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Memorial

David Wark, 1939–2005

Many in the meteoritical community will have heard of the Wark-Lovering (WL) rims that often surround calcium-aluminum inclusions (CAIs). Fewer will know of their namesake: David Wark.

In the middle of 2004, David received unwanted news: he had been diagnosed with cancer and had to undergo a rigorous treatment regime, where his probability of survival was around 10%. As ever, he was candid, humorous, objective, and very determined to survive. A continuous stream of friends and relatives rallied around David, and if emotional support could induce longevity, David would have survived to an impressive old age. Unfortunately, on June 8th of this year, at the age of 65, David died at his home in the company of his devoted wife, Emily.

John Lovering (left) and David Wark (right) (January 24, 2005).

David Wark was born on June 27th, 1939, in Melbourne, Australia. His parents took their newborn son to Nauru, a tiny Pacific island on the equator, northeast of Australia, where his father worked for the phosphate mining company that ran the island. A short time after their arrival, a German warship shelled the mining installations and this forced David and his family back to Australia, where they lived in Mt. Evelyn, a small country town near Melbourne.

Immediately after the war, his family returned to Nauru, which, inadvertently, had now become a small boy's paradise. The boys could play war games with the real thing—abandoned Japanese Zero fighters on the airstrip, heavy anti-aircraft guns that could still move, pillboxes, fortified caves, and so on. David used to dive 5 meters to the bottom of the boat harbor to pick up live ammunition, which he prized open for cordite to make crackers. "It's a miracle some of us weren't killed, those shells were so corroded."

At age 11, he was packed off to Scotch College in Australia for six years. Here he excelled at chemistry, physics, Latin, and French. He also taught himself to read Russian. "I was a very serious teenager. At that time in the early 1950s, the Russians were winning the Cold War and I expected that we would soon be fighting them, so I wanted to know my enemy." Later, at the University of Melbourne, he acquired a B.Sc. and Diploma of Education, and then taught in a high school for four years.

Afterwards, he moved to Zambia, Central Africa. "Having had a privileged childhood and education, I felt an obligation to share. 'Those to whom much has been given, from them much will be expected.' Teaching in Zambia was terrific because the students were grateful just to go to school. For many Aussie kids, school's a drag. My mother was terrified I'd be murdered because someone told her that 'the freedom fighters attack the schools and hospitals first.' On my first night in the country, two Africans beat up a man right outside my bedroom window. I yelled at them to go away—which fortunately they did. That's the only violence I witnessed in over two years in Zambia, though I was mistaken for a mercenary soldier and nearly shot in the Congo Republic during a hitchhiking trip to Angola and the Atlantic Ocean."

In Zambia, David married his first wife, Margaret, an English missionary nurse. They moved to England, where he taught for two years and improved his Russian with a tutor who had survived the Gulag. "I wanted to teach in Soviet schools to find out how they were producing so many engineers and beating the Americans in the space race." Unfortunately (or fortunately), the Russians rejected him, so he and Margaret went to Canada for a year before coming back to Melbourne. Here he had "two tremendous strokes of luck." Visiting the office of John Lovering, professor of geology at the University of Melbourne, he discovered that Lovering's tough old secretary came from the same town in Scotland as David's grandfather, whom she had known well—so she let David in to see the professor ("first miracle"), who then hired him as his research assistant to do fission track research on the Apollo lunar samples ("second miracle")! "I'll never know why 'the Prof' hired me, a re-treaded schoolteacher, over some Ph.D. student—but he did, and I am eternally grateful. It was a dream come true. I used to look up at the Moon and think: Wow! I work on that stuff!" According to Professor Lovering, he hired David because of his obvious enthusiasm and intelligence.

David devoted himself to his work and was soon producing some significant results. In particular, he used “Lexan” fission track maps to co-discover the new mineral tranquillityte in lunar material (Lovering et al. 1971). He used similar and other techniques to characterize other mineral phases such as zirconolite (Wark et al. 1973) and monazite (Lovering et al. 1974) in lunar rocks.

