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Historical Records of Australian Science

David Headley Green 1936–2024

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ABSTRACT

David Headley Green AM, FAA, FRS was an outstanding Australian geologist and world leader in experimental petrology and geochemistry. His research, initially at the Australian National University with A. E. Ringwood, and later at the University of Tasmania, shaped our understanding of the composition of the Earth's mantle and the origin of the wide spectrum of volcanic rocks erupted in different global tectonic settings. David also had a significant impact on Antarctic science through studies of high-grade metamorphic rocks, but more broadly in fostering marine and climate science by championing the establishment at the University of Tasmania of a multidisciplinary research centre (now the Institute for Marine and Antarctic Studies). His achievements and scientific leadership were recognised with many international and national awards, including membership of the Order of Australia. A considerate and compassionate man, David is also remembered for his interest in and care for others.

Keywords: Antarctica, basalt, experimental petrology, geochemistry, granulite, high temperature metamorphism, magma, mantle, peridotite, thermobarometry, volatiles (CO_2-H_2O).

Introduction and overview

David Headley Green AM, FAA, FRS (Fig. 1) was an outstanding Australian geologist and internationally renowned leader of research and education in the field of experimental petrology and geochemistry. His research, initially at the Australian National University (ANU) in partnership with A. E. (Ted) Ringwood, represents a major contribution to experimental petrology that advanced scientific knowledge concerning the nature of the Earth and Moon interiors, and the origin of magmas. He went on to establish a world-class experimental laboratory and research group with students and researchers from around the world at the University of Tasmania. He and his group produced a stream of outstanding results, which have had a profound impact on our understanding of the origin of the wide spectrum of volcanic rocks erupted in different global tectonic settings.

As well as initiating geological studies of high-grade metamorphic rocks in Antarctica, David recognised the importance of Antarctica as a laboratory for marine and climate science, and championed the establishment of a centre for multidisciplinary Antarctic research at the University of Tasmania (the Institute for Antarctic and Southern Ocean Studies, IASOS), the precursor to the Institute for Marine and Antarctic Studies (IMAS). He also had significant input to government scientific policy formulation through his roles on science advisory committees and councils, and directly as a scientific advisor to government.

This biographical memoir draws on a tribute published in the *Journal of Petrology*[1] and obituaries by former students and research associates.[2] It also incorporates David's personal perspectives on science and the important role science can play not only in shaping personal careers, friendships and relationships, but also in global collaboration and the building of bridges between nations.

[1]Yaxley and Brey (2008).
[2]Ellis and Yaxley (2024). Crawford (2024). Harley (2024).

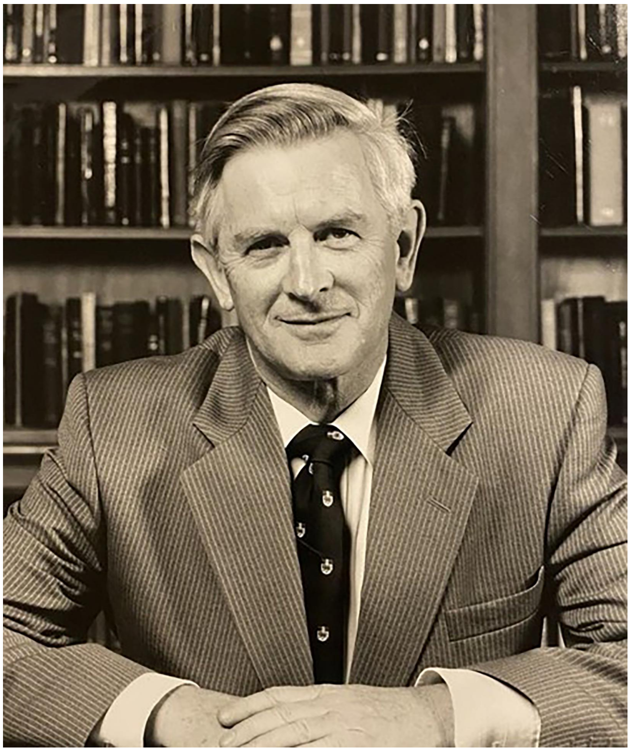

Fig. 1. Portrait of David Green at the Royal Society by A. C. Cooper, 1991. Reproduced with permission from the Royal Society.

Early years in Tasmania

David Headley Green was born on 29 February 1936 in Launceston, Tasmania, to Ronald Horace and Josephine May (née Headley) Green. David's paternal grandfather had been a steamship engineer and his maternal grandfather a ship's carpenter. His father finished school at age fourteen and worked in insurance, real estate, and banking throughout his life. His mother worked as a secretary until her marriage. As a bank clerk, David's father was subject to periodic relocation among small towns in northern Tasmania. David was the middle child of five siblings, with an older brother, Maurice, and sister, Judith, and a younger sister, Del, and brother, Trevor. David started school at Trevallyn, Launceston, before the family moved to the town of Penguin on the north coast of Tasmania, where he completed primary school, and then commenced high school at Burnie. Penguin always figured strongly and warmly in David's memory. The family lived on the main road directly across from the beach and a rock platform, and it was here and nearby that he developed an early interest in rocks that continued for the rest of his life.

The family moved to Hobart in 1949, and David completed his schooling at Hobart High School, where he developed some lifelong friendships and established academic recognition and sporting credentials in tennis and Australian Rules football. It was here that his innate curiosity and bent towards science was encouraged and his interest in geology kindled. David's future perspectives and scientific pursuits were shaped by his heritage as a boy from a remote corner of the world. This led to his conviction that one's origins need not be a limitation to making a contribution on the world stage, in his case in the field of geology. On the home front David was part of a stable, loving family, and was given every possible support and encouragement for his advancement despite his parents' limited finances. His parents guided and encouraged David and his siblings towards a living Christian faith, and this became a foundational part of David's life.

Education—the making of a geoscientist

David gained an Atomic Energy Commission Scholarship to enable him to undertake tertiary studies, enrolling in 1953 in a BSc course in geology at the University of Tasmania under Professor S. W. (Sam) Carey, an early advocate of continental drift. An excellent teacher and field geologist, Carey challenged his students to not only observe the natural world, but also to critically evaluate interpretations, including his own concepts of rheology, and tectonic models, such as his global synthesis of the assembly and breakup of Gondwana and the earlier other supercontinents, Laurasia and Pangea, based on his detailed fitting together of the continental blocks. David's interest and intellect frequently saw him take up this invitation to question and challenge his lecturers. This inherent curiosity and questioning were defining characteristics of David and underlaid his approach to science.

