CSIRO PUBLISHING
Historical Records of Australian Science, 2016, **27**, 192–210
http://dx.doi.org/10.1071/HR15011

Alan Forrest Reid 1931–2013

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Dr Alan Reid is remembered as the founding father of automated mineralogy. He achieved international recognition as a research scientist, and was also a visionary leader within CSIRO, Australia's largest scientific organization. Reid contributed a distinguished body of basic research to solid state chemistry, publishing on organometallics, thermodynamics, crystal structures, high pressure minerals and mineral processing. He went on to lead development of processes that greatly benefited industry. These included the solar absorber surface AMCRO, and the QEM*SEM analysis that automatically characterized mineral assemblages. As an Institute Director at CSIRO he made important contributions to the structure and business processes of the organization, during a period of upheaval unprecedented in its history. It was Reid's leadership and perseverance that led to the establishment of the Queensland Centre for Advanced Technologies, the Australian Resources Research Centre in Western Australia, and major redevelopment of the CSIRO site at North Ryde in NSW. A master of broad collaboration with researchers, academics, companies and government agencies, when he retired from CSIRO Reid further benefited Australian science as a consultant to government and industry. The mineral reidite, a high pressure phase of $ZrSiO_4$, is named after this tireless polymath.

Early Education and Family Life

Reid's long and interesting life began in Gisborne, New Zealand on 26 March 1931. He was the oldest child of Lenore Macdonald and railway worker Victor Reid, who celebrated the arrival of his first-born with such enthusiasm that he registered his son's name as 'Allen'. However, Reid mostly used the intended spelling 'Alan'. Victor died in an accident when Reid was just sixteen, leaving him the effective head of a family with four other children and little money. This 'school of hard knocks' gave Reid an unpretentious and highly self-reliant personality, as well as a forceful drive to succeed.

Reid attended Taumarunui District High School from 1939 to 1948, where he played Rugby and became Head Boy. His Form 6 teacher described Reid's 'adaptability in various situations, without loss of the single-minded purpose which inspired his effort'. Growing up in the hilly King Country of New Zealand's North Island, it was natural that Reid would develop a love of rocks, and of climbing them. At university he became an accomplished mountaineer and alpine photographer, climbing throughout the Southern Alps with the New Zealand Alpine Club. (In 1953 another member of that Club, Edmund Hillary, would become the first Westerner to summit Mt Everest.) Mountaineering continued Reid's schooling in extreme persistence, inculcating both physical and mental toughness. Critical decisions had to be made in an instant on the mountain side, and he saved the life of a fellow climber on more than one

occasion. Reid was always modest about these accomplishments later in life.

In 1949 he began studying for a Bachelor of Science at the University of Canterbury in the South Island. A Bursary student, Reid supported himself by working as a labourer, as a guide for tourists on the Fox Glacier, and as a Laboratory Demonstrator at the University. His Bachelor degree was conferred in 1952, and a Master of Science with First Class Honours in Chemistry followed in 1954. His MSc supervisor commended Reid as 'a chemist of first class calibre'. In that same year he qualified as a secondary school teacher at Auckland Teachers' Training College.

Reid married fellow scientist Mary Barwell in 1954, and their son Michael was born in 1957. Humanities teacher Eva Rosenbaum was Reid's second wife, and during their twenty-year marriage Reid adopted her son Thomas; the couple also had a daughter, Catherine. In 1986 Reid would marry artist Hetty Blythe, becoming step-father to her daughters Alison and Lindsay. He partnered in 1998 with Prudence Little, mother to Richard, Alexandra and Edward.

Reaction Kinetics in Inorganic and Biological Systems

Reid commenced studies at the Australian National University (ANU) in Canberra in 1955, on a doctoral scholarship in the Radiochemistry Department of the Research School of Physical Sciences. His PhD continued the themes of his MSc thesis, namely reaction kinetics and isotope exchange reactions in inorganic systems. This led to his being invited, by the Microbiology Department of the ANU John Curtin Research School of Medicine, to apply chemical kinetic theory to the reaction of viruses with antibodies. Reid showed that apparently un-neutralizable viruses were in fact an equilibrium population produced by chemical kinetic processes, a significant result in relation to immunization. The Professor of Microbiology supervising this work, Stephen Fazekas de St Groth, commented on Reid's capacity for 'recognizing the significant, for incisive and creative thinking and for sheer hard work'.

Grubbing blackberries back in New Zealand paid for the printing of Reid's doctoral thesis, and the degree was conferred in 1959. The thesis work was published the following year as two scientific papers with his PhD supervisor Dr Reg Mills, who noted that Reid 'combined practical inventiveness with an extensive theoretical knowledge'. In 1970 ANU would grant Reid a second doctoral degree, a DSc, 'for contributions to solid state chemistry'.

Research at CSIRO Division of Mineral Chemistry

Virtually all of Reid's career was spent at the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia's national government science agency and one of the world's most prominent research institutions. Industry engagement would prove to be one of Reid's cardinal strengths, built on the scientific expertise that made him 'one of CSIRO's best-known researchers'.[1]

He joined the Division of Mineral Chemistry (DMC) at Fishermans Bend, Melbourne in 1959, at around the time that he became an Australian citizen. Appointed as a Research Fellow in Minerals Utilization for two years, Reid began a sustained period of basic research. Permanently appointed in 1961 as a Research Officer, he was described as showing 'high competence in theoretical work combined with quite outstanding experimental ability'.[2] This was further recognized in 1970, when Reid received the CSIRO Officers' Association David Rivett Memorial Medal, 'for a decade of outstanding contribution to physical science, to a Research Officer under 40'. He also received a hearty letter of congratulation, signed by a mere 82 of his colleagues! Reid was honoured to accept an award named for such a giant of Australian science. Originally Professor of Chemistry at the University of Melbourne, Rivett was instrumental in the formation of both CSIRO and its predecessor CSIR, as well as the Australian Academy of Science.

Reid was promoted to Chief Research Scientist in 1972, 'an exceptionally productive and versatile research worker', and his Division's most prolific author.[3] Over his career he published 81 scientific papers, 42 as first author, and had 6 patents granted. Reid's complete bibliography (see Supplementary Material) lists these and his other papers; hyperlinks to most of them can be found there. Much of the assessment of

Reid's science that follows is drawn from his personal files.

Reid was ably assisted in the preparation of his earlier research publications by his wife Eva, who patiently typed them up on a manual type writer. In this era of slide rules and hand-plotted graphs, she performed calculations on an adding machine the size of a shoe box, operated by a crank handle.

Vapour Deposition of Metals

In the early 1960s Reid worked for several years on the reaction processes involved in the production of thorium, zirconium and titanium by halide vapour transport. In addition to kinetic and chemical studies directly related to such processes, he established new relationships between electron emission and electrical and radiant energy properties of heated filaments. He also contributed to the theory of thermal dissociation equilibria.

