Integument: Structure & Function

Terrestriality

- Insects are one of the few lineages to have successfully colonized terrestrial environments.
- What are some of the other major lineages?

Terrestriality

- What are some of the challenges that had to be overcome to evolve terrestriality?
- How do (e.g.) we cope with some of these challenges?

The integument

- The integument serves as the basis for the the success of insects.
- Why do we care about the integument?

The integument

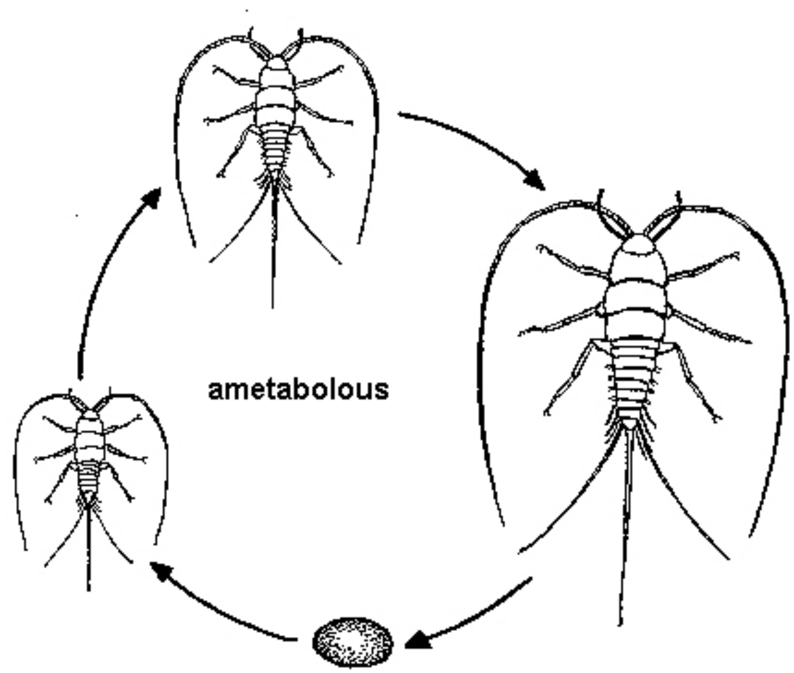
- Articulated exoskeleton is a defining feature of all Arthropoda

The integument

- Insect groups are differentiated by modifications of the exoskeleton and the appendages.
- Understanding structure and function of external anatomy essential for interpreting insect diversity and adaptations.

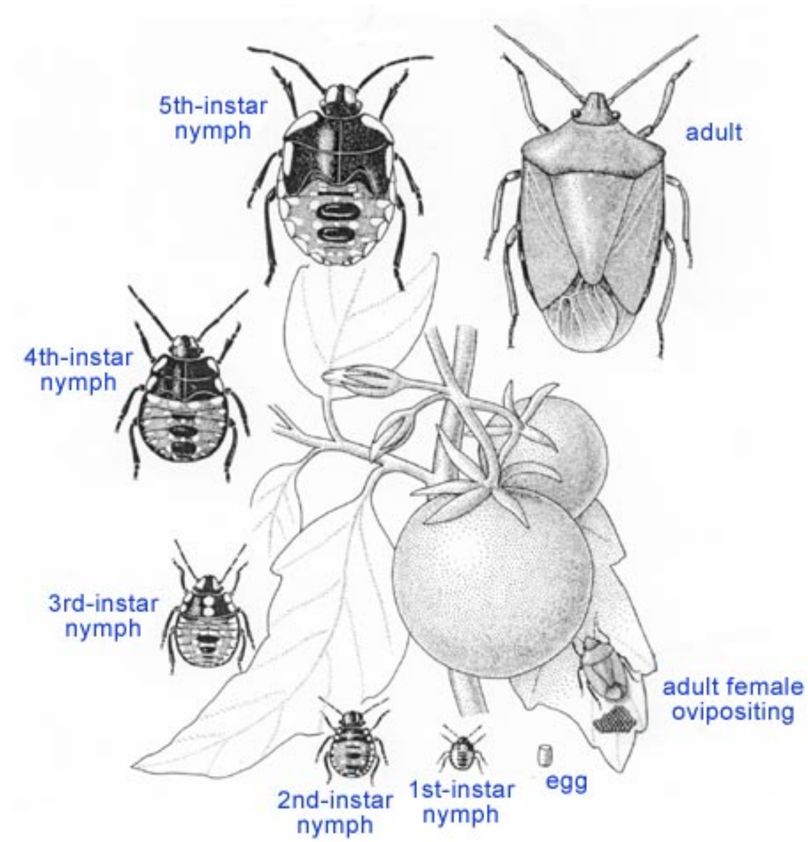
Some terminology
(review from book)

- Apterygote insects
  - Ametabolous development



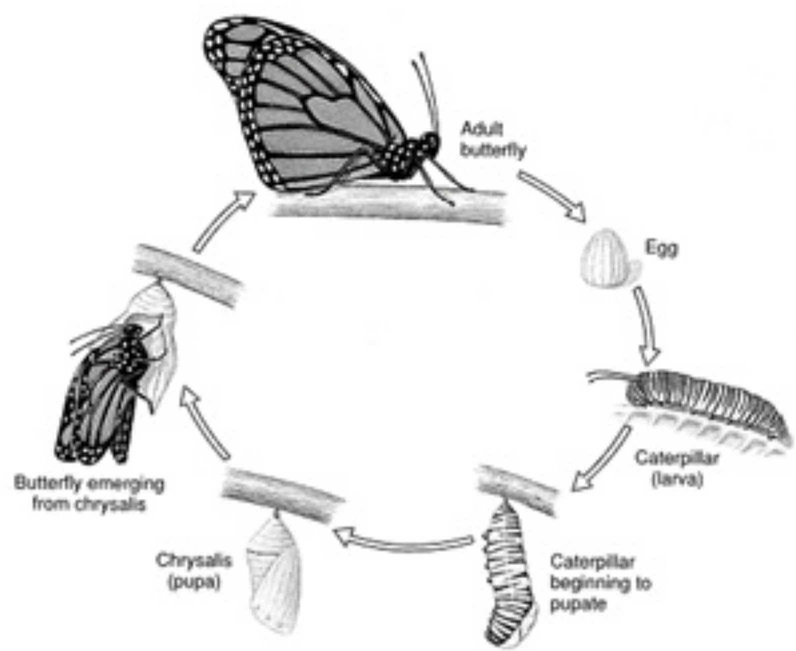
Some terminology
(review from book)

- Pterygote insects
  - Hemimetabolous development
  - Pre-adults are **nymphs**



Some terminology
(review from book)

- Pterygote insects
  - Holometabolous development
  - Transition from wingless immature to winged adult via pupal stage.
  - Active subadults are **larvae**; inactive **pupae**.

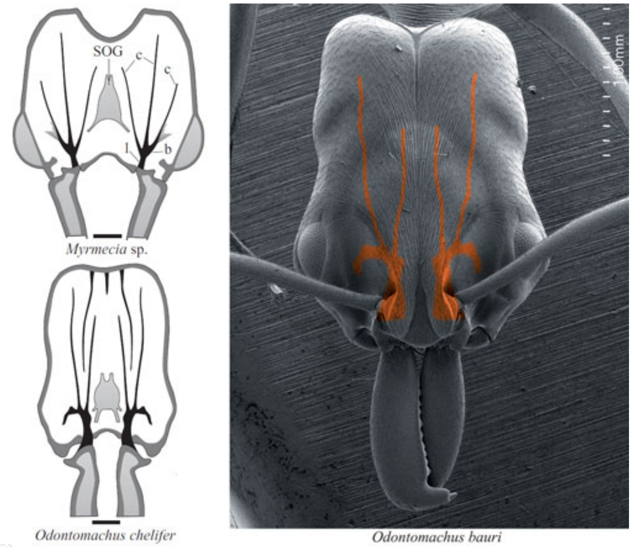


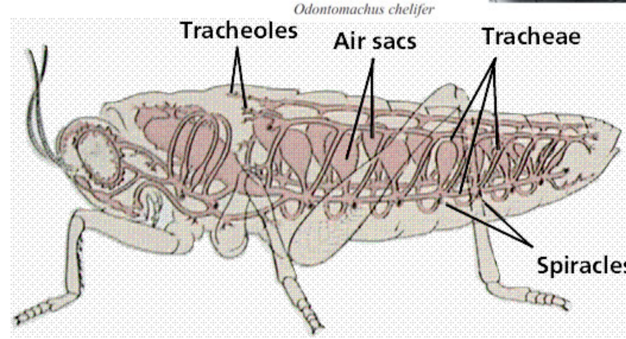
The Cuticle

- In insects, the integument is made up of the cuticle.
- This is the rigid exoskeleton that surrounds the insect **AND**…

The Cuticle

- Internal supports and muscle attachments known as **<u>apodemes</u>**
- Wings
- Lines tracheal tubes
- Lines foregut and hindgut.
- Essentially serves as the barrier between living tissues and the external environment

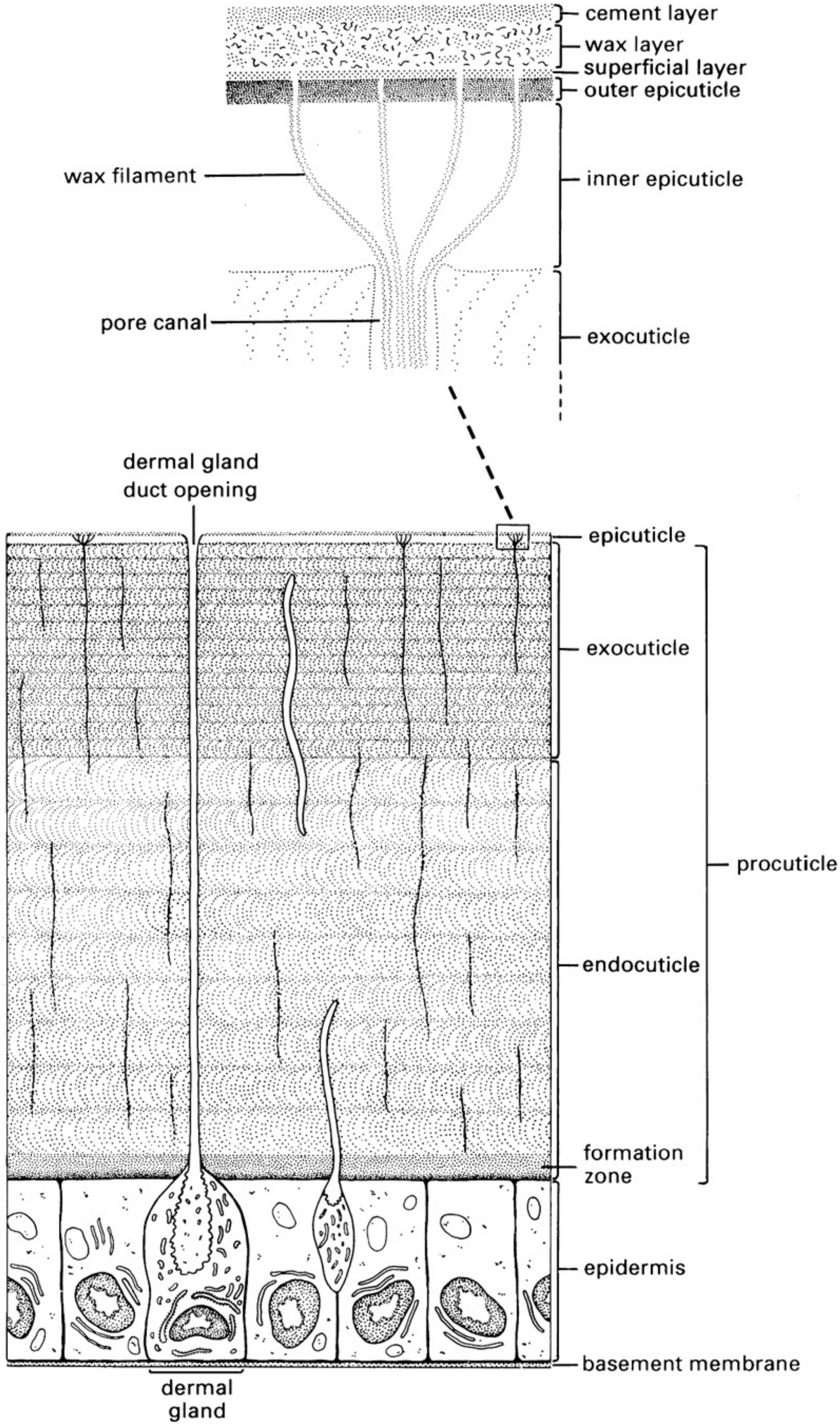




Features of the Cuticle

CUTICLE

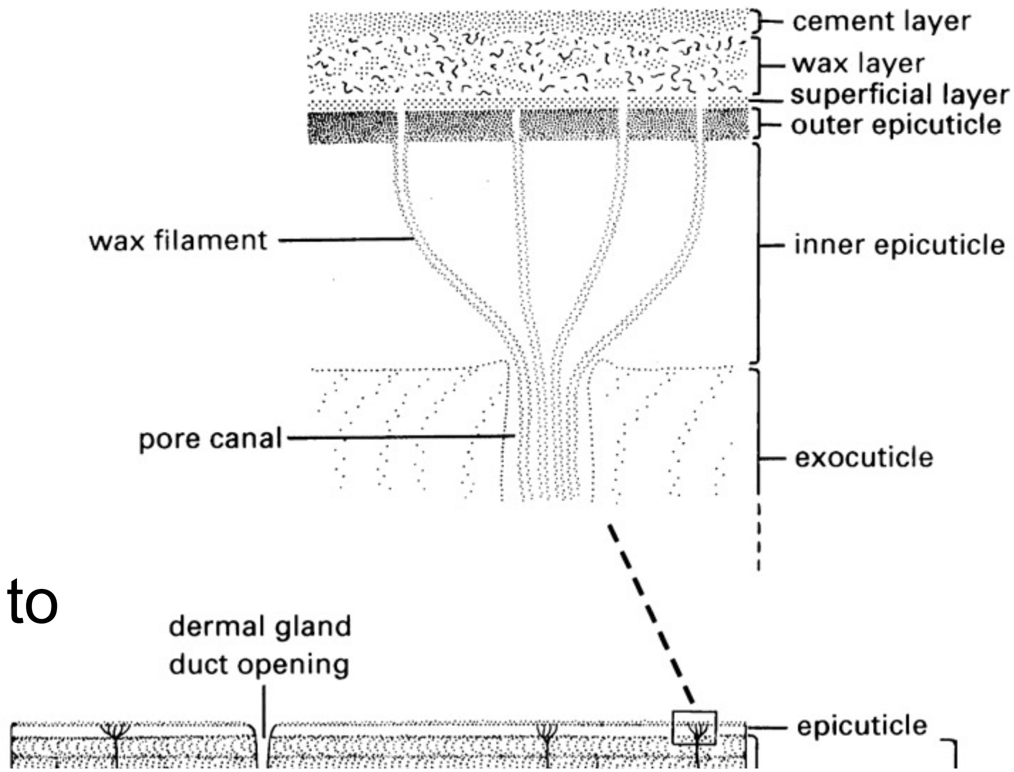
- Multi-layered structure separated from **hemolymph** by basement membrane.
- Living cells are **epidermal** layer.
  - Epidermal cells secrete all of the remaining layers of the cuticle **except**…
  - Dermal glands secrete the outermost **cement layer**.
- Thicker **procuticle** overlaid with thin **epicuticle**.


cement layer
wax layer
superficial layer
outer epicuticle
wax filament
inner epicuticle
pore canal
exocuticle
dermal gland
duct opening
epicuticle
exocuticle
procuticle
endocuticle
formation
zone
epidermis
basement membrane
dermal
gland

EPICUTICLE

- Inner epicuticle
- Outer epicuticle
- Superficial layer
- Free-wax layer and cement layer

- Functions primarily to prevent water loss.



