promoted in 1956 to Reader in Crystal Physics, and ultimately elevated to a well-deserved Personal Chair in 1987. Through regular periods of sabbatical leave he forged strong international links with colleagues in rock deformation and structural geology in the USA, UK, France, and Germany. After retirement in 1990, he maintained a close association with the Research School of Earth Sciences at ANU until the time of his death in 2020. Over more than sixty years, he served as a valued mentor and role model for a succession of PhD students (Doug Kemsley, Keith Gross, Ken Lyall, Chris Weaver, Jim Edmond, Mike Etheridge, Derek Morrison-Smith, Gordon Lister, Kumar Kekulawala, Ide van der Molen, Prame Chopra, David Mainprice, Steve Mackwell, Richard Hitchings, George Fischer, Jurriaan Gerretsen, Fuchun Luan, and Shuqing Zhang) and early-career researchers (notably Lionel Weiss, Win Means, Barry Raleigh, Rob Coe, Chris Wilson, Rob Twiss, Stephan Schmid, Tim Bell, Jesse Shore, Steve Cox, Renée Heilbronner, Martyn Drury, and Shun Karato). The design and commissioning of his HPT machine fostered additional important international collaborations, notably with Ernie Rutter, David Kohlstedt and Mark Zimmermann, Georg Dresen and Michael Naumann, Brian Evans, David Olgaard, Luigi Burlini, and Alexandre Schubnel.

Mervyn's early work included studies of kinking and folding in foliated metamorphic rocks, the mechanical properties of serpentinite, and seminal investigations of the transition with increasing pressure from brittle to ductile deformation. A comprehensive overview of brittle-field rock deformation was presented in Mervyn's influential 1978 monograph,[32] updated in 2005 in collaboration with Teng-fong Wong.[33] Later in his career, in collaboration with colleagues and students, he worked intensively on the plastic deformation of diverse crustal and mantle materials, on the coupling between porosity and permeability in deforming rocks, and on laboratory studies of seismic-wave attenuation. Testimony to the versatility of Mervyn's high-pressure equipment is the further, ongoing evolution of Rig #1, the green machine, and the attenuation apparatus through subsequent decades to meet the needs of new generations of researchers.

[32] Paterson (1978).
[33] Paterson and Wong (2005).

A hallmark of Mervyn's work was his unwavering commitment to rigorous analysis and open-minded interpretation of deformation phenomena. Thus, he recognised the need for careful microstructural characterisation of deformed materials through light and electron microscopy. Accordingly, he was instrumental in recruiting to ANU the talented early-career electron microscopists Jim Boland and John Fitz Gerald. During the early 1980s, Mervyn collaborated with Bruce Hyde of ANU's Research School of Chemistry and Tony Eggleton of ANU's Department of Geology to establish a Mineralogy Research Centre, to which both Alex McLaren (from Monash University) and John Fitz Gerald were appointed. Its state-of-the-art transmission electron microscopes were employed in important collaborative studies of both geological and ceramic materials, including high-temperature superconductors. Similarly, infrared spectroscopy was employed as an important tool for quantification of water incorporated within nominally anhydrous geological materials often with significant impact upon their mechanical behaviour. Mervyn also sought a rigorous thermodynamic basis for the behaviour of geological materials under non-hydrostatic conditions,[34] and for the incorporation of water in quartz.[35] He collaborated with Gordon Lister and Bruce Hobbs in the simulation of fabric development in deforming rocks.[36] Other examples of the depth and influence of Mervyn's analysis include his widely used calibration of the influence of hydroxyl on infrared absorption,[37] and his theory of granular flow.[38] An authoritative review of the materials science background for structural geology was published in 2012.[39] A full list of Mervyn Paterson's publications is available in Supplementary Material.

Mervyn's strong commitment to the application of the findings of laboratory studies of rock deformation in structural geology and tectonics saw him play a pivotal role during the 1960s in establishing and subsequently regularly attending meetings of what became the Structural Geology and Tectonics Specialist Group (SGTSG) of the Geological Society of Australia. He attended his last SGTSG meeting at Waratah Bay in 2012. During his career, Mervyn collaborated closely with several distinguished structural geologists including Lionel Weiss, Win Means, Bruce Hobbs, Stefan Schmid, Gordon Lister, and Stephen Cox.