Organometallic Compounds

In response to CSIRO interest in organometallic compounds as catalysts, in 1963 Reid proposed a series of new synthetic reaction routes to these compounds, initially based on the lower halides of zirconium and titanium. Performed in collaboration with Dr P. C. Wailes of the Division of Organic Chemistry, this work led to several novel methods for preparation of organometallic 'sandwich' compounds. The methods included the use of molten magnesium cyclopentadienide, and the preparation of this intermediate via molten lead-magnesium alloy, carried through to small pilot plant scale. Two patents were obtained for the preparation of these compounds, that were then of considerable interest as catalysts in the preparation of organic polymers. The work expanded to thermodynamic investigation of the properties of 'sandwich' compounds, and to several spectroscopic studies on the characterization of organometallics, by means of their readily accessible near-infrared spectra. The experience gained in the preparation of extremely air-sensitive organometallic compounds led Reid to the vacuum synthesis of lower-valent oxide compounds, for studies being carried out by Dr A. D. Wadsley and others in DMC. Reid's interest in the crystal structures and chemical phase systems of these compounds culminated in a postdoctoral appointment in the Chemistry Department of Cornell University, in Ithaca, New York, from 1964 to 1966. There he worked under the direction of Professor Michell J. Sienko, an inorganic chemist interested in metal-ammonia systems, nonstoichiometric oxide bronzes and layered compounds.

Oxide Compounds

While at Cornell, Reid extended his knowledge of crystallography and crystal chemistry. During this period and subsequently, he synthesized and studied a large number of new oxide compounds with electronic transport or magnetic ordering properties, and his work was important in the delineation of the nature of such materials. It included the discovery of several previously unknown classes of oxide compounds, and significant contributions to an understanding of long-range order in non-stoichiometric compounds. This broad experience was followed up in two main strands of research: high-pressure transformation of minerals in the mantle of the earth, and the upgrading of ilmenite and other minerals by chemical and metallurgical means.

High Pressure Transformations in the Mantle of the Earth

In ten years of activity, mainly in collaboration with geochemist Professor A. E. Ringwood of the ANU, and initially in collaboration with Dr A. D. Wadsley, Reid discovered new phase transformations of silicates to dense forms, in which silicon shows six-coordination to oxygen rather than the four-coordination usually found in the minerals of the earth's crust. Phase transformations offered a new perspective on the seismic velocity and density discontinuities across the Transition Zone of the Earth's mantle.[4] The high pressure structures of mantle silicates cannot always be experimentally determined, and 'model' structures must be used to extrapolate their behaviour. In addition to a large number of individual transformation studies on such models, Reid's particular contribution was to systematize the chemistry of substantially all the dense crystal classes to which mantle minerals could be expected to conform. He predicted the densities of the major mantle phases with considerable precision. This work laid a broad basis for describing mantle mineralogy and chemistry, as well as the host structures for a wide range of radiogenic and other elements.

Ringwood subsequently used this body of crystal chemistry as the basis of his Synroc (SYNthetic ROCk) process for disposal of radioactive waste. Synroc is a titanate-based ceramic, whose crystal lattices can safely sequester nuclear wastes for hundreds of thousands of years. The compound was originally envisaged as a solution for handling uranium waste products, when Australia began exporting yellowcake in the mid-1970s amidst much controversy. Subsequently the Australian Nuclear Science and Technology Organisation (ANSTO) would use Synroc to immobilize waste from its nuclear medicine production.

Reid's sophisticated research on mantle silicates had other outcomes of particular interest. He was part of a world-wide research effort to analyse samples collected during manned Apollo landings on Earth's moon between 1969 and 1972: with J. F. Lovering and D. A. Wark, geologists at the University of Melbourne, Reid described a completely new silicate in lunar basalt, 'tranquillityite'. Then in 2002 B. P. Glass and colleagues at the University of Delaware reported the discovery of a naturally occurring high-pressure zircon polymorph in a meteorite impact crater at Chesapeake Bay. This high-pressure phase of $ZrSiO_4$ had been produced by Reid in the laboratory in 1969. He was understandably delighted when it was named 'reidite'.[5]

Leadership of the Division of Mineral Chemistry

In 1969 Reid stepped onto the first rung of the executive ladder, as Head of the Solid State Chemistry Section of DMC. The group was by now housed in a refurbished paint factory at Port Melbourne, due to over-crowding at the Fishermans Bend site. The appointment was occasioned by the sudden death of Dave Wadsley, aged only fifty and at the height of a career so stellar that he was nominated for the 1969 Nobel Prize for Chemistry. Wadsley is remembered particularly for his work on the crystal chemistry of non-stoichiometric oxides, as well as the high-pressure mineralogy of the earth's mantle described above. Wadsley had created 'an international centre of excellence in solid state chemistry',[6] and under Reid's research leadership the group 'introduced a wider range of structure studies, [with] a growing awareness of the need to relate [them] to the practicalities of mineral treatment'.[7] An example was the tremendous contribution made to ilmenite beneficiation, a major Australian industry.

Phase Equilibria and Reaction Studies in Ilmenite Processing

Starting in 1970, Reid directed and took part in a substantial effort to establish the high temperature phase equilibria and thermodynamics of the reactions occurring in Western Titanium Ltd's process for upgrading the titanium ore ilmenite to commercial-quality rutile, a mineral form of titanium dioxide that is used to produce titanium metal.[8] This work included the establishment of new experimental methods for carrying out such studies. The complicated phase systems governing the behaviour of commercial kilns were interpreted to predict yield, and to determine operating conditions. The research was of great importance to the company, which continued to fund it through 1982 and beyond. Reid obtained a patent in this field with colleague Dr Hari Sinha.

Reid's blossoming executive skills now saw him appointed as Assistant Chief of DMC in 1974. During this period of research leadership, Reid built up several strong groups with international reputations in thermodynamics, crystal structures of minerals and inorganic materials, and in mineral processing. Particularly successful programs of research were conducted for solar absorber surfaces and magnesite beneficiation. As well as providing scientific and technical leadership, Reid was genuinely interested in the personal and professional welfare of his staff, and had a tremendous ability to establish rapport with people at all levels of the organization. While he did not suffer fools gladly, he was quick to appreciate and acknowledge the worthwhile contributions of others. First and foremost, he was focused on research outcomes. Much later, a colleague would remark that 'as a research leader [Reid] had what I regard as two essential characteristics; a distinguished record as a researcher,