The 'Continental Drift Symposium', held in Hobart in 1956,[3] showcased Carey's detailed reconstructions of the Gondwana and Laurasia supercontinents. It also featured E. Irving's palaeomagnetic study of the Jurassic dolerites of Tasmania that tested and confirmed the Jurassic re-assembly of Gondwana by showing their near-polar palaeo-latitude at that time,[4] and thus established palaeomagnetism as an important tool for demonstrating continental drift. David recognised the importance of peridotite in the interface between the crust and upper mantle, which prompted him to undertake field mapping and petrological studies of ultramafic and related rocks in the Beaconsfield area in northern Tasmania for his BSc Honours project. As part of his Honours project, he undertook an assessment, based on a survey of the published literature, of the status of palaeomagnetism, then a relatively new and promising field of geophysics. These formative experiences shaped David's career-long commitment to geology and its integration with geophysics, and particularly to his enduring interest in ultramafic and mafic rocks and their place in global tectonics. They also

[3]Carey (1956).
[4]Irving (1958).

Fig. 2. David Green on graduating from the University of Tasmania with BSc (Honours) in 1957. Reproduced with permission of the University of Tasmania, photograph courtesy of the Green family.

engendered a scepticism of authoritarian fundamentalism and his iconoclastic attitude towards scientific dogma that later extended to his own iconoclasm towards his PhD students, and a passion for experimental approaches to test established or novel models.

Following his graduation with BSc (Honours) in 1957 (Fig. 2), he joined the Australian Bureau of Mineral Resources (now Geoscience Australia) and spent two years engaged in field mapping and petrological study, firstly of ultramafic complexes and associated nickel mineralisation at Greenvale in north Queensland, and then in the Musa Valley of southeast Papua New Guinea (PNG). In PNG he mapped and studied mafic and ultramafic rocks of the Papuan Ultramafic Belt, a large mass of ocean floor and underlying mantle thrust over continental rocks of the Papuan Peninsula.

David was awarded an MSc from the University of Tasmania in 1960 for his work on the Papuan Ultramafic Belt. He then won an award of the Royal Commission for the Exhibition of 1851 for PhD studies at the University of Cambridge (UK) in 1959–62, under the supervision of Professor C. E. Tilley. His PhD involved geological mapping and petrological studies of the Lizard peridotite and associated rocks exposed on the southwest coast of Cornwall. While in the field, he became unwell and the doctors at the local hospital were initially baffled by his illness, but then were delighted when it became apparent that he had malaria—a disease that, not surprisingly, none of the doctors had encountered before—as a result of his earlier time in PNG. David's careful and detailed petrological studies were published in two influential papers that presented evidence for the preservation of solid-state, high-pressure, high-temperature lherzolite assemblages that underwent decompression during diapiric emplacement that imposed high-temperature, granulite-facies metamorphism during a period of amphibolite facies regional metamorphism.[5] The Lizard is still of scientific interest today, and David's model has been adapted in light of more recent research.[6]

Australian National University 1962–76: the Green and Ringwood partnership

On completion of his PhD studies, David was recruited in 1962 by Professor J. C. Jaeger, head of the newly formed Department of Geophysics and Geochemistry at the ANU, to work with A. E. (Ted) Ringwood. The specific intention was to employ the recently developed internally heated Boyd-England piston-cylinder apparatus, which could reproduce the pressure and temperature conditions found at depths of up to approximately 150 km inside the Earth to investigate the composition and processes in the Earth's upper mantle (Fig. 3). Thus began a fruitful fourteen-year (1962–76) collaboration at ANU which was to become one of the most creative and influential research collaborations in the earth sciences at the time.[7] Two papers in *Nature* in 1964 gave notice of three pioneering landmark papers[8] that demonstrated a new direction and methodology in experimental petrology, combining the solid media piston-cylinder apparatus to reproduce the high pressure and temperature conditions of the deep crust and uppermost mantle with the newly developed electron probe microanalyser (EPMA) to methodically study mineral reactions, including partial melting, in complex natural rock compositions.[9] Their experiments showed the importance of solid solutions in minerals in natural bulk compositions

[5] Green (1964*a*, 1964*b*).
[6] Mackay-Champion and others (2024).
[7] Yaxley and Brey (2008).
[8] Ringwood and Green (1966). Green and Ringwood (1967*a*, 1967*b*).
[9] Yaxley and Brey (2008).

Fig. 3. David Green in the high pressure laboratory at ANU with pressure vessel, circa late 1960s. Reproduced with the permission of the Australian National University, photograph courtesy of the Green family.

in determining the stability field of minerals in pressure-temperature space compared to their ranges inferred from experiments on simple system analogues.

Their initial studies focused on quantifying the 'pyrolite' (*pyr*oxene and *ol*ivine rock) model developed by Ringwood that proposed that the Earth's upper mantle was composed of peridotite. They showed in their high-pressure melting experiments that 'pyrolite' is equivalent to fertile upper mantle peridotite with the capacity to yield basaltic magma by partial melting, and defined the four major mineral associations (facies) expected at various depths for pyrolite.[10] Their landmark paper on the genesis of basaltic magmas[11] remains a major reference in mantle petrology. It demonstrated the effect of pressure on the liquidus phase relations of primitive basalts, and that a continuum of basaltic compositions could form by variations in the depth and extent of partial melting of mantle pyrolite, ranging from alkaline magmas formed at depth by low degrees of melting to the more common basalts, such as those formed at mid-ocean ridges at higher temperatures and shallower depths. Another early experimental study explored the origin of high-alumina basalts found in a range of tectonic settings and their relationships with alkali basalts and more common basaltic magmas.[12] Parallel experiments explored the high-pressure mineralogy of basaltic compositions, and the role of water in melting of the mantle.

In another landmark paper[13] they compared their experimental results directly with observations on natural high pressure metamorphic rocks, and showed that the low-pressure mineral assemblage of basalt (plagioclase and pyroxene) converted through phase changes to garnet-bearing granulite, and thence eclogite (garnet and pyroxene), with increasing pressure, and that the associated density changes in this transformation played an important geodynamic role in initiating, and driving, plate tectonics.