One day ‘the Prof’ handed David some Allende meteorite samples with the instruction to “see what you can find in those white inclusions…” David pored over Allende’s Ca-Al-rich inclusions (CAIs). The equipment he used, such as a scanning electron microscope (SEM) and a microprobe, had been acquired by Professor Lovering’s research grants and were free for staff to use around the clock on a booking system. So, somewhat to the distress of his young, neglected family, David spent many, many hours—often into the wee small hours—searching the samples. John Lovering once said: “Warkie, it’s no wonder you discover so many things, because you spend so much more time on the samples than those jokers overseas who have to pay by the hour, rush in, and do a quick-and-dirty job.” Among his many finds, David demonstrated that thin layers of spinel-plus-perovskite, alteration products, and pyroxene were ubiquitous on coarse CAIs, and that this sequence of layers was identical to that making up the individual bodies in fine-grained aggregates (Wark and Lovering 1977). Glenn MacPherson began the tradition of calling these layers “Wark-Lovering” (WL) rims. “I am very grateful to him because it’s nice to have something named after you.” The “discovery” of rims and of their similarity to fine-grained CAI bodies was David’s most important work and has stimulated many other studies, although the origin of rim layers still remains uncertain almost 30 years later. David demonstrated that the second rim layer of nepheline, grossular, and sodalite in Allende CAIs had been initially melilite, before alteration. Meteorites like Efremovka that are not very altered often show the primary melilite rim layer (Wark and Lovering 1980). He also classified type B CAIs into zoned type B1 and unzoned type B2, and concluded that type B1 had been completely molten, while type B2 had not (Wark and Lovering 1982a).

These and other discoveries was made possible by the free hand that John Lovering gave to David and by Lovering’s generous support with equipment, travel funds, and funding to do a Ph.D. “At that time, I just looked over samples in very great detail with optical microscope, SEM and fission track maps, and some strange observation or question always presented itself, such as: ‘What are those bright specks? How is this sample zoned?’ It was real, curiosity-based research.” In the first decade after the fall of Allende and the discovery that its ‘white inclusions’ (CAIs) had bizarre O isotopic compositions, there were so many things waiting to be discovered—the types of CAIs, their major and trace element compositions, their zonation, mineralogy, etc., their formation conditions, their Pt-alloy nuggets (Wark and Lovering 1976) and “Fremdlinge” (Wark and Lovering 1978), their rims, their Al/Mg and I/Xe interval ages, their isotopically anomalous FUN inclusions, etc. Thus David’s “random walk,” as John Lovering used to say, was well suited to this era of CAI research.

After presenting his “Rims” work at the Lunar Science Conference in Houston, David was invited by Gerry Wasserburg to give a seminar at the California Institute of Technology. “How ignorant and naïve I was in those days! I thought I was doing Gerry a great favor in accepting his invitation, under the impression that Caltech was a trade college like our Melbourne Institute of Technology, rather than one of the premier universities of the world! Gerry’s smart-arse naming of his lab as ‘The Lunatic Asylum’ didn’t help. At Caltech I soon realized my gross mistake! The two-hour, free-for-all seminar was terrifically exciting, and Gerry followed up by inviting me to work with him at Caltech. I accepted.”

Once at Caltech, however, relations deteriorated. David thought he was going to do exciting work on Pt-metal grains and CAIs. However, he spent most of his time doing sample preparation. The research approach was very rational, but utterly different from John Lovering’s easy-going style. “Gerry micro-managed everything, including how to put samples into the SEM. After one argument, Gerry was so infuriated that he hurled a full (plastic) cup of coffee at the wall and stormed off up the stairs.” Despite these tensions, David’s time at Caltech led to new ways of classifying CAIs and also a method for distinguishing “framboids” from “palisades,” where he described the latter as captured CAIs-within-CAIs (Wark and Lovering 1982b).

By this time, the basic facts about CAIs such as Larry Grossman’s CAI types, Ross Taylor’s chemical groups, and Bob Clayton’s CAI oxygen isotopic compositions were established, but most samples tended to be interpreted simply as condensates according to Grossman’s condensation sequence in a hot nebula collapsing under the impact of a supernova shock wave, à la Al Cameron. “In Gerry’s mass-spectrometer laboratory, the thrust was to establish a relative ^{26}Al-based nebula chronology for CAIs and chondrules. He also wanted us to uncover isotopic mass-fractionations as monitors of condensation or volatilization, and to discover isotopic anomalies as indicators of nucleosynthetic inputs to the solar nebula from supernovae and red giant stars … hence, my Pt-alloy nuggets got short shrift. I learnt invaluable skills in Gerry’s lab, and really appreciate the privilege of working with him, but we were both happy for me to return to Melbourne at year’s end.”