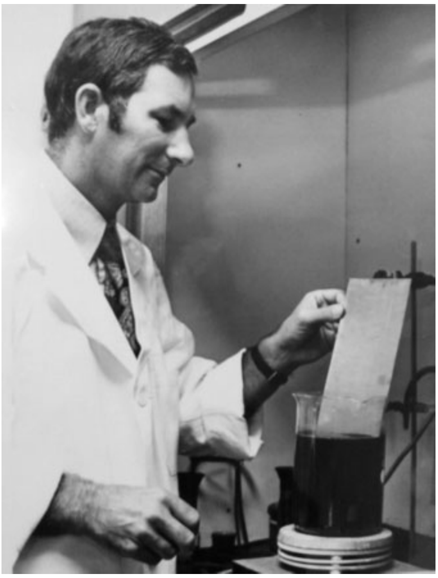

Figure 1. Reid preparing a surface with the AMCRO process.

and leading by example (do as I do, rather than do as I say—or perhaps more accurately in his case, do as I do and do as I say!)'.[9]

Solar Absorber Surfaces

In 1974 Reid was asked by the Division of Mechanical Engineering if he could improve the 'copper black' surfaces used for solar energy absorption in domestic hot water heater systems. This led Reid to invent and patent a new process for improving the efficiency and durability of such surfaces, the ammonium dichromate panel treatment process (AMCRO) (Fig. 1). This formed an insoluble protective coating over the cuprous oxide crystallite panels. The process was licensed to companies in South Australia and Victoria (Beasley and Rheem) as well as in Japan and New Zealand. Some 6,000 m^2 of solar absorber panels with this surface treatment were produced annually during the 1980s.

Magnesite Beneficiation to Magnesium Oxide

Others also turned to Reid for assistance with their problems. In 1977 an approach was made to CSIRO by the Tasmanian Mines Department for a method to beneficiate magnesite to high-purity magnesium oxide. Australia is thought to hold the world's largest deposits of this magnesium carbonate mineral, in fields in both Tasmania and Queensland. There is a substantial world market for magnesium oxide as a refractory for steel making but limits on impurity levels are stringent, particularly for iron impurities. Reid proposed a reinvestigation of an earlier but non-commercial process, namely aqueous dissolution of magnesium oxide by use of pressurised carbon dioxide. The process was modified to allow formation of an insoluble mixed carbonate-hydroxide of magnesium, iron and aluminium that reduced iron in the finished product to acceptable levels.

His proposal was supported by Industrial & Mining Investigations Pty Ltd (IMI), whose Chairman E. Hudson noted that Reid was 'able to combine his academic qualifications with a down-to-earth understanding of the difficulties and economics inherent in establishing a new industry'. The process studies were carried out by Dr John Canterford and Dr Malcolm Frost, on drill core samples from the Tasmanian deposit, and Canterford and Reid patented this work. The process was successful in a small-scale pilot plant, with a final product of more than adequate purity. Costings by IMI showed the route to be considerably more energy-effective than existing 'sea-water' routes that produced magnesium oxide from the magnesium chloride in sea water, but the cost of chemical beneficiation was still very high. When Queensland Metals Exploration Pty Ltd discovered the large high-purity Kunwarara deposit of magnesite in central Queensland in 1985, commercial processing of the Tasmanian magnesite was not pursued. CSIRO's expertise would later be called on to exploit the Kunwarara reserves too.

Move to the Division of Mineral Engineering

After eight years as Assistant Chief of Mineral Chemistry, Reid was promoted to Chief of the Division of Mineral Engineering (DME) in 1982 for a proposed term of seven years. This group was housed at the Clayton site adjacent to Monash University. Reid's role expanded to structuring strategic choices in research, and assuming responsibility for the performance, management and training of others. He introduced a much stronger emphasis on a permanent

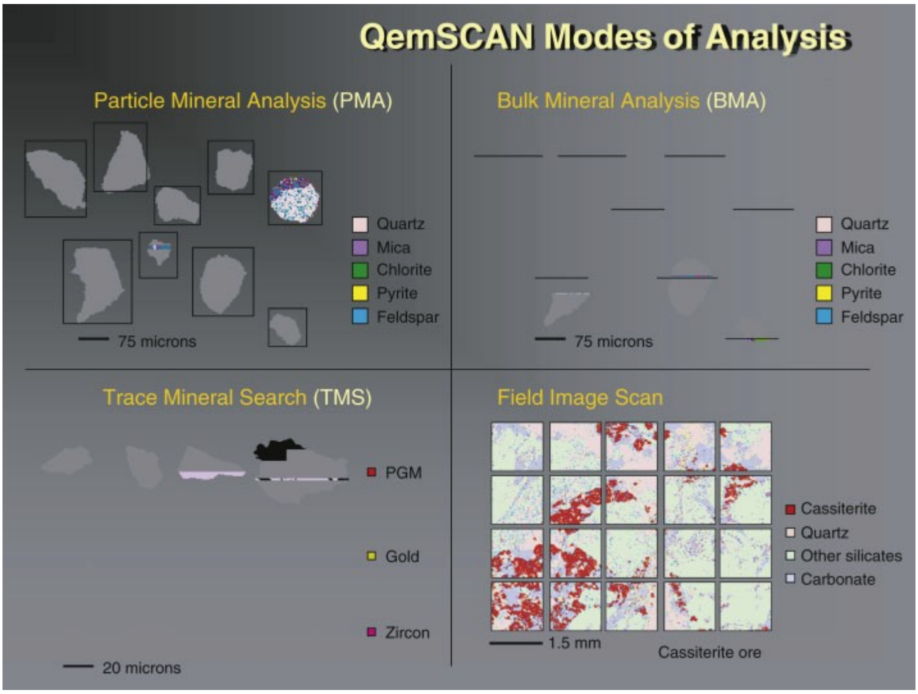

Figure 2. Introduction to QEMSCAN Applications (CSIRO promotional CD, 2002).

contribution to science and engineering as part of applications research, and restructured the Division to enhance the career contributions of several middle level scientists. He was responsible for initiating, supervising and conducting industry-sponsored research over a truly impressive range of fields. During this period the Division progressed the science for which Reid is best remembered: 'Quantitative Evaluation of Minerals by Scanning Electron Microscopy' (QEM*SEM), the world's first[10] automated process for mineral analysis. This would eventually create the field of automated mineralogy, rendering obsolete the use of manual microscopy to estimate a product's mineral profile.

*Automated Mineral Image Analysis (QEM*SEM)*

In 1972 Reid had introduced into the Division of Mineral Chemistry its first scanning electron microscope and electron microprobe, as the applicability of microprobe methods to characterization of particles in mineral processing had become evident to him. Reid's insight coincided with the radical developments concurrently occurring in computing, and he now led work to blend these two technologies.[11] After the proving of a prototype based on the Divisional microprobe, the Australian Mineral Industry Research Association (AMIRA) sponsored an extensive program to develop automated mineral image analysis. Electron impact was used to excite metal atoms that subsequently emitted characteristic X-rays.[12] The research was supported by eight major Australian mining companies, and culminated in QEM*SEM.[13] Experimental and image analysis techniques were used to automatically obtain, process and statistically interpret mineral image maps. Sophisticated data was summarised in visual outputs that were readily understood, especially in later iterations of the technology (Fig. 2).