This series of studies based on complex natural rock compositions, where the compositions of the different mineral phases and partial melts were determined by EPMA, coupled with (and building on) the early experimental studies of chemically simplified analogue systems and natural compositions by other researchers,[14] notably from the Geophysical Laboratory of the Carnegie Institution of Washington, laid the foundations for modern experimental petrology. These findings are fundamental to our understanding of the petrology of the Earth's upper mantle, as well as the deep continental crust and subducted oceanic crust.

The gabbro to eclogite studies led to experimental studies of high-pressure and high-temperature mafic granulites, by then recognised as typifying high grade metamorphic belts worldwide. David's recognition that mafic rocks could only provide a partial view of high-grade metamorphism stimulated a series of complementary experimental studies of granulites formed from the metamorphism of shale-like sedimentary rock compositions, pelites, deep in the Earth's crust.[15] These innovative experiments not only established the stability fields and mineral compositional relations of the high-grade mineral assemblages involving garnet and cordierite, but also paved the way for the future recognition of ultrahigh temperature metamorphism, recorded in mineral assemblages such as sapphirine and quartz, which formed beyond the stability of garnet with cordierite[16]

The seminal experiments of Hensen and Green on granulite pelites were later built on and extended by David at the

[10]Green and Ringwood (1963).
[11]Green and Ringwood (1967*a*).
[12]Green and others (1967).
[13]Green and Ringwood (1967*b*).
[14]Yoder and Tilley (1962). O'Hara (1963). Wyllie (1965).
[15]Hensen and Green (1971). Hensen and Green (1973).
[16]Harley (1998).

University of Tasmania through experimental studies of garnet-cordierite assemblages in H_2O and CO_2-bearing systems.[17] These experiments provided a robust pressure-temperature-mineral assemblage framework for understanding high-grade metamorphic rocks, which was then quantified by David and his students through experimental calibration of the pressure-temperature dependencies of sensitive equilibria between co-existing mineral pairs such as garnet and cordierite, clinopyroxene and orthopyroxene, garnet and clinopyroxene, and garnet and orthopyroxene.[18] Their quantification enabled their use as geothermobarometers applicable to granulites, eclogites and peridotites. A succession of David's students at ANU, and then at the University of Tasmania in Hobart, progressively refined these thermometers to improve their accuracy and enable their application to increasingly wider ranges of pressure-temperature conditions and rock compositions.

Recognition by America's National Aeronautics and Space Administration (NASA) of the expertise and quality of the research team at ANU led to an invitation to work on the origins of lunar mare basalts returned from the Apollo 12, 15 and 17 lunar missions. David, Ringwood and their co-workers combined petrological study of the natural lunar glasses and their phenocryst compositions to identify parental magmas in different suites with high pressure experiments to determine eruption temperatures, and to constrain the pressures (depths) and temperatures of their origin. Their studies undertaken in the period 1972–5 showed that olivine-rich basalts of the lunar mare had erupted on the Moon's surface at high temperatures ($\geq$1250°C), and were derived by partial melting of pyroxene-rich source rocks deep in the lunar interior.[19]

University of Tasmania 1976–94

Following the retirement of Carey, David returned to the University of Tasmania in late 1976 as Professor and Head of the Geology Department. With the assistance of long-term technical assistant Bill Hibberson, he established a new experimental petrology laboratory from which to explore the origins of, and the relationships between, the diverse range of magma types erupted on the Earth's surface and their relationship to global geodynamics. With his increased administrative commitments as head of department, postgraduate students and post-doctoral and visiting scientists from other academic institutions played an increasing role in David's research, with students and visitors coming from many parts of the world to undertake studies under his supervision (Fig. 4). Over the following eighteen years, under David's keen guidance, and with technical support initially from Bill and later with Keith Harris, this laboratory generated an exceptional research output that has had a major influence on igneous and metamorphic petrology globally.

Fig. 4. David Green with a group of his students at a conference on experimental petrology held at Monash University in January 1984. Photograph taken by Cliff Ford for Simon Harley, photo provided by Simon Harley.

David drew on his experience and knowledge of field geology and petrology to successfully combine the fields of natural and experimental petrology. He was particularly adept at identifying significant petrological phenomena or hypotheses and devising experimental strategies to investigate them.[20] Building on the earlier experiments with Ted Ringwood these studies included more detailed definition using both model pyrolite and natural mantle lherzolite compositions of the stability fields, and melting relationships of plagioclase lherzolite, spinel lherzolite, garnet lherzolite and pargasite lherzolite as functions of pressure (*P*), temperature (*T*), and with different volatile contents including water, carbon dioxide, and methane. These studies showed that magmas produced by melting of mantle in the plagioclase and spinel peridotite fields were subalkaline and of tholeiitic composition, whereas those produced at higher pressure in the garnet lherzolite field were of alkaline composition at low degrees of melting, but became less alkaline and increasingly olivine-rich at higher degrees of melting.[21]

A series of high-pressure experimental studies by David and his students (the Hobart group) showed that the presence of H_2O and CO_2 had a significant impact on the mineralogy of the mantle with amphibole (pargasite) stabilised under hydrous conditions at low pressure (up to 3 GPa) above which water is present as an aqueous vapour phase

[17] Bertrand and others (1991).
[18] Ellis and Green (1979). Harley and Green (1982). Nickel and Green (1985).
[19] Green and others (1971).
[20] Yaxley and Brey (2008).
[21] Green (1973, 1976), Falloon and others (1988). Green and Falloon (1998).

which depresses the temperature of the upper mantle solidus. These features define the distinctive *P*, *T* shape of the vapour-undersaturated or dehydration solidus of mantle peridotite, and provide the basis for understanding the nature of the lithosphere–asthenosphere boundary (LAB) in the ocean basins and in other regions of thin lithosphere.[22]

