

Single pollen grain of chamomile (*Matricaria recutita* L., Asteraceae)  
(SEM, critical point dried, magnified 9,313 times actual size).

# A Closer Look

## Secretory Structures of Aromatic and Medicinal Plants

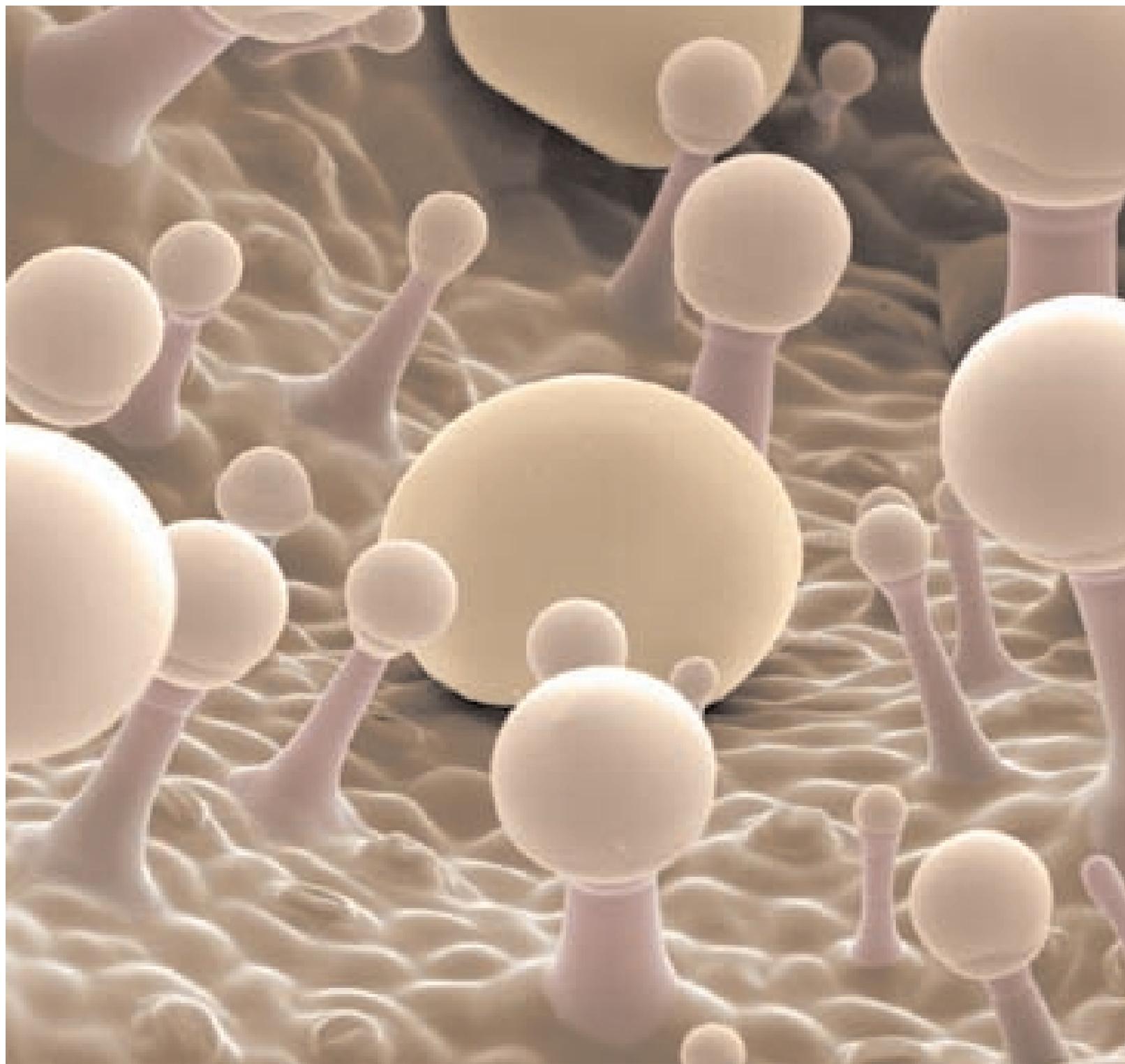
*Editor's note: The following images and text are excerpted and adapted from Secretory Structures of Aromatic and Medicinal Plants: A Review and Atlas of Micrographs. The text was written by Katerina P. Svoboda, Ph.D., and Tomas G. Svoboda. Andrew D. Syred created the stunning micrograph images. Polly M. Syred designed and edited the book. In keeping with HerbalGram's educational mission, we share these images to carry classical pharmacognosy to a deeper level of detail through the modern technology of scanning electron microscopy. We also share images of these plants as they are usually seen with the naked eye, and through the camera lens of Steven Foster. Examining plant structures not only helps to differentiate between species to assure proper identification, but it also brings a clearer understanding of these beneficial, and beautiful, life forms.*

For thousands of years, plants have provided humanity with many of the basic and important materials required for day-to-day living, including oxygen, food, clothing and timber, as well as being a source of compounds such as oils, resins, rubbers, gums, dyes, pesticides, and drugs. Plants might be considered biochemical factories that have been evolving over the last 440 million years. Researchers elucidate chemical pathways and various industrial applications of plant products, and anatomical description is one of the most important aspects of economic uses of these plants. Clearly, we should also safeguard and conserve the diversity of our planet's flora and consider carefully our exploitation of plant resources.