Back at Melbourne University, John Lovering had moved into senior university administration and could no longer support David. As a consequence, David worked as a dogsbody in the geology department while finishing his Ph.D. part-time on nights, weekends, and holidays. This put more strain on his long-suffering wife and children. Eventually, he got a job in Bill Boynton's neutron activation laboratory in Tucson, where he was generously given a few months to finish his thesis in Arizona. "Working with Bill was good fun. He was smart, good humoured and calm—I never once saw him angry in six years at Tucson. Bill had calculated that the common group II inclusions had to be condensates from a refractory-depleted gas, demonstrating the occurrence of large-scale nebular fractionations between gas and condensed matter. Hence, we concentrated on getting trace element data on big and small CAIs in order to unravel CAI fractionations and the effects of volatility and fO_2. The lab also had a good SEM/microprobe to relate the trace element chemistry to the mineralogy/petrology of CAIs."

In this relaxed and conducive environment, David thrived and was able to show there was no difference between CAI size and composition (Wark and Boynton 1984). He discovered large (still unexplained) anomalies in the Fe, Ni, S, and chalcophile abundances in CAIs (Wark 1984) and published a scheme for classifying CAIs according to both chemistry and petrology (Wark 1985).

One of his major projects was to microsurgically separate and analyze representative rims from CAIs of groups I and II and types A and B in the CV meteorites Allende and Efremovka. This work revealed, somewhat to his surprise, that rims have the same trace element pattern, but are much richer in ultra-refractory elements, than the CAI underneath (Boynton and Wark 1987; Wark and Boynton 1987). "Bill Boynton deserves all the credit for this discovery, because I was convinced that the work was a waste of time and that rims would have the same refractory-poor group II pattern as fine-grained aggregates, which I had earlier shown were made of the same layers as rims. Bill further elaborated the discovery to show that it possibly required extremely high nebular temperatures (to volatilize the less refractory rim material) but for a very short time (so as not to melt the whole inclusion). This requirement for 'flash heating' posed grave difficulties for models of a large, slowly cooling nebula."

Besides co-authoring a major review on refractory inclusions in CV meteorites (MacPherson, Wark, and Armstrong 1988), David demonstrated that the Allende hibonite-bearing type A CAI 3643 consisted of two successive condensates: an ultra-refractory, OsIrRuMo-nugget-rich core inside a complementary, refractory-depleted, PtRhNiFe-nugget-rich, mantle (Wark 1986). This work showed that refractory metals can be used, analogous to the rare earths, to define "group II" condensates from a gas depleted in ultra-refractory metals.

David's time in Tucson came to an end when his family returned to Australia so that his daughter, Heather, could attend university in Melbourne. En route, David stopped at the Max-Planck Institut in Mainz, fulfilling a long-delayed wish to work with Herbert Palme. For David, this was a wonderful time of discussion and research. "Herbert has a great personality, keen mind, and delightful sense of humour." But David's wife felt increasingly isolated in the German environment, and eventually continued back to Melbourne with his daughter, leaving David and his son, Ian, in Mainz for the rest of the year. The neutron activation laboratory in Mainz was also well-equipped with furnaces for high-temperature experiments. By this time, the main types and properties of CAIs were known. The emphasis for David and Herbert Palme was on investigating the importance of high temperature fO_2 and volatility-dependent nebular processes relative to lower-temperature, parent body metamorphic processes, in particular for the depletions of Mo and W found in CAIs and the presence of Fe in CAIs, chondrules, and matrix.