EPICUTICLE

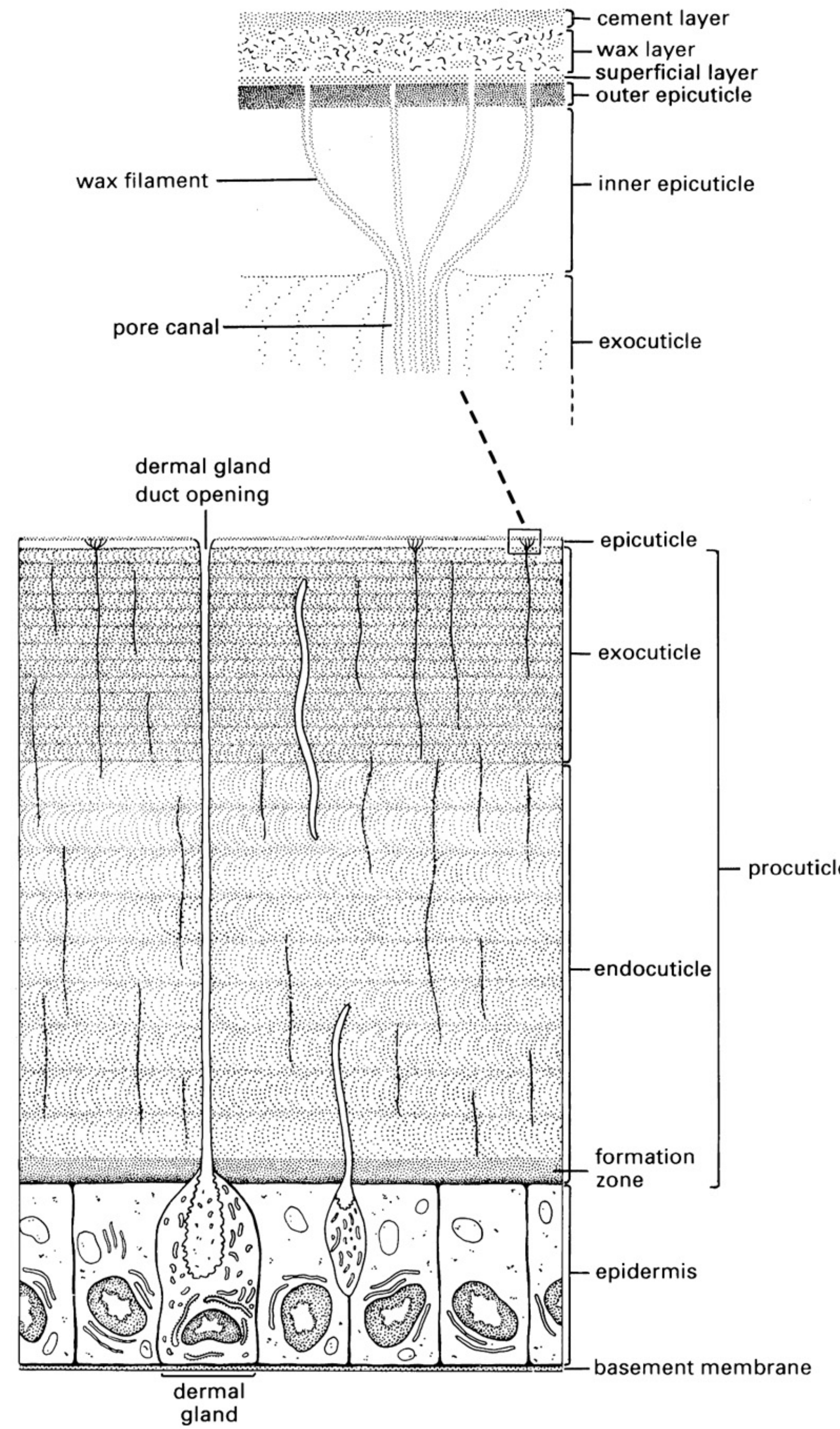
- Hadley and Schultz 1987 studied two species of tiger beetle in Utah.
  - *Cicindela tranquebarica*
    - Occupies dry microhabitats
  - *C. oregona*
    - Occupies moist microhabitats.
- Tested resistance to desication
  - *C. oregona* lost water at twice the rate of *C. tranquebarica.*
  - Why?

Other features of the epicuticle

- May have important compounds for predator deterence;
- Repel rainwater;
- Provide sunscreen;
- Give olfactory cues.

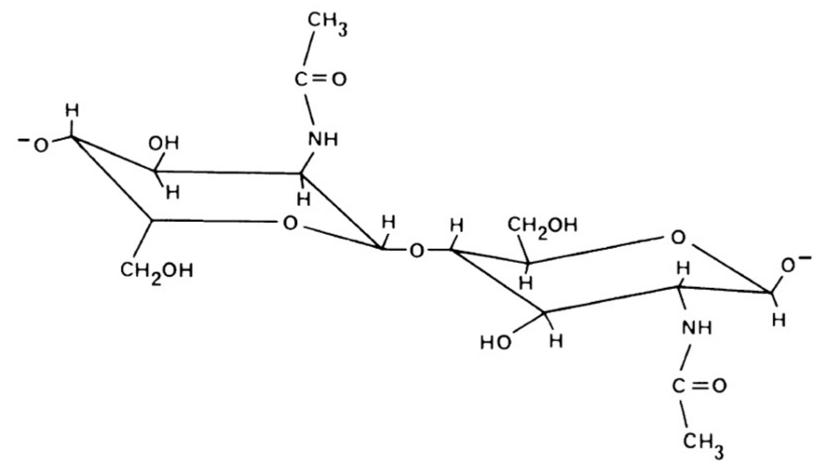
PROCUTICLE

- Epicuticle does not provide structural support.
- This is done by the **procuticle**.
  - Divides into **endocuticle** and **exocuticle**
  - Contains **chitin**.



CHITIN

- Where else in the diversity of life is chitin found?
- Cross-linked amino-sugar polysaccharide.
- This is embedded in a protein matrix and laid down in sheets.
- Provides considerable tensile strength.



PROCUTICLE

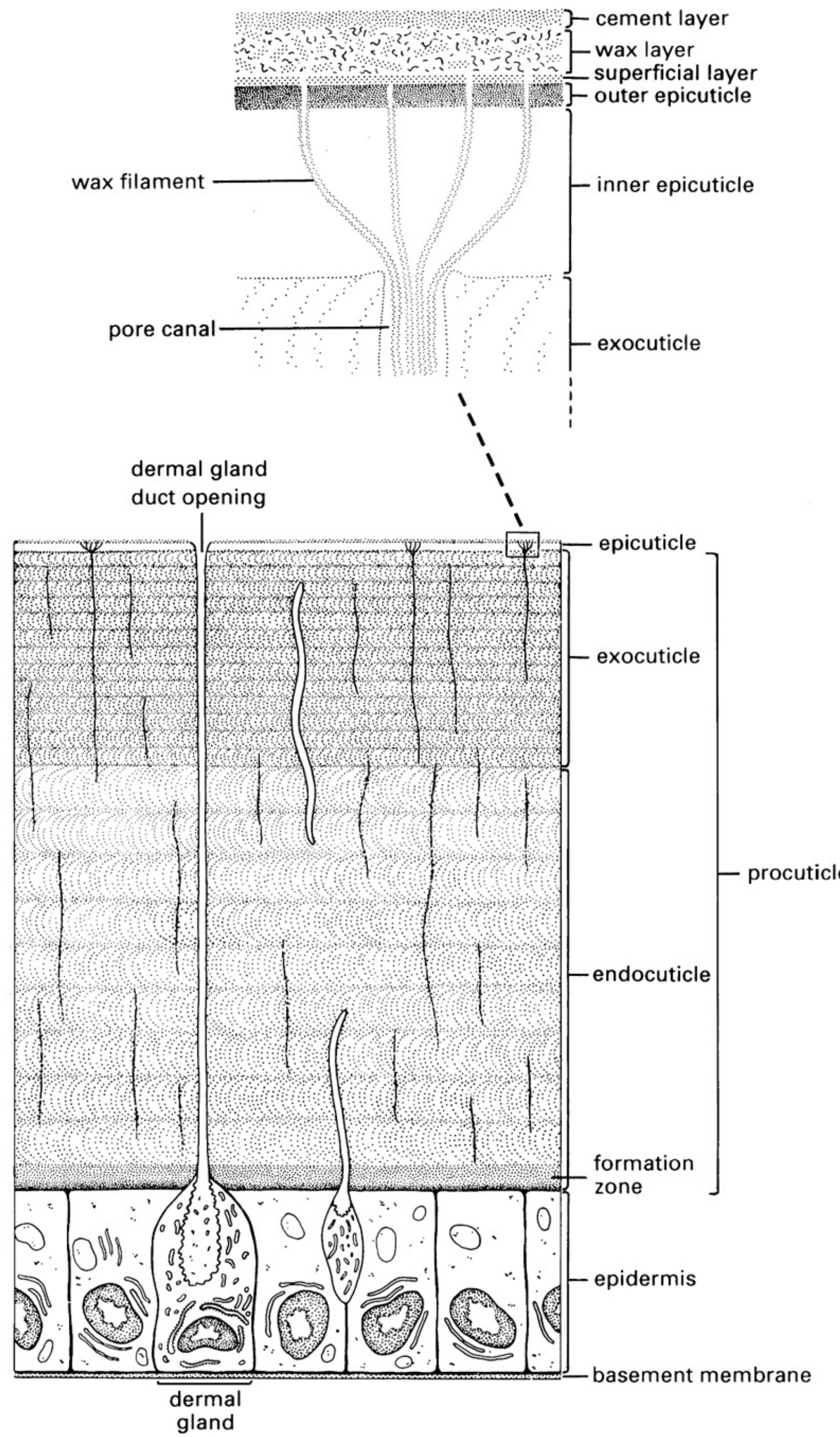
- Procuticle separates into endocuticle and exocuticle when the latter undergoes **sclerotization**.
  - Same process as tanning.
  - Adjacent protein chains become linked and/or are dehydrated.
  - Results in strengthening and stiffening of cuticle.

PROCUTICLE

- Protein matrix can also be modified to be tough yet highly flexible or resilient.
  - **Resilin** permits cuticle to function much like ligaments and tendons.
  - **Arthrodial membrane** permits distension of body.

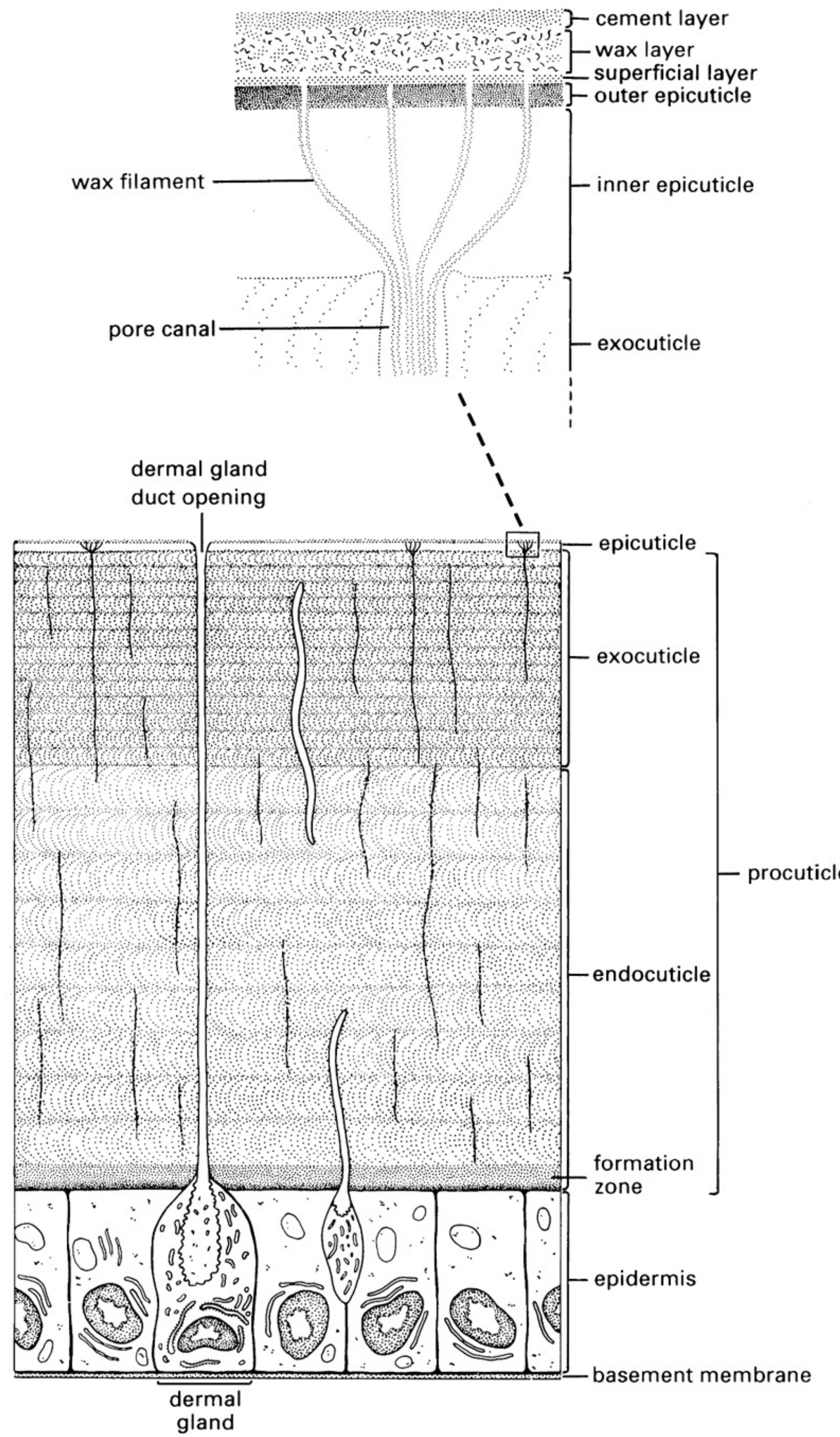
EPIDERMIS

- These are the living cells that secrete the cuticle.
- Also produce structural components, waxes, cements, pheromones.
- Closely associated with **ecdysis.**



EPIDERMIS

- Compounds are secreted to the outside of the insect epicuticle via **pore canals** that branch into **wax canals**.