The applications of the system initially included the description of mineral particles produced during grinding, and in the various stages of mineral flotation or gravity concentration. Subsequent uses were the characterization of: drill cores; slags and other metallurgical materials; the size and distribution of nucleation sites in zinc electro-deposition; and coal impurities.

Reid initiated and then managed the QEM*SEM project for six years, contributing to the physical realization of the QEM*SEM instrument, and personally devising computer-based image analysis algorithms for the system.[14] However when he became Chief of DME, he gave up day-to-day responsibility for the project, and it fell to Dr Paul Gottlieb[15] to guide the subsequent research that culminated in the commercial instrument QEMSCAN. In 1983 the analogue system gave way to a digital prototype, the redesign being prompted in part by a fire that destroyed the existing equipment.

QEM*SEM was patented and commercialized, in an agreement between CSIRO and Australian Pacific Resources Pty Ltd involving more than $1M in agreed payments.[14] Subsequently in 2003 CSIRO created the company Intellection,[15] to market the more advanced QEMSCAN. By then, the system allowed 12,000 mineral analyses per minute,[16] with such accuracy that minerals could be detected at concentrations as low as 1 ppm. QEMSCAN is used in many fields outside of mining: the oil, gas and coal industries; building materials science; environmental studies; and forensic investigation. The financial impact of automated mineralogy in the mining sector alone is enormous. Mount Isa Mines (MIM) reported gains of $15–20M a year through increased performance in its lead-zinc concentrators from using QEM*SEM measurements. Automated systems are installed worldwide—for example, by 2003, Anglo Platinum had installed a third unit at its research centre in South Africa. CSIRO estimates the worldwide industry benefit of QEMSCAN to be greater than $200M per year.[17]

Intellection, an Australian company, was acquired by American company FEI in 2009 for the bargain basement price of $2.8M.[18] Sadly, this loss of an Australian research outcome to an overseas buyer has been a common phenomenon over the years, reflecting 'an entrenched sentiment in many Australian boardrooms that it is easier to buy than to develop'.[19]

Another major research project undertaken while Reid was Chief of DME was revitalization of the SIROSMELT process. SIROSMELT is a highly original form of metal smelting developed by Dr John Floyd, in which a submerged lance injects fuel and air below the surface of a molten bath of metal and slag. Fuel burning at the tip of the lance melts the incoming feed material, creating vigorous combustion and chemical reactions. The technique was independently commercialized in 1981 by Floyd when he founded the company Ausmelt; Ausmelt would go on to enjoy global success before being acquired by the Finnish company Outotec in 2010. DME adapted SIROSMELT to lead smelting, proved at MIM as ISASMELT.[20] Another highly successful DME smelting program was that of direct iron bath smelting of iron ore to metal.

Since multi-Divisional projects were now being encouraged by CSIRO,[21] the Divisions of Mineral Engineering and Mineral Chemistry worked with Aberfoyle Pty Ltd, to maximize metals extraction and profitability at the company's new Hellyer mine in Tasmania.[22] This polymetallic ore body was identified in 1983, and QEM*SEM analyses had been crucial to the decision to open the $1B operation.[23] DME also undertook projects in diatomaceous earths for filter aids; phosphate fertilizer production; recycling of paper pulp chemicals; and zircon pigment production for ceramic bodies.[24]

Broad Involvement

Alongside his research and administrative commitments sat Reid's active membership of professional societies and learned academies. He joined the Royal Australian Chemical Institute (RACI) in 1961, chaired specialist groups in the 1960s and 1970s, and became a Fellow in 1983. He was a long-term member of the Australian Institute of Mining and Metallurgy, and he served on several government advisory bodies and editorial advisory boards. He contributed to the Royal Chemical Society as Australian Lecturer in 1988, and to the University of Sydney Chemical Society as President from 1988 to1989.

Reid's contributions to Australian and international science were rightly recognized by Australia's learned academies. He was elected to Fellowship of the Australian Academy of Science (AAS) in 1982, and of the Australian Academy of Technological Sciences and Engineering (ATSE) in 1988. He made important contributions to ATSE in particular, serving on sectional committees in his fields of expertise. In

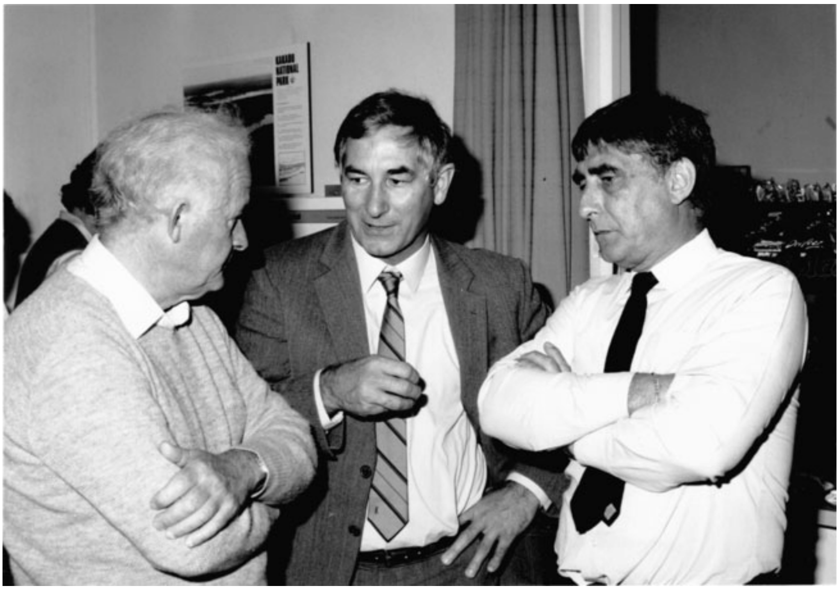

Figure 3. Dialogue with colleagues in the 1980s.

1997 he led the development and publication of ATSE's report *Urban Air Pollution in Australia*.

Reid made it a priority throughout his career to collaborate with a wide range of international and Australian scientists, including those of other CSIRO Divisions (Fig. 3). In this he upheld the CSIRO ethos of contributing to a global scientific community though the sharing of knowledge.[25] He was instrumental in scientific exchanges between CSIRO and the USSR Academy of Sciences (in energy and mineral exploration), and between CSIRO and the Chinese Academy of Geological Sciences (in mineral exploration). This collaborative approach saw Reid deliver lectures at national and international conferences, and at numerous universities and research institutes in Australia, North America, Europe, Sweden and China. He also found time to work with colleagues to organize professional conferences on metal-organic chemistry, mineralogy, crystallography, stereology and image analysis. Reid's career synopsis (see Supplementary Material) details his many professional activities, nicely illustrating that contribution and recognition are complementary aspects of a significant career.