While in Mainz, David also continued his analysis of CAIs. In particular, he microsurgically removed and analyzed by neutron activation analysis (NAA) the rim and interior of Vigarano CAI VI-1. The results were similar to those for Allende and Efremovka CAIs, suggesting that refractory enrichment is a universal property of CAI rims (Wark et al. 1988). Although flash heating was a useful concept for partially understanding WL rim formation, it still did not explain their composition. This led David to propose a two-step rim formation process, with the second step being a metamorphism of the initial ultra-refractory aluminous residue to form the spinel, melilite, and pyroxene layers (Esat, Wark, and Taylor 1988). David also re-examined how small CAIs formed and concluded that they are collision "splash droplets" (Wark 1988a) of big CAIs, thereby explaining their similar trace element signatures to large CAIs. His time in Mainz concluded with an invited article on CAIs for *Nature* (Wark 1988b).

Back in Australia, David was unable to obtain funding for meteorite research and obtained a job in industrial research, first on coal combustion and then on beach sand minerals. During this stressful time, he divorced his long-suffering wife of 23 years. He also lost his industrial research position, so he returned to teaching in schools throughout Melbourne. His life began to settle after his marriage to Emily, a librarian. After several years he began, alongside his teaching, to do part-time, self-funded research, following up on his unfinished rim research. He focused on ways to confirm the reality of flash heating (which was not universally accepted) and on diffusion experiments to reproduce the rim layers of spinel + perovskite, melilite, and pyroxene, and so to determine the post-flash heating conditions experienced by CAIs.

With help from friends in the CSIRO and Melbourne, Monash, and Australian National universities, David performed many experiments to reproduce the spinel-melilite-pyroxene rim layers by diffusing Mg and Si (from forsterite or enstatite or the gas) into a synthetic ultra-refractory "flash heating residue." These experiments consistently produced layers of spinel and anorthite, not melilite or pyroxene, indicating either that this process did not occur in nature, or that the correct conditions have not yet been found (Wark 1997). Despite an initial bout of bowel cancer in 2000, David published a comprehensive review of rim formation (Wark and Boynton 2001) and started exploring the idea that WL rims were formed by "subsolidus vaporization" (Wark et al. 2005), a slower, lower temperature alternative to flash heating for rim formation. This alternative model would ease the problem astrophysicists have in finding a mechanism to create a flash of extremely high temperature for only 1–2 seconds in the nebula. David's last paper was a set of recipes for making artificial CAIs. He hoped that his many years of experience in making CAI analogues would be a useful tool for future researchers who were attempting to understand CAI formation and processing via experimental methods (Wark 2005).

This self-funded research over the last seven years of his life typified his determination and passion for understanding the formation of meteorites and the solar system. David's life illustrates that a combination of hard work, intelligence, and luck can produce results, which have a significant, long-term impact. In David's case, it was his good fortune that he arrived at the University of Melbourne at a time where he could be sponsored and nurtured by Professor Lovering. It also shows that even the most dedicated researcher cannot reach his potential if he is denied even basic research facilities. In Australia, this situation has only recently been partially rectified by the establishment of the Planetary Science Institute at the Australian National University, but, unfortunately, David did not live long enough to take advantage of this new facility.

Many of David's original experimental pictures and data have been submitted to the Museum of Victoria, Melbourne, Australia for safekeeping and for future retrieval. Interested readers may wish to approach Bill Birch of the Museum of Victoria for more information.

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SELECTED PUBLICATIONS OF DAVID WARK

Lovering J. F., Wark D. A., Reid A. F., Ware N. G., Keil K., Prinz M., Bunch T. E., El Goresy A., Ramdohr P., Brown G. M., Peckett A., Phillips R., Cameron E. N., Douglas J. A. V., and Plant A. G. 1971. Tranquillityte: A new silicate mineral from Apollo 11 and Apollo 12 basaltic rocks. Proceedings, 2nd Lunar Science Conference. pp. 39–45.

Wark D. A., Reid A. F., Lovering J. F., and El Goresy A. 1973. Zirconolite (versus Zirkelite) in lunar rocks (abstract). 4th Lunar Science Conference. pp. 764–766.

Lovering J. F., Wark D. A., Gleadow A. J. W., and Britten R. 1974. Lunar monazite: A late-stage (mesostasis) phase in mare basalt. *Earth and Planetary Science Letters* 21:164–168.

Wark D. A. and Lovering J. F. 1976. Refractory/platinum metal grains in Allende Ca-Al-rich clasts (CARCs): Possible exotic presolar material (abstract)? 7th Lunar Science Conference. pp. 912–914.