Mervyn's degrees included a BE from the University of Adelaide (1945), and a PhD (1949) from the University of Cambridge. Recognition of Mervyn's research achievements includes the award of a Doctor of Science (ScD) degree by the University of Cambridge (1968), election to Fellowship of the Australian Academy of Science (1972), the Mineralogical Society of America (1982), and the American Geophysical Union (AGU, 1986), Honorary Fellowship of the Geological Society of America (1987), and the award in 2004 of the AGU's lifetime-achievement Walter H. Bucher Medal in recognition of original contributions to the basic knowledge of crust and lithosphere.

Recognising the importance to students of the chance to travel overseas to attend major conferences and visit other universities, Mervyn established and funded the Mervyn and Katalin Paterson Fellowship which annually provides such opportunities for ANU PhD students. In this connection, in his later years, Mervyn greatly appreciated the support and friendship of RSES Development Officer Mary Anne King.

Fig. 9. Mervyn and Katalin Paterson following their marriage in January 1952 (photo courtesy of the Paterson family).

Private life

As previously mentioned, Mervyn met Katalin Schmidt/Sarosy in Chicago in 1950 and they were happily married in Adelaide in January 1952 (Fig. 9). The following exchange concerning Katalin's influence on Mervyn occurred during an interview conducted by Kurt Lambeck for the Australian Academy of Science:

> *Lambeck*: Not only did the Chicago year change your science, but I believe it was in that big and foreign city that you met your wife to be.
> *Paterson*: Yes, that's another opening-out of one's life. I was a Protestant colonial from remote parts of the Earth, she was a Hungarian Catholic with all the cultural background of Europe, including food.
> *Lambeck*: So this was the civilisation of Mervyn, was it?
> *Paterson*: Oh yes, I'm sure she'd like the idea that she had civilised me.[40]

Following their move from Melbourne to Canberra in June 1953, Mervyn and Katalin lived for many years in an ANU rental property

[34] Paterson (1973).
[35] Paterson (1986).
[36] Lister and others (1978), Lister and Paterson (1979).
[37] Paterson (1982).
[38] Paterson (1995).
[39] Paterson (2012).
[40] Lambeck (2006).

in Yarralumla, along with son Barrie (b. 1954) and daughter Elizabeth (b. 1956). Much later, they enjoyed a fruitful collaboration with renowned architect Enrico Taglietti to design and build a stylish multi-level house on the edge of the Aranda bushland. Following Katalin's death in 2011, Mervyn continued to live independently in their beloved Aranda house until late 2019, with increasing assistance from Elizabeth during his last couple of years.

Over the years, Mervyn became an inveterate traveller. During his time in Cambridge, he made bicycle trips around England, and a road trip through the war-ravaged Netherlands and Germany as far as Prague. Subsequently, he made sabbatical visits to Berkeley, California in 1960, Cambridge in 1965–6, London in 1970, and subsequently to Nantes and Paris, France, followed by a lecture tour of China in 1987. Such travel led to enduring professional relationships and friendships notably with Hugh Heard, Bob Schock, Jean-Claude and Nicole Doukhan, Adolphe Nicolas, and Jean-Paul Poirier. Mervyn travelled the world to participate in conferences, very often enjoying the associated geological field trips. He last travelled overseas (to Laos and Cambodia) with family in 2014, but continued to travel widely within Australia, including to Hobart, Adelaide, Melbourne, Darwin, and Broome.

Mervyn's abiding interest in the natural world dated from childhood experience on the farm. Much later it became his daily habit to walk through the Black Mountain bush to ANU—through which activity he successfully addressed a diagnosed heart condition. Following his arrival each day at ANU, sometimes in the company of fellow Aranda resident and RSES colleague Ted Lilley, he would report, for example, on gang-gang cockatoos nesting in a tree hollow or on ground orchids springing up after recent rain. Similarly, his visits to son Barrie's remote property near Araluen, NSW provided a welcome opportunity to enjoy the Australian bush and its wildlife.

