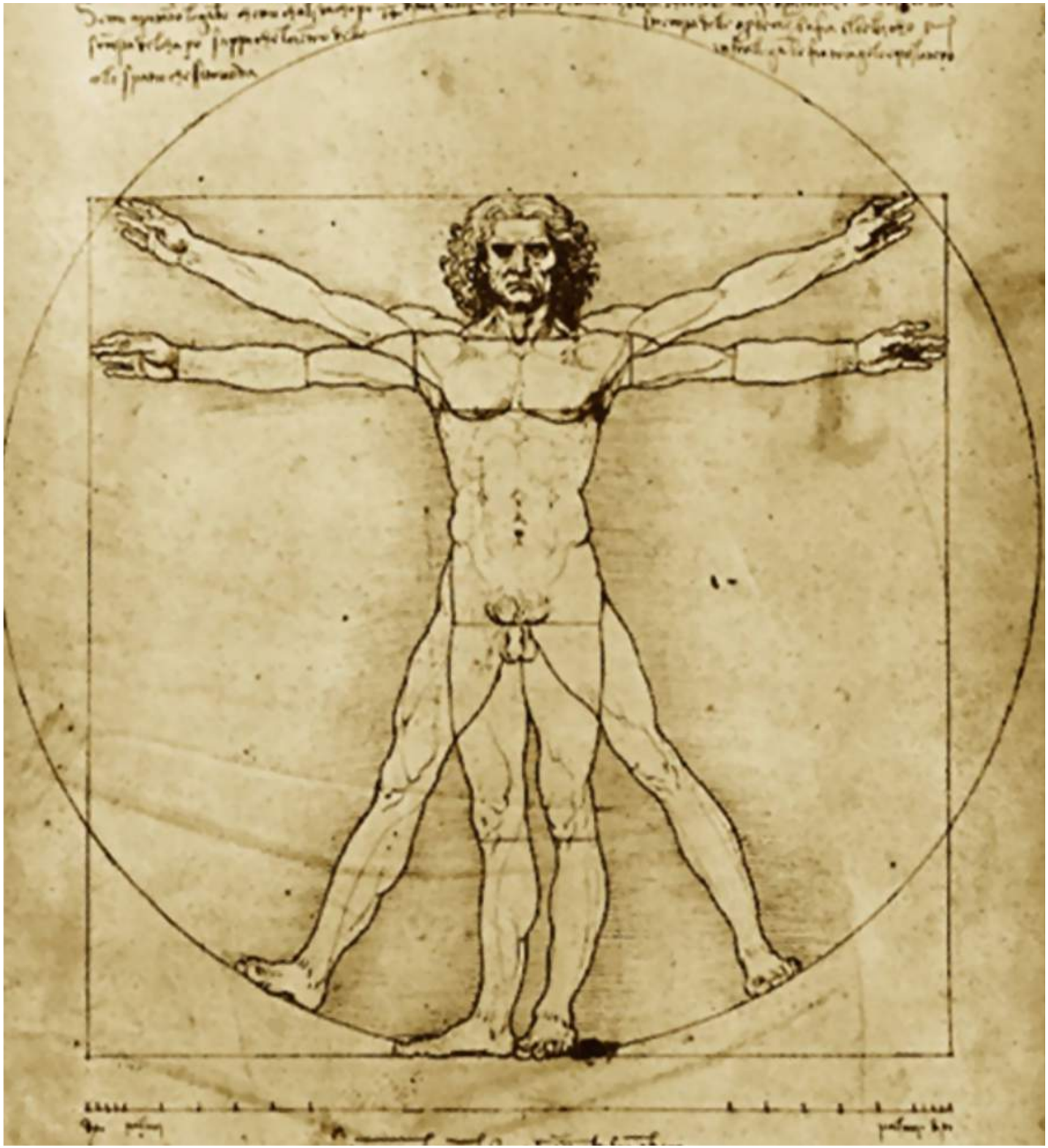
Design principles of biological architecture
(at the organismal level)