Moreover, the experiments showed a strong depression of mantle melting temperatures that results in a broad incipient melting regime capable of producing a wide spectrum of magma compositions.[23] Carbon dioxide was shown to have a similar effect on the mantle solidus to H_2O, depressing the solidus of carbonated peridotite by several hundred degrees (at mantle depths greater than 50 km) and, at higher pressures, the carbonated mantle solidus curve is depressed to much lower temperature than the water-undersaturated due to the stabilisation of solid carbonate minerals in place of CO_2 vapour. The effect of CO_2 on mantle melting has a marked effect on melt compositions which become increasingly silica undersaturated. This confirmed earlier experiments that identified the importance of CO_2 as a key component in mantle melting, essential in producing a range of highly silica-undersaturated liquids, such as olivine melilitites.[24] Another important outcome of the Hobart group experiments on melting of peridotite in the presence of H_2O and CO_2 was the identification of a field where sodic, dolomitic carbonatite melt co-existed with pargasite lherzolite.[25] This showed that the upper boundary of the carbonatite field is defined by a decarbonation reaction which progressively converts lherzolite wall-rock to wehrlite (olivine-clinopyroxene peridotite) by eliminating orthopyroxene and releasing CO_2 vapour. These studies confirmed the important roles played by H_2O and CO_2 in melting of mantle peridotite to yield a spectrum of compositions, and provided experimental evidence for the widely observed process of metasomatism of the lithospheric mantle, whereby the original mantle minerals may be progressively replaced by secondary phases of a different composition or mineralogy by invading H_2O-CO_2-rich melts.[26] The resultant metasomatism is commonly accompanied by significant changes in the trace element composition of the invaded lithospheric mantle, as David and co-workers had shown earlier in an integrated experimental and detailed geochemical study of mantle xenoliths and their basalt hosts.[27]

Experiments by David and students and co-researchers in Hobart and the ANU also demonstrated the effects of differing oxygen states on melting of the Earth's mantle. Under reducing conditions in the presence of H_2O and CH_4, the mantle assemblage does not contain CO_2, and the carbon species is either graphite or, at higher pressure, diamond. Melting under oxidised conditions depresses the relevant melting curve compared to the reduced solidus. The term 'redox melting' was initially coined to describe partial melting induced by the oxidation of reduced H_2O and CH_4 fluids.[28] This concept was later expanded to encompass any process by which melt is generated by the contact of a rock with a fluid or melt with a contrasting oxidation state.[29] The interaction of oxidised, hydrous carbonate-rich melts with reduced, depleted mantle peridotite, termed 'redox freezing', is now thought to be an important and widespread process occurring at the base of cratonic lithosphere.[30]

In addition, David and his students used the high-pressure experimental melting studies on peridotite to further refine the mineral exchange equilibria involving orthopyroxene-clinopyroxene, garnet-clinopyroxene, and garnet-orthopyroxene, and thereby extend their utility as geothermometers and, in the case of garnet-orthopyroxene, develop its use as a geobarometer involving Al–Cr exchange.[31] A separate study showed that the ferric content of spinel in the mantle assemblage olivine-orthopyroxene-spinel was dependent on the prevailing fugacity of oxygen, and developed an oxygen barometer with application to a wide range of mantle rocks and mantle-derived magmas.[32] These thermobarometers have proven to be powerful tools in determining the depths (pressure) and temperature of equilibration in the mantle xenoliths carried in kimberlites and alkali basalts, minute mineral inclusions in diamonds, and ocean floor peridotites thrust onto old continental margins. The P-T arrays of mantle xenoliths carried in kimberlite and alkali basalts record the mantle thermal conditions (geotherms) and the state and structure of the lithospheric mantle at the time of volcanic eruption. The application of the oxygen barometer to these samples enables direct measurement of the oxidation state of the lithospheric mantle.

David and his students conducted a series of parallel high-pressure liquidus studies of primitive basalts inferred to have been erupted directly from the mantle, based on the presence of mantle xenoliths and other petrological features, examining the effects of H_2O, CO_2, H_2O and CO_2, and C + H + O fluid under controlled (reduced) oxygen

[22] Green and others (2010). Niu and Green (2018).
[23] Green (1973, 2015). Wallace and Green (1988).
[24] Brey and Green (1975, 1976). Ryabchikov and Green (1978).
[25] Wallace and Green (1988).
[26] Green and Wallace (1988). Yaxley and others (1991). O'Reilly and Griffin (2013). Pintér and others (2021).
[27] Frey and others (1978).
[28] Taylor and Green (1988).
[29] Foley (2011).
[30] Pintér and others (2021).
[31] Nickel and Green (1985).
[32] Ballhaus and others (1990, 1991).

fugacities. These studies included both the tholeiitic basalts erupted at mid-ocean ridges (mid-ocean ridge basalts or MORB) that form the oceanic crust and the much less voluminous more alkaline intraplate magmas found on the continents. These studies showed that, in contrast to MORB which have very low water contents, small quantities of both H_2O and CO_2 in the mantle source regions of alkaline rocks play a very significant role in their genesis.[33] Further experiments showed the importance of the combined effects of H_2O, CO_2, CH_4 and HF on partial melting of a model phlogopite harzburgite mantle to the production of ultrapotassic magmas.[34] Similarly, volcanic rocks in island arcs formed mostly by melting of mantle at relatively shallow depths under water-rich conditions with the water contributed from dehydration reactions as the underlying oceanic lithosphere is subducted at the plate margin.[35]

While head of department at the University of Tasmania, David appointed Ross Large to the Earth Sciences staff in 1983, and supported the establishment of CODES (Centre for Ore Deposits and Earth Sciences) in the department, initially as a National Key Centre in 1989, then a National Special Research Centre, and eventually, as a National Centre of Excellence (2005–13) under the Australian Research Council's Centres of Excellence Program. The Centre grew substantially over the years with the support of the minerals industry to become a global leader in ore deposit research, particularly in relation to the formation of base and precious metal deposits.

Antarctic studies

Antarctica held a particular fascination for David. Despite never having visited there himself, David was committed to stimulating and supporting excellent scientific research in Antarctica. Of particular interest to him initially were the high-grade metamorphic crustal rocks found in several of the mountain belts of Enderby Land, some of which contain unusual minerals such as osumilite and sapphirine which are formed only under unusually high temperature conditions, now recognised as ultrahigh temperature metamorphism.[36] Initially through contacts and existing links with the Bureau of Mineral Resources, he was successful in attracting a large cohort of postgraduate students, research fellows, and collaborating scientists from other institutions, and developed an outstanding research program focused on Antarctic geology at the University of Tasmania. Between 1977 and 1992 he funded, was responsible for, guided, or supported some twelve students and researchers across seven Antarctic field seasons in Enderby Land, Mawson, the Northern Prince Charles Mountains, Rauer Islands, and Vestfold Hills.[37] The field studies were supported by, and integrated with, high pressure experimental studies in the laboratory to establish the phase equilibria and the P–T conditions of their formation. This enabled reconstruction of the metamorphic and tectonic history of the metamorphic belts.