Plant chemistry became an established university discipline at the end of the 19th century; since then many new structures have been discovered. The number of natural products obtained from plants exceeds 100,000 and each year new chemical compounds are discovered. Although the functions of some plant chemicals have not been fully established, it is known that some regulate growth while others are involved in pollination and seed dispersal, or serve as antifungal or defense agents. Still others are involved in mutually beneficial (symbiotic) associations with other organisms, such as the partnership between plants that provide food and shelter to bacteria in their roots that convert nitrogen from the air into ammonia fertilizer, fungi that help the plant's roots to absorb more water and minerals, or ants living in the branches that protect and help nourish the plant.

The complex nature of these chemicals, which are usually produced in various types of secretory structures, is also influenced and controlled by genetic and ecological factors, and, significantly, by the mode of extraction from the plants. The type of secretory structure is an important and differentiating characteristic of many plant families. Detailed anatomical description of these structures is relevant to the market value of the plants, the verification of authenticity of a given species, and for the detection of substitution or adulteration. It also provides a guide to the method of processing.

Microscopic investigation of plant structures is an important part of the complex biological research process that includes plant growth and development, genetics and breeding. Observing the endless variability in form and structure with the microscope allows us to discover Nature in one of its most powerful forms.



Andrew Syred operates the scanning electron microscope.

### Microscopy 101

Plant material received for these investigations was chemically-fixed and critical point dried (CPD) for scanning electron microscopy (SEM) or cryogenically fixed for Cryo-SEM. Neither technique is ideal for all purposes since each has its own limitation and risk of introducing artifacts. By employing the two methods, these difficulties were reduced to give a clearer understanding of the structures. SEM allowed high magnifications together with improved depth of field, giving an overall view of the structures. Since SEM is incapable of recording color, all images produced using this method were manually enhanced using computer techniques.

Clary sage (*Salvia sclarea* L., Lamiaceae) showing stalked and sessile secretory glands on the calyx trichomes (Cryo-SEM, magnified 752 times actual size).

## Secretory Structures in Plants

Plant chemicals are classed as primary or secondary metabolites. Primary metabolites are biochemicals that are essential for plant growth and survival. Universally present in all plants, they include sugars, amino acids, nucleic acids and the chlorophylls. Secondary metabolites make up the remaining plant chemicals, from alkaloids to phenols, and are probably found in all plant species.

Essential oils are complex, volatile mixtures of certain secondary plant metabolites. A wide range of plant species — including annual, biennial or perennial herbaceous plants, evergreen or deciduous shrubs and trees — produce essential oils. The ecological and evolutionary role of secondary metabolites has been associated with defense against animals, healing of plant organ wounds, protection from harmful insects, resistance to microbial attacks, and attraction of insects and animals for pollination. Several species and varieties of plants, mostly those of commercial interest, have been investigated systematically and in depth. Recently, research groups in university biological and pharmacological departments have undertaken various studies concerned with secretory structures and factors influencing their development.