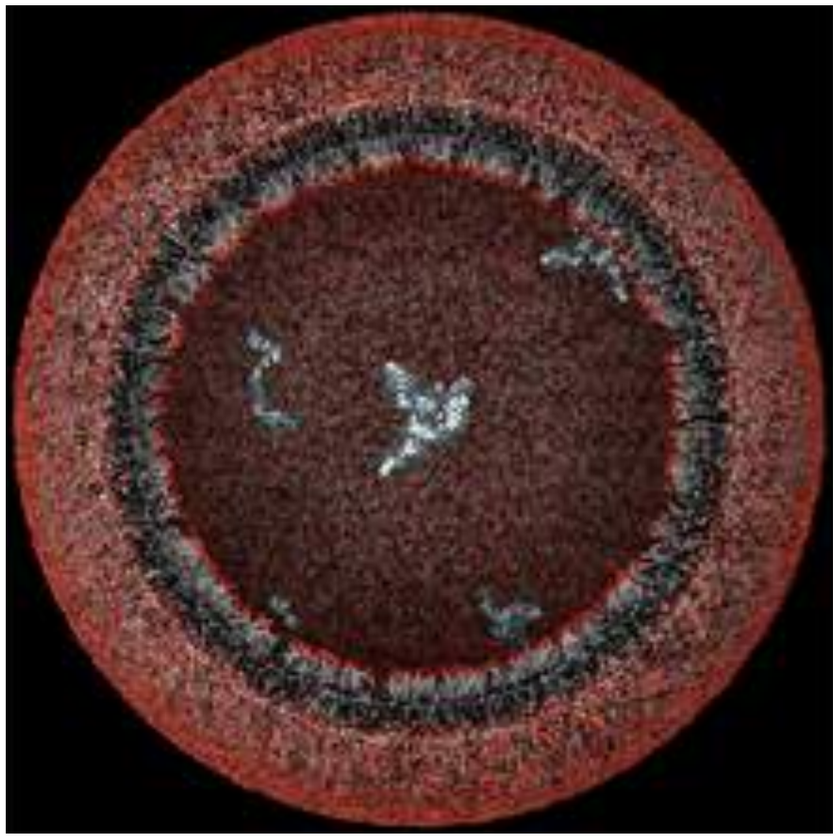
MSc Bio-Architecture
12.03.2018

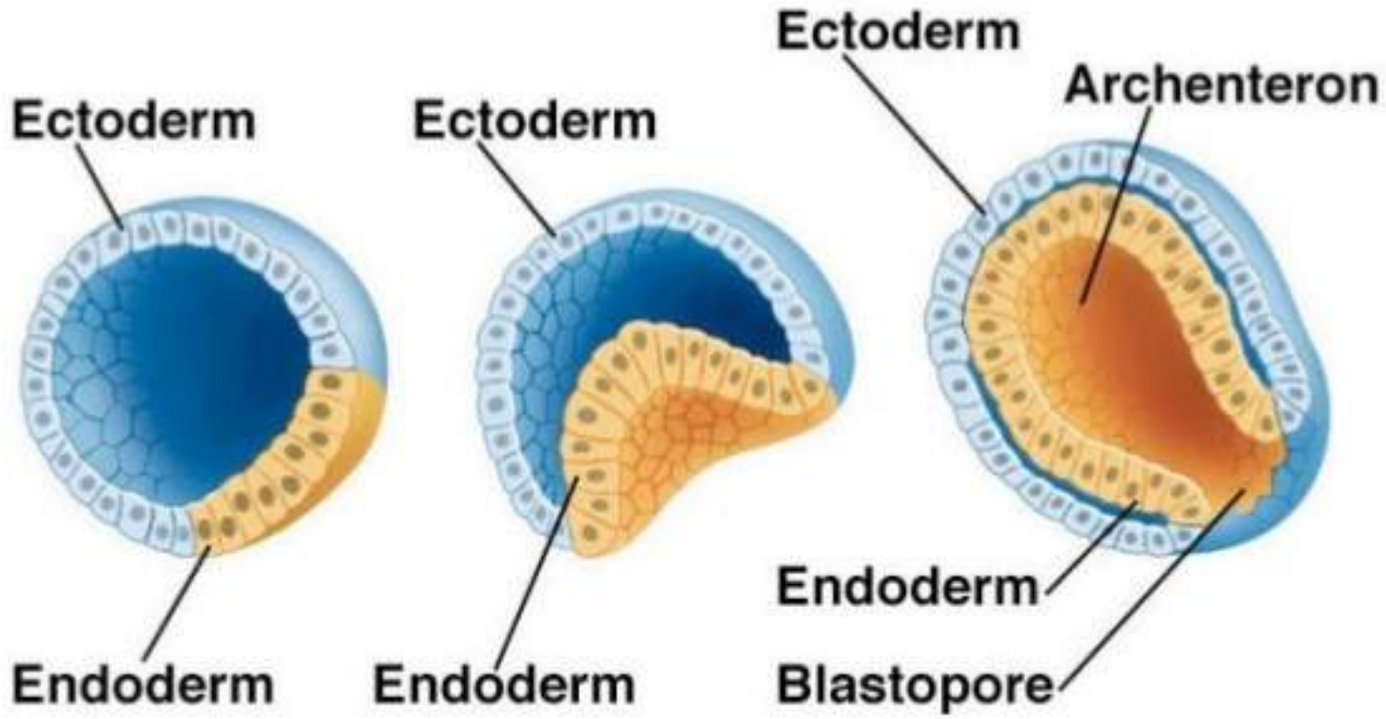
Biological
Form +
Function Lab

Naomi Nakayama PhD
