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OBITUARY

In memoriam – Ian Moore

Chris Hawes

It is with great sadness that I have to report that Ian Moore, Associate Professor in Plant Sciences and Fellow of Wadham College, University of Oxford, finally succumbed peacefully to cancer in the early hours of Friday 31 August 2018 at a local Oxford hospice surrounded by his family. At only 54 years old when he died (born on 14th May 1964), this was far too early for the cell biology community to lose such a talented scientist and mentor. After being appointed as a departmental lecturer in the Department of Plant Sciences at Oxford in 1994 and a Senior Research Fellow in 2010, he was appointed as a tenured Associate Professor in Plant Sciences in 2012 due to his outstanding contribution to both research and teaching. Despite initially being a critic of the Oxbridge college system, Ian was elected to a Wadham Fellowship in 2010, and to a Tutorial Fellowship from 2013 and embraced college life to the full. In what turned out to be a far too short academic and research career, Ian made major contributions to plant molecular biology, gene expression systems, the secretory pathway (concentrating on plant Rab GTPases) and, laterally, in plant development.

Ian Moore.

The early years

After completing his undergraduate degree in Molecular Biology at Edinburgh University in 1985, Ian was offered a place on a PhD course on developing mitochondrial transformation, jointly supervised by Chris Leaver in Edinburgh and Jeff Schell at the Max Planck Institute (MPI) in Köln. Apparently, there are tales of wine and jacuzzis that are better not dwelt on here! Although his PhD work was not entirely successful, his talent as a molecular biologist was recognised and Ian was awarded a postdoctoral fellowship at the MPI to work with Klaus Palme on targeted gene expression (Moore et al., 1998), and here he kindled his interest in Rab GTPases (Moore et al., 1995).

Rabs and the secretory pathway

In 1994 Ian returned to the Leaver fold after a one-year postdoc at Andrew Staehelin's lab in Boulder, CO, and I have to admit to being reticent about another plant secretory pathway researcher coming to Oxford just one km down the hill. This was because he appeared to believe in the existence of COPII vesicles on the plant ER (Staehelin and Moore, 1995), a concept I have been trying to disprove for 30 years or so. How wrong can one be? Ian had an open mind to all ideas, and so we started a wonderful on–off collaboration that lasted for 23 years.

In the early days of using GFP to highlight the secretory pathway we employed transient viral expression systems, but of course we knew that a transient agrobacterium system would be preferable. I remember flying with Ian one day in the mid-90s to Karl Oparka's lab, at what was then the SCRI in Dundee, to discuss secretory pathway work, and one of Karl's staff demonstrated infiltration of water into pea leaves using a needle-less syringe appressed to the lower-leaf epidermis. The penny quickly dropped and, on return to Oxford, we got a PhD student to make a broth of agrobacterium hosting, if my memory is correct, an HDEL–GFP-expressing plasmid. This raw broth we injected into the lower epidermis of tobacco leaves, and to our surprise, within a day or so all the endoplasmic reticulum (ER) in epidermal cells lit up. Pretty quickly Ian embraced this technology (See 'Unpublished early images' below), which resulted in the first publication using this system showing the inhibitory effect of a Rab1 mutant on the secretion of GFP (Batoko et al., 2000). This spawned a number of successful collaborative projects between our labs on Golgi–ER interactions, secretion and Rabs in the plant secretory pathway. For instance, with Claude Saint-Jore and Federica Brandizzi, we demonstrated that the cytoskeleton was not involved in transport between the ER and Golgi (Saint-Jore et al., 2002). With Hugo Zheng it was demonstrated that the well-known GTPase mutant root hair defective 3 plays a role in ER-to-Golgi transport, work which Hugo is still continuing today (Zheng et al., 2004).