EPIDERMIS

- These are notably well developed in *sessile* insects that would drown without the hydrophobic wax.

Integument

- What other traits are provided by the integument?

Cuticular extensions

- Vary from fine to robust and spine-like.
- Involved as sensory apparati (setae), defense, production of visual cues.

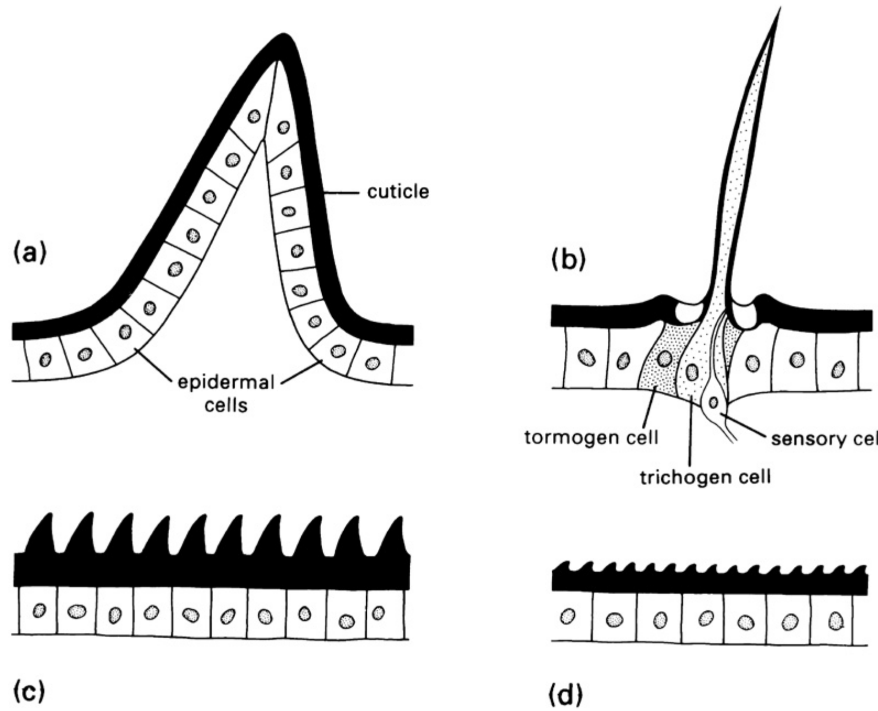
Cuticular extensions

a) Spines.

b) Setae.

c) Acanthae: unicellular in origin.

d) Microtrichia: subcellular in origin.



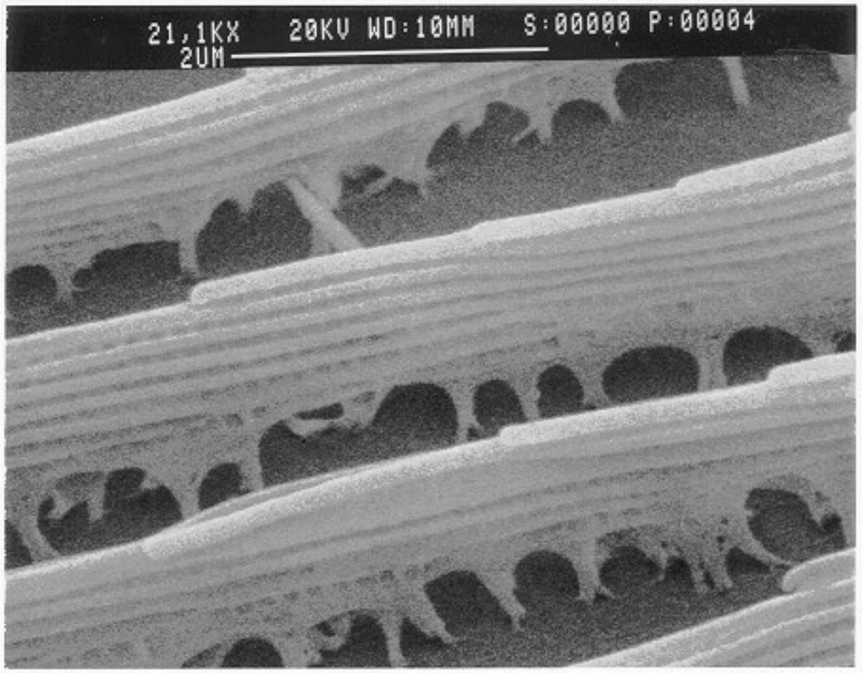
Color production

- How is color produced?
- How is color production achieved?
- Why do I have these two pictures here to illustrate this point?

Color production

Physical or Structural colors

- Microsculpture of surface such that only certain wavelengths are reflected.
- **Interference** results in iridescence seen in many insects.



Color production

Physical or Structural colors

- Microsculpture of surface such that only certain wavelengths are reflected.
- **Interference** results in iridescence seen in many insects.
- **Scattering** also produces structural colors.

Color production

<u>Pigmentary colors</u>

- Reflect certain wavelengths of light; the rest are dissipated as heat.
- Depends on structure of molecular compounds
  - Double bonds important
  - $-NH_2$ and -Cl functional groups shift pigment to absorb longer wavelengths.

Color production

<u>Pigmentary colors</u>

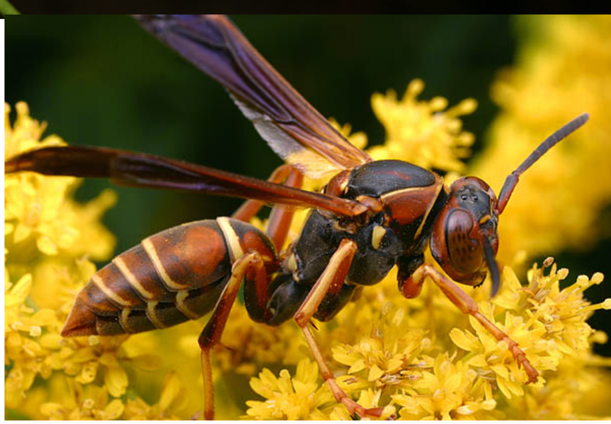
- Insects can synthesize most pigments.
- Flavonoids (yellow) and carotenoids (yellows to reds) acquired in the diet.

Color production

Pigmentary colors

- Melanins: granular pigments that give a black, brown, yellow, or red color.
- Tetrapyrroles: reds, blues, greens.
- Ommochromes, papiliochromes, pteridines: yellows to reds.

What are some of the functions of insect colors?



Introduction to Body Organization

Morphology

- Why do we study morphology?

Morphology: 2 Questions

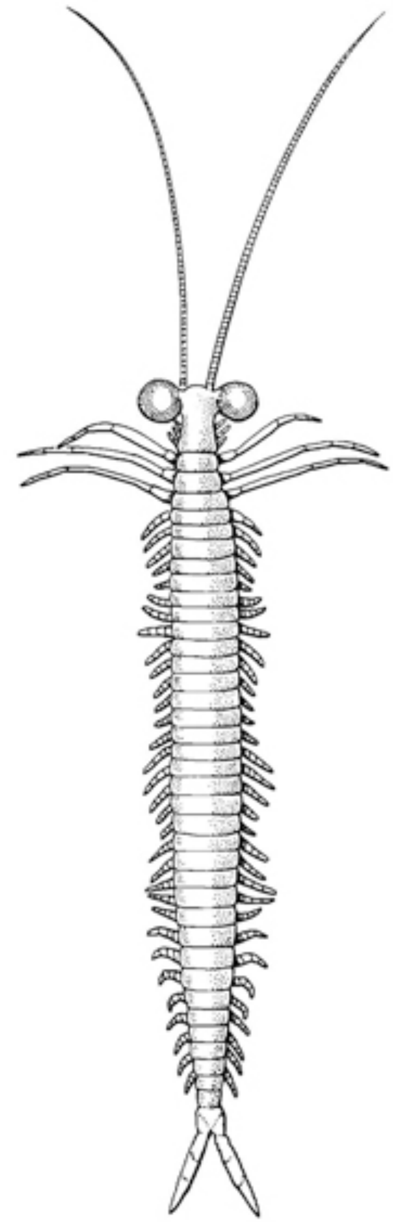
1. What does it do?
   a. A question of biomechanics or *functional morphology*.
2. Where did it come from?
   a. A question of its evolutionary history and origin, or *comparative morphology*.

- Structure is a result of both its *function* and its particular *evolutionary history*.
- For the purpose of this course, it is important to have a working knowledge of the general structure, or ***bauplan***, of the insects.

The Insect Bauplan

- Insects are composed of a series of repeated units (segments or **metameres**).

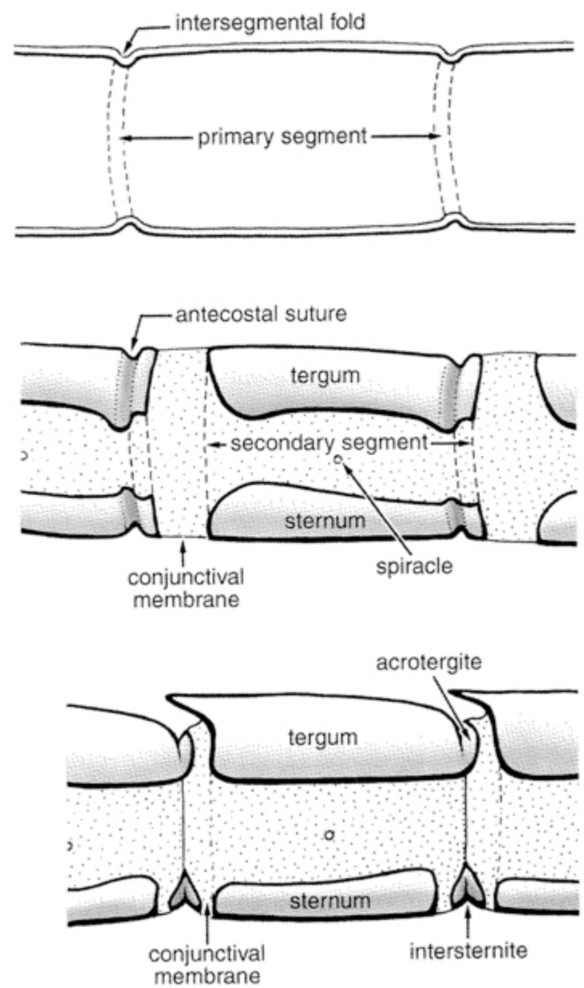
- **Tagmosis**.



Devonohexapodus

Secondary Segmentation

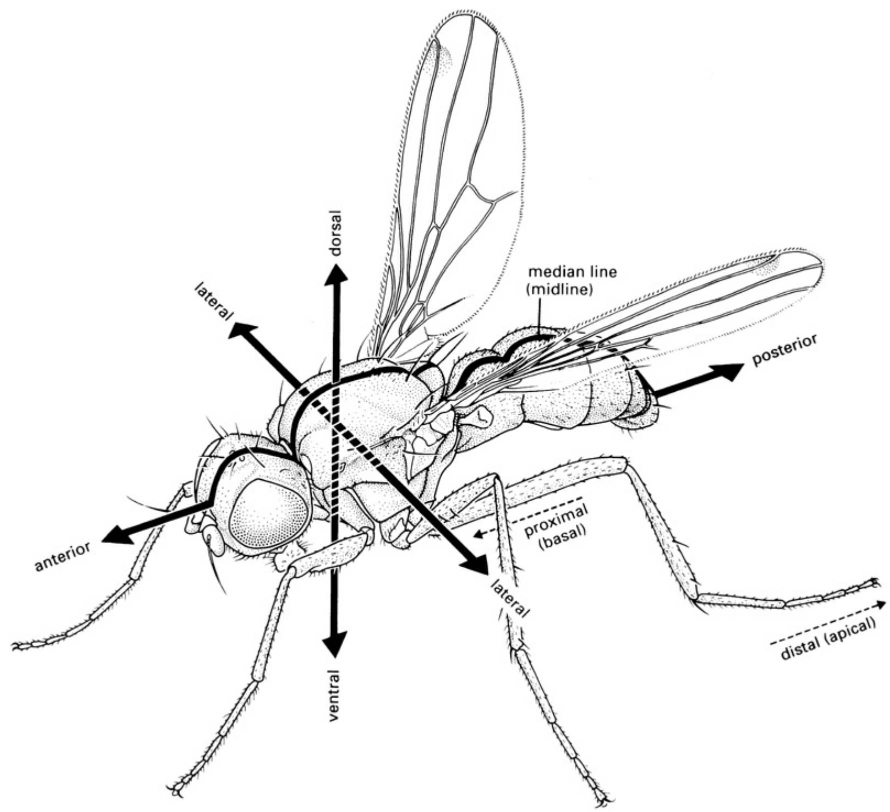
- Ancestral or primary segmentation can be difficult to detect in extant insects.
- Prominent in thorax and abdomen.
- Terga overlap each other posteriorly
  - Posterior border of tergum overlaps anterior border of successive tergum

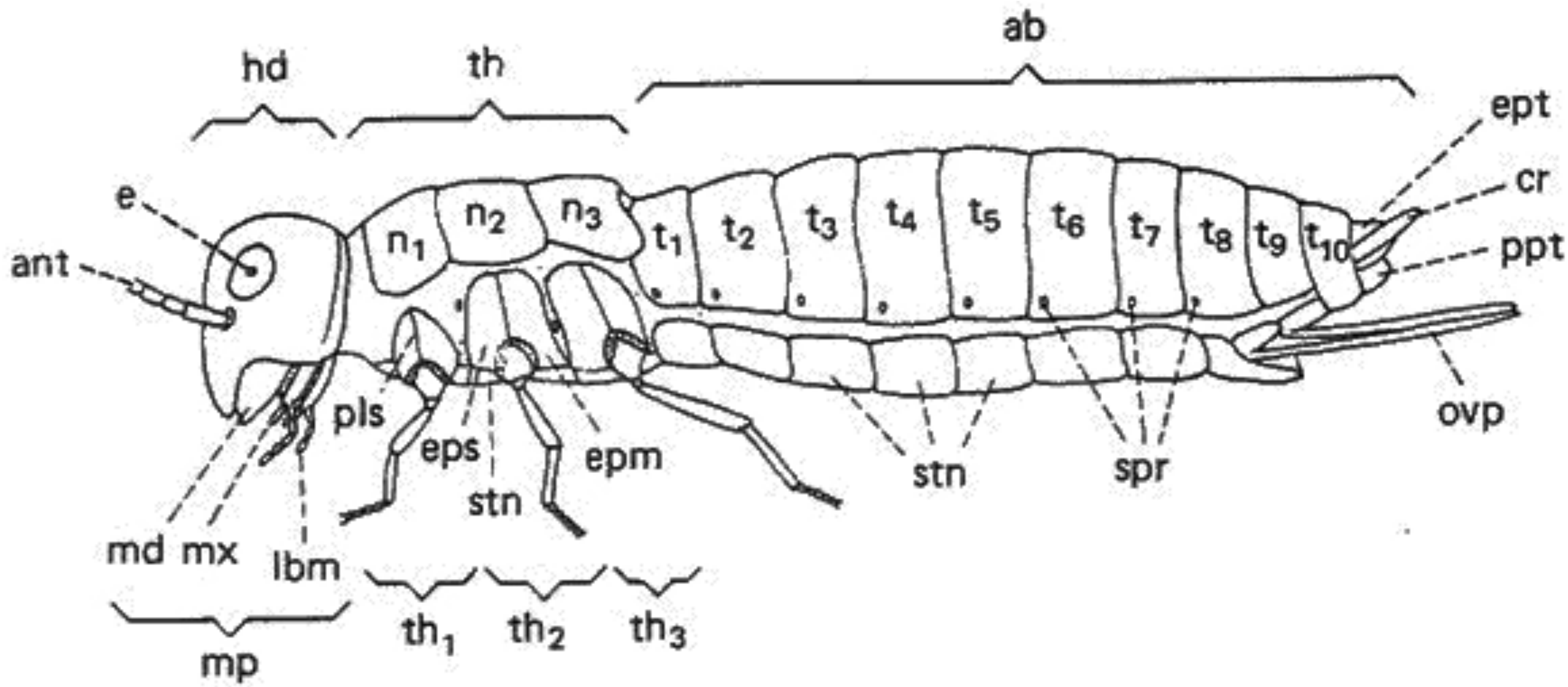


Stages in the development of secondary segmentation in insects.