Recognising the importance of Antarctica as a laboratory for studies not only of geology, but also of marine and climate science, David was keen to provide a stable and positive research environment to support ongoing multidisciplinary internationally significant research in Antarctica. He played a key role in the establishment at the University of Tasmania of the Institute of Antarctic and Southern Ocean Studies (IASOS) in the early 1980s, initially gaining funding from the Australian Government for six years. At the time of its inception, IASOS was unique in being both multi-disciplinary and truly cross-institutional, involving the University of Tasmania, the Australian Antarctic Division, and the CSIRO Marine Division.[38] The multidisciplinary approach and ethos owed much to the vision and foresight of David, who then acted as its inaugural Director. IASOS was the precursor to the Institute for Marine and Antarctic Studies (IMAS), an internationally recognised centre for excellence in marine and Antarctic research based in Hobart, and a lasting legacy to David's commitment to and vision for the conduct of research in Antarctica.[39] David was also actively involved in successfully attracting to the University of Tasmania the first Australian Secretariat of the Ocean Drilling Program, the premier global earth sciences project.

Broader contributions to Australian science and science policy

David's interest in broader scientific matters and his commitment to fostering excellence in science led him to make significant contributions to broader national scientific issues, serving for periods on a number of science bodies and committees. These included the Australian Research Grants Committee (1977–81), the Australian Science and Technology Committee (1982–5), the Bureau of Mineral Resources Advisory Committee (1985–7), the Geological Society of Australia as council member then Vice President and President (1978–81, 1990–2), the Australian Space Council (1993–4), Richards Review of the Bureau of Mineral Resources (1992–3), and Chair of National Greenhouse Scientific Advisory Committee (1997–2001). He also served from 1984 to 1990 as Chair of the Steering

[33] Green and others (2014). Green (2015). Pintér and others (2021).
[34] Foley and others (1986).
[35] Green and others (2014). Green (2015).
[36] Harley (1998).
[37] Harley (2024).
[38] Harley (2024).
[39] Harley (2024).

Committee for the National Research Facility, the research vessel the 'RV Franklin'.

David's interest in the broader scientific issues prompted him to accept a position from 1991 to 1993 as Chief Science Adviser to the Department of the Arts, Sport, the Environment and Territories, where he advised the Australian government on a wide range of matters including climate change, nuclear waste disposal, and Antarctica.

Return to ANU as Director of the Research School of Earth Sciences 1994–2001

In 1994 David returned to the ANU where he served until 2001 as Director of the Research School of Earth Sciences (RSES), combining his research with administrative duties. From February to October 1998 David served as acting Deputy Vice-Chancellor of ANU. His tenure as RSES Director coincided with a time of considerable change in the funding environment of the School. In 1995, an international team of expert scientists was appointed by the ANU and the Australian Research Council (ARC) to review the effectiveness of the block funding model to ANU's Institute of Advanced Studies (IAS), including RSES. Despite their recommendations for continued separation of the block fund from ARC funds (because this model was demonstrably highly effective in terms of research outcomes), and for an increase in the size of the block fund, in 1999 the IAS entered the ARC at a cost of 20% of the IAS research budget, with the first implementation scheduled for 2002.

Despite this and other reductions in Federal Government funding for basic research, RSES continued to prosper and conduct excellent and world-leading basic research under David's wise and patient leadership. His tenure as Director saw the commencement of a large number of important research initiatives, many of which continue to this day and have been extremely influential in facilitating research innovation and excellence at RSES. To highlight just three examples, David oversaw the transfer of several academic staff and analytical facilities from the Research School of Pacific and Asian Studies at ANU to RSES, thereby establishing an outstanding program in Quaternary research led by Professor John Chappell. He also facilitated the launch of the Australian National Seismic Imaging Resource (ANSIR), a national research facility managed by the Australian Geological Survey Organisation (now Geoscience Australia) and RSES. Under his leadership, RSES secured funding from ANU's Major Equipment Committee under a Crustal Fluids initiative, to develop a new analytical technique, Laser-Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS), which ultimately could quantitatively determine precise trace element abundances in a wide range of geological materials. Of these initiatives, the latter two continue to exist and evolve to this day, and have been critical in maintaining RSES as a leading institute for basic and applied geoscience research.

Despite the ever-increasing administrative load which characterises leadership roles in universities in the early twenty first century, David continued a high level of productive research in experimental petrology during his second stint at ANU, supervising several PhD students and postdoctoral fellows from Australia and overseas. The research focused on and refined some earlier themes, namely the compositions of near-solidus melts in the upper mantle, and the distribution of melts and their migration in olivine-rich lithologies under upper mantle conditions. David had long recognised this issue as key in resolving debates around equilibrium versus fractional mantle melting, and problems around extraction of melts from the deep mantle to the crust. He continued to work on the very high temperature hornblende granulites and amphibolites of the sole of the Papuan Ultramafic Belt, and on the stability and composition of amphibole in upper mantle assemblages.

University of Tasmania and 'retirement'

David retired from ANU in 2001, and he and wife Helen returned to Hobart in December 2008 (Fig. 5). David's interest in and commitment to science was undiminished and unwavering. He continued his studies on the petrology of the Earth's mantle and the effects of volatiles on mantle melting to generate the spectrum of mantle-derived magmas observed in diverse tectonic settings. In this period he authored and co-authored several papers based on earlier unpublished experimental studies and seminal review papers integrating the results of nearly fifty years of experiments by him and his students and co-researchers on this topic.[40]

A key outcome of the extensive program of high-pressure experiments by David and his students and co-researchers over fifty years has been the development of a 'petrogenetic grid' that defines the likely origin of many magma types erupted at surface in terms of depth, temperature, and likely volatile conditions in the melting regime. The experiments also provided broader key insights into the composition, structure and processes occurring in the Earth's mantle. The experimental studies of David and his group showed that the lithosphere-asthenosphere boundary (LAB) in the ocean basins is a petrological phase boundary defined by the intersection of the geotherm with the solidus of amphibole (pargasite)-bearing peridotite. This unifying concept explains why the LAB depth increases away from the spreading centres at mid-ocean ridges but reaches a maximum and constant thickness (approximately 90 km) as required by the petrological phase equilibria.[41]

[40] Green (2015). Green and others (2014). Green and Falloon (2015).
[41] Green and others (2010). Niu and Green (2018).