One major service, some may say disservice, Ian made to the plant Rab community was sorting out the dreadful muddled nomenclature that had evolved, with almost every plant Rab lab using different terminology (Rutherford and Moore, 2002). Thus, we reported on the role of Rab F2b in the post-Golgi pathway

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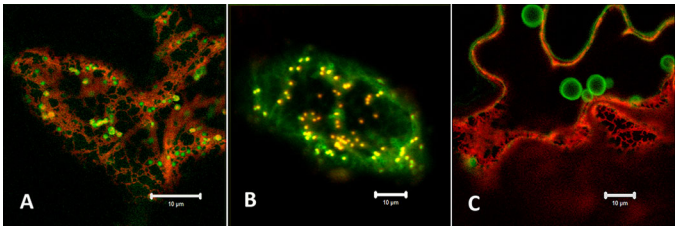
Happy days! Ian in a lighter moment (arrow) dressed as a cactus at a Plant Sciences summer barbeque with a Wild West theme. His idea and the lab members made the suits – of course they won the best costume competition!

(Kotzer et al., 2004) and AtRAB-H1[b] plus AtRAB-H1[c] in the Golgi (Johansen et al., 2009).

Ian also set up an extremely successful collaboration with Patrick Hussey's lab in Durham, UK, looking at the interaction of Rab-E GTPases with plasma membrane phosphatidylinositol-4-phosphate kinase, and demonstrated that the kinase was stimulated by Rab binding (Zheng et al., 2005; Camacho et al., 2009). Interestingly, this interaction proved to be plant specific, with the Rab-binding domain in the kinase being absent in the fungal and animal kinases.



Unpublished early images of the plant homologue of Rab2A (as it was then known) transiently expressed via agrobacterium in tobacco leaf epidermal cells. (A) GFP–Rab2A and YFP–HDEL showing punctae associated with the ER. (B) GFP–Rab 2A and ST–YFP confirming Golgi location of the Rab. (C) GFP–Rab2A-Q65L mutation and YFP–HDEL showing the mutant form located to vacuolar-like structures. (Note by using a derivative of wild-type GFP, it was possible to exploit the UV peak and colocalise constructs with YFP.) Micrographs courtesy of Ulla Neumann (in collaboration with Ian), Central Microscopy, Max Planck Institute for Plant Breeding Research, Cologne.

Inducible expression systems

Another major contribution to the plant cell biology community was that, over the years, Ian developed a range of inducible expression systems (Moore et al., 2006).

In his own words, "We have also developed the pOp/LhG4 and pOp/LhGR systems for spatial and temporal control of transgene expression in plants. These are based on a chimaeric transcription factor, LhG4, comprising a high-affinity DNA-binding mutant of the *E. coli* lac repressor fused to a transcription activation domain from the yeast Gal4 protein. This molecule activates transcription from the pOp promoter which is otherwise physiologically silent in transgenic plants. We are nearing the end of a programme that has generated a collection of lines expressing LhG4 under a series of defined promoters and enhancer traps and these can be used in conjunction with the pOp promoter to express genes of interest in many tissue- and cell-specific patterns. This system is of particular value if a gene of interest needs to be studied in a variety of selected cell types and especially where the expression of the transgene is likely to compromise plant viability or fertility. In recent years this system has been used by our collaborators and others to investigate various aspects of *Arabidopsis* biology including embryogenesis, cytokinin metabolism, and meristem control." (Quote from Ian Moore's Wadham College website.)

Perhaps even more importantly for many of us cell biologists, he developed the dexamethasone-inducible system in which he fused the ligand-binding domain of the rat glucocorticoid receptor to LhG4 to generate a steroid-inducible molecule (Craft et al., 2005; Samalova et al., 2005). This has enabled many of us to inducibly express GFP constructs through the treatment of plants with dexamethasone.

So it was that Ian developed an inducible expression system based around a synthetic glucocorticoid hormone, only to end up taking the drug as part of his chemotherapy regime and without the necessity of the dreaded COSHH forms – an irony that was not lost on him and that we talked about on a number of occasions.