Institute of Energy and Earth Resources

The late 1970s and 1980s were years of enormous change at CSIRO. The 1977 *Birch Report*[26] to Liberal Prime Minister Fraser argued that the principal role of CSIRO should be to carry out 'strategic mission-oriented' research relevant to Australian needs. To achieve this objective, Birch proposed that the CSIRO Divisions should be grouped into Institutes. One such was the Institute of Energy and Earth Resources (IEER), headed by Ivan Newnham.[27] Newnham was a key contributor to the development of the zirconium industry in Australia, working out a process for removing the tenacious contaminant hafnium: high-purity zirconium is need for the construction of nuclear reactors. Newnham had put CSIRO minerals-related research on a business footing since the mid-1970s. His illness and sudden retirement[28] made Reid the acting Director of IEER in 1984, and he was permanently appointed five months later for a proposed term of five years. Letters and teleprints of congratulation poured in from Federal Science and Technology Minister Barry Jones, RACI, the South African government, MIM, Western Mining, CRA, Hamersley Iron, Comalco and the like.

It is a truism that Australia's prosperity in the 1960s and 1970s was heavily dependent on mineral exports,[29] but in the 1980s growth in the sector was flat, driving greater vertical integration[30] and value-adding. Reid would spend thirteen years as an Institute Director in this evolving context, as the mining industry became a showcase for Australian technology.[31] His personal traits of adaptability and extreme persistence, coupled with his distinguished research record, gave him the tools he needed to direct his scientific colleagues effectively. It was now that his contributions to the organizational life of CSIRO became increasingly prominent. Then-Chief of Geomechanics Professor Bruce Hobbs would later recall that Reid had 'an overpowering desire to see his own work and that of others applied to the mineral processing industry, and in his role as Director of Institutes within CSIRO, was a dedicated and visionary leader. He insisted on the highest quality of science, but at the same time insisted that the science had application to the minerals and energy industries. One of his greatest successes was to create an environment where great science and direct application came together as a seamless blend'.[32]

During three years as Institute Director, Reid consistently encouraged an increase in the level of industry interaction of the Divisions for which he was responsible, with the expectation of industry funding and application. In 1986–7, direct company funding to lEER Divisions doubled from $2.6 to $5.5M, and under Reid's direction the Divisions of lEER earned the highest level of direct company funding of any CSIRO Institute.[33] Reid now restructured the composition of several Divisions, to give greater consonance between their research capabilities and industry needs. Both control instrumentation and process control proper were placed in Mineral Engineering, and geophysics and geochemistry were integrated in Mineral Exploration. He initiated and oversaw the complete revision of lEER mineral exploration programs across CSIRO's Sydney and Perth-based operations; recast the programs in liquid fuels production and coal combustion; and initiated a large AMIRA-based project in gold exploration, sponsored by 30 companies committing funds totalling $1.5M.[34] IEER scientists became international leaders in several areas, and their level of international exchange was high. There was also increased recognition of the Institute by Australian minerals and energy industries, and by State and Federal agencies.

IEER was involved in some 280 collaborative or contract agreements with Australian companies, and Reid streamlined procedures for establishing such agreements. As was required across CSIRO, the Institute maintained a complete project database, encompassing all 180 projects in the Divisions. Each Divisional Chief was required to develop a rolling five-year plan that was reviewed with and approved by Reid. The number of projects was in fact reduced, to provide concentration of effort in areas of higher significance. Opportune synergy flowed from the establishment of the commercialization company Sirotech in 1984, as CSIRO sought to promote its research to Australian industry.

An extension of Reid's research management focus was his co-chairing of the CSIRO Research Evaluation Committee, with Professor Adrienne Clarke from the University of Melbourne. (Clarke would go on to chair the CSIRO Board from 1991 to 1996.) Reid also continued to gain experience selecting senior staff. Amongst the four Divisional Chiefs he appointed was chemical engineer Dr Robin Batterham, who went on to become Australia's Chief Scientist in 1999.

Typical of Reid's commitment to his Institute was his participation in high-level executive management training. In 1985 he attended a two-week course on R&D management at the International Management Institute (IMD), Geneva, affiliated with the University of Geneva and sharing course leaders with MIT, Cambridge. The corporate approach taught at IMD materially assisted him in structuring relationships with Australian mining and mineral processing companies, and in mentoring Chiefs to do likewise. Reid subsequently encouraged his Chiefs to attend similar courses, and in-house used the AMIRA gold project as a framework for management training of project leaders by an external consultant. Reid was quite radical, by CSIRO standards of the time, in appointing external experts to support change management.

Two years after the first course, Reid attended a more advanced management course at IMD Geneva for senior executives of large organizations, focusing on vision, strategy and corporate change. A third round of management training,

Figure 4. 'Hands-on' management in the 1990s.

this time on governance of Boards, was undertaken with IMD in Lausanne in 1992, and was complemented by becoming a Fellow of the Australian Institute of Company Directors in 1995. All this further enhanced Reid's perspectives on corporate management, but he was first and foremost a content expert. He viewed management as adding value to content, not as a skill set that could operate in isolation from it (Fig. 4).

Upheaval at CSIRO

In 1985, the Australian Science and Technology Council (ASTEC) undertook a second major CSIRO review *Future Directions for CSIRO*,[35] this time for Labor Prime Minister Hawke. Professor Geoffrey Oldham provided an excellent commentary on this review in his 1988 sabbatical paper *Commentary on the ASTEC Review of CSIRO*.[36] CSIRO was experiencing the full range of internal problems so disappointingly common in large public organizations. The recommendations of the 1977 Birch Report had not been fully implemented: the governance paradigm was not internally consistent, with Institutes partially discipline-based and partially industry sector-based. Scientists were not always skilled managers, and nor were all accepting of an approach more focused on industry and applications. Funds for the Divisions continued to be allocated on historic grounds rather than according to quality or industry applicability of research, and Divisions were unable to retain the industry monies they did generate.

Multiple external factors were putting pressure on CSIRO funding at this time. Science world-wide was experiencing a flattening growth/funding curve,[37] consequent on the global economic down-turn ushered in by the oil crises of the 1970s. In Australia, the term 'Razor gang' emerged in the 1980s, as successive governments embarked on radical reductions in public spending. Nationally, R&D was lagging in the private sector,[38] and previously plentiful research funding from the wool industry was drying up.[39] Oldham stated 'Australia's economic situation was worsening. It was argued that the huge scientific talent residing in CSIRO should be harnessed, to generate high technology for producing the exports which would reduce Australia's burgeoning foreign debt'. There was tremendous pressure for either substantial cuts to the CSIRO budget or evidence of economic returns, and for the first time in thirty years the organization had to operate under zero or slightly negative growth.[40] It was fortunate that this national treasure enjoyed at least some independence from Government, being constituted under its own Parliamentary Act. Other events contributed to the growing public concern about the role of CSIRO: these included publicity given to what some people regarded as failures, such as the dung beetle program, the Animal Health Laboratory, and the cloud seeding program. They were publicized without corresponding publicity for successes, notable examples being the Interscan microwave aircraft landing system, and pioneering Greenhouse effect research. There was also criticism of CSIRO from industry and academia: industry because it did not see many benefits accruing to it, and academics because they saw CSIRO's budget for research relatively protected, while their own was declining.