In 1953, Mervyn became a foundation member of the Canberra Wine and Food Club to which he remained committed throughout the subsequent decades. His regular participation in the club's activities including dinners and wine tastings provided welcome companionship that was particularly valuable during the difficult years following Katalin's death. Overcoming his teetotal upbringing, Mervyn became thoroughly knowledgeable about Australian and international wines, with particular loyalty to his favourite Barossa shiraz. Memories of informal discussion evenings involving deformation processes with colleagues and PhD students, which Mervyn organized with wine and cheese at ANU will never be forgotten. Mervyn also took an active interest in the arts, regularly attending performances in Canberra and at the Adelaide and Darwin Festivals.

By 2020, the metamorphosis was complete: with a powerful intellect and a wonderful open-ness to new ideas, this boy from the bush had evolved into a cultured and fully engaged citizen of the world (Fig. 10). After a long and fulfilling life, Mervyn passed away peacefully on 4 June 2020 at St Andrews Village, Hughes. Mervyn and Katalin Paterson are survived by Barrie and his wife Helen, and their sons Felix and Edward, and by Elizabeth and her partner Keith Talbot, along with the legion of former students and colleagues whose lives he touched.

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Fig. 10. Mervyn Paterson in retirement (March 2019, photo by Beck Rocchi courtesy of the Paterson family).

Conflicts of interest

The author declares no conflicts of interest.

Data availability statement

Data sharing is not applicable as no new data were generated or analysed during this study.

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References

Barrett, C. S. (1943) *Structure of Metals, Crystallographic Methods, Principles, and Data*, New York.

Chopra, P. N., and Paterson, M. S. (1981) The experimental deformation of dunite, *Tectonophysics*, **78**(1–4), 453–473. doi:10.1016/0040-1951(81)90024-X

Chopra, P. N., and Paterson, M. S. (1984) The role of water in the deformation of dunite, *Journal of Geophysical Research*, **89**, 7861–7876. doi:10.1029/JB089IB09P07861

Coe, R. S., and Paterson, M. S. (1969) The alpha-beta inversion in quartz: a coherent phase transition under non-hydrostatic stress, *Journal of Geophysical Research*, **74**, 4921–4948. doi:10.1029/JB074I020P04921

Cowley, J. M., and Paterson, M. S. (1947) X-Ray diffraction studies of yielding in mild steel, *Nature*, **159**, 846. doi:10.1038/159846A0

Edmond, J. M., and Paterson, M. S. (1972) Volume changes during the deformation of rocks at high pressures, *International Journal of Rock Mechanics and Mining Sciences*, **9**(2), 161–182. doi:10.1016/0148-9062(72)90019-8

Etheridge, M. A., Hobbs, B. E., and Paterson, M. S. (1973) Experimental deformation of single crystals of biotite, *Contributions to Mineralogy and Petrology*, **38**, 21–36. doi:10.1007/BF00371724

Faul, U. H., and Jackson, I. (2007) Diffusion creep of dry, melt-free olivine, *Journal of Geophysical Research*, **112**, B04204. doi:10.1029/2006JB004586

Faul, U. H., Fitz Gerald, J. D., Farla, R. J. M., Ahlefelft, R., and Jackson, I. (2011) Dislocation creep of fine-grained olivine, *Journal of Geophysical Research*, **116**, B01203. doi:10.1029/2009JB007174

Fischer, G. J., and Paterson, M. S. (1992) 'Measurement of permeability and storage capacity in rocks during deformation at high temperature and pressure', in *Fault mechanics and transport of rocks*, eds B. Evans and T. Wong, London, pp. 213–252.