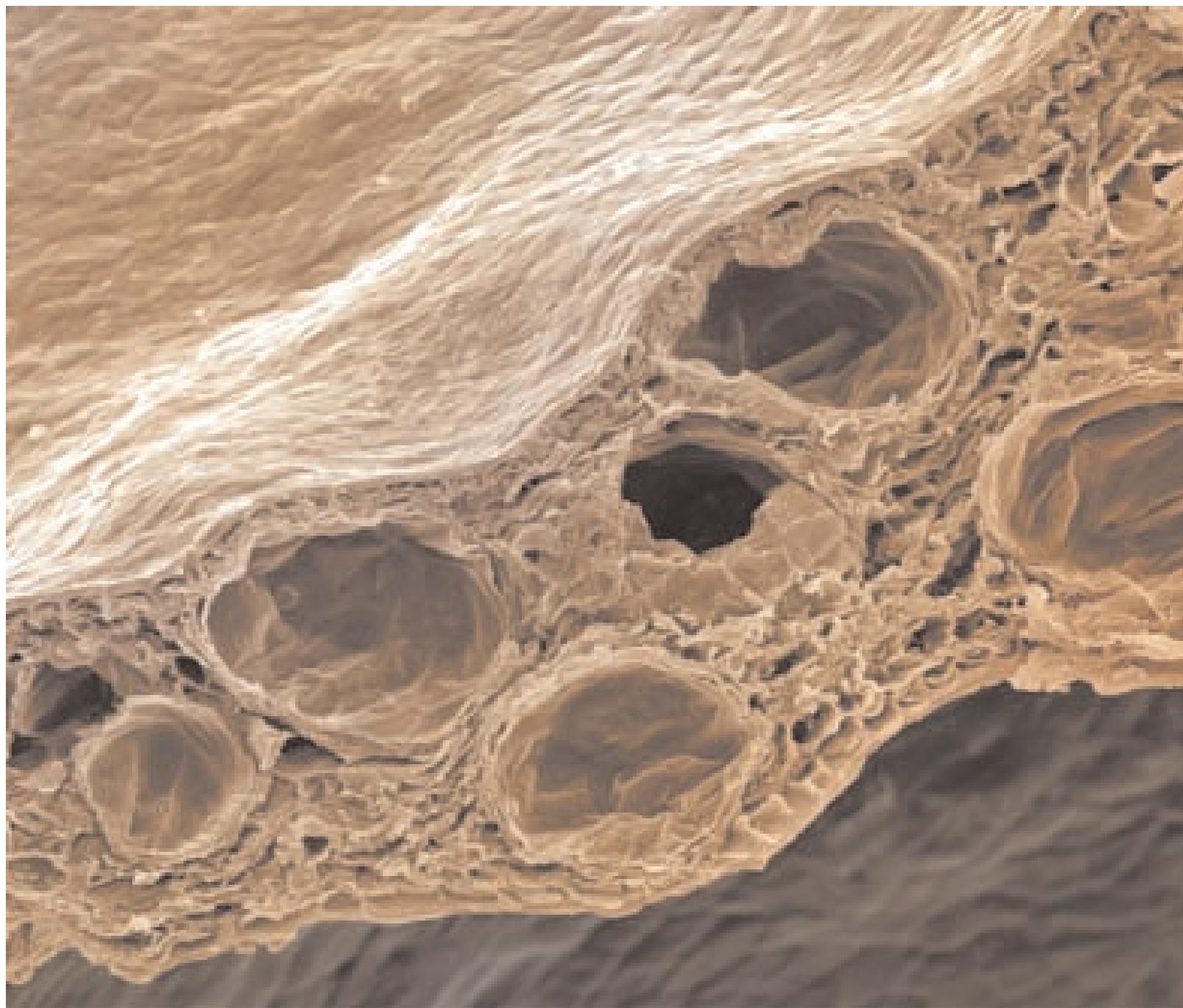
A common feature of living cells, secretion involves the discharge of substances to the exterior (exotropic secretion) or into special intercellular cavities (endotropic secretion). The secreted material may contain various salts, latex, waxes, fats, flavonoids, sugars, gums, mucilages, essential oils and resins. It has been assumed that these products are biosynthesized *in situ*, and direct evidence for the biosynthetic capacity of gland cells has become available recently with the development of procedures for gland isolation. These methods have yielded definitive proof of the presence of enzymes specifically within gland cells.

Trichomes (described below) present on the leaf surface and other secretory tissues can be examined using light, scanning, and transmission electron microscopy, which enables detailed observation of major stages in the development of secretory cells, including their membrane system and nuclei, the overall size of the gland, and the amount of material released into the subcuticular cavity.

Essential oils, with or without accompanying resins and gums, are most commonly found in special secretory structures either on the surface of the plant or within the plant tissues. The type of structure is specific to the family or species. This can be useful to identify plant material and verify the authenticity of the plant source in the case of suspected adulteration.



Clary sage blossom  
Photo © 2001 stevenfoster.com



The dried petal of clove (*Syzygium aromaticum*, (L.) Merr. & L.M. Perry, Myrtaceae), showing its many endogenous oil glands (SEM, CPD, magnified 607 times actual size).



Clove fruit Photo © 2001 stevenfoster.com

## Secretory cells

The simplest secretory structure is a single secretion-containing cell where it is only the actual content that distinguishes it from adjacent non-secretory cells. However, it may also be larger than the other cells or have a thick cuticularized lining. This cell type is found in many different plant tissues, such as in the rhizome pith and cortex of ginger (*Zingiber officinale* Roscoe, Zingiberaceae) and in the perisperm and embryo of nutmeg (*Myristica fragrans* Houtt., Myristicaceae).