Change Management

In this turbulent environment Reid's robust management skills were of great value to his Institute, and indeed to CSIRO as a whole. Initiatives he led or was part of would heavily influence the management practices and structure of the organization at large. A prime example was work undertaken by the CSIRO Research Evaluation Committee whilst co-chaired by Reid and Clarke. The Committee sought to evaluate the suitability and efficacy of research projects, and now commissioned management consultancy firm McKinsey to undertake the *Rare Earth Study*. This looked at both the extraction of rare earths within IEER, and their utilization in new magnetic materials and super-conductors within the Applied Physics group.[41] The study determined a framework for prospective evaluation and financial management of research within CSIRO that would be rolled out nationally.

The 1985 ASTEC review of CSIRO had resulted in the formation of an external governing Board in 1986. The Board was impressed with McKinsey's work on the *Rare Earth Study*, and in 1987 commissioned it to conduct yet another review of CSIRO, this time of the top management structure. The *McKinsey Report* identified the need for 'profound changes in the Organisation's ethos and working arrangements' to achieve a leaner and more commercial structure. Science Minister Barry Jones had stated that CSIRO's primary role should continue to be applications-oriented research in support of major industry sectors, but with more emphasis on value-adding and on sun-rise industries such as ICT and new materials.[42] The McKinsey review focused on these objectives, and led to the creation of an *Institute Structure Task Force*. Reid was elected by his colleagues as its Chair.[43] The Task Force recommended 'structural changes to allow the vigorous application of scientific research results', as well as 'a streamlined management structure giving greater authority, autonomy and support to research managers at all levels'. Reid's Institute piloted implementation of the paradigm outlined in the *Institute Model Study* of 1987,[44] and it was subsequently rolled out across the organizsation. This required extensive consultation and change management with Divisional Chiefs, three Unions, and the many staff affected by restructuring, relocation or redundancy.

All of this went 'smoothly under Reid's leadership',[45] but it was personally exhausting for him. Dr Keith Boardman, CSIRO Chief Executive during this period, noted in a letter of thanks to Reid that 'the responsibilities of Directors are onerous enough without devoting considerable effort to steering major changes in the structure of the Organisation'. There were certainly some individuals who did not thank Reid for his efforts: on one memorable occasion he received a written death threat in relation to this work.[46] More broadly, the reforms were seen by some scientists as requiring them to spend 'more time hustling for funds than doing research'.[47]

Amazingly, while the CSIRO-wide Institute restructure was unfolding, Reid was also asked to take responsibility for the new Division of Water Resources Research.[48] He assisted it to relate strongly to the major state institutions responsible for water and its environmental context, by meeting with numerous Government agencies. Concurrently, programs for the new Division were discussed in meetings of senior Divisional staff, analysing State requirements and CSIRO's capabilities. These processes established the role of the Division and its research programs. A final corporate contribution was Reid's major role in the *Report on the CSIRO Corporate Centre* into corporate services. Conducted around 1988 with management consultancy firm Pappas Carter Evans and Koop, this study too recommended sweeping changes.

Institute of Minerals, Energy and Construction

After three years as Director of IEER, in 1988 Reid was appointed Director of its successor Institute, IMEC—the Institute of Minerals, Energy and Construction. The application[49] he submitted to lead IMEC was characterized by high-order strategic thinking. Reid outlined his ambitious objectives for IMEC—to 'ensure and enhance its continuing contribution to Australian industry, expand its areas of application, allow it to cope with an increasingly stringent appropriation budget, and maintain its ability to perform basic research as the foundation for its future industrial applications'. Specific techniques proposed to accomplish all this included: identifying the longer term goals of the companies or agencies with whom the Divisions worked; increasing company acceptance of the need to invest both in CSIRO's and their own strategic research; orienting research and support staff to attitudes of commitment to industry needs; using project management techniques to focus effort on evaluation of research; selectively funding creative individuals; and maintaining the standard of basic research so as to keep scientists in the Institute at or above the level of their peers in the international scientific community.

Nationally relevant goals were articulated for IMEC as a whole, and for its Divisions. The Institute was to increase the international competitiveness, export earnings, gross domestic product and value of services provided by the industries it interacted with. In Minerals, the objective was to enhance the technology of Australian mineral and energy operations and processes, adding value to their products, so as to keep Australia in the forefront of nations exporting minerals, metals and coal. Within Energy, research was to serve production of electricity from coal, alternative transport fuels, efficient energy usage and transport system operations. In the new Division of Construction Engineering (formed from Energy Technology and Building Research) the emphasis on renewal in the urban environment was to be maintained. Closer interaction with large construction companies was envisaged, as well as attention to the future major sources of wealth in Australia, and what their construction, accommodation and building requirements would be. Geotechnical Engineering was to extend work in mining engineering into broader civil engineering projects in and on rock and earth, such as tunnels and dams. Reid envisaged that 'the success of the Institute will be measured by the benefit it creates for its customers; the support, financial and other, it receives from customers; the rate of adoption by customers of information and technologies it develops; the reputation it achieves for quality and timely work; and the quality of staff it attracts'. No wonder Reid described IMEC as 'audacious'.[50]

In 1991, a third of the way through his tenure as IMEC Director, Reid gave a presentation to the CSIRO Board that confirmed the success of his approach.[51] Total funding had increased from $18M in 1989–90 to $31M in 1991–2. At 35% in 1991–2, the percentage provided by external funding had exceeded the Government-imposed target of 30%.[52] This achievement was in no small part because 'the minerals industry was keenly attuned to the value of supporting research, especially through AMIRA'.[53] With characteristic directness, Reid pointed out that 'external earnings are the result of commitment and delivery, not a reason to discount [appropriation to] IMEC'. Restructuring of the Institute had better aligned it to industry sectors, so that research programs could be directed to key elements in the production chain, from discovery and raw material extraction to saleable products. A broad suite of 32 research areas was outlined in the report to the Board. Mineral/metals exploration and processing commanded 91% of the research budget, reflecting the fact that the mineral/metals industry provided 40% or $16 B of Australian commodity exports in 1990–1.