SynthSys Centre for Synthetic and Systems Biology



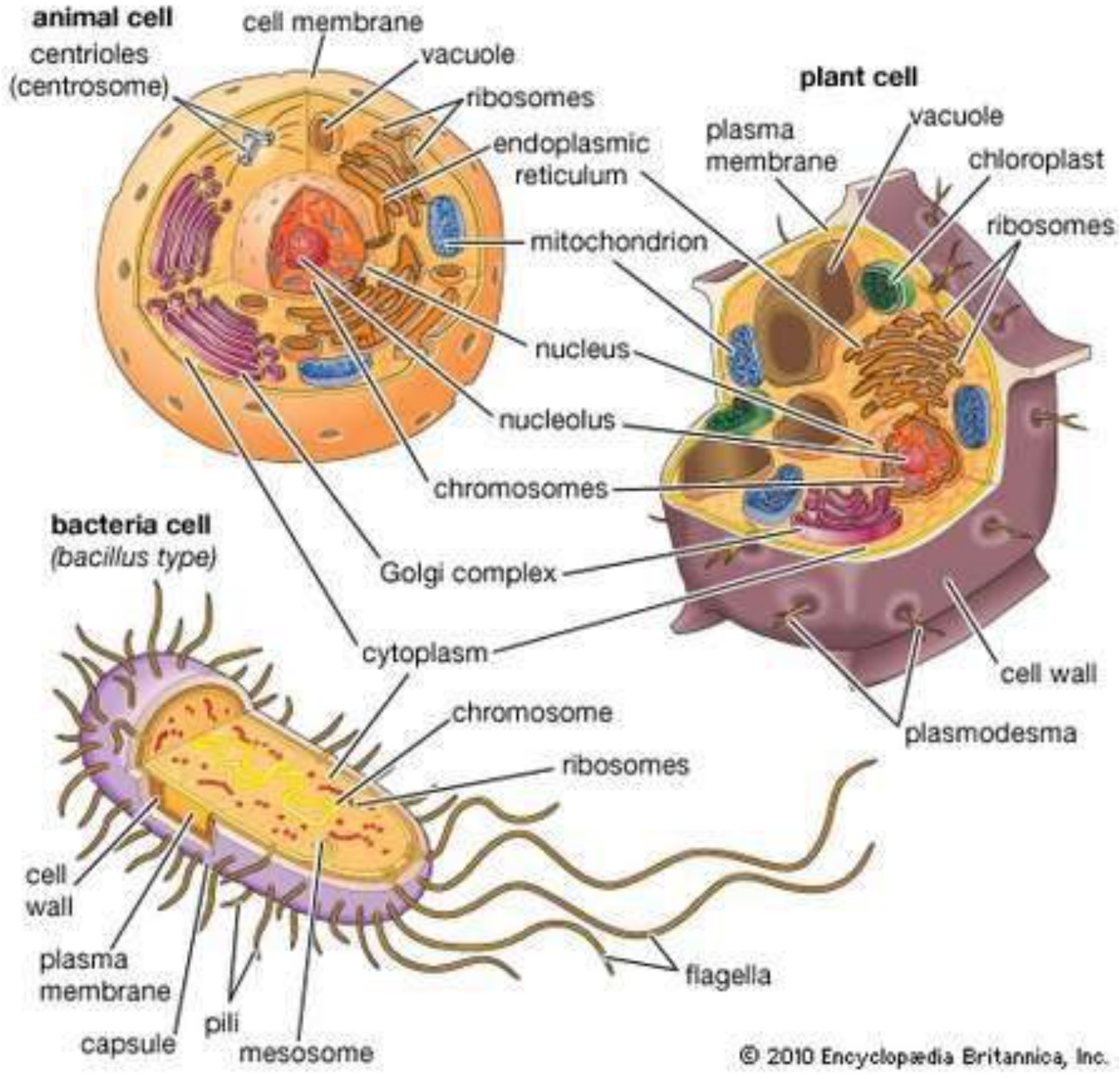
A cell or an organism =
a bag of chemicals (sac of molecules)