Tagmosis

- Segments in insects are organized into three major **tagmata.**
- **Head**
- **Thorax**
- **Abdomen**





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Terminology

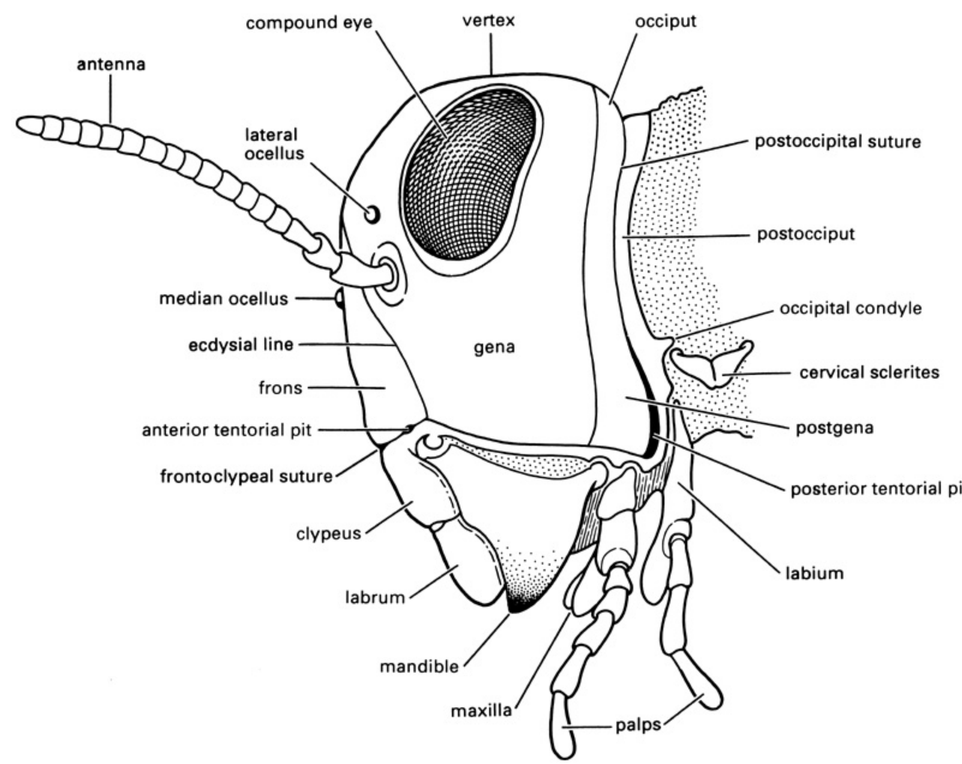
- **Dorsal:**
  - Dorsum: entire upper portion of an insect.
  - Tergum or notum: dorsal exoskeletal plate or plates of a segment.
  - Tergite: a subdivision of the tergum.

- **Lateral:**
  - Pleural area: the lateral portions of a segment or of the whole insect.
  - Pleuron: the lateral exoskeletal plate or plates of a segment
  - Pleurite: a sclerotized subdivision of a pleuron.

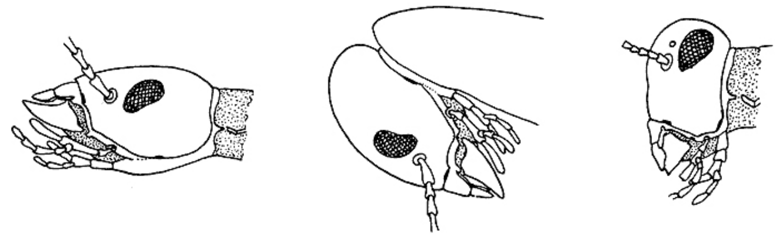
- **Ventral:**
  - Venter: the entire undersurface of a segment or of the whole insect.
  - Sternum: the ventral exoskeletal plate or plates of a segment.
  - Sternite: a subdivision of the sternum.

Head

- Derived from **six** fused metameres.
- Primary functions are sensory input and feeding.
- Most radically modified tagma as a result of cephalization.



Head



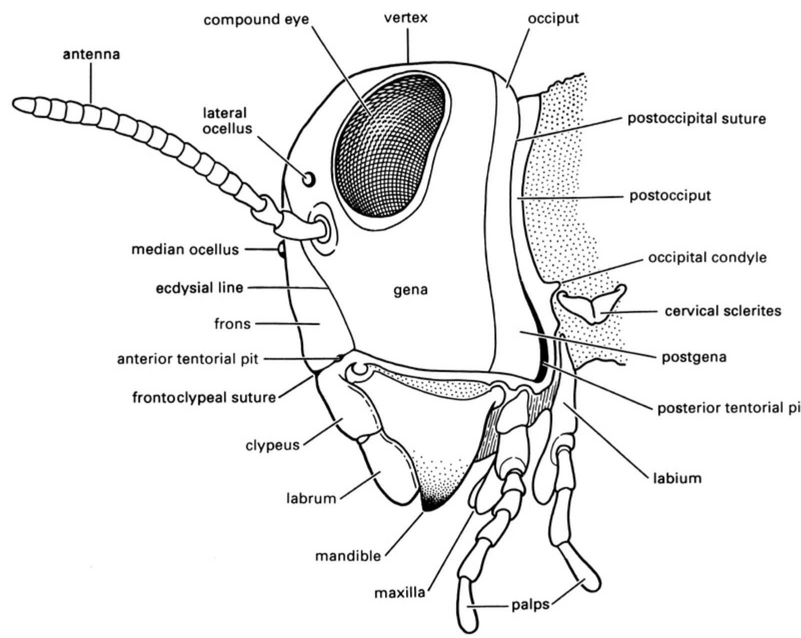
- Hypognathous heads:

- Prognathous heads:

- Opisthognathus heads:

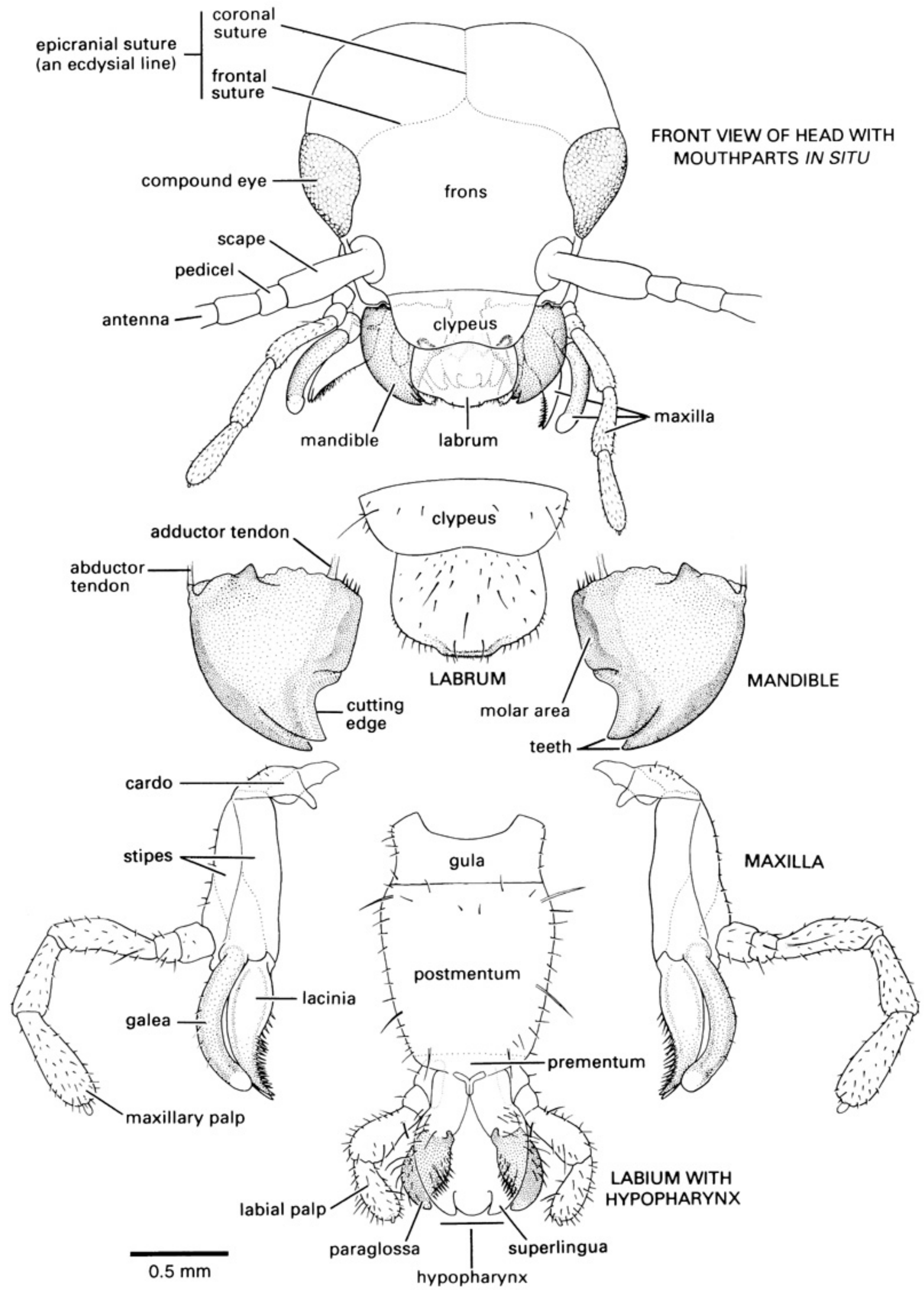
Head segments

- How do we hypothesize how many?
- Rempel (1975):
  - Pair of appendages.
  - Pair of apodemes.
  - Neuromere (ganglion).
  - Mesodermal somites = coelomic sacs during development.



Head segments & appendages

- Using gene expression, embryology, and morphology, there are hypothesized to be six head segments:
  1. Labral or pre-antennal
  2. Antennal
  3. Postantennal or intercalary
  4. Mandibular
  5. Maxillary
  6. Labial

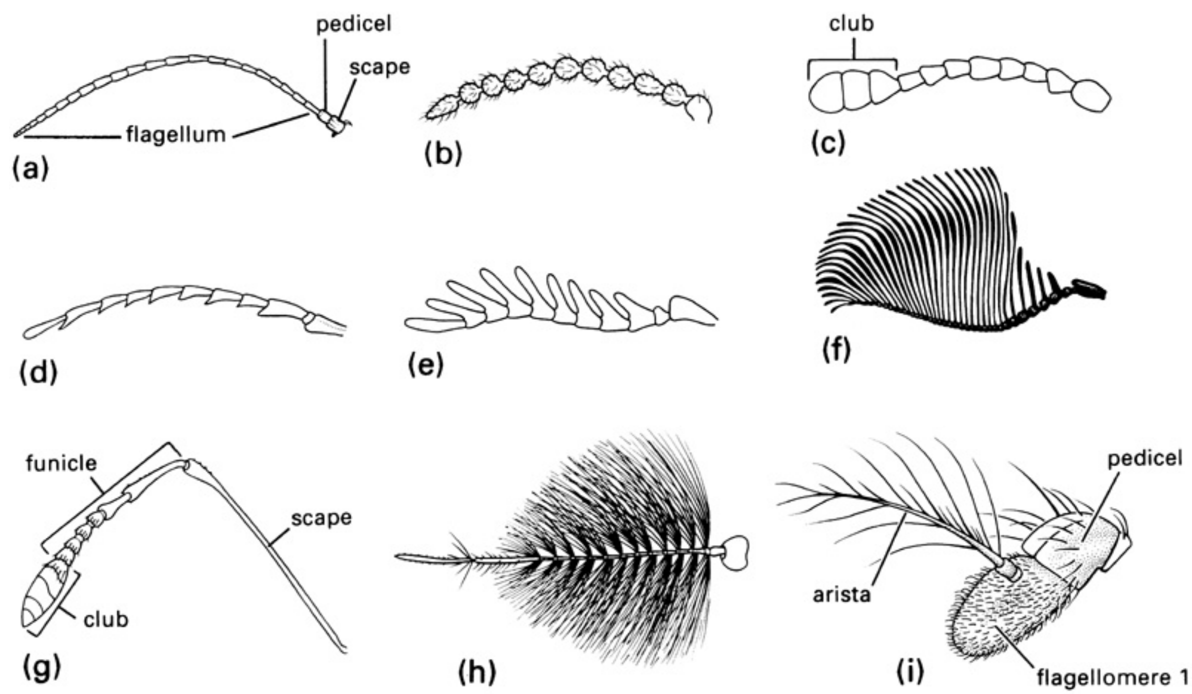


Eyes

- Two compound eyes
  - Each with two to 28,000 ommatidia.
- Three ocelli
  - Simple eyes
  - Cannot form images
  - Very sensitive to low light levels.