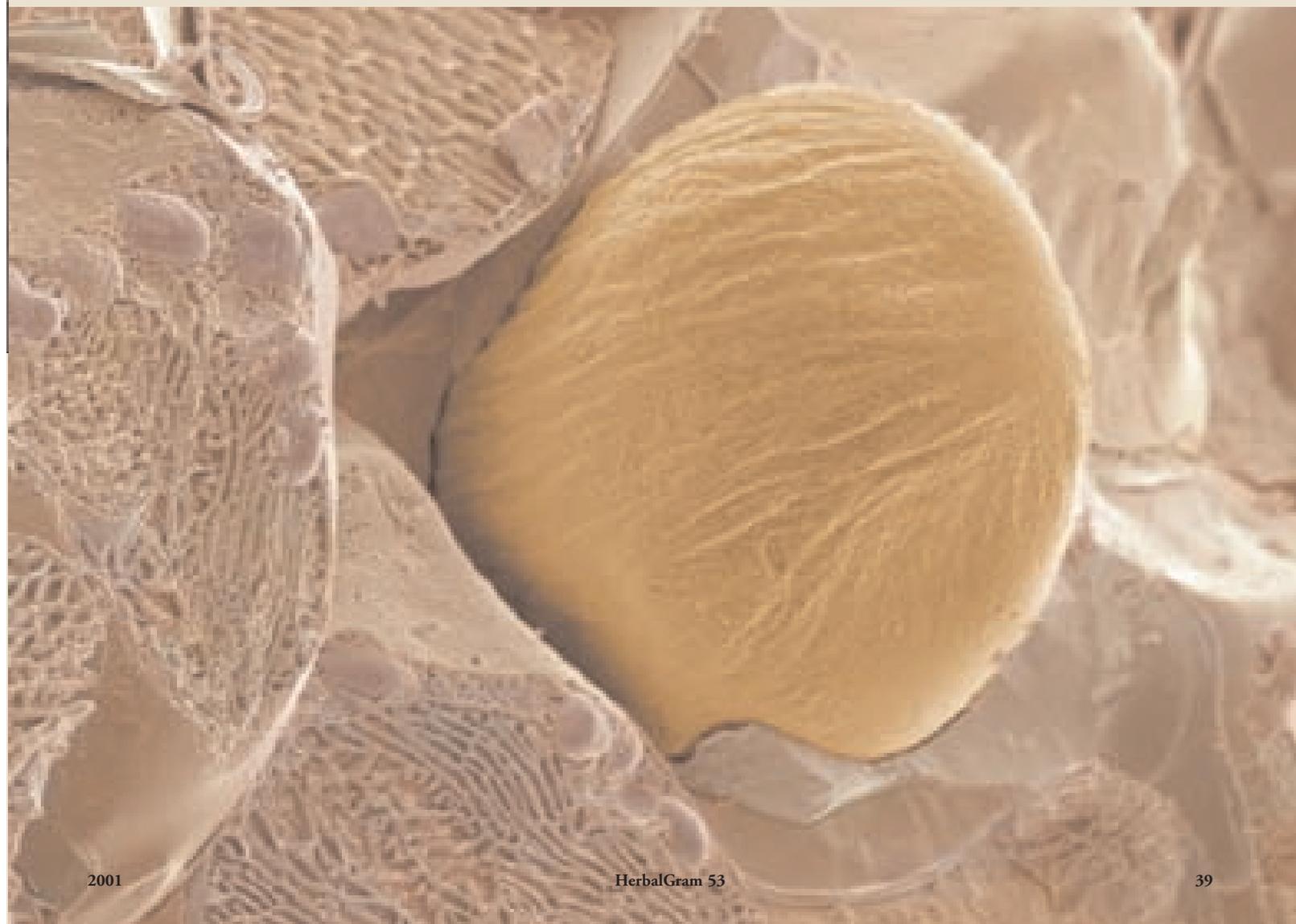
## Secretory cavities

These cavities are more or less spherical structures that can be formed in two ways: the parenchyma cells (i.e., the soft plant tissue composed of thin-walled, relatively undifferentiated cells that may vary in structure and function) can separate one from another, leaving intercellular spaces called lumina or lacuna, or an actual cell can disintegrate and leave a cavity within the tissue. These spaces are lined with secretory cells, or an epithelium, that produces the essential oils. In high oil-yielding plants, several layers of these secretory cells are formed. The cavities continually enlarge and some become filled with cells with thin, convoluted walls that also store the oil produced from within their plastids (a class of cytoplasmic organelles). Included in this group are fruits and leaves of plants in the Citrus family (Rutaceae) as well as *Eucalyptus* spp. (Myrtaceae). Secretory cavities are also present in the flower buds of cloves (*Syzygium aromaticum* (L.) Merr. & L.M. Perry, Myrtaceae), and in the elongated cavities in the bark of frankincense (*Boswellia* spp., Burseraceae).



Dried ginger rhizomes  
Photo © 2001 stevenfoster.com

Rhizome of ginger (*Zingiber officinale* Roscoe, Zingiberaceae), showing oil globules within the membrane of its secretory cell (Cryo-SEM and etched, magnified 2,149 times actual size).



