

The Fifth Mathematics in the Plant Sciences Study Group – January 3-6 2012

Dynamic modeling of cell shape during oscillatory pollen tube growth

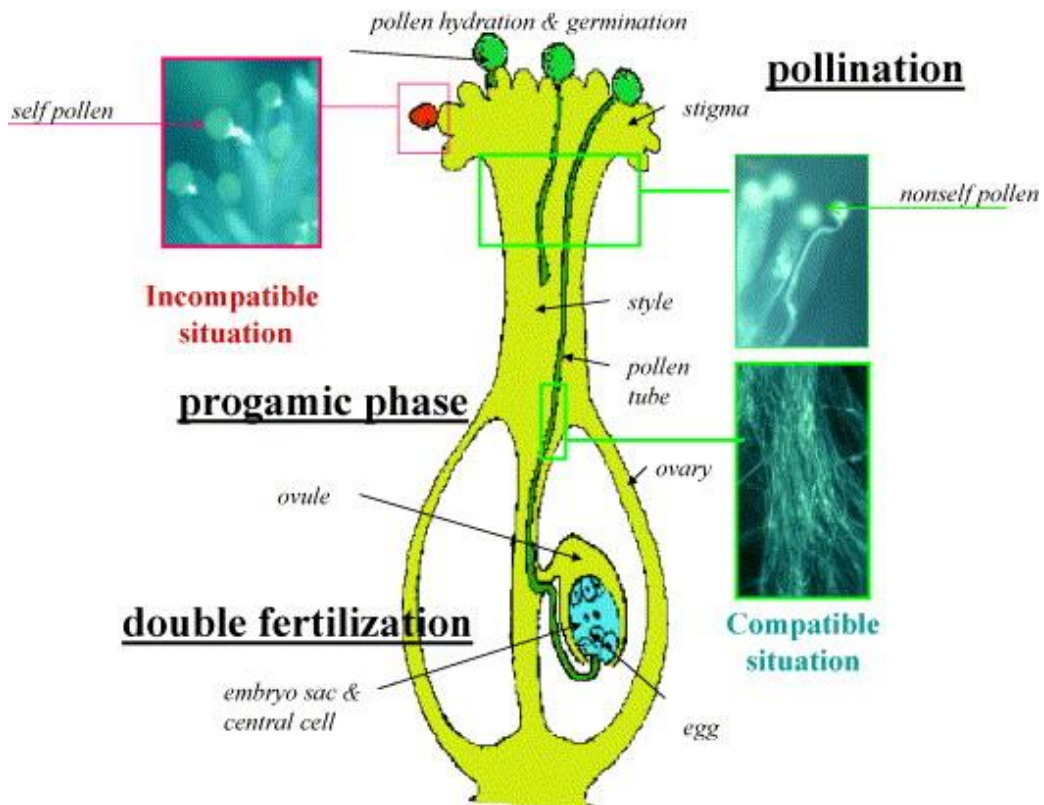
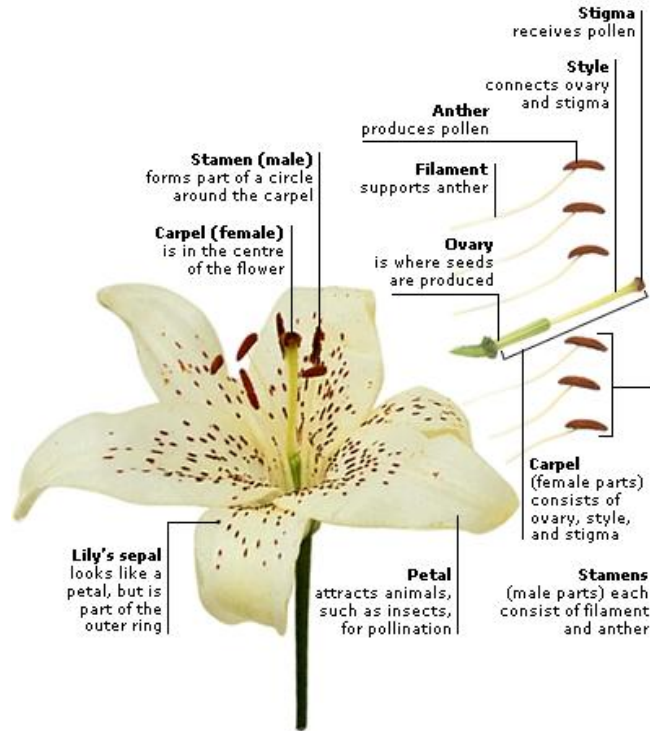
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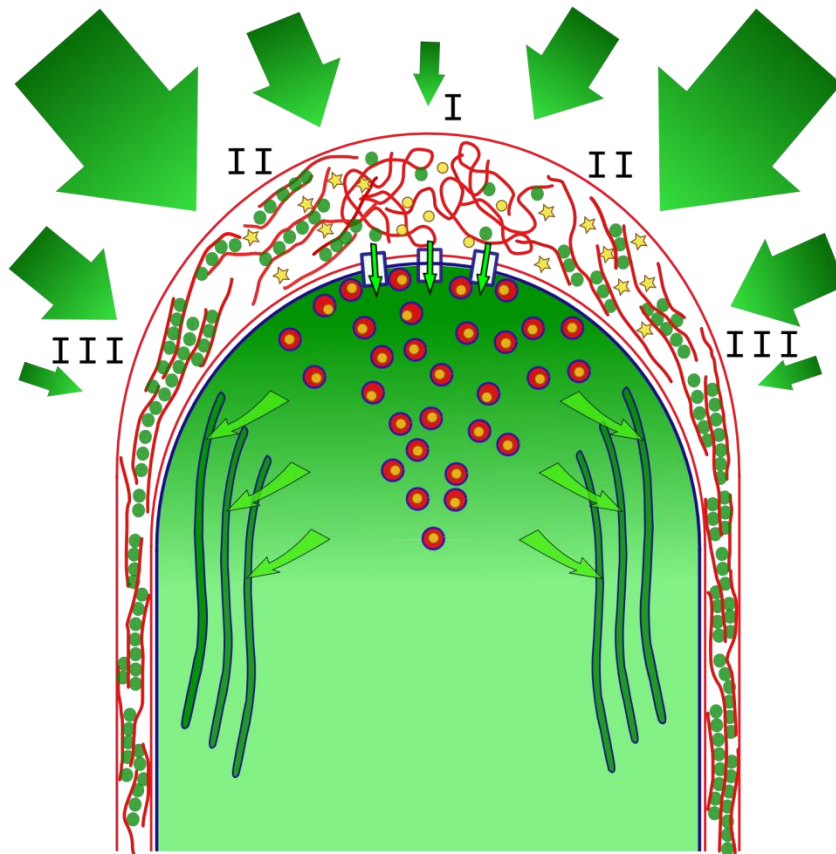
The System

