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1	Article Title	A cell biologist on Mars—the exotic world of algal cells	
2	Article Sub- Title		
3	Article Copyright - Year	Springer-Verlag Wien 2013 (This will be the copyright line in the final PDF)	
4	Journal Name	Protoplasma	
5		Family Name	Nick
6		Particle	
7		Given Name	Peter
8	Corresponding	Suffix	
9	Author	Organization	
10		Division	
11		Address	Karlsruhe, Germany
12		e-mail	peter.nick@bio.uka.de
13		Received	
14	Schedule	Revised	
15		Accepted	
16	Abstract		
17	Keywords	separated by ' - '	
18	Foot note information		

A cell biologist on Mars—the exotic world of algal cells

Peter Nick

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In his famous book “An anthropologist on Mars,” Olivers Sacks presents exotic cases of neural disorders, and while describing the seemingly extraterrestrial world of these patients, he unveils the hidden wonders in the brain of the “normal” majority. In the history of science, very often, the fascination for the abnormal, exotic and mysterious has paved the way for a deeper understanding of the apparently “conventional.” Cell biology is no exception to this rule. It seems that the era of channelling towards a few model systems accessible for molecular approaches is now progressively replaced by a wider approach towards the variations of life. The renewed interest for “off-track” models is certainly fuelled by the advances in sequencing technologies that allow molecular insights even for models carried by only smaller research communities. Why are these “off-track” models important for science? New complex traits, such as new morphogenetical programmes, physiological achievements or metabolic pathways seem to emerge mainly from functional shifts of the underlying cellular and molecular events. These shifts would not be possible in systems where a function is exactly fitted to its current function. However, to quote a famous metaphor by François Jacob (1977), evolution is tinkering (and therefore neither design nor intelligent...), which means that most proteins are not exactly fitted, but in addition to their main function, maintain the ability for other hidden functions. In a different functional context, these moonlighting functions (Kurakin 2005) can take the lead. The heterogenous group of “algae” comprising highly diverse life forms with a mostly phototropic lifestyle provides good examples to illustrate the case, and the study of these seemingly extraterrestrial models might help us to get track of one or the other “moonlighting function” hidden in the cell biology of “higher” life forms. The current issue assembles several fine examples of algal cell biology:

The tinkering approach of evolution is neatly illustrated by the generation of new life forms through endocytosis. The review by Stork et al. (2013) in the current issue gives a survey on the

current state of the highly dynamic and highly controversial field of secondary endosymbiosis with green or red algae (that unlike stated in the last editorial to the current state of knowledge arise from primary endosymbiosis, as stated by attentive readers). Secondary endosymbiosis gave birth to many important groups of “algae” including heterokontophytes (for recent review, see Beakes et al. 2011), haptophytes, cryptophytes, and flagellate parasites. A core element for the functional integration of formerly independent organisms into a novel supraorganism is the protein transport across the membranes between the symbiotic partners. Especially the transport across the second outermost plastid membrane that is derived from the former endosymbiont represents a major challenge. The review shows how the ER-dependent degradation machinery of the endosymbiont was remodelled and relocated to generate a novel transport machinery carrying the new task of importing proteins across the former cell membrane. Thus, evolution is not only “tinkering” by recycling pre-existing machineries into a new functional context, evolution apparently is also playing with modular “LEGO” bricks of function. The challenge will be to understand how tinkering is reflected in the networks of gene regulation.

One of the most mysterious and fascinating groups of “algae” are the diatoms that are treated by even two research publications in the current issue. Already by their lifestyle as pure diatoms, they appear a bit alien within the plant kingdom and their mysterious mode of locomotion, as well as their beautiful silica shells (that have inspired art and architecture alike) support the impression of a highly exotic form of life. Although minute in size, diatoms are of global impact and account for an estimated one fourth of the global cycles for silicium and carbon. Despite this impact, the question, how the unique, filigrane and species-specific silica patterns (the so called *frustulae*) are actually formed, has remained enigmatic. It was in this journal, where for the first time the electron microscopical detection of minute particles in the cytoplasm of diatoms was reported and these particles were proposed to represent transport vesicles for silicon (Schmid and Schulz 1979). This observation is now revisited by the work of Annenkov et al. (2013) in the current issue, but using a fluorescent dye specific for growing siliceous frustulae such that the function of these vesicles could be addressed by life-cell