Other aspects of the secretory pathway

Of course, Ian was involved in helping various groups over the years, including mine, with their research on other aspects of the plant secretory pathway, but far too much to cover in detail here. However, he also strayed away on occasion from his first love, the Rab family. In one notable Nature paper (Teh and Moore, 2007), Ian wandered off into the world of *Arabidopsis* ARF GEFs. He showed that the *Arabidopsis* GBF protein, GNOM-LIKE1 (GNL1), related to the well-characterised GBF protein GNOM, has an ancestral function at the Golgi, but is also required for selective internalisation from the plasma membrane (PM) in the presence of brefeldin A (BFA). Mutants rendered the plants BFA sensitive with the classic result of the Golgi membranes being re-absorbed into the ER. A wonderful piece of work.

More recent work – Rabs, cell walls and development

The acquisition of cell walls early in the green plant lineage and its continued evolution in composition and organisation to give rise to multicellular, terrestrial embryophytes was accompanied by a significant adaptation of the ancestral membrane trafficking pathways. As related above, Ian's long-standing research interest was on Rab GTPases as key regulators of membrane trafficking, and in particular, how the astonishing independent diversifications in different Rab GTPase clades in animals and land plants, compared to the last eukaryotic common ancestor, related to specific cellular functions. While both the Rab-A and Rab-E clades in *Arabidopsis*

are associated with post-Golgi trafficking to the PM, the Rab-A clade has undergone a substantial plant-specific diversification (26 members in *Arabidopsis*; two members in humans: Rab11a and Rab11b), whereas the RAB-E clade has remained small in plants and diversified in animals (five members in *Arabidopsis*; over 30 in humans, typified by Rab8). How do these diversification patterns map onto plant-specific or cell-type specific functional specialisations?

Recent work in Ian's lab involved a systematic analysis of genetics, cellular localisation, proteomes, secretomes and cell wall analysis of selected *Arabidopsis* members of the Rab-A family and a Rab-E family member to understand whether they contributed to the general bulk flow to the plasma membrane or had a specialised secretory role.

This work revealed distinct functions within the Rab-A clade in interphase cells, with Rab-A2 and Rab-A3 marking separate domains of the trans-Golgi network that differ from VHAa1, identified as the plant early endosome. By contrast, RAB-A5 members that were labelled as novel compartments localised to the cell edges in young organ primordia. Furthermore, recent work revealed that the Golgi-localised AtRAB-E members curiously localise to microtubules in *Arabidopsis* cells undergoing cessation of growth (Kirchhelle et al., 2016). These data triggered Ian to link findings on the cellular level to tissue- and organ-level processes such as growth. Through collaborations with colleagues in the Departments of Physics and Engineering at Oxford University, he developed a multi-disciplinary strategy to tackle the difficult question of how spatial organisation of the endomembrane system is regulated and in turn contributes to cellular growth direction, organ morphogenesis and response to environmental cues.

Ian's dedication to his science and to beer (real ale of course) is legendary. As much was probably achieved in the Harcourt Arms in the Jericho area of Oxford as in the lab. Working late into the night was routine to Ian and I always remember telling my postdocs and our joint PhD students to make sure they had another appointment after any scheduled meeting with Ian, otherwise they would be stuck in the pub or outside all night discussing their data! Biology and beer, what a brilliant combination. Talking to his lab members, exactly the same story emerges. New lab members very quickly learned to enter Ian's office well fed and with a sweater (his office was the ambient outside air temperature in winter!) as he took the time (and it was not short) and effort to discuss their projects.

Ian treated his students, postdocs, collaborators and colleagues with kindness, constant encouragement, interest, generosity and good humour, which makes his loss hard on a personal level to us all, as well as on a scientific level. While his death is an irreplaceable loss, he has instilled in the members of his group, and many others, his unique enthusiasm and desire to unravel the mysteries of the plant endomembrane system, and he will remain an inspiration to all of them continuing his work.

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