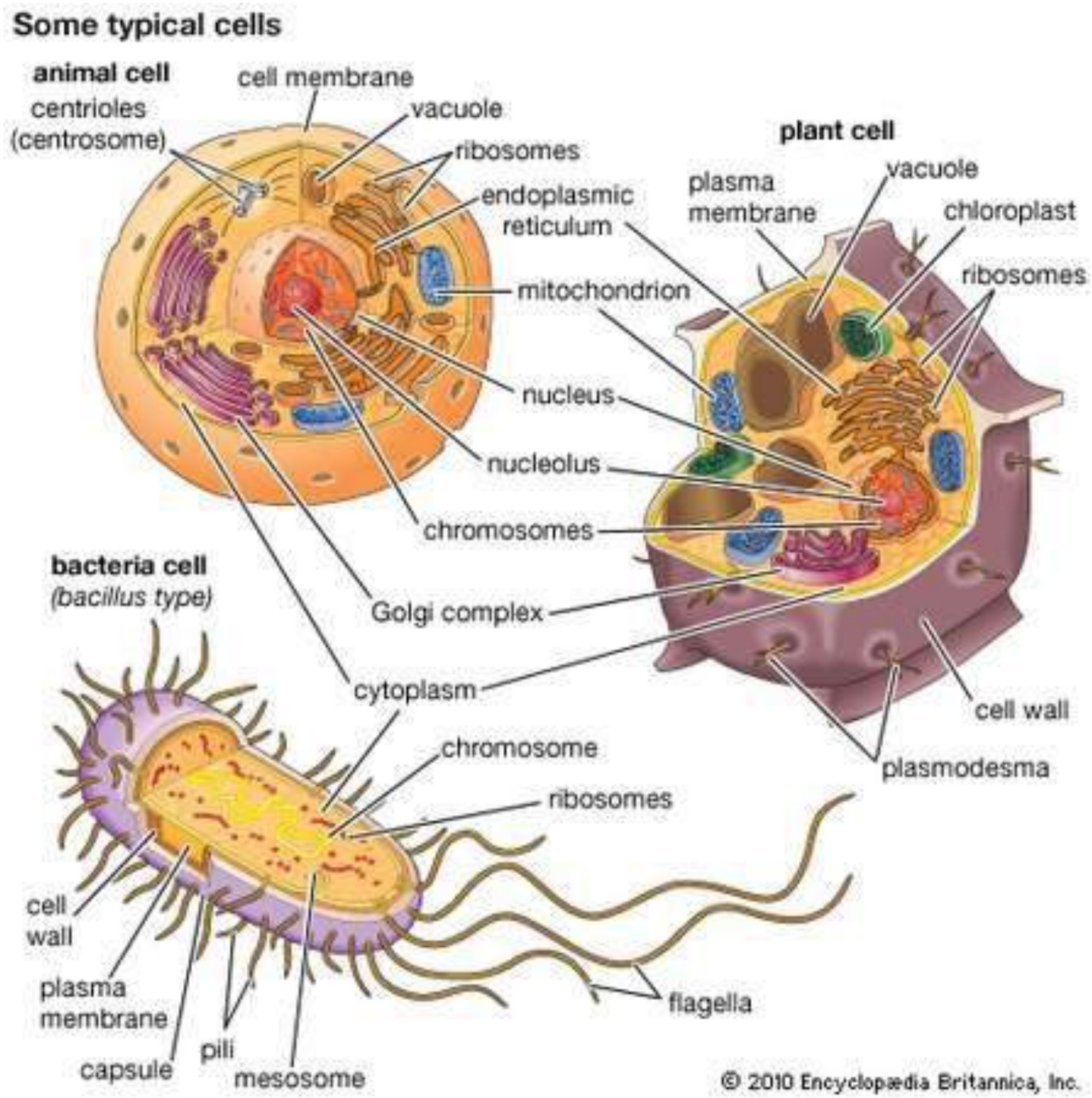


The plasma membrane or the skin/dermal layer is the surface - the boundary against the environment