Fig. 5. David and Helen Green in 2020 in his office. Photo courtesy of Maddison Green.

David also sought to link magmatism to global geodynamics. He did not subscribe to the popular model that links linear volcanic chains, such as the islands of Hawaii, to 'hot spots' associated with rising hot buoyant plumes from the deep mantle, preferring to explain this volcanism as the result of melting in the presence of higher water and carbonate contents derived from old subducted lithospheric slabs within or beneath the base of the asthenosphere.[42] The experiments of David and his group underpin more generalised recent models of magmatism in which lithosphere thickness is considered to be the governing variable that controls mantle melt compositions in all tectonic settings on earth, commonly referred to as the 'lid effect', as the depth of the LAB determines the PT and extent of decompression melting of the mantle.[43]

David actively promoted new experimental approaches and designs, bringing greater precision to, and control of, the experimental conditions, and new analytical methods to analyse the products of the experiments.[44] These included imaging and analysis by electron microprobe, FTIR and Raman spectroscopy, and quenched vapour analysis. He also initiated the study of minute melt inclusions in natural rocks and experiments in Hobart. All are now routinely employed in modern experimental petrology.

Despite his achievements, David remained as keen as ever on his science to the end. He was concerned about not completing research on new ideas that he had, and tying up all 'loose ends' on incomplete or unpublished studies by former students.

Honours and awards

Over his career David authored and co-authored more than 230 scientific papers that have been cited in more than 40,000 papers by other scientists. These figures do not truly do justice to his impact on experimental petrology and geochemistry, as many of his publications predated the digital age and the research outcomes of many of his early studies have been integrated into modern undergraduate earth science courses.

David's outstanding contribution to the earth sciences and Australian science policy has been recognised by awards by numerous Australian and international scientific societies (see also EOAS[45] and Supplementary Material S1). These include: the Edgeworth David Medal of the Royal Society of New South Wales; the F. L. Stillwell Medal of the Geological Society of Australia; the Mawson and Jaeger medals by the Australian Academy of Science; the RM Johnston Memorial and the Royal Society of Tasmania medals by the Royal Society of Tasmania; the Abraham Gottlieb Werner Medal, Deutsche Mineralogische Gesellschaft; the Murchison Medal by the Geological Society of London; the Humboldt Research Prize by the Humboldt Foundation, Germany; the International Gold Medal by the Geological Society of Japan; International Mineralogical Society medal; and the Centenary Medal for service to Australian society and science in petrology and geochemistry. These culminated in him being made a Member of the Order of Australia (AM) in 2006 for 'service to the earth sciences, particularly in the fields of petrology and geochemistry through research, educational and advisory roles and contributions to public policy formulation'.

Recognition also included election as a fellow or member of national and international learned scientific societies including: the Australian Academy of Science; the European Union of Geosciences; the Geological Society of Australia; the

[42]Green (2015). Green and Falloon (2015).
[43]Niu (2021).
[44]Yaxley and Brey (2008).
[45]Encyclopedia of Australian Science and Innovation.

Geological Society of America; the Australasian Institute of Mining and Metallurgy; Russian Academy of Sciences; the Mineralogical Society, London; American Geophysical Union; and The Royal Society, London, in recognition of his work on the 'origin of magmas and the nature of Earth and Moon interiors'.

Family, and reflections and perspectives on science

David married Helen in 1959 after first meeting at a dance in 1955 when he was nineteen and she sixteen years old. Helen and David enjoyed sixty five years of marriage and had six children—Kathryn, Ronald, Elizabeth, Paul, and twins Ian and Jeanette (Fig. 5). Sadly, Helen passed away four months before David, who passed away on Friday 6 September 2024 at his nursing home in Hobart. David valued family life very highly, and his Christian faith guided him throughout his family and professional life. His six children, seventeen grandchildren and five great grandchildren all looked up to and respected him for his achievements but, even more than that, loved him for his sense of humour and fun, ability to listen, and positivity even in the face of Parkinson's disease and fading health over the past several years.

In all, David supervised some twenty nine postgraduate students, with more than half of them coming from more than ten countries, notably Germany, the UK, New Zealand, and Japan. Amongst them was the first student from Papua New Guinea to obtain a PhD in geoscience. As well as sharing his knowledge and providing direction and guidance, David took a keen personal interest in the welfare of his students, and he and Helen welcomed them into their home and family life. He played a very significant role in the careers of many young earth scientists, after stimulating their interest in geoscience, providing support as a friend, teacher, mentor and colleague. A significant number went on to carve out academic careers in earth sciences around the world. For most, he remained a life-long mentor and friend, always happy to listen and offer his wisdom.

As well as his extensive engagement with his postgraduate students David collaborated widely with scientists around the world. He especially valued the opportunity to meet leading senior researchers who shared their knowledge across national borders. His international collaborations commonly involved sabbaticals or visits by overseas researchers to the ANU and University of Tasmania, and from time-to-time overseas visits by David, sometimes with Helen. Special visits saw David accompanied by Helen and one or more of their children to attend conferences and geological excursions and visit colleagues at universities in overseas including Japan, Italy, and the United Kingdom. Such visits were viewed by the family as a privilege and honour.

Again, David and Helen welcomed visitors into their home and family life, and these collaborations often resulted in life-long friendships. David's sabbaticals included Oslo, Caltech (Pasadena, USA), the Woods Hole Oceanographic Institution (USA), and Hokkaido University (Japan). David firmly believed that international science had the ethics, the people, and the methods to build bridges between nations even where they may be in conflict, pointing to the important role played in the organisation of science by decadal international programs such as the Ocean Drilling Program (now the International Ocean Discovery Program).

David was a considerate and reflective man, a natural leader who employed his unique style of gentle suggestion and prodding, coupled with persuasive reasoning, to bring out the best in people and achieve outstanding results. He was proud of Tasmania's rich scientific heritage, and that 'discoveries could be made in a small remote corner of our planet as well as at traditional established learned academies'. He felt fortunate for the career opportunities that he had been afforded, especially to have been able to build, lead and support research groups with access to excellent research infrastructure and technical support. He lamented the decline in tenureships in many academic institutions and the discontinuous nature of career paths that are common today. He noted the broadening of petrology that had occurred over his career to be transitional with geochemistry, including isotope geochemistry and geochronology using advances in micro-analytical and microbeam instrumentation, and with geophysics with observations and measurements from mineral grain scales to the scale of plate tectonics and planetary exploration. He considered the body of geological knowledge to have grown so large over his lifetime as to be beyond the capacity of any individual scientist, increasingly emphasising a team approach, to maintain in-depth familiarity across the spectrum with regard to both the theory and the analytical techniques.