The Board presentation contained an impressive roll call of the industry and government stakeholders that IMEC was engaging with, including AMIRA, Comalco, BHP, MIM, LendLease, Boral, Transfield, the State governments of Western Australia and Queensland, DITAC and the Prime Minister's Science Council. Value-adding to mineral processing was emphasized. ISASMELT installations were pending for companies in Britain and the USA, with each installation providing a royalty to CSIRO of $0.25M; and a 13-year R&D agreement had been entered into with Queensland Metals Corporation, for processes to convert magnesite to value-added products. IMEC's extensive capital works programme was outlined in the Board presentation, including a $40M contribution to the redevelopment of the multi-Divisional North Ryde site described below. There was $13M for the Queensland Centre for Advanced Technologies (QCAT) at Pinjarra Hills, with the Queensland government contributing $20M; and $11M toward a Remote Sensing Industry Development and Education Centre at Floreat Park (later the Leeuwin Centre for Earth Sensing Technologies), in conjunction with the Western Australian government . Reid's work paved the way for the establishment of the $22M CSIRO National Centre for Petroleum and Mineral Resources Research, later the Australian Resources Research Centre (ARRC). Located in Bentley WA, construction began in 1999. IMEC would also make significant changes to the Clayton site in Melbourne. Existing facilities were refurbished, and new ones were opened in 1997 under the direction of Dr Rob La Nauze to house staff arriving from Port Melbourne: a Division

Figure 5. Reid conferring with colleagues Tom Biegler and Rob La Nauze in 1994.

of Minerals had been formed by the amalgamation of Mineral and Process Engineering with Mineral Products in 1994. Reid orchestrated the merger with MPE Chief La Nauze and MP Chief Dr Tom Biegler (Fig. 5).

Value-adding—the Magnesite Story Continued

Reid's publications while Director focused on value-adding for the mining, minerals and metallurgy industries, the main thrust of his executive work. His report (see Supplementary Material) to the Prime Minister's Science Council in 1990, republished here with permission, demonstrates his nuanced understanding of value-adding in the Australian minerals industry. Reid's expertise in this sphere was also seen in his role in the genesis of the magnesium metal industry. Queensland Metals Corporation (QMC) was formed after the discovery in 1985 of Kunwarara, possibly the largest single resource of crystalline magnesite in the world. A major new Australian business was envisaged, namely the supply of ultra-light magnesium alloys to the automotive industry.[54] A joint venture between QMC and industry partners was created, with CSIRO providing the research input. A large-scale pilot plant was sought, as a joint venture with the Federal and Queensland governments. It was Reid who convinced both governments to support this initiative,[55] and in 1991 the Australian Magnesium Research and Development Project (AMRDP) was formed. It was funded by $25M of government monies, with another $25M supplied by industry, and Reid sat on the Management board. His CSIRO colleague Dr Malcolm Frost became the manager of AMRDP. A commercial plant did not eventuate for business reasons,[56] but this venture's underpinning research was the main factor[57] in the creation of a Co-operative Research Centre (CRC) for light metals in 1993. The CRC produced alloy research of a high standard that was taken up commercially. Similarly, a Centre of Excellence for the Design of Light Metals was established in 2006, and CSIRO continued to fund a significant research program into new methods of magnesium production. Value-adding is sometimes a long-term proposition! Dr Ian Gould, Chancellor of the University of South Australia and former head of CRA, would later comment about Reid: 'the minerals industry appreciated his push for science with practical application and accountability. He was also a forthright champion of the industry, when it had plenty of detractors, and he saw that its vital contribution to the Australian economy justified government backing'.[58]

Development of CSIRO's North Ryde Site

When he was appointed as IMEC Director in 1988, Reid transferred his office to the multi-Divisional North Ryde site. The site's building stock was in need of rejuvenation, and IMEC proposed to Government an extensive capital works program, including construction of a Gene technology laboratory for the Division of Biotechnology, and a Geophysics laboratory for the Division of Minerals Exploration. Although the Parliamentary Standing Committee on Public Works approved the proposal it did not proceed.[59] This was because CSIRO was able to purchase extra land adjoining the site around the same time. Reid now became instrumental in a proposal that envisioned the expanded site as a high technology business park, and this concept was eventually realized as the Riverside Corporate Park. Hi-tech private companies were able to purchase sub-divided parcels of land, but while this strategy was effective in raising funds, it did not really bring the collaboration between CSIRO and its new neighbours that Reid had hoped for.[60] Nevertheless, the CSIRO capital works program that now proceeded did greatly improve the site's functionality for its CSIRO occupants.

Reid was accompanied in his move from Melbourne to Sydney by his third wife, artist Hetty Blythe, whom he had married in 1986, and her daughters Alison and Lindsay. He now began to greatly expand his interest in fine art, and started building a significant private collection of Australian works with Hetty. He particularly enjoyed getting to know artists and gallery owners personally, and round this time met Di Wu, an emerging talent on the Sydney art scene. Wu planned to enter the 1989 Archibald Prize portraiture competition, and was looking for an 'eminent Australian' to sit for him. The resulting work (Fig. 6) now hangs at North Ryde, watchfully overlooking the laboratories that Reid worked to establish. The portrait's striking imagery powerfully evokes the world of science that Reid loved, and to which he contributed so much.

Figure 6. Dr Alan F. Reid AM *Di Wu* 1988.

Co-operative Research Centres

The Australian CRC program commenced in 1991, bringing together Universities, companies and public research organizations for seven-year and later five-year projects. Altogether 209 CRCs have been funded since the inception of the program, with the Australian Government committing \$4B in funding, and participants a further \$12B in cash and in-kind contributions. In 1991 IMEC was participating in three of the fifteen first-round CRCs: the Australian Petroleum CRC, the Centre for Mining Technology & Equipment, and the G. K. Williams Centre for Extractive Metallurgy. The Institute had also submitted eight proposals for the second round of funding, three being successful bids to continue its first-round programs.

One of these was the Australian Petroleum CRC (1991–2004), which conducted research in areas such as petroleum geology and geophysics, organic geochemistry and petrography, and rock mechanics. Participants in the second round were CSIRO Petroleum; Geoscience Australia; the Department of Exploration Geophysics and the Petroleum & Environmental Organic Chemistry Centre, Curtin University; the National Centre for Petroleum Geology & Geophysics, University of Adelaide; the School of Petroleum Engineering, UNSW; and the Australian Petroleum Production and Exploration Association, the peak national body representing Australia's oil and gas exploration and production industry. The indefatigable Reid's contributions to the petroleum industry were substantial. He drove the applications for first- and second-round funding of the Petroleum CRC, and chaired it for twelve years. He was responsible for establishing the CSIRO Division of Petroleum Resources in 1993, as the result of a restructure involving the Division of Geomechanics and parts of the Division of Exploration Geoscience.[61] Finally, he ensured the Government collaboration and IMEC capital funding that would later establish the CSIRO National Centre for Petroleum and Mineral Resources Research at Bentley in West Australia. All this involved remarkable amounts of travel—on one flight Reid was amused to receive a pin from Qantas to mark his fiftieth trip to Perth.