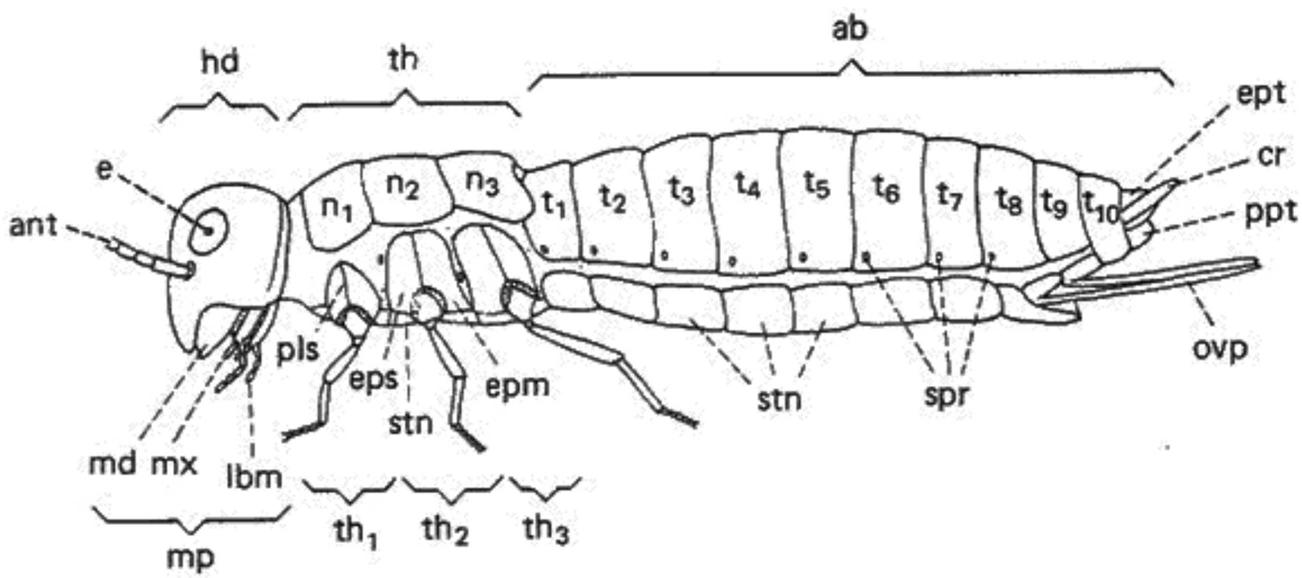
Antennae

- Mobile, segmented, paired appendages.
- Three principal units:
  1. Scape
  2. Pedicel (contains Johnston's organ)
  3. Flagellum (separated into flagellomeres)



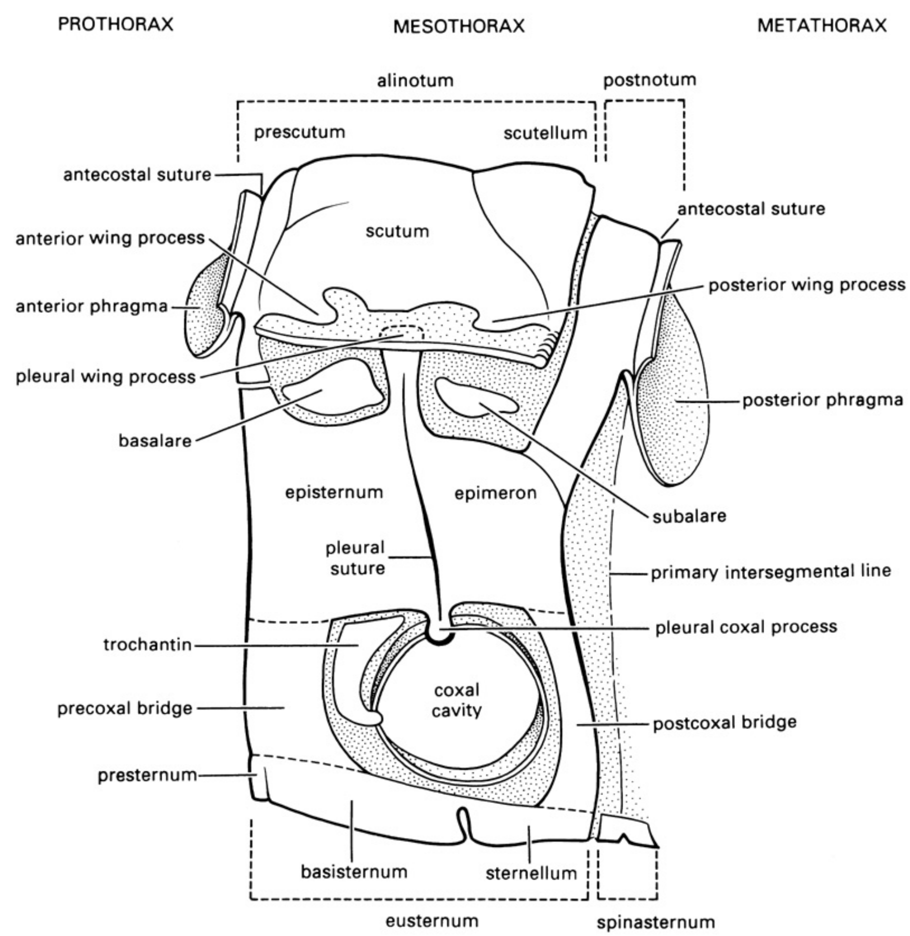
Thorax

- Derived from three fused metameres
  - Pro-, meso-, and metathorax
- Primary function is in locomotion.
- Segments are readily distinguished. How?
- Wings are on meso- and metahorax (pterothorax).



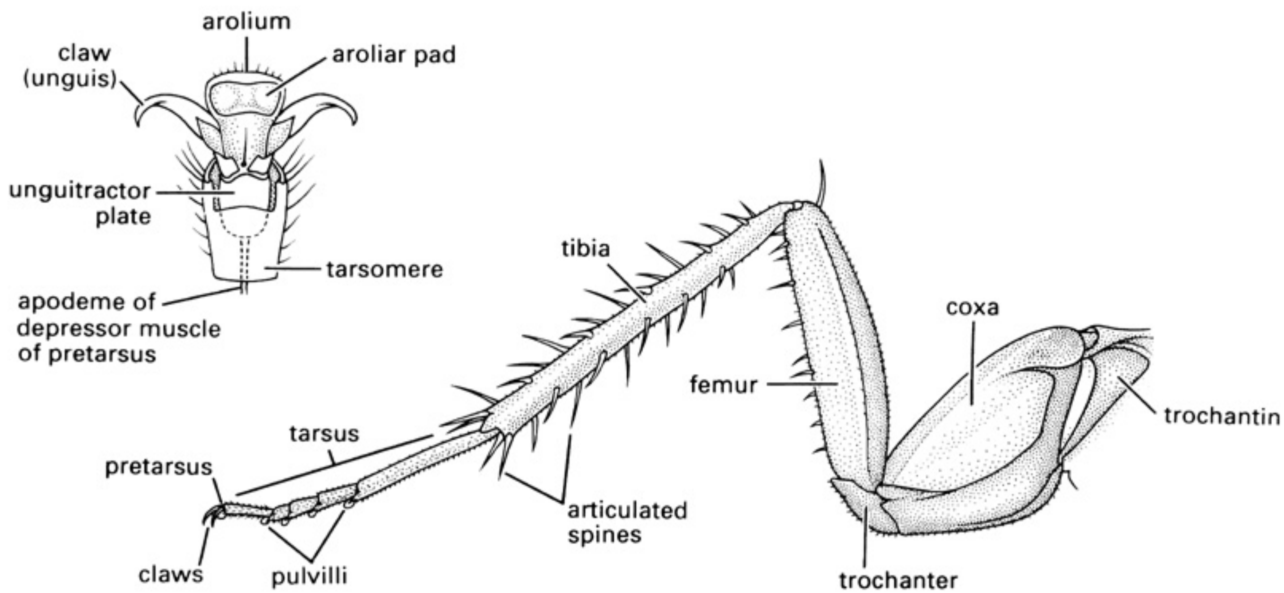
Thoracic structures.

- Thoracic terga = nota (e.g. mesonotum).
- Pterothoracic nota with two divisions:
  - Alinotum bears wings;
  - Postnotum bears phragma.
- Modifications of plates and sutures largely involved with articulation of wings and insertion of musculature.



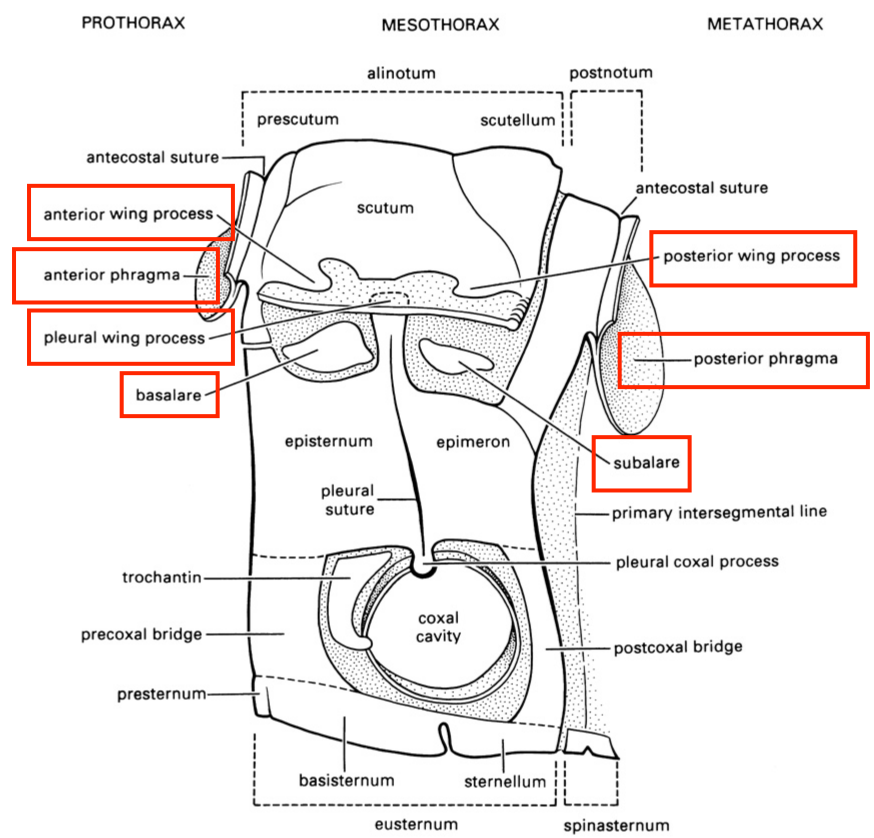
Legs

- Consists of six segments (or podites):
  - Coxa
  - Trochanter
  - Femur
  - Tibia
  - Tarsus
  - Pretarsus (with claws)



Wings

- Cuticular extensions from between the notum and the pleuron.
- Insertion points on these plates function in wing's articulation.
  - Actively operated only at its base.
  - No muscles *within* wing that permit deliberate movement.

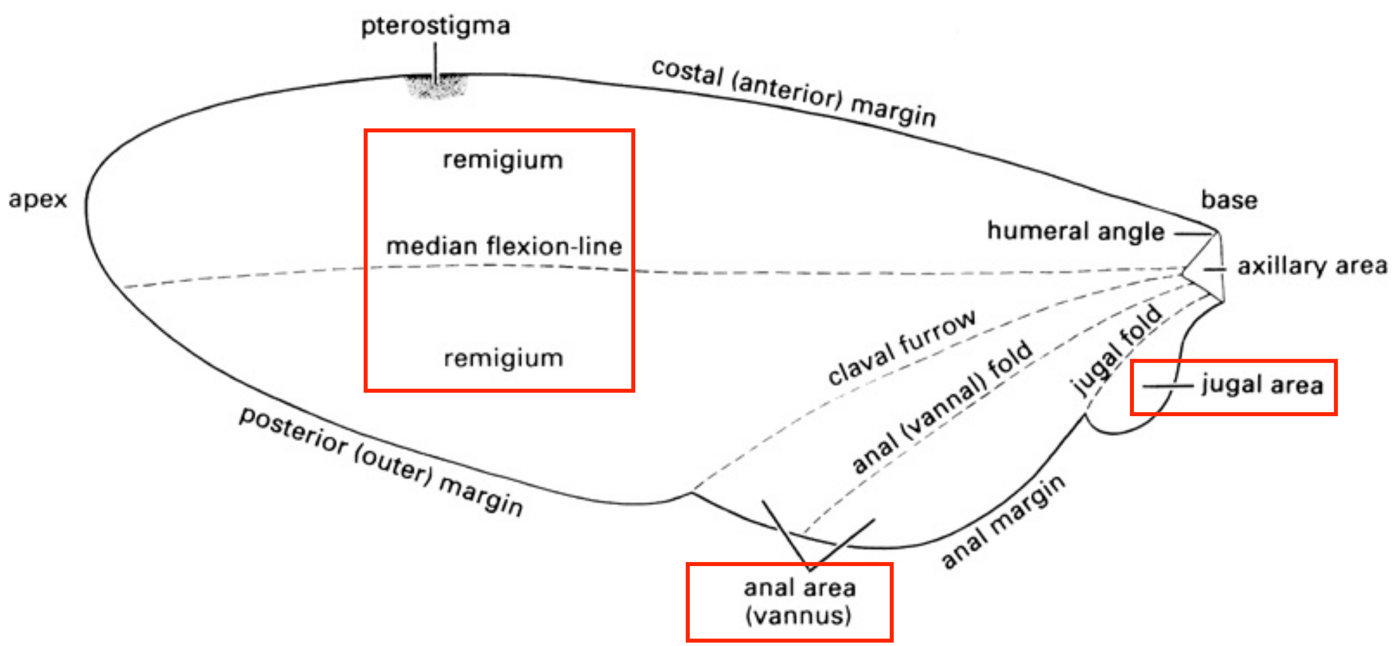


Insect Flight

- This does not mean that insects only flap their wings up and down.
- Insertion points and numerous muscle attachments pull the wing in different ways to create flexion and tilt by manipulation of veins, folds, and flexion lines.

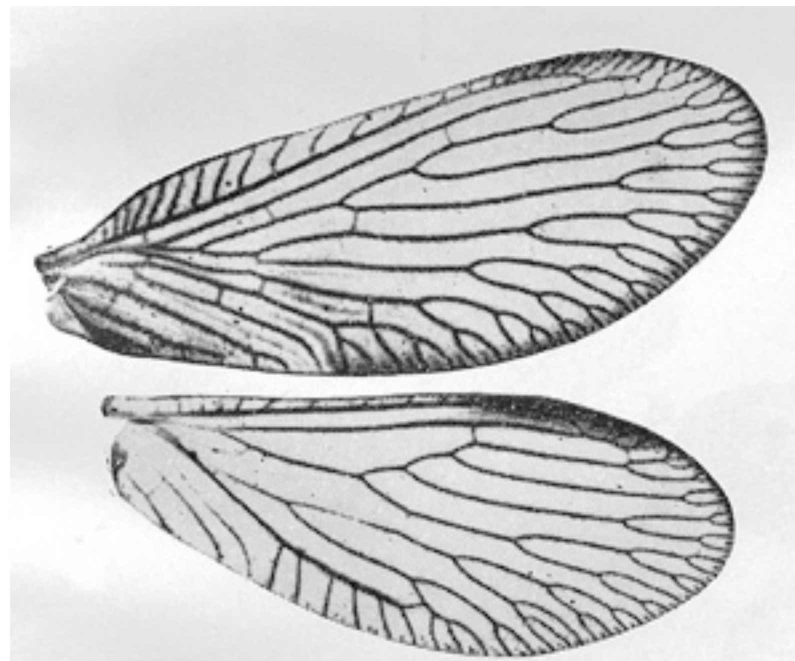
Wings

- Wing areas are delimited by these fold-lines and flexion lines.
- Three main areas.



