A Celebration of Fred David Sack

In this special Focus Issue on Stomata, it is only fitting to pay tribute to one of the stomatal development field’s founders and greatest champions, Fred David Sack (1947–2015). Fred was born in New York City and raised in a progressive tradition that valued an understanding and appreciation of the human and scientific worlds. Fred attended Stuyvesant High School and Antioch College, where he majored in Sociology and was active in school and antiwar politics. After his graduation, Fred returned to New York City to work as a Research Analyst for the Health Services Mobility Study sponsored by the Research Foundation of the City University of New York. In 1973, he became an Assistant Management Analyst for New York City’s Prison Health Service. While living in Brooklyn, Fred discovered the Brooklyn Botanic Garden and quickly cultivated a love of plants and natural habitats that would guide his interests and passions for the rest of his life.

Following his new-found love of plants, Fred enrolled as a PhD student in Plant Biology at Cornell University, where he started his work on stomata, writing his dissertation on “The development and ultrastructure of the stomata of Funaria hygrometrica, Hedw.” After earning his PhD in 1982, Fred stayed in upstate New York, becoming a postdoctoral Research Fellow with Professor Carl Leopold, a noted plant physiologist, conservationist, and environmental ethicist, at the Boyce Thomson Institute. Here, Fred began the gravitropism work that defined much of his career. He used video microscopy to study amylolast movement in living corn columella cells (Sack et al., 1986). These elegant studies showed that amylolast sedimentation occurs within a timeframe consistent with the starch statolith hypothesis for gravity perception.

His new ways of addressing classic questions in plant physiology launched Fred’s independent research career. In 1984, Fred was recruited to an assistant professorship at The Ohio State University. In his 22 years at OSU, Fred rose through the ranks, becoming an associate and full professor, culminating in formal recognition by the university president for his contributions to scholarship and from 2004 to 2006 serving as Chair of the Plant Cell and Molecular Biology program. Although Fred had worked with a number of plant species, notably bryophytes, in his early work, by the late 1980s Arabidopsis thaliana was being recognized as a powerful model organism. The fascinating discovery by Chris Somerville’s group, who isolated a starchless mutant of Arabidopsis in order to study carbohydrate metabolism, gave Fred and Postdoc John Kiss an opportunity to test long-standing hypotheses about gravity perception. Interestingly, it had been reported that when the starchless mutant was reoriented, it still responded to gravity, thus seemingly contradicting the classical starch-statolith hypothesis. More careful work by Fred and John, however, ended up turning the argument around 180 degrees! Fred and John reported that while the starchless mutant did respond to gravity, this mutant also exhibited a much longer presentation and perception time (Kiss et al., 1989). Thus, starch was needed for full gravitropic sensitivity, and data from the studies using the starchless mutant provided strong evidence for a statolith-based model of perception. Numerous other studies using very different approaches also have supported a key role for statoliths in perception (Sack, 1997).

Fred made use of another single-celled model system to study gravitropism: protonemata of the moss Ceratodon purpureus. These studies eventually led to the development of a spaceflight experiment that was performed on the ill-fated space shuttle Columbia STS-107 mission in 2003. Amazingly after the loss of this spacecraft, the fixed moss samples from Fred’s experiment were recovered on the ground. Fred went on to publish a paper (Kern et al., 2005) that demonstrated the existence of default nonrandom growth patterns that developed in microgravity and suggested that this response was overridden and masked by a constant g-vector on Earth.

Throughout his life and career, Fred explored new fields and engaged with different people, but he held a constant love of shape and form in plant biology. In the mid-1990s Fred returned to working on stomata. He combined his expertise in ultrastructural work (harking back to his PhD studies) with his newer appreciation of Arabidopsis genetics to launch an ambitious project to understand how stomata, with their perfectly symmetric two epidermal guard cells flanking a pore, were made, and how their beautiful and orderly patterned distributions on aerial organs (two stomata never touch each other) were organized. This project would intrigue Fred for the rest of his career, as well as inspire a new generation of plant developmental biologists.

Before Fred embarked on his genetic studies of stomatal development in Arabidopsis, there was a long history of stomatal physiology and of using stomatal patterns to put living and fossil plants into species groups. Yet, development was rarely considered. Fred was one of the first to consider the dynamics of stomatal development and how cellular choices made early in leaf development enabled or restricted the choices that could be made later. Stomata are visually stunning and could be approached as a simple system upon which layers of complexity could later be added, a system to which Fred seemed intuitively drawn. Whatever his initial motivation for reinvigorating his stomatal research, it would be fair to say that Fred is considered the father of Arabidopsis stomatal development.

Fred’s critical publications began in 1995 with the characterization of the first two mutants in the field, *too many mouths* (tmm) and *four lips* (fip); Yang and Sack,
Fred was hopelessly enamored of science puns (imagine someone asking you, on a bad day, “What’s stomata?“ in an emphatic New Yorker accent) and stomata is the Greek word for mouths. Fred can take credit for inspiring all of the other amusing gene names (SPEECHLESS, CHORUS, SCREAM…) in this field.

It took another 5 years for the stomatal development field to gather more momentum, but in 2000, three key papers came out. Thomas Altmann’s group cloned the first gene involved in stomatal development, SDD1 (STOMATAL DENSITY AND DISTRIBUTION1, one player to escape Fred’s naming influence; Berger and Altmann, 2000). Julie Gray identified a mutant, high carbon dioxide, linking stomatal development to environmental information (Gray et al., 2000). Fred, along with his PhD student Matt Geisler, made a comprehensive analysis of stomatal development in wild type and in TMM mutants—they essentially figured out the “rules” of patterning (Geisler et al., 2000). To this day, the goals of several research groups are to identify the signaling mechanisms and pathways responsible for enforcing these rules. Fred’s group made its own contributions to identifying the proteins encoded by TMM and FLP a few years later; Postdoc Jan Nadeau found that TMM encoded a Leu-rich repeat receptor-like protein (Nadeau and Sack, 2002), and Postdoc Lien Lai found that FLP encoded an atypical MYB transcription factor (Lai et al., 2005).