“Pollen tube” is the name given to the long, thin cell that grows out of a pollen grain when it germinates. In fertilization of flowers, pollen carries the “male” genome from the anther to the stigma, where the pollen germinates and the pollen tube grows down the style to the ovary. The pollen tube plays a crucial role, creating path for the sperm nuclei to reach the egg, deep inside the flower. The tube ultimately bursts, releasing the sperm nuclei so that they can fuse with the egg cell, creating an embryo that ultimately becomes a seed inside a fruit. Besides being a vital link in our food chain, the pollen tube is quite easy to study and so has become the subject of a large, diverse research literature.











Pollen tubes grow by tip expansion coupled with secretion (exocytosis) of new wall material, mainly pectins. The driving force for growth is internal pressure, generated by a gradient in salts across the cell membrane. The internal force is balanced by tensile strength of the wall and the local rate of expansion is a function of local wall properties.

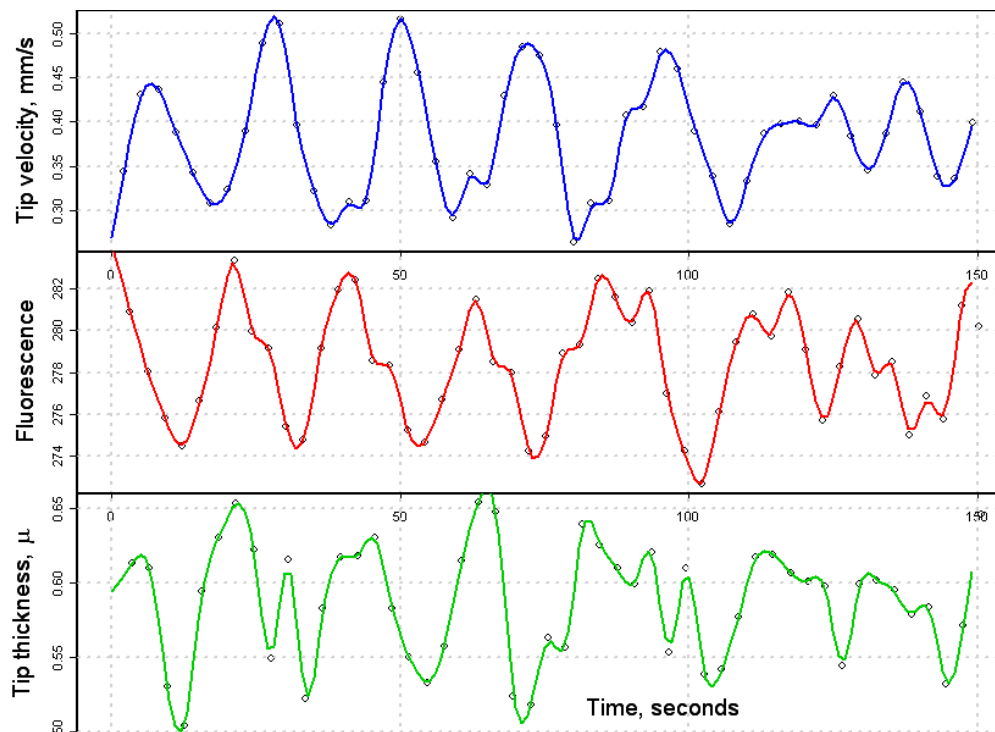
Pectins are polymers of acidic sugars secreted in an esterified form, with a methyl group attached to each acid group. An enzyme called Pectin Methyl Esterase is secreted with the pectins and over time removes the methyl groups creating negative charges that bind to calcium entering from the medium. Once cross-linked, pectins are more resistant to tensile stress in the wall. We think this may be the main mechanism by which pollen tubes control local expansion rates.