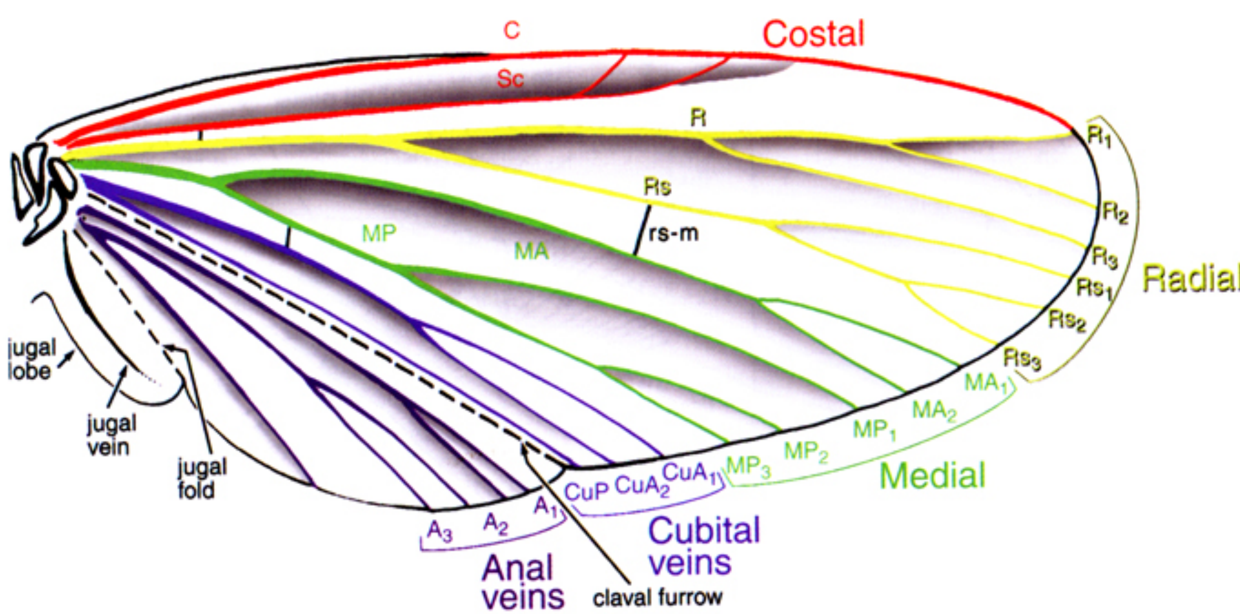
Wings

- Veins
- Rich source of characters
- Corrugated
- All winged insects share the same *basic* wing venation.



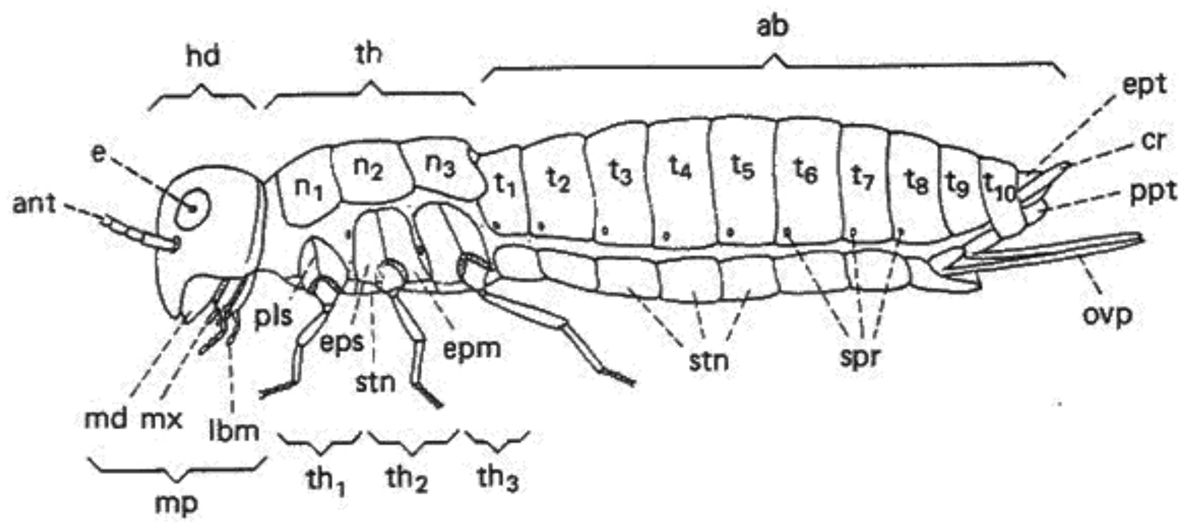
Wings

- Major longitudinal veins (and major branches) given names indicated by uppercase letters with branches indicated by subscripts.
- *Crossveins* run between longitudinal veins and are indicated by lowercase letters; a hyphen separates the anterior-posterior longitudinal veins that they connect.



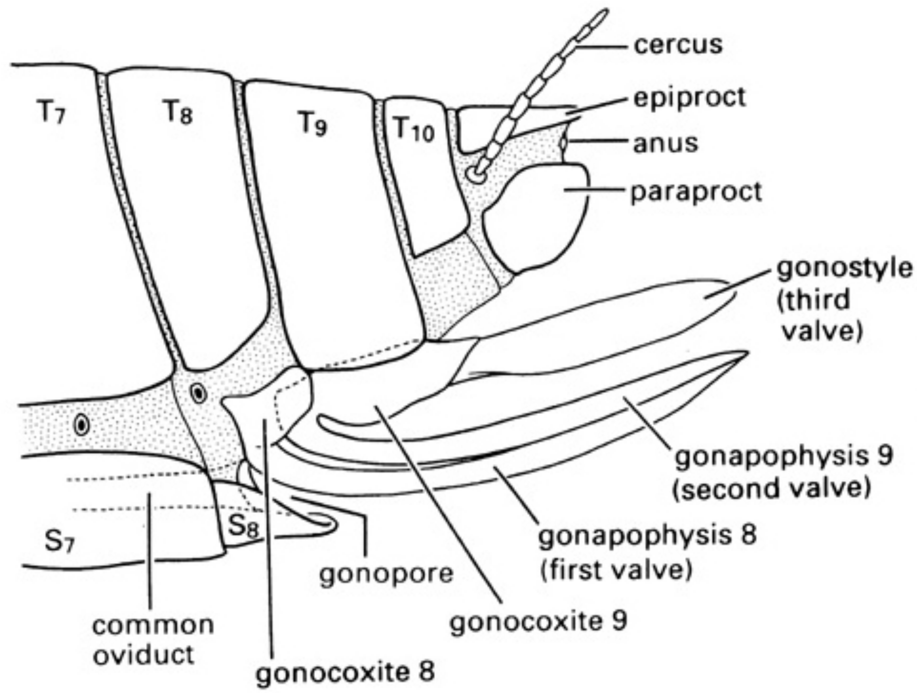
Abdomen

- Primitively composed of 11 metameres + telson.
- Specialized for “visceral” functions.
- Least modified tagma from the arthropod groundplan.
- Most flexible structure (how? Recall cuticle lecture).



Abdominal segments

- Complete lack of locomotory appendages.
- Segment 1 often incorporated into thorax.
- Segment 10 always reduced in size or absent.
- Segments 8 and 9 form the genital segments.
- Segment 11 has non-reproductive appendages: <u>cerci</u>.

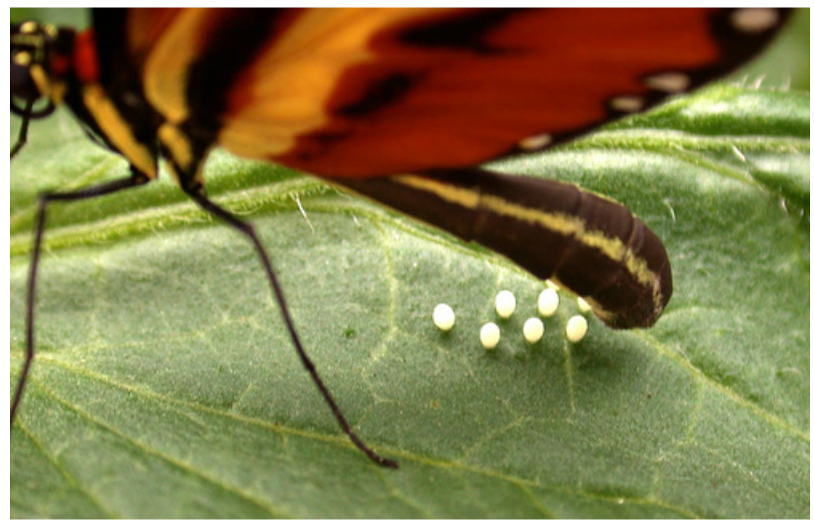


Reproduction: Terminalia

- Most fundamental function of abdomen.
- Eggs can be matured and laid singly or as many as 86,400/day (termite queen).

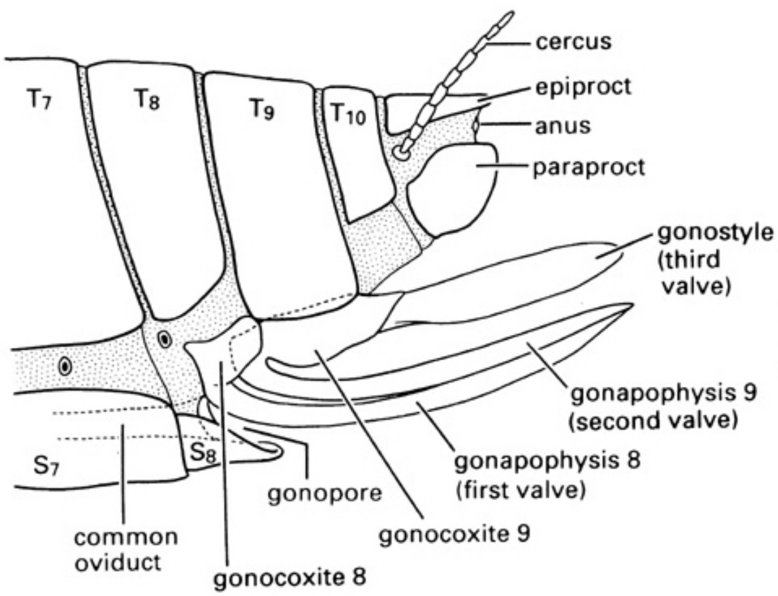
Female Genitalia

- Internal structures for receiving male copulatory organ and spermatozoa.
- External structures for oviposition.



Female Genitalia

- Appendages (valves) of 8th and 9th segments form a tubular ovipositor.
- Second valve (segment 9) slides against first valve (segment 8) and these are encased in third valve (segment 9)



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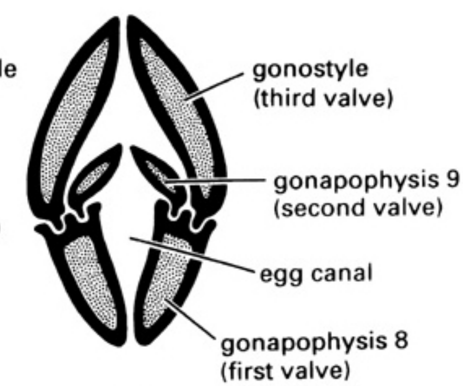


(c)

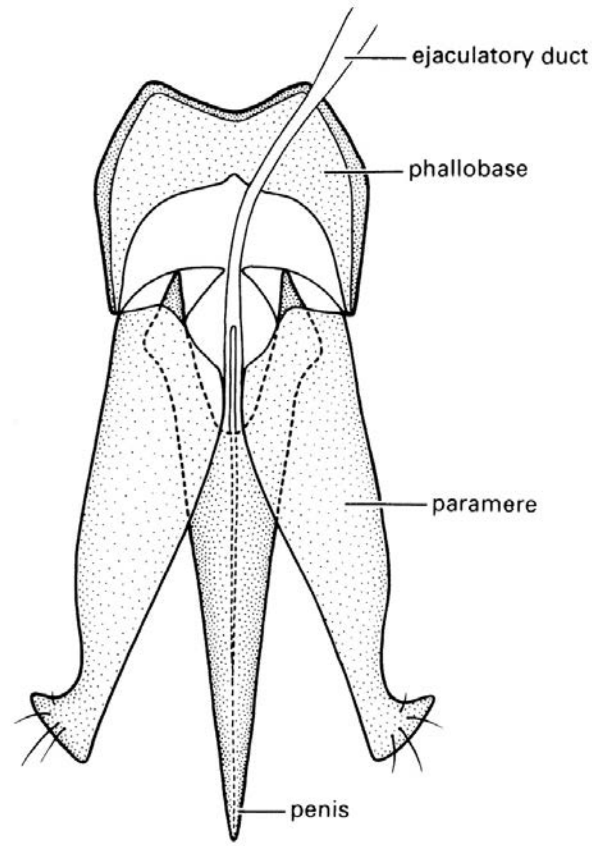
Male genitalia

- Extraordinarily diverse and complex (difficult to find homologies).
- Two functions:
  1. Delivery of sperm
  2. Seizing and holding of females during copulation.


Colored scanning electron micrograph of a mating pair of *Cimex lectularius*

Male genitalia

- Derived from appendages on segment 9.
- Entire structure known as aedeagus.
- Penis delivers sperm.
- Parameres provide clasping service.



Insect Morphology

- More diversity in insect morphology than can be encapsulated in a single lecture.
- Intimately linked with function and physiology.
- We will return to many of these topics again later.