In July 2006, Fred and his wife Dian Clare moved to Vancouver, BC, where Fred became the Head of the Botany Department at the University of British Columbia. Despite his heavy administrative load, Fred continued to be an active researcher, with Research Associate EunKyoung Lee’s support and the momentum from PhD student Jessica Lucas’ decision to come along to Vancouver providing continuity to the lab. Dr. Jie Le was a postdoctoral fellow in the new lab, and he made important contributions with his dissection of the role of auxin transport in stomatal development (Le et al., 2014). Jie Le continued to work together with Fred, often traveling from the Chinese Academy of Sciences in Beijing to work on manuscripts. In the last years of Fred’s lab, he saw both a satisfying integration of his major projects, where he found that FLP was actually expressed in roots and had a role in gravitropism (Wang et al., 2015), and a new direction of research when he found that the genes required for guard cell differentiation were also used to make myrosin idioblasts, cells involved in the “mustard gas” defense system in Brassicas (Li and Sack, 2014).

Fred not only made direct contributions to plant cell biology, gravitropism, and stomatal development, but he also was a generous mentor for the next generation of plant cell biologists (Fig. 1). Dominique Bergmann remembers being drawn to the stomatal field (after a PhD studying Caenorhabditis elegans embryogenesis) because of Fred’s work and because of Fred himself; when they met in 2003, he was enthusiastic and welcoming and served in many ways as a second postdoctoral mentor, even inviting her to coauthor an Annual Review article on stomatal development (Bergmann and Sack, 2007). Through the conversations and revisions of that work, Dominique grew to appreciate his encyclopedic knowledge of plants (and particular fondness for ferns and mosses) and saw how clearly he laid out the big questions. Looking at the stomatal development field today, it is vibrant, fast moving, and integrative. The genes Fred introduced in 1995 are central to our understanding of cell-cell communication, of cell cycle, and of cell fate. For example, genetics studies from Elena Shpak and Keiko Torii identified the ERECTA family kinases as partners of TMM (Shpak et al., 2005), and subsequent work from the Torii lab elegantly confirmed physical interactions between these coreceptors, as well as interaction with their ligands in the EPIDERMAL PATTERNING FACTOR family (Lee et al., 2012; Rychel et al., 2010). The Bergmann group has worked on proteins that share the spotlight with FLP and used TMM to reveal interesting signaling cross talk (Abrash et al., 2011; Ohashi-Ito and Bergmann, 2006). It turns out that TMM is a bit like Fred. It’s always in the middle of things and tends to buffer situations, but it is sometimes mischievous.

Fred was unfailingly enthusiastic and a champion for the field. But to only talk about Fred’s contributions to the scientific field of stomatal biology is to miss many of the finest points of Fred. He loved music of all types, folk dancing, and playing the guitar, and he enjoyed

Figure 1. Fred Sack at the center of the stomatal development world, circa 2006. Fred is surrounded by students, postdocs, and colleagues at the 2006 ICAR in Madison, WI. Top row (left to right): Lynn Pillitteri, Tanya Falbel, Jan Nadeau, and Jessica Lucas. Bottom row (left to right): Keiko Torii, Jessica McAbee, Fred Sack, Dominique Bergmann, Cora MacAlister, and Zidian Xie.
travelling. Fred was a community builder, and that community was inclusive. He was a joy to be around, the life of the party at ASPB and ICAR meetings, and many remember late nights in Madison with Fred holding court or dancing up a storm.

In 2011, Fred was diagnosed with mild cognitive impairment, a diagnosis that seemed to echo his mother’s Alzheimer’s disease that led to her death. He went to a reduced scope appointment where his undergraduate teaching duties were eliminated, and with help from EunKyoung and Jie Le, he continued to mentor his graduate students and produce strong papers. He had decided to retire in June 2015, and colleagues and staff in the Botany Department had organized a reception at the UBC Botanical Garden in his honor. Sadly, 2 weeks before the party, he was hospitalized and died from a rare form of cancer of the blood vessels. His wife Dian and her family, many friends, and colleagues came together at the Botanical Garden to remember Fred. Although this was a sad occasion, the tribute to Fred included much music and many stories. One remembrance was of Fred’s humor and enthusiasm and his debut at the OSU football stadium.

Although he claimed to never have watched an entire OSU Buckeyes football game, Fred had a starring role in one of a series of video advertisements played on the OSU stadium screens. In his ad, Fred was decked out in a lab coat and bright yellow rain boots and filmed walking through a greenhouse gesticulating wildly and saying things about stomata and cell communication and Arabidopsis as the caption and voiceover proclaimed “Really Smart People, Doing Really Smart Things.” The idea, one supposes, was to both promote and poke fun at the academic eggheads during the sport, but you could tell Fred was in on the joke and enjoying every single second of it.

**LITERATURE CITED**


Li M, Sack FD (2014) Myrosin idioblast cell fate and development are regulated by the Arabidopsis transcription factor FAMA, the auxin pathway, and vesicular trafficking. Plant Cell 26: 4053–4066


Dominique Bergmann  
Dian Clare  
Lacey Samuels  
John Z. Kiss  
0000-0003-0873-3543 (D.B.).