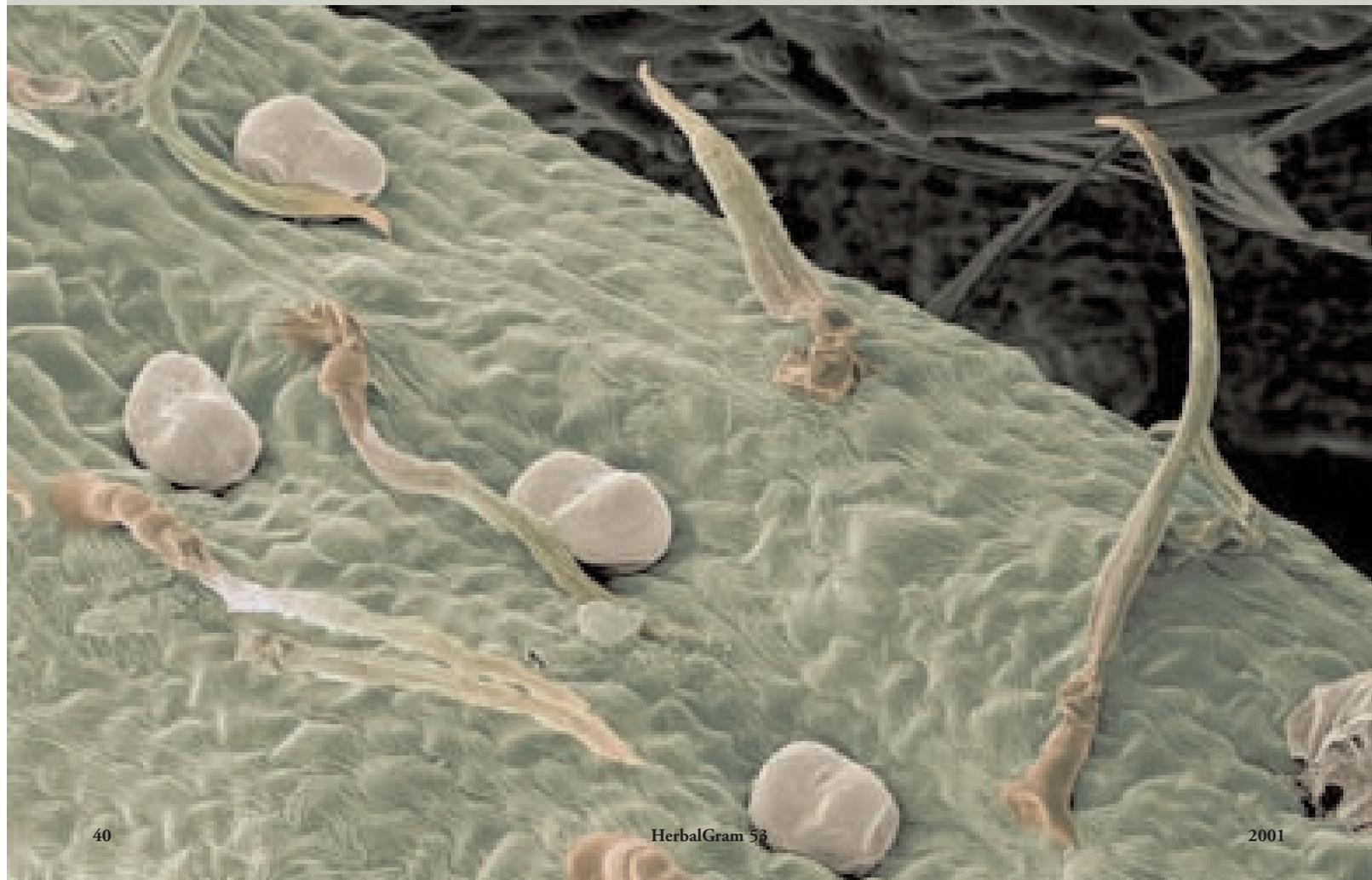
## Secretory ducts

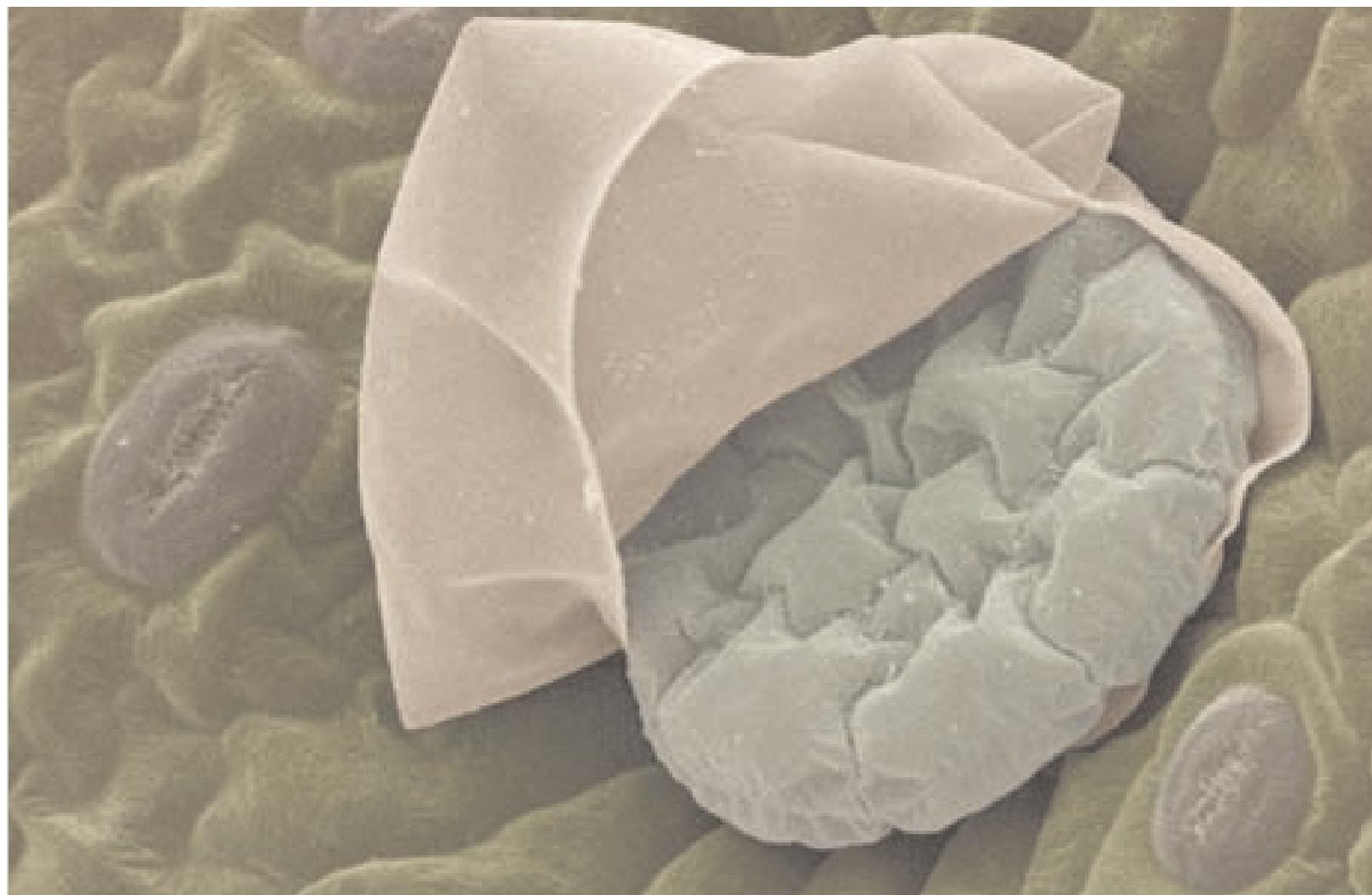


Roman chamomile flower  
Photo © 2001 stevenfoster.com

Ducts are elongated cavities. They can often branch to create a network extending from the roots through the stem to the leaves, flowers and fruits. They are composed of an epithelium that surrounds a central cavity. Several predisposed cells within the parenchyma undergo asynchronous division and in doing so, they expand the initial space in the middle, where the cells are adjacent, to form a cavity. Some of these cells forming the wall of the cavity will change into secretory epithelial cells. The oils are biosynthesized within their leucoplasts and move via the endoplasmic reticulum into the cavity. These cavities then become joined to form ducts. They can be found in all of the family Apiaceae (Umbelliferae) as well as the families Asteraceae (Compositae), Clusiaceae (Hypericaceae) and Pinaceae.

Upper leaf surface of Roman chamomile (*Chamaemelum nobile* (L.) All., Asteraceae) with sessile secretory glands and non-secretory trichomes (SEM, CPD, magnified 417 times actual size).





Sessile secretory gland on lower leaf surface of oregano (*Origanum vulgare* L., Lamiaceae) with ruptured cuticle revealing individual secretory cells. Nearby stomata are also clearly visible (SEM, CPD magnified 1,979 times actual size).

## Epidermal cells

Essential oils obtained from flowers are not usually secreted by glandular hairs but merely diffuse through the cytoplasm, the cell walls and the cuticle to the outside. The yield of essential oils from these species is generally very low. Examples include rose (*Rosa* spp., Rosaceae), 0.075% (w/v), acacia (*Acacia* spp., Fabaceae) 0.084% (w/v) and jasmine (*Jasminum* spp., Oleaceae) 0.04% (w/v).

Buds of numerous plant genera, such as *Aesculus* (Hippocastanaceae), *Alnus* (Betulaceae), *Betula* (Betulaceae), *Populus* (Salicaceae), *Prunus* (Rosaceae), and *Rhamnus* (Rhamnaceae), also secrete lipophilic substances, mainly flavonoid aglycones mixed with essential oils. Secretion here occurs from epidermal cells that are covered by a cuticle. The secreted material is first eliminated into a space formed between the outer walls of the cells and the cuticle covering them, forming a blister that subsequently bursts.