Recognition

In 1986 the University of Melbourne considered Reid for the position of Vice-Chancellor, and he also applied for that role at the University of Sydney in 1988. Although he was not successful in his application for either position, Reid did enjoy a substantial association with Macquarie University, sitting on its Council for several years in the 1990s.[62] He was also a member of its Finance Committee, and a Director of the University's business centre, Macquarie Research Ltd.

In 1990, Keith Boardman retired from the position of Chief Executive Officer of CSIRO. Aspiring to the position, Reid hoped that Boardman's successor would come from within the ranks of the Institute Directors, but the CSIRO Board made the decision to appoint an external candidate for the first time. Dr John Stocker held the position until 1995, although Reid did briefly act as Chief Executive in 1991.

Over the course of his career Reid received numerous honours and awards. A federal Bicentennial Technology Medallion in 1988 followed the Rivett Memorial Medal of 1970, and in 1993 he was very proud to be awarded an Order of Australia, Member in the General Division (AM).[63] Reid received this honour for 'service to science and technology, particularly in the fields of minerals and energy'. Characteristically, at the Award Ceremony he responded to the Governor General's questions about his work by sincerely praising the contributions of his colleagues. Other awards were the federal Centenary Medal in 2001, for service to Australian society and science, and the Ian Wark Medal and Lecture[64] bestowed by the Australian Academy of Science in 2008. This medal is awarded for 'research which contributes to the prosperity of Australia, where that prosperity is attained through the advancement of scientific knowledge or its application'. Reid was delighted to have with him at the Presentation dinner in Adelaide all four of his siblings, Dennis, Kate, Carole and Jess. His lecture topic was 'Chemistry and mineralogy: Key inputs to Australian industry'.[65]

After CSIRO

After thirty-seven years dedicated to CSIRO, Reid left the organization in early 1996, although he never regarded himself as retired. This was a watershed year for Minerals groups in the organization. A 'new paradigm of customer-directed marketing rather than program-directed research' was adopted, following the release of an internal review of CSIRO headed by Deputy Chief Executive Dr Bob Frater.[66] It lead to the establishment of five Alliances, one of which was Minerals and Energy. Reid would doubtless have continued working at CSIRO, were it not for the organization's policy of compulsory retirement at age sixty-five. He immediately took up appointments as Chair of QMC and of Australian Environmental Resources NL, and continued as Chair of the Australian Petroleum CRC. Involvement in two major independent reports to government followed, as described below. Reid also took the opportunity to resume hands-on research project management, this time for Arumpo Bentonite (Fig. 7).

The Murray–Darling basin is home to Arumpo, a major bentonite deposit of exceptional purity. It is a clay with strong clumping properties, giving it application in production of cat litter and in the fining of wine. Because of its extremely low permeability when compacted, it is used in fields such as drilling, and waterproofing of civil engineering projects. Browns

Figure 7. Inspecting the Arumpo bentonite deposit c.1995.[69]

Creek Gold NL explored and mined the Arumpo deposit from 1987, and was later known as Australian Environmental Resources NL. Reid was briefly appointed as Chair of the latter in 1996–7. When the company became Arumpo Bentonite, Reid provided advice as Technical Director on materials processing and market applications. His last scientific paper, published in 2008 when he was 77, dealt with the origin of the deposit from a nearby chain of volcanic vents.

Urban Air Pollution in Australia[67] was an Inquiry commissioned by the Minster for Environment. It was undertaken by the Australian Academy of Technological Sciences and Engineering in 1997, with Reid as Inquiry Director. The Inquiry sought 'to determine the need for and to propose actions to maintain or improve urban air quality'. Supporting reports from specialized task groups were synthesized with pollutant data collected by government over many years. Reid noted in his Executive Summary that urban growth and vehicle use were increasing pressure on urban air quality, with Australia's vehicle fleet being the single greatest source of atmospheric pollutants. This was despite the benefits achieved through unleaded petrol, and catalytic convertors to minimize vehicle emissions. The Inquiry proposed coordination of transport planning, infrastructure development and environmental management. This was to be underpinned by appropriate investment decisions by government, as well as education of the whole community.

Australia State of the Environment 2001[68] was another independent report to Government, this time for the Minister for Environment and Heritage. It catalogued a disheartening list of environmental threats—salinity, lessening water quality and availability, habitat fragmentation and species loss. Reid sat on the Committee to provide input on air quality, and also offered review comments for the 2006 report.

Later Years

In 1999 Reid moved to Adelaide to join his new partner, Prue Little. He was increasingly impacted by a muscle-wasting disease that would later see him require a motorized wheelchair, built to his own high-tech specifications. Drawing on his mountainteer's endurance, he tolerated this affliction with quiet stoicism. Never the amateur, at sixty-eight Reid enrolled

Figure 8. With a QEMSCAN installation, 2003.

at the independent Adelaide Central School of Art to study painting and drawing. It was inevitable that he would involve himself in the governance of the School, becoming a board member for several years. He became a skilled landscape and portrait painter, and contributed a monograph[70] on the collected works of artist Chris Orchard. He also encouraged Prue in becoming a commercially established line drawing artist.

Reid enjoyed a wide social circle of friends in Adelaide. It included Qian Qian, a Masters candidate whose thesis in geotechnical engineering Reid supervised in his last years and indeed days. Qian described Reid as ‘friendly and helpful, not only to me, but also to every ordinary person and the society…I will try to become a person like him, modest, talented and helpful’. This assistance to Qian was recognized by the posthumous award of a Premier’s Certificate, ‘for outstanding volunteer service’.

Reid lived life fully until his death in 2013—painting, caring for his impressive garden and orchid collection, building up his wine cellar and above all, delighting in his immediate and extended family. He remained, as always, modest about his professional achievements, but his legacy (Fig. 8) is beautifully described in a letter that he received on his retirement. The words of Dr Graham Price, of the Division of Exploration and Mining, exemplify the warmth and admiration that so many of Reid’s colleagues afforded him. They provide apt summation of a magnificent career:

> ‘I would like to offer my sincerest thanks and gratitude for steadfastly pushing and prodding IMEC, and CSIRO, to create significant improvements in Australia’s industry. Your influence will endure, because you have been influential in ensuring that an important part of Australian society is firmly set on a bright and positive path for the future.’

Acknowledgements

The author is indebted to Professor Bruce Hobbs for his generous stewardship of this memoir. Warmest thanks also go to Professor Ian Rae for his mentoring of the writing process, and Professor Tom Spurling and Dr Rob La Nauze for their insights. Artist Di Wu very generously gave permission to reproduce his portrait of Reid, and the input provided by Professor Adrienne Clark and Dr Malcolm Frost is also most gratefully acknowledged.

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