Wark D. A. and Lovering J. F. 1977. Marker events in the early evolution of the solar system: Evidence from rims on Ca-Al-rich inclusions in carbonaceous chondrites. Proceedings, 8th Lunar Science Conference pp. 95–112.

Wark D. A. and Lovering J. F. 1978. Refractory/platinum metals and other opaque phases in Allende Ca-Al-rich inclusions (abstract). 9th Lunar and Planetary Science Conference. pp. 1214–1216.

Wark D. A. and Lovering J. F. 1980. Second thoughts about rims (abstract). 11th Lunar and Planetary Science Conference. pp. 1211–1213.

Wark D. A. and Lovering J. F. 1982a. The nature and origin of type B1 and B2 Ca-Al-rich inclusions in the Allende meteorite. *Geochimica et Cosmochimica Acta* 46:2581–2594.

Wark D. A. and Lovering J. F. 1982b. Evolution of Ca-Al-rich bodies in the earliest solar system: Growth by incorporation. *Geochimica et Cosmochimica Acta* 46:2595–2607.

Wark D. A. and Boynton W. V. B. 1984. The relationship between size and composition of Allende CAIs (abstract). 15th Lunar and Planetary Science Conference. pp. 888–889.

Wark D. A. 1984. Unexplained Fe, Ni, and S anomalies in CV chondrite components. *Meteoritics* 19:329–330.

Wark D. A. 1985. Combined chemical/petrological classification of Ca-Al-rich inclusions (abstract). 16th Lunar and Planetary Science Conference. pp. 887–888.

Boynton W. V. and Wark D. A. 1984. Trace element abundances in rim layers of an Allende type A coarse-grained Ca-Al-rich inclusion. *Meteoritics* 19:195–197.

Boynton W. V. and Wark D. A. 1987. Origin of CAI rims. I. The evidence from rare earth elements (abstract). 18th Lunar and Planetary Science Conference. pp. 78–79.

Wark D. A. and Boynton W. V. 1987. Origin of CAI rims. II. The evidence from refractory metals, major elements and mineralogy (abstract). 18th Lunar and Planetary Science Conference. pp. 1054–1055.

MacPherson G. J., Wark D. A., and Armstrong J. T. 1988. Primitive material surviving in chondrites: Refractory inclusions. In *Meteorites in the early solar system*, edited by Kerridge J. F. and Matthews M. S. Tucson, Arizona: The University of Arizona Press. pp. 746–807.

Wark D. A. 1986. Evidence for successive episodes of condensation at high temperature in part of the solar nebula. *Earth and Planetary Science Letters* 77:129–148.

Wark D. A., Spettel B., Palme H., and El Goresy A. 1988. Rim formation by flash heating and metasomatism: evidence from Vigarano CAI VI-1 (abstract). 19th Lunar and Planetary Science Conference. pp. 1230–1231.

Esat T. M., Wark D. A., and Taylor S. R. 1988. Mg isotopic composition of rim layers in the Vigarano inclusion VI-1 (abstract). 19th Lunar and Planetary Science Conference. pp. 307–308.

Wark D. A. 1988a. Small compact CAIs: Collisional splash droplets (abstract)? 19th Lunar and Planetary Science Conference. pp. 1226–1227.

Wark D. A. 1988b. News from the early solar system. *Nature* 331: 387.

Wark D. A. 1997. Conditions for forming calcium-aluminum-rich-inclusion rim layers: Preliminary experiments. LPI Technical Report #97-02. Houston: Lunar and Planetary Institute. pp. 63–64.

Wark D. A. and Boynton W. V. 2001. The formation of rims on Ca-Al-rich inclusions: Step I—Flash heating. *Meteoritics & Planetary Science* 36:1135–1166.

Wark D. A., Shelley J. M. G., and O'Neill H. 2005. The first step in CAI rim formation: Flash heating or subsolidus evaporation (abstract #1643). 36th Lunar and Planetary Science Conference. CD-ROM.

Wark D. 2005. Recipes for making synthetic CAIs, refractory residues, and minerals for rim-forming experiments. *Meteoritics & Planetary Science* 40:711–720.