Mouthparts and Feeding

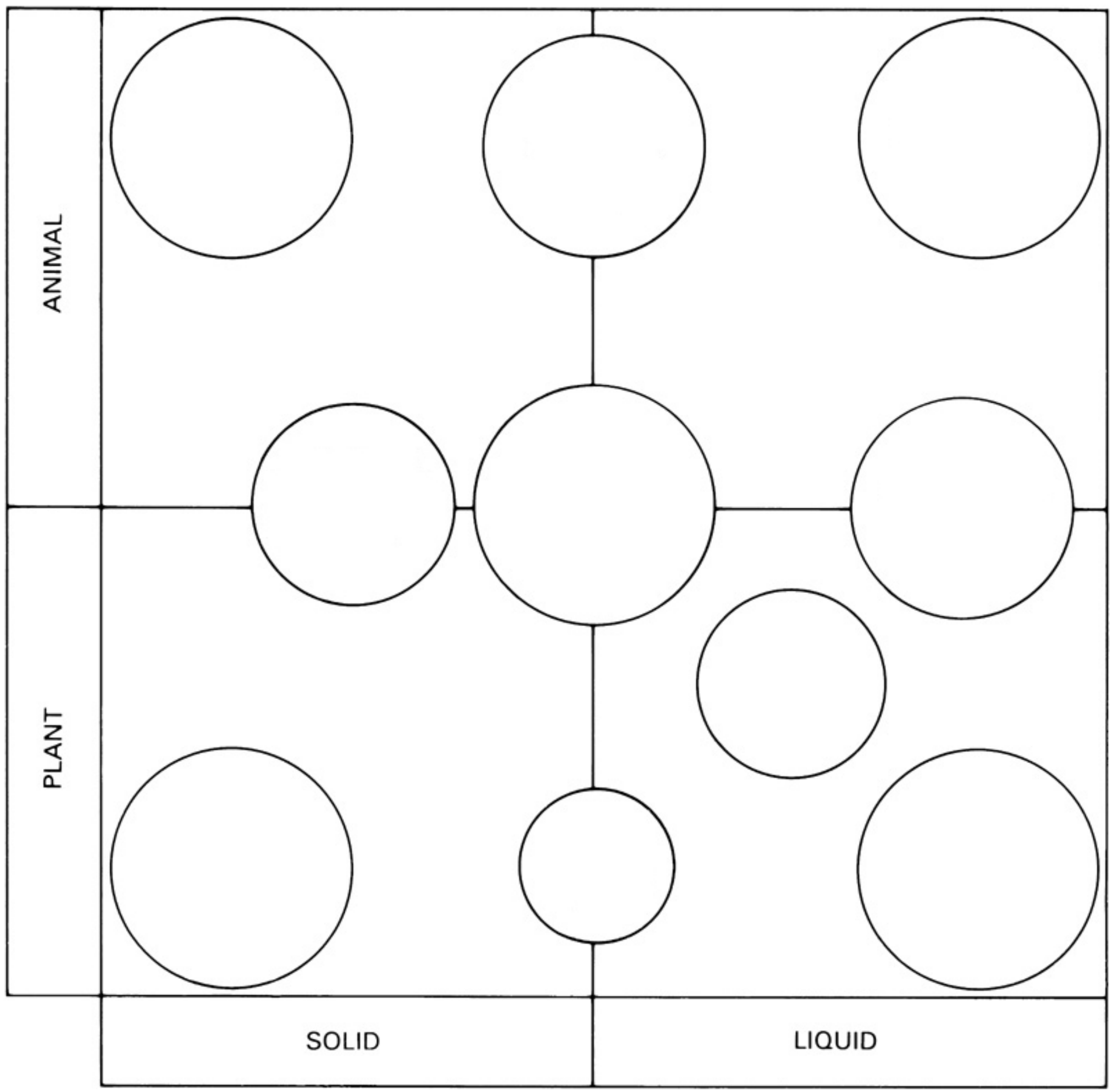
- Of course, what an insect does for a living is largely dependent upon what it can eat.
- What are some ways that insects go about doing this?

Types of Foods

- Plant feeders: **Phytophagous** or **Herbaceous**
- Fungus feeders: **Fungivorous**
- Detritus feeders or scavengers: **Saprophages, Coprophages**
- Animal feeders: **Carnivorous**, **Parasitic**, **Parasitoids**, **Haemophages**

Types of Food

- Mouthparts will also depend on whether food consumed is **solid** or **liquid**.
- This is where you find a fundamental distinction in the functional morphology of insect mouthparts.


ANIMAL
PLANT
SOLID
LIQUID

Mouthparts

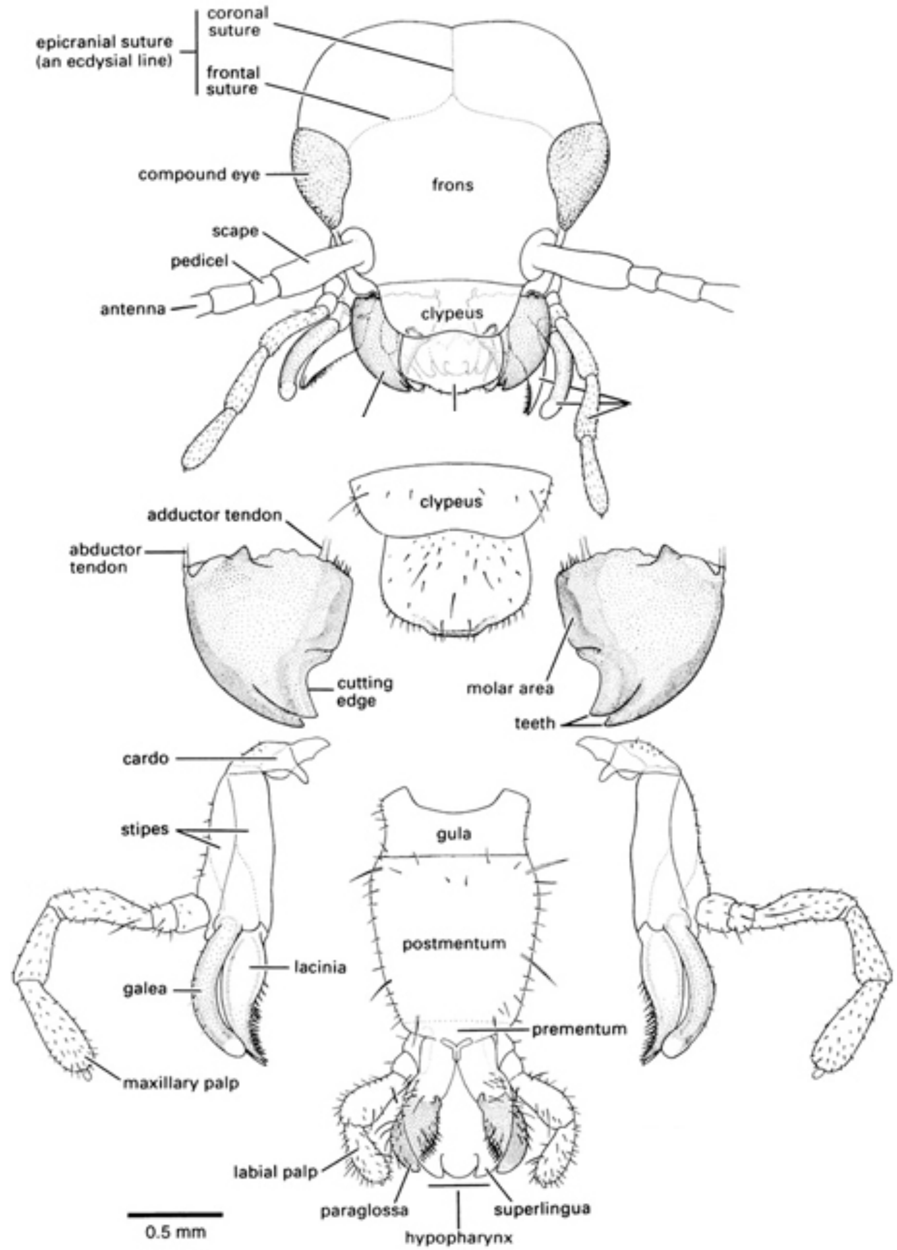
- Many of these mouthparts are stylized enough to allow us to characterize feeding habits of insects from the fossil record.
- What could this tell us?

INSECT MOUTHPARTS: Ascertaining the Paleobiology of Insect Feeding Strategies

Conrad C. Labandeira
Department of Paleobiology, Smithsonian Institution, National Museum of Natural History, Washington, DC 20560; e-mail: labandeira.conrad@simnh.si.edu

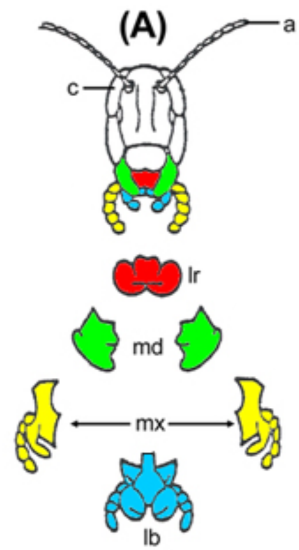
Mandibulate mouthparts

- Review of mouthparts:
- What are they, from posterior to anterior?
- All mouthpart types are derived from this basic design.
- Even radical departures have these homologous structures.



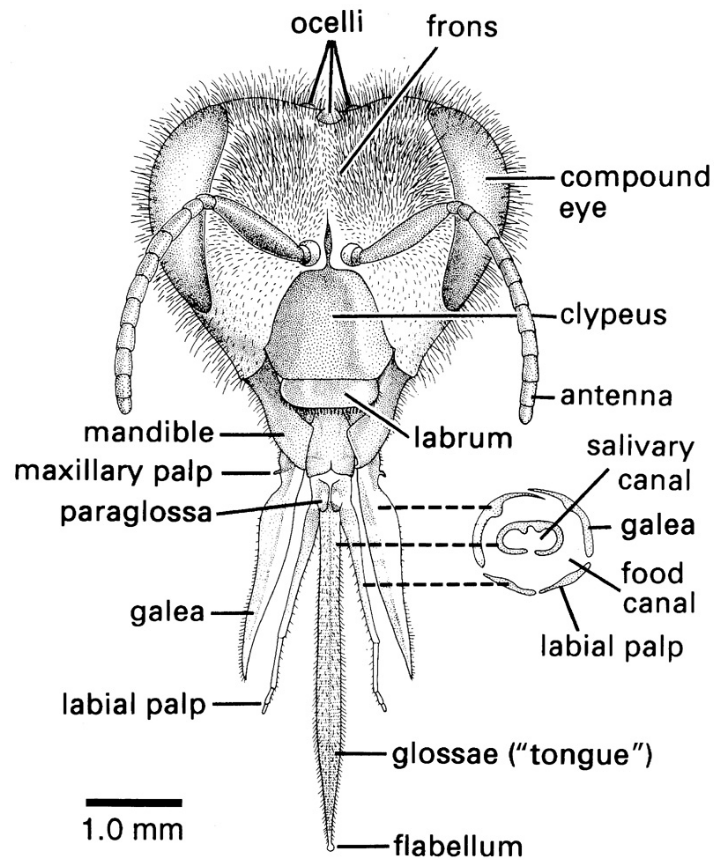
Modifications on this theme for Liquids…

A. Mandibulate plesiomorphic state
B. Lapping (liquid and solid major part of diet).
C. Haustellate.
D. Piercing-sucking.
E. Sponging (not shown yet).



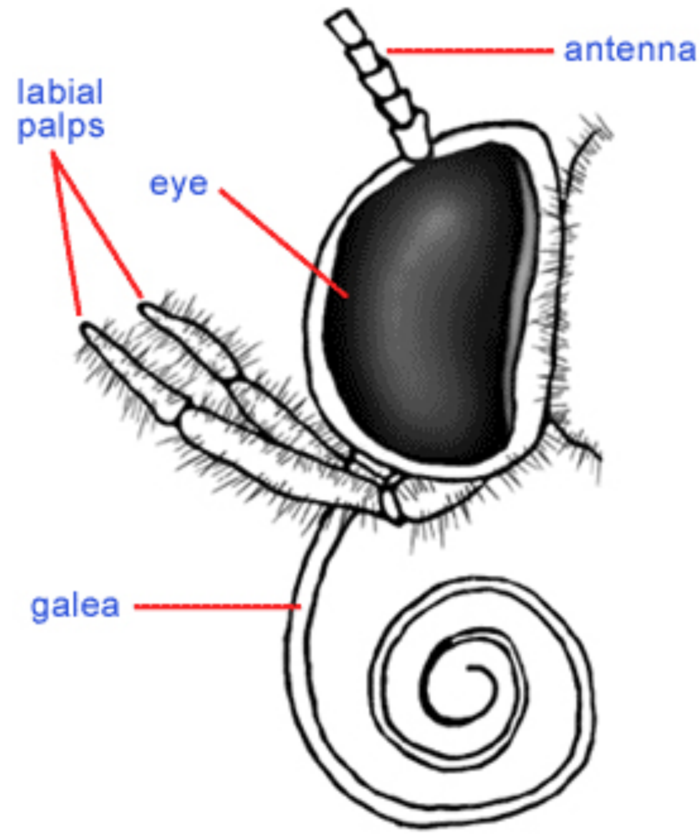
Modifications for Liquids

- Honeybee: Chewing and Lapping.
- Mandibles still clearly apparent.
- **Labial glossae** are fused and form tongue.
- Maxillary galeae and labial palps form tubular proposcis.
- Tongue laps, muscular **cibarium or pharynx** pumps.



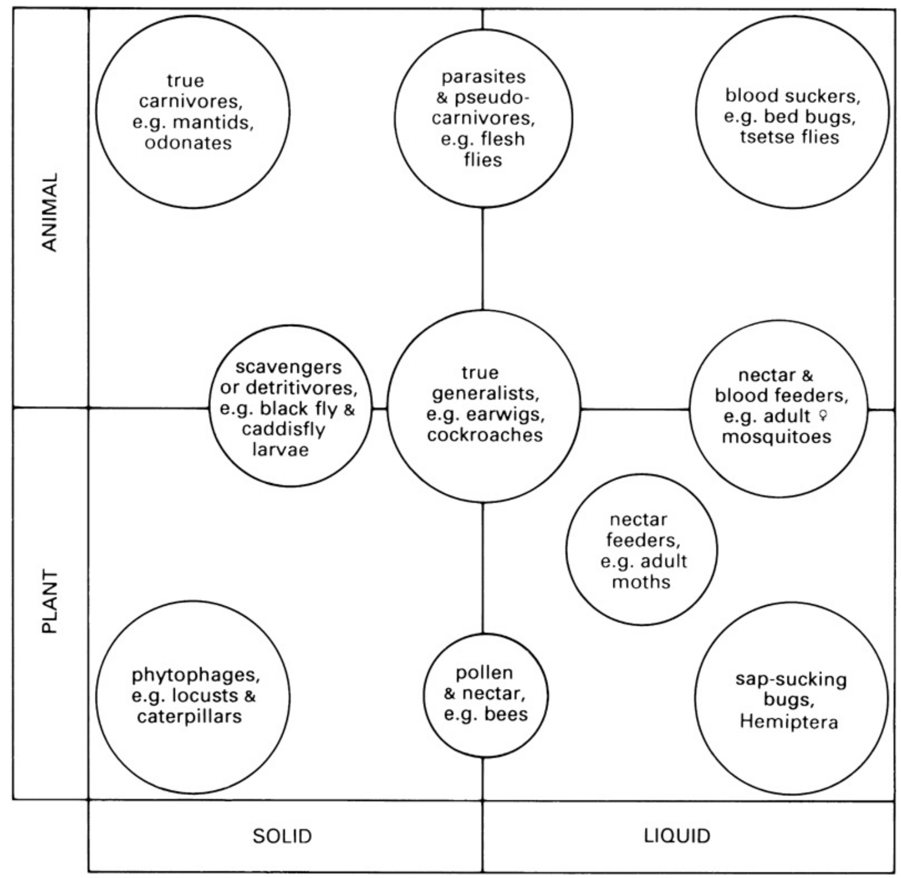
Siphoning insects

- **Haustellate** mouthparts.
- Generally, Lepidoptera, some flies.
- Proboscis is a long tube that is formed by heavily modified maxillary galeae.
- Mandibles lost.
- In butterflies, remaining mouthparts lost.