Griggs, D. T. (1936) Deformation of rocks under high confining pressures: I Experiments at room temperature, *The Journal of Geology*, **44**(5). doi:10.1086/624455

Hayward, K. S., Cox, S. F., Fitz Gerald, J. D., Slagmolen, B., Shaddock, D., Forsyth, P., Salmon, M., and Hawkins, R. P. (2016) Mechanical amorphisation, flash heating and frictional melting: dramatic changes to fault surfaces during the first millisecond of earthquake slip, *Geology*, **44**(12), 1043–1046. doi:10.1130/G38242.1

Hobbs, B. E., McLaren, A. C., and Paterson, M. S. (1972) 'Plasticity of single crystals of synthetic quartz', in *Flow and Fracture of Rocks* (*AGU Geophysical Monograph Series, vol. 16*), pp. 29–53.

Jackson, I., and Paterson, M. S. (1993) A high-pressure, high temperature apparatus for studies of seismic wave dispersion and attenuation, *Pure and Applied Geophysics*, **141**, 445–466. doi:10.1007/BF00998339

Jackson, I., Fitz Gerald, J. D., Faul, U. H., and Tan, B. H. (2002) Grainsize-sensitive seismic wave attenuation in polycrystalline olivine, *Journal of Geophysical Research*, **107**(B12), 2360–2375 (ECV 5–1–ECV 5–16). doi:10.1029/2001JB001225

Karato, S., Paterson, M. S., and Fitz Gerald, J. D. (1986) Rheology of synthetic olivine aggregates: influence of grain size and water, *Journal of Geophysical Research*, **91**, 8151–8176. doi:10.1029/JB091IB08P08151

Kekulawala, K. R. S. S., Paterson, M. S., and Boland, J. N. (1978) Hydrolytic weakening in quartz, *Tectonophysics*, **46**(1–2), T1–T6. doi:10.1016/0040-1951(78)90101-4

Lambeck, K. (2006) 'Professor Mervyn Paterson, geophysicist', *Interviews with Australian Scientists*, https://www.science.org.au/learning/general-audience/history/interviews-australian-scientists/professor-mervyn-paterson, viewed June 2021.

Lister, G. S., and Paterson, M. S. (1979) The simulation of fabric development during plastic deformation and its application to quartzite: fabric transitions, *Journal of Structural Geology*, **1**(2), 99–115. doi:10.1016/0191-8141(79)90047-6

Lister, G. S., Paterson, M. S., and Hobbs, B. E. (1978) The simulation of fabric development in plastic deformation and its application to quartzite: the model, *Tectonophysics*, **45**(2–3), 107–158. doi:10.1016/0040-1951(78)90004-5

Mackwell, S. J., Kohlstedt, D. L., and Paterson, M. S. (1985) The role of water in the deformation of olivine single crystals, *Journal of Geophysical Research*, **90**, 11319–11333. doi:10.1029/JB090IB13P11319

Mainprice, D. H., and Paterson, M. S. (1984) Experimental studies of the role of water in the plasticity of quartzites, *Journal of Geophysical Research*, **89**, 4257–4269. doi:10.1029/JB089IB06P04257

Means, W. D., and Paterson, M. S. (1966) Experiments on preferred orientation of platy minerals, *Contributions to Mineralogy and Petrology*, **13**, 108–133. doi:10.1007/BF00518022

Morrison-Smith, D. J., Paterson, M. S., and Hobbs, B. E. (1976) An electron microscope study of plastic deformation in single crystals of synthetic quartz, *Tectonophysics*, **33**(1–2), 43–79. doi:10.1016/0040-1951(76)90051-2

Nabarro, F. R. N., and Argon, A. S. (1995) Egon Orowan, 2 August 1902 – 3 August 1989, *Biographical Memoirs of Fellows of the Royal Society*, **41**, 316–340. doi:10.1098/RSBM.1995.0020

Paterson, M. S. (1952) X-Ray diffraction by face-centered cubic crystals with deformation faults, *Journal of Applied Physics*, **23**, 805–811. doi:10.1063/1.1702312

Paterson, M. S. (1954) X-ray line broadening from metals deformed at low temperatures, *Acta Metallurgica*, **2**(6), 823–830. doi:10.1016/0001-6160(54)90035-8