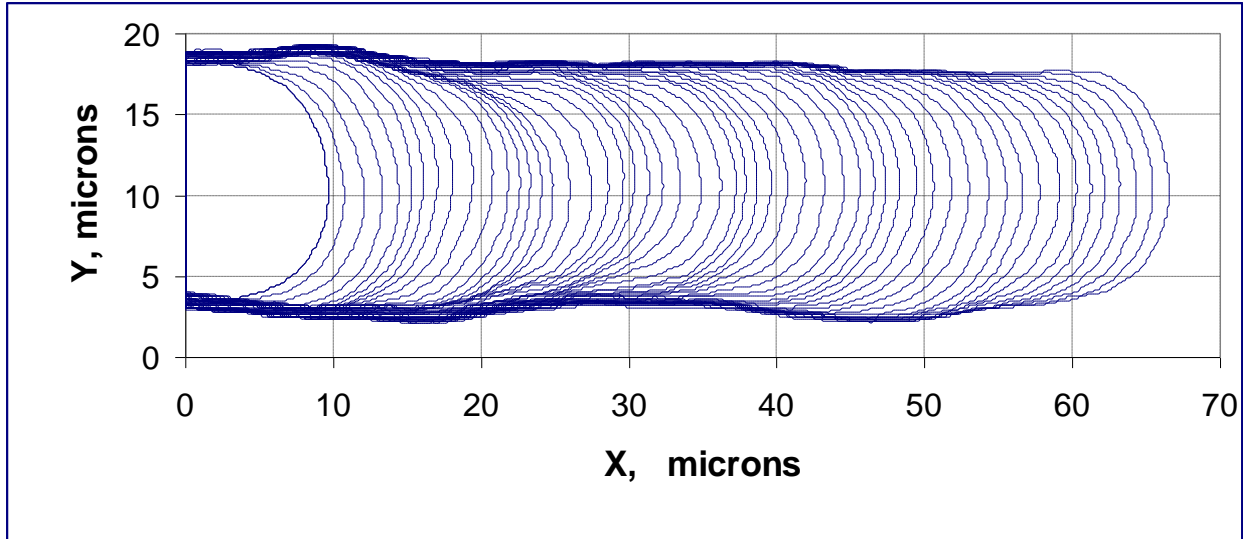
LEGEND

-  Calcium Flux
-  Calcium Ion
-  E.R.
-  Pectin chain
-  Pectin Methyl Esterase, active
-  Pectin Methyl Esterase, inactive
-  Secretory vesicle
-  Stretch-activated Channel

In culture and *in vivo* growth can be very rapid, and typically, in culture, develops a stable oscillatory pattern. Growth rate alternately accelerates and decelerates with a period of 25 to 40 seconds and with high amplitude. We have used these stable oscillations as a way to unravel the connections between cellular processes, trying to determine both the sequence of events in wall expansion and also the regulatory feedback mechanisms.



Several published models of tip growth have successfully replicated the shape of the tube tip and oscillatory growth, and have incorporated a variety of different feedback mechanisms. In all cases, these models have assumed a self-similar tube shape that does not change during growth. In our hands, oscillating pollen tube tips actually display a distinct pattern of shape change during growth, from oblate to spherical and sometimes all the way to prolate and then back again. We think these shape changes might be used to correlate with measurements of other properties, such as vesicle densities and locations, internal ion gradients, actin density, and propidium iodide staining (relates to calcium binding) as a way to understand the regulation of cell wall expansion during tip growth.



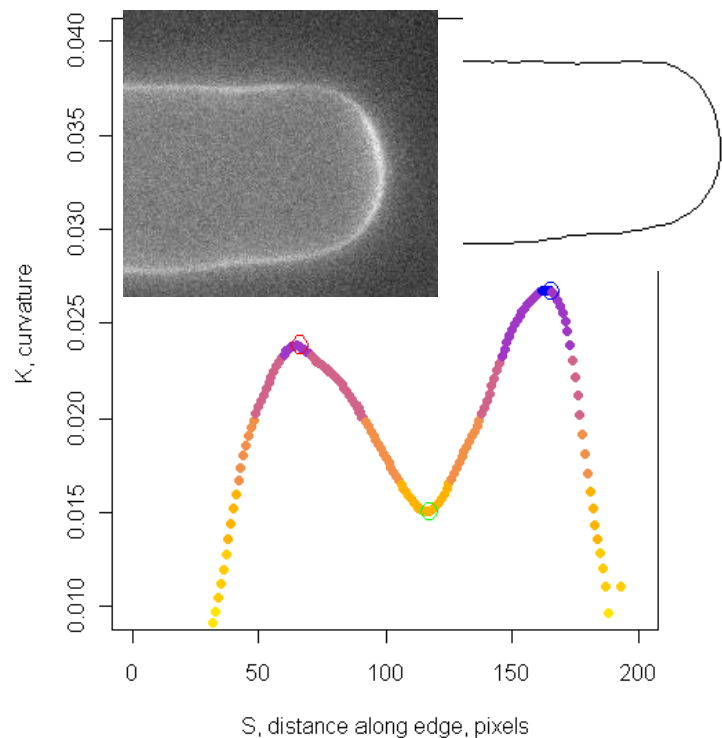
Outlines of a pollen tube during oscillatory growth.

From basic principles of stress and strain in thin shells, we can estimate local stress in the wall quite well from the local curvature, an estimate of thickness (from electron micrographs) and pressure. We assume pressure is isotropic and constant (well substantiated in the literature) so local relative rates of expansion must be solely a function of geometry and wall properties. Put another way, for the shell to become locally more flattened (less curvature) that zone must be “stiffer” than other parts of the dome.