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87 imaging. They used silicon starvation to achieve a synchronisation
 88 of silicon deposition—a simple, but smart approach from
 89 classical physiology to resolve the temporal sequence of causal
 90 chains. They can show that within minutes after readdition of
 91 silicon together with the specific dye, fluorescent vesicles appear
 92 in the cytoplasm and subsequently disappear again while sili-
 93 ceous valves are deposited. This study not only supports the
 94 classical hypothesis by Schmid and Schulz (1979) that the cyto-
 95 plasmic particles are silicon transport vesicles but also resolves a
 96 two-stage mechanism of rapid Si uptake followed by a slower
 97 deposition of silicon into the growing frustulae. A second mys-
 98 tery of diatoms, their enigmatic mode of locomotion, is addressed
 99 by the work of Wang et al. (2013) in the current issue. Again, the
 100 starting point was an observation published in this journal (Edgar
 101 1983): diatoms moving over benthic surfaces secrete consider-
 102 able volumes of mucilage, and the so called Edgar model as-
 103 sumed that motility is generated by a conformational change of
 104 the adhesive mucilage during its secretion. The direction of
 105 secretion was thought to be confined by actin to one end of the
 106 cell such that it is pushed forward. This model, although
 107 appearing plausible, suffers from several weak points that stim-
 108 ulated the authors to search for a better model. For instance, it
 109 is not clear how sign reversals of movement might be generated by
 110 the Edgar mechanism. The authors analysed cell structure, move-
 111 ment, mucilage and bending deformation for the benthic pennate
 112 diatom *Navicula* and come up with a new model, which is also
 113 supported by biophysical modelling, where pseudopodia pro-
 114 trude from the frustulae attach to the surface through secreted
 115 extracellular polymers and where other pseudopodia push
 116 against the substrate providing the driving force for locomotion.
 117 Brown algae harbour the most differentiated life forms among
 118 the algae and can produce highly sophisticated architectures. Due
 119 to this complexity, these architectures have to be tuned with
 120 respect to their environment mainly with the distribution of light
 121 in their benthic habitat. Therefore, the zygotes and spores of
 122 brown algae are photosensitive and adjust axis and polarity with
 123 the direction of light during a photosensitive period. The
 124 photopolarisation of the *Fucus* zygote has been extensively
 125 studied in the second half of the last century and led to a model,
 126 where light-triggered calcium currents drive a transcellular gra-
 127 dient of actin-dependent calcium channels such that initial weak
 128 gradients are self-amplified into a robust polarity by a process
 129 that had been termed “self-electrophoresis.” A drawback of
 130 *Fucus* system has been the lack of molecular information and
 131 during the abovementioned channelling upon few models; this
 132 beautiful system for cellular development has been mostly aban-
 133 doned. It seems that the new move towards genomics of “off-
 134 track” models will also bring a renaissance of brown algae as
 135 systems for plant development. The related species *Ectocarpus*
 136 *siliculosus* has been sequenced and is currently pushed as new
 137 genetic model. Here, the mitospores can be polarised by light in a
 138 manner that resembles the situation in the *Fucus* zygote. The
 139 work by Green et al. (2013) in the current issue investigates the
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role of microtubules in polarisation. They show that pharmaco-
 logical manipulation of microtubules impairs polarisation, an
 even stronger inhibition can be produced by inhibitors of vesicle
 flow. By confocal microscopy, they visualise a radial array of
 microtubules emanating from an organelle that resembles a
 centrosome and is localised close to the nuclear rim. Upon
 germination, this array gives rise to longitudinal microtubules
 that reach into the bulging filament. Within the filament, mitotic
 spindles are aligned with the axis of growth. The characterisation
 of these cellular events is important as phenomenological frame-
 work to interpret phenotypes for future studies on the functional
 genetics of polarity induction. *Ectocarpus* differs in a curious
 detail from the classical *Fucus* system: polarity induction in
Fucus is a matter of actin and microtubules seem to be
 dispensible in this context. In the *Ectocarpus* system, it is
 microtubules that take the lead—the authors suggest that this
 difference might be linked with the presence of a centrosome in
 case of the *Ectocarpus mitospores*, whereas in *Fucus*, the cen-
 trosomes are paternally inherited (Motomura 1994). This detail
 shows that even in cell biology, often perceived as science
 searching for general laws, details and particularities of models
 are relevant and can when they are seriously considered by
 comparison allow for new mechanistic insights (a topic
 addressed in a previous editorial, Nick 2009).

Conflict of interest The author declares that there is no conflict of interest.

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