Supplementary material

The attached supplementary data includes a list of medals and memberships awarded to David Green by national and international scientific societies, and a list of peer-reviewed publications authored or co-authored by him. Supplementary material is available online.

References

Ballhaus, C., Berry, R. F., and Green, D. H. (1990) Oxygen fugacity controls in the Earth's upper mantle, *Nature*, **29**, 437–40. doi:10.1038/348437a0

Ballhaus, C., Berry, R. F., and Green, D. H. (1991) High pressure experimental calibration of the olivine-orthopyroxene-spinel oxygen geobarometer: implications for the oxidation state of the upper mantle, *Contributions to Mineralogy and Petrology*, **107**, 27–40. doi:10.1007/BF00311183

Bertrand, P., Ellis, D. J., and Green, D. H. (1991) The stability of sapphirine quartz and hypersthene-sillimanite-quartz assemblages: an experimental investigation in the system FeO-MgO-Al_2O_3-SiO_2 under H_2O and CO_2-bearing conditions, *Contributions to Mineralogy and Petrology*, **108**, 55–71. doi:10.1007/BF00307326

Brey, G., and Green, D. H. (1975) The role of CO_2 in the genesis of olivine melilitite, *Contributions to Mineralogy and Petrology*, **49**, 93–103. doi:10.1007/BF00373853

Brey, G., and Green, D. H. (1976) Solubility of CO_2 in olivine melilitite at high pressure and role of CO_2 in the Earth's upper mantle, *Contributions to Mineralogy and Petrology*, **55**, 217–230. doi:10.1007/BF00372228

Carey, S. W. (1956) *The Tectonic Approach to Continental Drift,* Continental Drift – A symposium. Convener: S. Warren Carey, University of Tasmania Press, Hobart, pp. 177–355.

Crawford, A. J. (2024) Vale 'Prof Green': A life devoted to geology, *Ore Solutions, Newsletter of CODES Centre for Ore Deposit and Earth Sciences*, **Summer 2024**(No. 50), 3–4.

Ellis, D. J., and Green, D. H. (1979) An experimental study of the effect of Ca upon garnet-clinopyroxene Fe-Mg exchange equilibria, *Contributions to Mineralogy and Petrology*, **71**, 13–22. doi:10.1007/BF00371878

Ellis, D. J and Yaxley, G. M. (2024) Obituary – Professor David Green. https://earthsciences.anu.edu.au/news-events/news/vale-professor-david-green/obituary-professor-david-green

Encyclopedia of Australian Science and Innovation. https://www.eoas.info/biogs/P004123b.htm

Falloon, T. J., Green, D. H., Hatton, C. J., and Harris, K. L. (1988) Anhydrous partial melting of fertile and depleted peridotite from 2 to 30 kbar and application to basalt petrogenesis, *Journal of Petrology*, **29**, 257–282. doi:10.1093/petrology/29.6.1257

Foley, S. F. (2011) A reappraisal of redox melting in the Earth's mantle as a function of tectonic setting and time, *Journal of Petrology*, **52**(7–8), 1363–1391. doi:10.1093/petrology/egq061

Foley, S. F., Taylor, W. R., and Green, D. H. (1986) The role of fluorine and oxygen fugacity in the genesis of the ultrapotassic rocks, *Contributions to Mineralogy and Petrology*, **94**, 183–192. doi:10.1007/BF00592935

Frey, F. A., Green, D. H., and Roy, S. D. (1978) Integrated models of basalt petrogenesis—a study of quartz tholeiites to olivine melilitites from southeastern Australia utilizing geochemical and experimental petrological data, *Journal of Petrology*, **19**, 463–513. doi:10.1093/petrology/19.3.463

Green, D. H. (1964*a*) The petrogenesis of the high-temperature peridotite intrusion in the Lizard area, Cornwall, *Journal of Petrology*, **5**, 134–188. doi:10.1093/petrology/5.1.134

Green, D. H. (1964*b*) The metamorphic aureole of the peridotite at the Lizard, Cornwall, *Journal of Geology*, **72**, 543–563. doi:10.1086/627013

Green, D. H. (1973) Experimental melting studies on a model upper mantle composition at high pressures under water-saturated and water-undersaturated conditions, *Earth and Planetary Science Letters*, **19**, 37–53. doi:10.1016/0012-821X(73)90176-3

Green, D. H. (1976) Experimental testing of "equilibrium" partial melting of peridotite under water-saturated, high-pressure conditions, *Canadian Mineralogist*, **14**, 255–268.

Green, D. H. (2015) Experimental petrology of peridotites, including effects of water and carbon on melting in the Earth's upper mantle, *Physics and Chemistry of Minerals*, **42**, 5–122. doi:10.1007/s00269-014-0729-2

Green, D. H. and Falloon, T. J. (1998) 'Pyrolite: A ringwood concept and its current expression', in *The Earth's Mantle: Composition, Structure and Evolution*, ed. I. N. S. Jackson, Cambridge University Press, Cambridge, pp. 311–380.

Green, D. H., and Falloon, T. J. (2015) Mantle-derived magmas: intraplate, hot-spots and mid-ocean ridges, *Science Bulletin*, **60**(22), 1873–1900. doi:10.1007/s11434-015-0920-y

Green, D. H., and Ringwood, A. E. (1963) Mineral assemblages in a model mantle composition, *Journal of Geophysical Research*, **68**, 937–945. doi:10.1029/JZ068i003p00937

Green, D. H., and Ringwood, A. E. (1967*a*) The genesis of basaltic magmas, *Contributions to Mineralogy and Petrology*, **15**, 103–190. doi:10.1007/BF00372052

Green, D. H., and Ringwood, A. E. (1967*b*) An experimental investigation of the gabbro to eclogite transformation and its petrological applications, *Geochimica et Cosmochimica Acta*, **31**, 767–833. doi:10.1016/S0016-7037(67)80031-0

Green, D. H., and Wallace, M. E. (1988) Mantle metasomatism by ephemeral carbonatite melts, *Nature*, **336**, 459–462. doi:10.1038/336459a0

Green, T. H., Green, D. H., and Ringwood, A. E. (1967) The origin of high-alumina basalts and their relationships to quartz tholeiites and alkali basalts, *Earth and Planetary Science Letters*, **2**, 41–51. doi:10.1016/0012-821X(67)90171-9

Green, D. H., Ringwood, A. E., Ware, N. G., Hibberson, W. O., Major, A., and Kiss, E. (1971) Experimental petrology and petrogenesis of Apollo 12 basalts, Proceedings of the Second Lunar Science Conference, 1, 601-615.