Paterson, M. S. (1958) Experimental deformation and faulting in Wombeyan marble, *Geological Society of America Bulletin*, **69**(4), 465–476. doi:10.1130/0016-7606(1958)69[465:EDAFIW]2.0.CO;2

Paterson, M. S. (1964) Effect of pressure on Young's modulus and the glass transition in rubbers, *Journal of Applied Physics*, **35**, 176. doi:10.1063/1.1713063

Paterson, M. S. (1970) A high-pressure, high-temperature apparatus for rock deformation, *International Journal of Rock Mechanics and Mining Sciences*, **7**(5), 517–526. doi:10.1016/0148-9062(70)90004-5

Paterson, M. S. (1973) Non-hydrostatic thermodynamics and its geological application, *Reviews of Geophysics and Space Physics*, **11**, 355–389. doi:10.1029/RG011I002P00355

Paterson, M. S. (1978) *Experimental Rock Deformation: the Brittle Field*, Heidelberg.

Paterson, M. S. (1982) The determination of hydroxyl by infrared absorption in quartz, silicate glasses and similar materials, *Bulletin de Minéralogie*, **105**, 20–29. doi:10.3406/BULMI.1982.7582

Paterson, M. S. (1986) The thermodynamics of water in quartz, *Physics and Chemistry of Minerals*, **13**, 245–255. doi:10.1007/BF00308276

Paterson, M. S. (1995) A theory for granular flow accommodated by material transfer via an intergranular fluid, *Tectonophysics*, **245**, 135–151. doi:10.1016/0040-1951(94)00231-W

Paterson, M. S. (2008) 'MSP scientific history', unpublished document held by the Paterson family.

Paterson, M. S. (2010) 'Mervyn Paterson Family History', unpublished document held by the Paterson family.

Paterson, M. S. (2012) *Materials Science for Structural Geology*, Dordrecht, Heidelberg, New York, London.

Paterson, M. S., and Luan, F. C. (1990) 'Quartzite rheology under geological conditions', in *Deformation Mechanisms, Rheology and Tectonics* (Geological Society of London Special Publication 54), eds R. J. Knipe and E. H. Rutter, London, pp. 299–307.

Paterson, M. S., and Olgaard, D. L. (2000) Rock deformation tests to large shear strains in torsion, *Journal of Structural Geology*, **22**(9), 1341–1358. doi:10.1016/S0191-8141(00)00042-0

Paterson, M. S., and Weiss, L. E. (1966) Experimental deformation and folding in phyllite, *Geological Society of America Bulletin*, **77**(4), 343–374. doi:10.1130/0016-7606(1966)77[343:EDAFIP]2.0.CO;2

Paterson, M. S., and Wong, T. (2005) *Experimental Rock Deformation: the Brittle Field*, edn 2, Berlin, Heidelberg.

Raleigh, C. B., and Paterson, M. S. (1965) Experimental deformation of serpentinite and its tectonic implications, *Journal of Geophysical Research*, **70**, 3965–3985. doi:10.1029/JZ070I016P03965

Schmid, S. M., Boland, J. N., and Paterson, M. S. (1977) Superplastic flow in finegrained limestone, *Tectonophysics*, **43**(3–4), 257–291. doi:10.1016/0040-1951(77)90120-2

Schmid, S. M., Paterson, M. S., and Boland, J. N. (1980) High-temperature flow and dynamic recrystallization in Carrara marble, *Tectonophysics*, **65**(3–4), 245–280. doi:10.1016/0040-1951(80)90077-3

van der Molen, I., and Paterson, M. S. (1979) Experimental deformation of partially-melted granite, *Contributions to Mineralogy and Petrology*, **70**, 299–318. doi:10.1007/BF00375359

Zhang, S., Cox, S. F., and Paterson, M. S. (1994) The influence of room temperature deformation on porosity and permeability in calcite aggregates, *Journal of Geophysical Research*, **99**, 15761. doi:10.1029/94JB00647