Oregano leaves  
Photo © 2001 stevenfoster.com

## Glandular trichomes

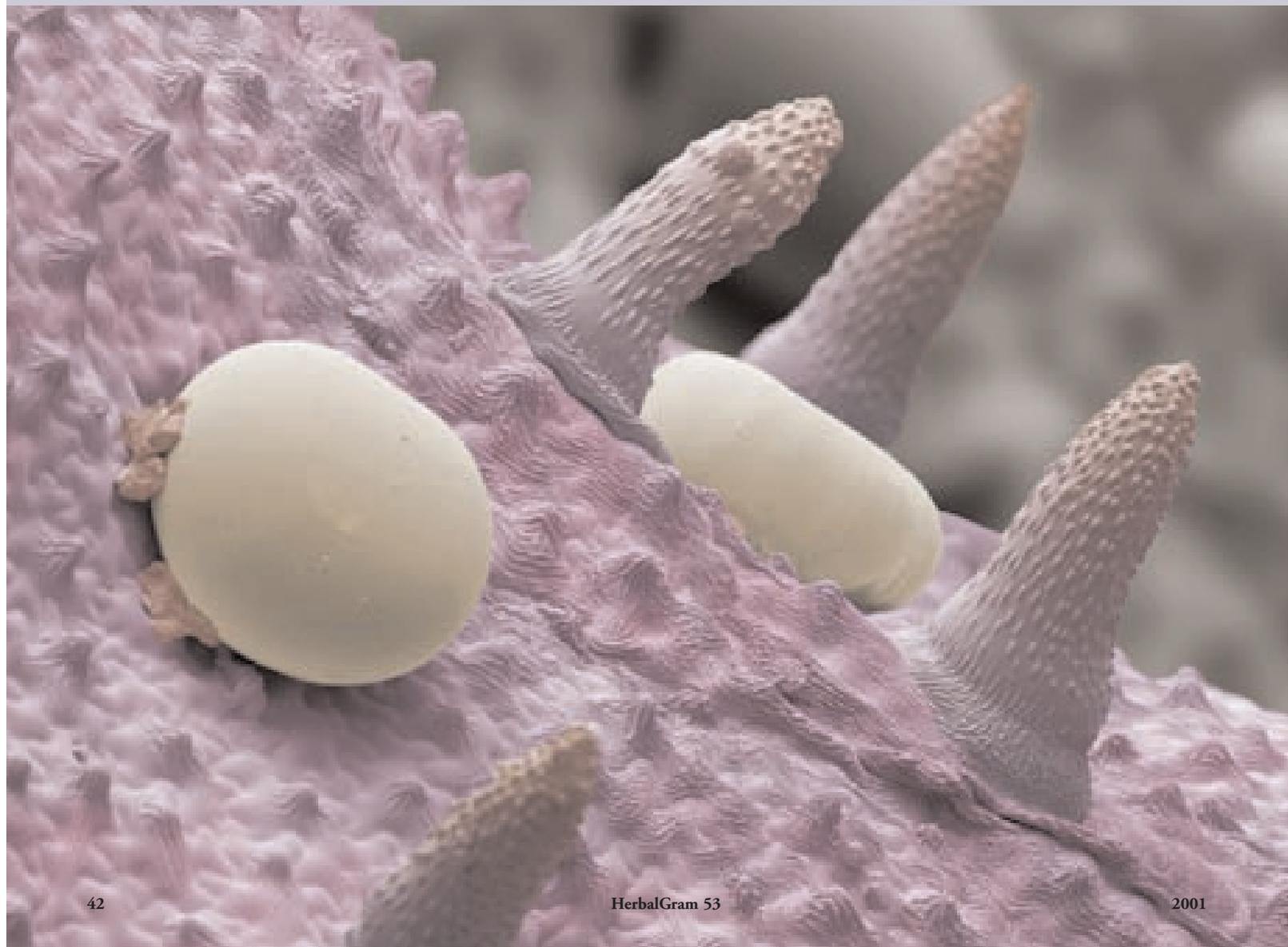
Glandular trichomes are modified epidermal hairs and can be found covering leaves, stems, and even parts of flowers such as the calyx in many plants of the Lamiaceae (Labiatae) family. These include lavender (*Lavandula* spp.), marjoram and oregano (*Origanum* spp.), and mint (*Mentha* spp.). The secretory cells are attached by a single stem or basal cell in the epidermis. The outer surface of the gland is heavily cutinized. A toughened cuticle, in which no pores or perforations are present, usually completely covers the trichome. The essential oils accumulate in subcuticular spaces and are thought to diffuse outwards through the cuticle. The glandular cells differ from normal plant cells in that they have a very large nucleus and dense protoplasm that lacks a large central vacuole. There are numerous plasmodesmata (i.e., cytoplasmic threads running through cell walls, connecting cytoplasm of adjacent cells) across the walls of the gland cells, especially between the stalk cell and the collecting cell. In the very young gland the intracellular organization is almost identical to that of the adjacent cells, but as the secretory cells develop, complex changes occur. The membrane system progressively degenerates and in the fully developed glands only a fine granular cytoplasm (i.e., the living cell parts within the membrane, except the nucleus) remains.