Green, D. H, Hibberson, W. O., Kovács, I., and Rosenthal, A. (2010) Water and its influence on the lithosphere–asthenosphere boundary, *Nature*, **467**(2010), 448–451. doi:10.1038/nature09369

Green, D. H., Hibberson, W. O., Rosenthal, A., Kovacs, I., Yaxley, G. M., Falloon, T. J., and Brink, F. (2014) Experimental study of the influence of water on melting and phase assemblages in the upper mantle, *Journal of Petrology*, **55**, 2067–2096. doi:10.1093/petrology/egu050

Harley, S. L. (1998) 'On the occurrence and characterization of ultrahigh-temperature crustal metamorphism', in *What Drives Metamorphism and Metamorphic Reactions?* eds P. J. Treloar, P. O'Brien, vol. 138, Special Publication Geological Society of London, pp. 75–101.

Harley, S. L. (2024) Professor David Headley Green AM FAA FRS, (29/2/1936-6/9/2024), Geologist, *Aurora*, **44**(2), 25.

Harley, S. L., and Green, D. H. (1982) Garnet-orthopyroxene barometry for granulites and peridotites, *Nature*, **300**, 697–701. doi:10.1038/300697a0

Hensen, B. J., and Green, D. H. (1971) Experimental study of the stability of cordierite and garnet in pelitic compositions at high pressures and temperatures. 1. Compositions with excess aluminosilicate, *Contributions to Mineralogy and Petrology*, **33**, 309–330. doi:10.1007/BF00382571

Hensen, B. J., and Green, D. H. (1973) Experimental study of the stability of cordierite and garnet in pelitic compositions at high pressures and temperatures, Part III: Synthesis of experimental data and geological applications, *Contributions to Mineralogy and Petrology*, **38**, 151–166. doi:10.1007/BF00373879

Irving, E. (1958) The magnetization of the Mesozoic dolerites of Tasmania, *Papers and Proceedings of the Royal Society of Tasmania*, **90**, 157–168.

Mackay-Champion, T. C., Searle, M. P., Tapster, S., Roberts, N. M. W., Shail, R. K., Palin, R. M., Willment, G. H., and Evans, J. T. (2024) Magmatic, metamorphic and structural history of the Variscan Lizard ophiolite and metamorphic sole, Cornwall, UK, *Tectonics*, **43**, e2023TC008187. doi:10.1029/2023TC008187

Nickel, K. G., and Green, D. H. (1985) Empirical geothermabarometry for garnet peridotites and implications for the nature of the lithosphere, kimberlites and diamonds,, *Earth and Planetary Science Letters*, **73**, 158–170. doi:10.1016/0012-821X(85)90043-3

Niu, Y. (2021) Lithosphere thickness controls the extent of mantle melting, depth of melt extraction and basalt compositions in all tectonic settings on Earth – a review and new perspectives, *Earth-Science Reviews*, **217**, 103614. doi:10.1016/j.earscirev.2021.103614

Niu, Y., and Green, D. H. (2018) The petrological control on the lithosphere-asthenosphere boundary (LAB) beneath ocean basins, *Earth-Science Reviews*, **185**, 301–307. doi:10.1016/j.earscirev.2018.06.011

O'Hara, M. J. (1963) Melting of garnet peridotite and eclogite at 30 kilobars, *Carnegie Institution of Washington, Year Book*, **65**, 71–77.

O'Reilly, S. Y. and Griffin, W. L. (2013) 'Mantle metasomatism', in *Metasomatism and the Chemical Transformation of Rock*, eds D. E. Harlov and H. Austrheim, Springer, Berlin, Heidelberg, pp. 471–533.

Pintér, Z., Foley, S. F., Yaxley, G. M., Rapp, R. P., Lanati, A. W., and Rushmer, T. (2021) Experimental investigation of the composition of incipient melts in upper mantle peridotites in the presence of CO_2 and H_2O, *Lithos*, 396–397. 106224. doi:10.1016/j.lithos.2021.106224

Ringwood, A. E., and Green, D. H. (1966) An experimental investigation of the gabbro–eclogite transformation and some geophysical implications,, *Tectonophysics*, **3**, 383–427. doi:10.1016/0040-1951(66)90009-6

Ryabchikov, I. E. and Green, D. H. (1978) 'The role of carbon dioxide in the petrogenesis of highly potassic magmas', in *Problems of the Petrology of the Earth's Crust and Upper Mantle*, Akademy Nauk. USSR, Siberian Region, Trudi, Institute of Geology and Geophysics, pp. 49–64.

Taylor, W. R., and Green, D. H. (1988) Measurement of reduced peridotite–C–O–H solidus and implications for redox melting of the mantle,, *Nature*, **332**, 239–352. doi:10.1038/332349a0

Wallace, M. E., and Green, D. H. (1988) An experimental determination of primary carbonatite magma composition, *Nature*, **335**, 343–346. doi:10.1038/335343a0

Wyllie, P. J. (1965) Melting relations in the system CaO-MgO-CO_2-H_2O, with petrological applications, *Journal of Petrology*, **6**, 101–123. doi:10.1093/petrology/6.1.101

Yaxley, G. M., and Brey, G. P. (2008) Foreword: the roles of petrology and experimental petrology in understanding global tectonics, *Journal of Petrology*, **49**(4), 587–589. doi:10.1093/petrology/egn016

Yaxley, G. M., Crawford, A. J., and Green, D. H. (1991) Evidence for carbonatite metasomatism in spinel peridotite xenoliths from Western Victoria, Australia, *Earth and Planetary Science Letters*, **107**(2), 305–317. doi:10.1016/0012-821X(91)90078-V

Yoder, H. S., and Tilley, C. E. (1962) Origin of basalt magmas: an experimental study of natural and synthetic rock systems, *Journal of Petrology*, **3**, 342–532. doi:10.1093/petrology/3.3.342

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