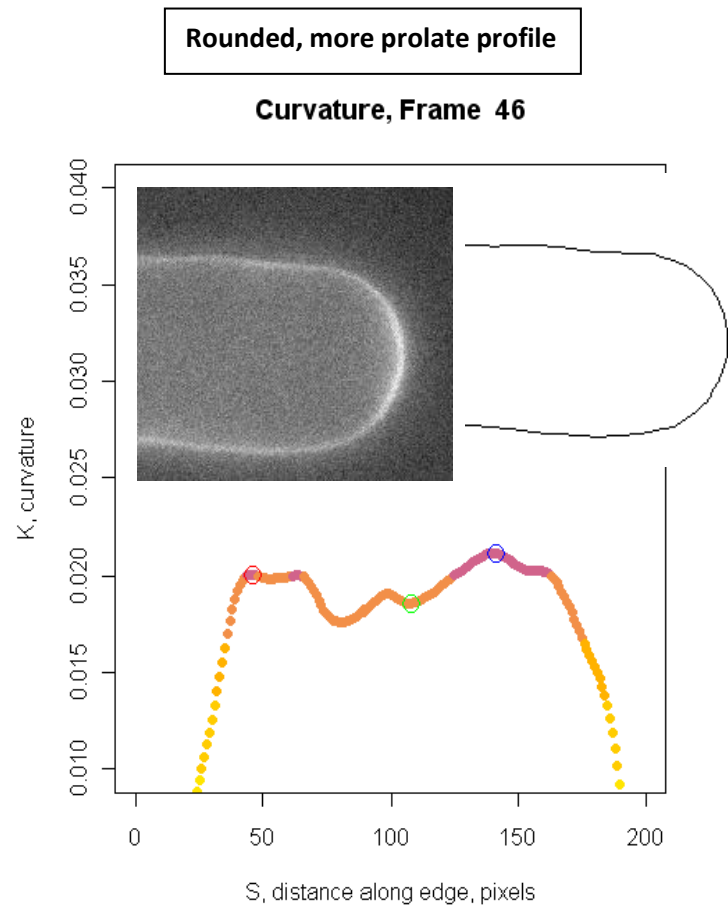
Conversely, to become more curved, and to bulge out, that zone must be more extensible or “softer.” It is almost as if there is a process “painting” the underside of the dome with pectin or other substance that enters the wall and causes local changes in extensibility, and that this imaginary painter moves back and forth across the dome as growth accelerates and decelerates. Alternatively, rates of pectin modification and calcium binding in the wall may contribute spatial and temporal patterns that influence expansion rates. Regardless of the mechanism that controls wall stiffness, the spatial pattern of curvature must relate to the spatial pattern of expansion.

Flattened, oblate profile

Curvature, Frame 55



The process of shape change is also constrained in at least two important ways. The wall does not shrink, so flattening of one area means that the surrounding area expanded more rapidly. A bulge implies a locally “softer” region. The base of the dome retains a quite constant diameter, implying a consistent temporal and/or spatial pattern of local stiffening. We also have experiments which stop and start expansion in interesting ways, and the patterns of shape change and relative expansion rates in those experiments may also be very illuminating.



Work to Pursue

1 – I would like to develop a more sophisticated and hopefully realistic picture of changes in wall stress in 3 dimensions as cells grow and oscillate, based upon an analysis of curvature in R3.

2 – I want to pursue the notion that only a certain set of local expansion rates on the surface of the pollen tube can account for the changes in shape we observe. If we can even narrow the range of possible local expansion rates at a given location on the tip we can compare them to wall stress and thus build up a 3 D map of wall viscosity over time. The final step would be to compare changes in wall properties to other cytological features and perhaps to an improved model of the pollen tube wall.

3 – I would like very much to think about what kinds of wall structures would allow for the features in items 1 and 2 above. That is, how do methoxylated HGI, de-methoxylated HGI, and calcium ions interact to provide both the strength to withstand 0.4 MPa and the viscous flow to grow so rapidly? Is there a role for cellulose or other polysaccharides in the structure of the pollen tube tip? Some sort of composite material?