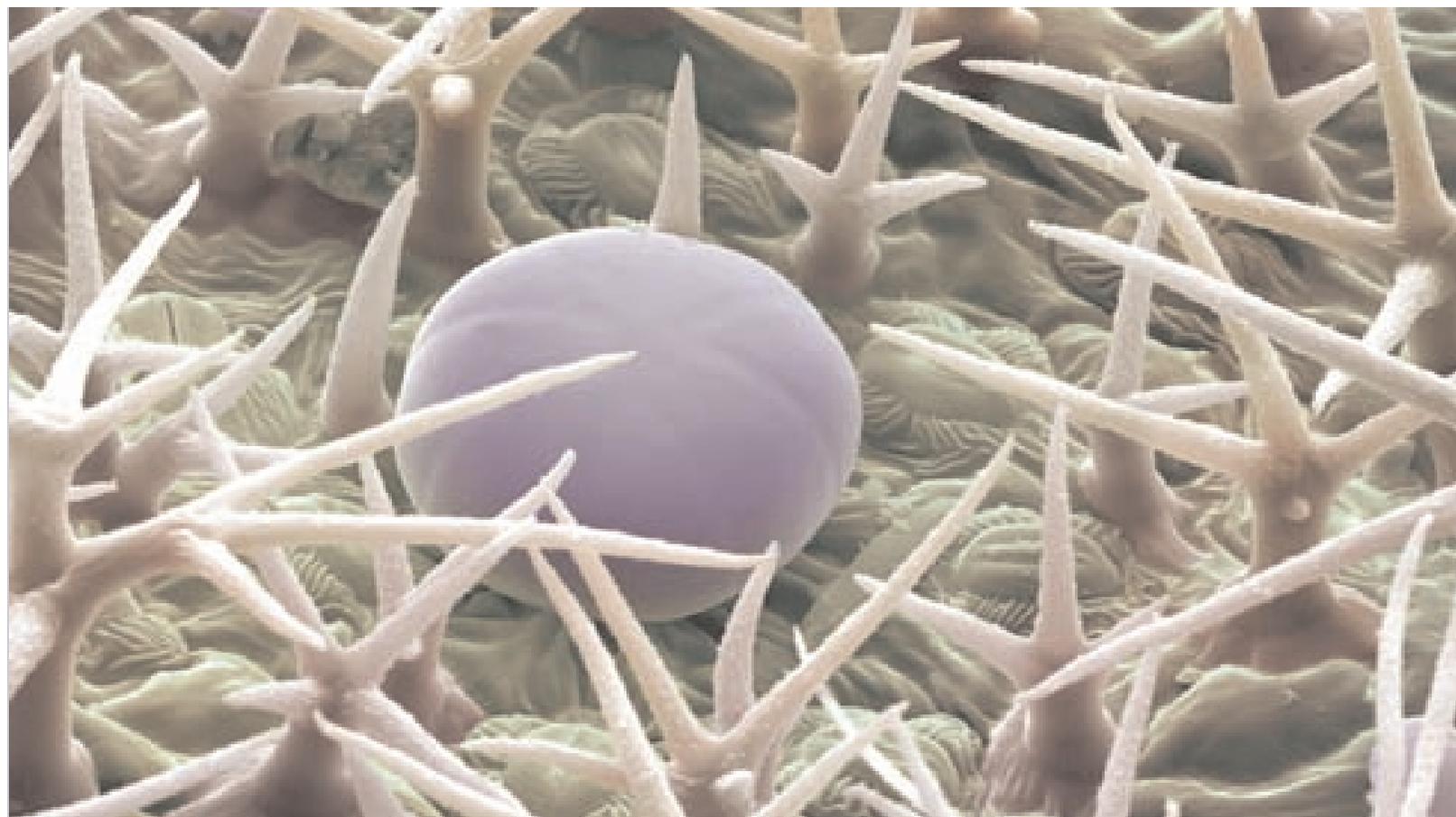


Peppermint leaves

Photo © 2001 stevenfoster.com

Detail of the calyx surface of peppermint (*Mentha x piperita* L., Lamiaceae), showing yellow rounded sessile secretory glands and pointed non-secretory trichomes (Cryo-SEM magnified 742 times actual size).





Detail of lower leaf surface of English lavender (*Lavandula angustifolia* Mill., Lamiaceae), showing a sessile secretory gland surrounded by non-secretory trichomes, which help to trap a layer of air around the leaf to reduce transpiration, or water loss (SEM, CPD magnified 931 times actual size).

**Katerina Pavla Svoboda, Ph.D.**

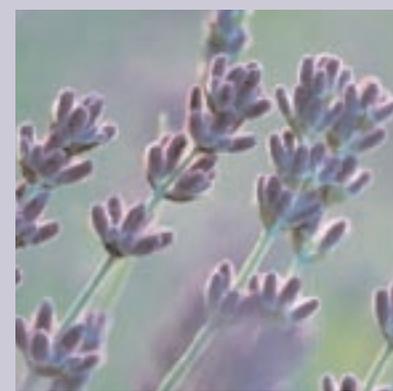
Dr. K. P. Svoboda lectures on plant anatomy, plant breeding and biotechnology at the Scottish Agricultural College (SAC), Auchincruive. She is also responsible for research on aromatic and medicinal plants, including botany, physiology, chemotaxonomy and the production of secondary metabolites and their application. Over the last 10 years she has published 78 refereed and general articles on aromatic and medicinal plants and has contributed more than 75 papers and posters to national and international conferences. She has traveled extensively in the course of her work and in 1992 spent a year in Japan.

**Tomas Galen Svoboda**

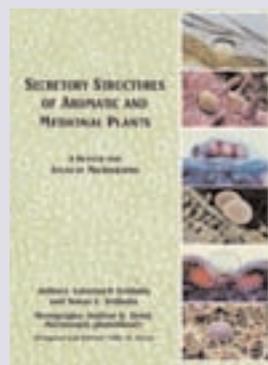
T.G. Svoboda is a second-year student at Medical University, Dundee. Interested in aromatic plants and essential oils, he has operated a large-scale distillation plant at a chamomile farm in Norfolk. He completed a project at Scottish Agricultural College on the phytochemical investigation and genetic fingerprinting of chamomile, and has contributed to several papers on various other aromatic plants.

**Andrew Syred**

A.D. Syred started Microscopix Photolibrary in 1986, producing stock images as well as commissioned images for such clients as educators, researchers, book and magazine publishers, TV producers, and advertising agencies. He produces micrographs from both light and scanning electron microscopes that are aesthetically beautiful as well as technically informative.



Lavender flowers  
Photo © 2001 stevenfoster.com



**Secretory Structures of Aromatic and Medicinal Plants: A Review and Atlas of Micrographs** by Katerina P. Svoboda and Tomas G. Svoboda. Micrographs by Andrew D. Syred. 2000. Secretory structures on plant tissues are responsible for producing and releasing aromatic components and essential oils, and are not ordinarily visible to the naked eye. This book presents anatomic descriptions of the various types of secretory structures (i.e., cells, ducts, trichomes, and cavities) and color plates of the microscopic structures. Features 36 light micrographs, 42 scanning electron micrographs, 64 pages in full color, 31 plant species, a glossary and an index of English and Latin names. Softcover, 60 pp. \$45. ABC Catalog #B495