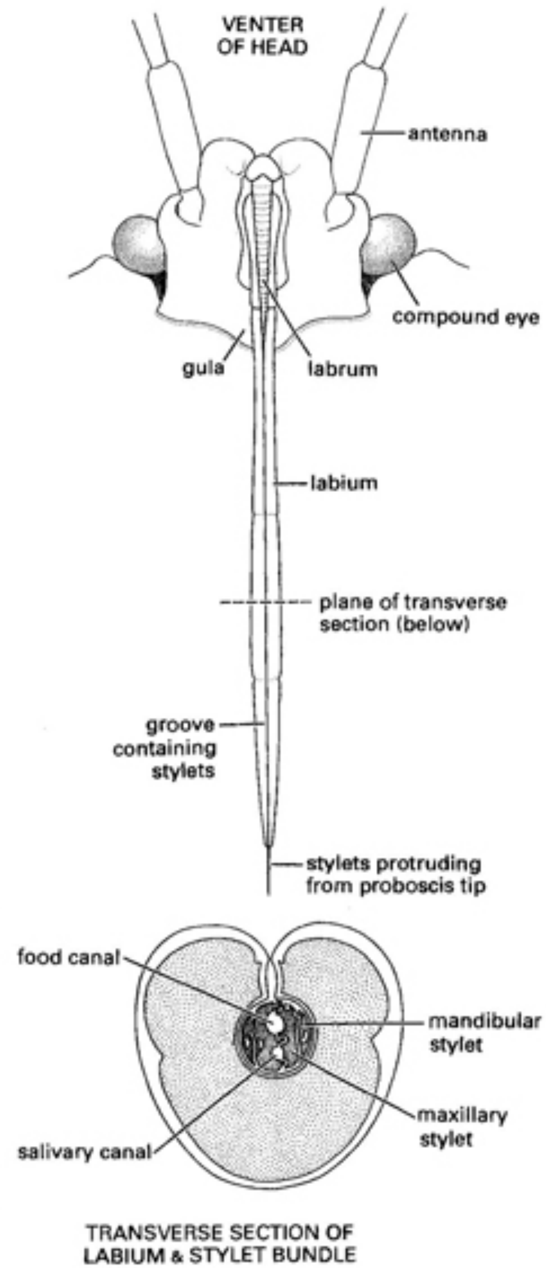
Piercing-Sucking Mouthparts

- We see piercing-sucking mouthparts in two functional groups.
- What are they?



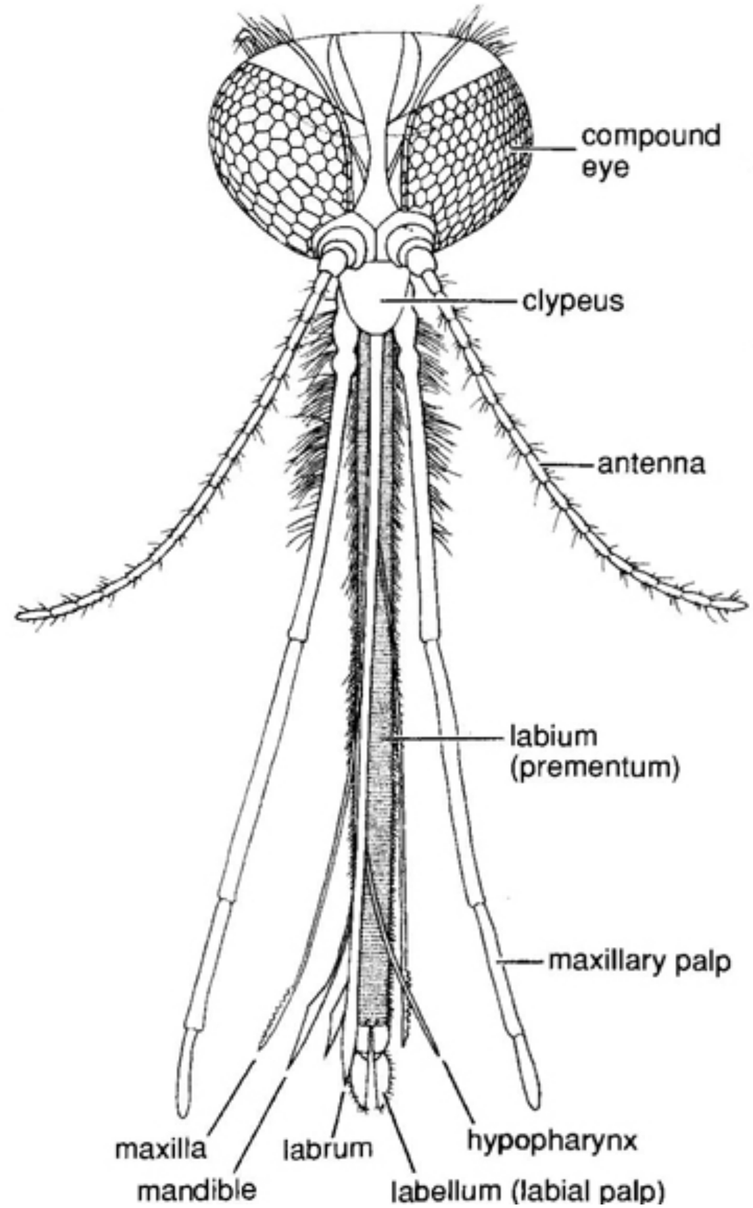
Hemipterans

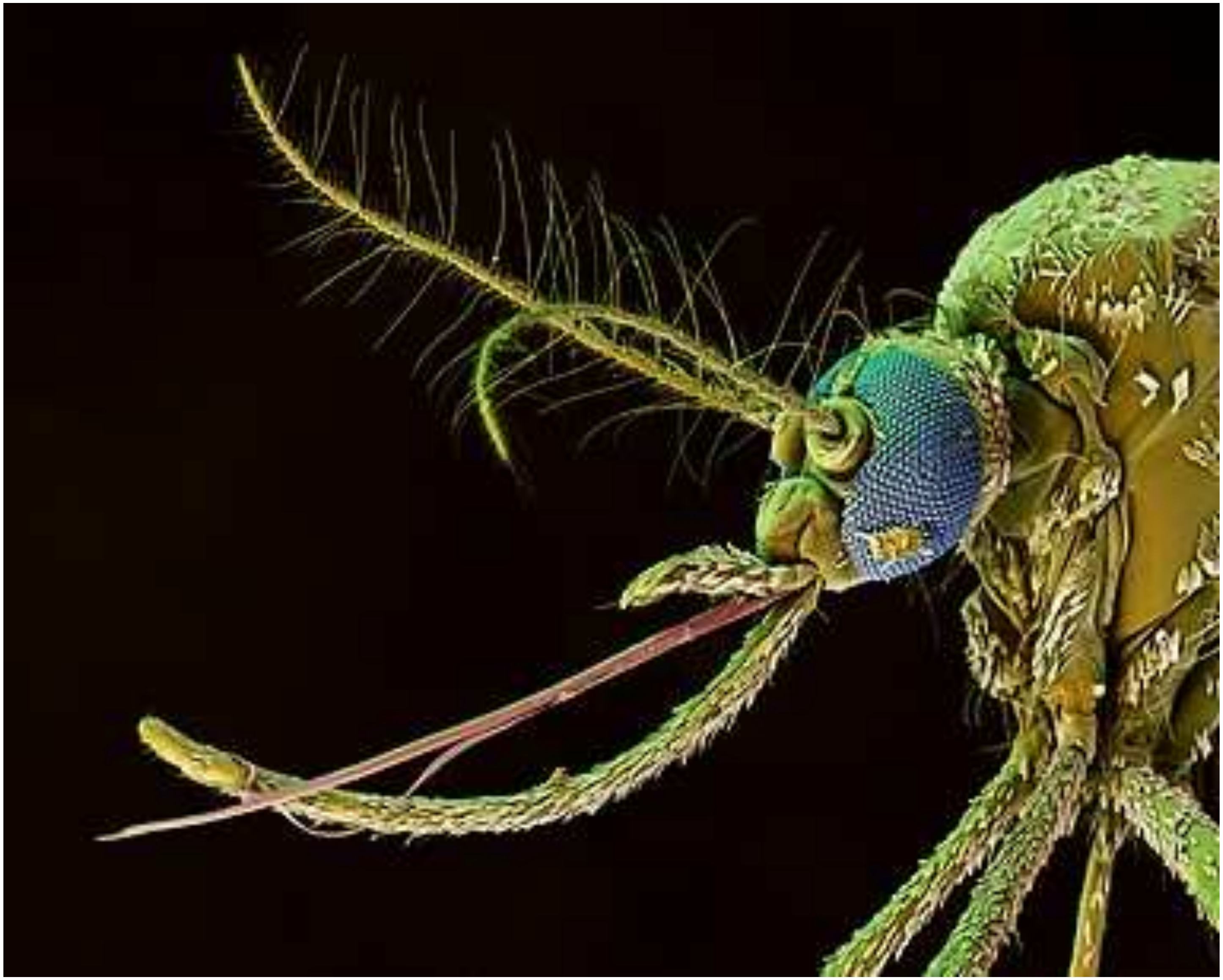
- Include sap-feeders and haemophages.
- Mandibles and maxillae modified as needle-like stylets.
- Beak is highly modified grooved labium.



Dipterans

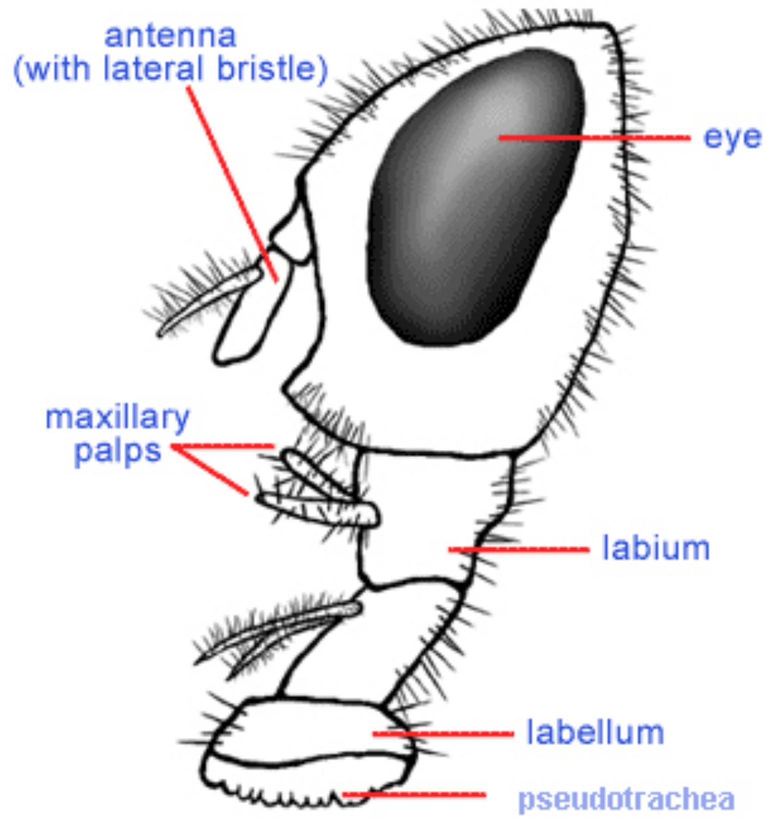
- Ancestral is a tubular sucking organ with adaptations for piercing and sucking.
- Labium forms protective grooved sheath.
- Mandible, maxilla, and labrum are serrated and driven through skin.
- Tube is formed from curled labrum sealed by mandibles or hypopharynx.



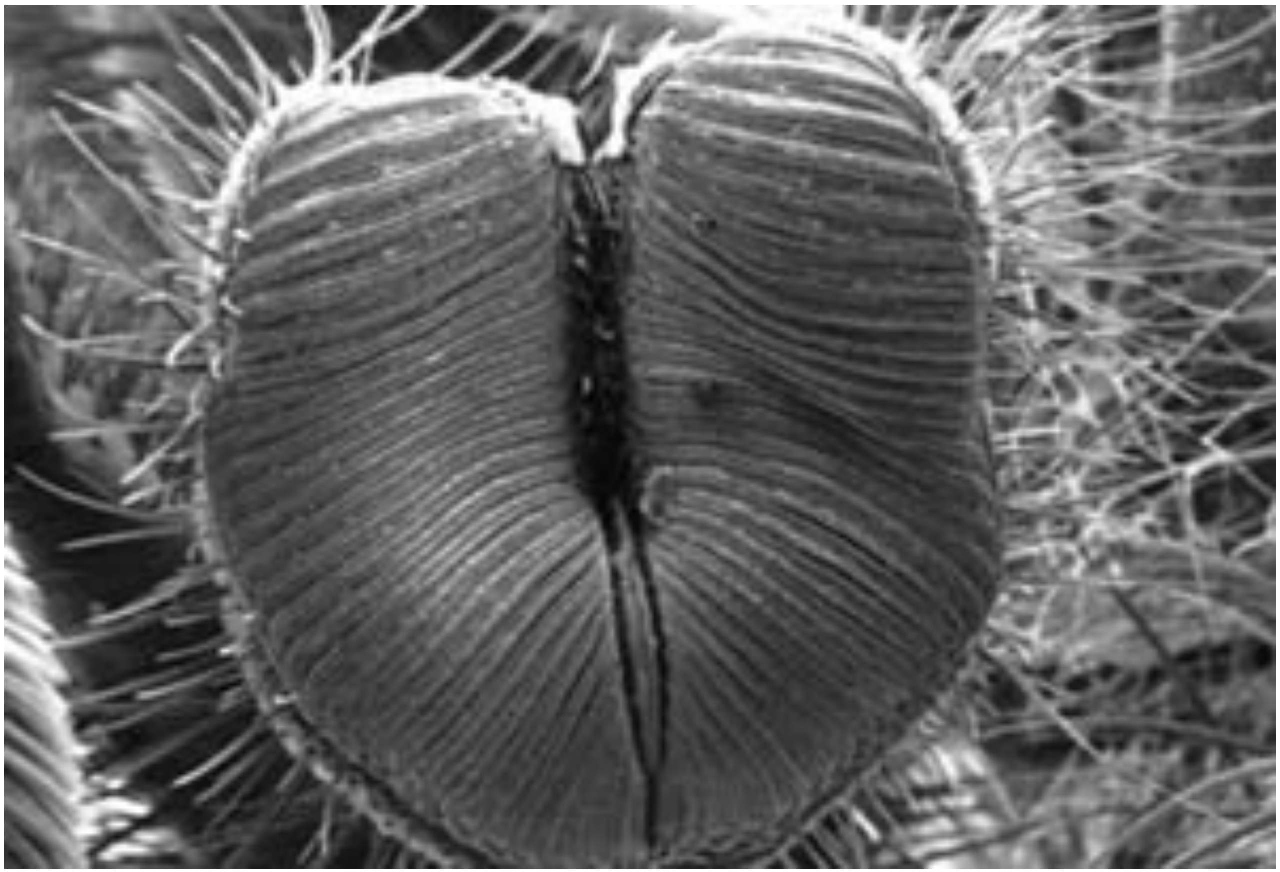


Sponging mouthparts

- Dipteran sponging mouthparts (think house-fly or *Drosophila*) are derived from this.
- Elbowed labium forms entire tubular structure.
- Mandibles lost, maxillae reduced.



Pseudotracheae



Mouthparts and Feeding

- There are many more modifications on this theme (your book discusses some).
- What are the two fields of morphology?

- How does this examination of feeding illustrate this?