Some typical cells

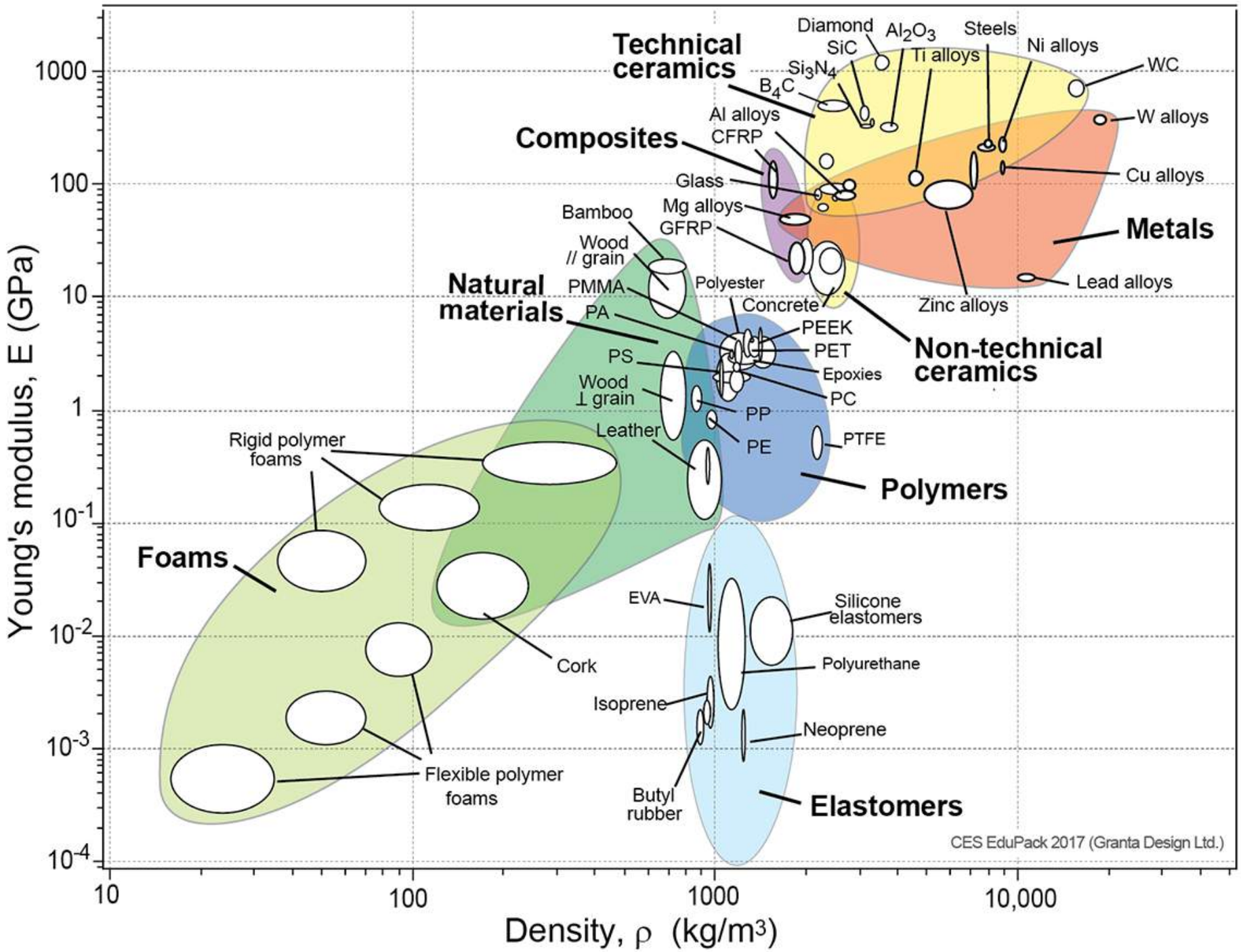


Cell wall Vs not



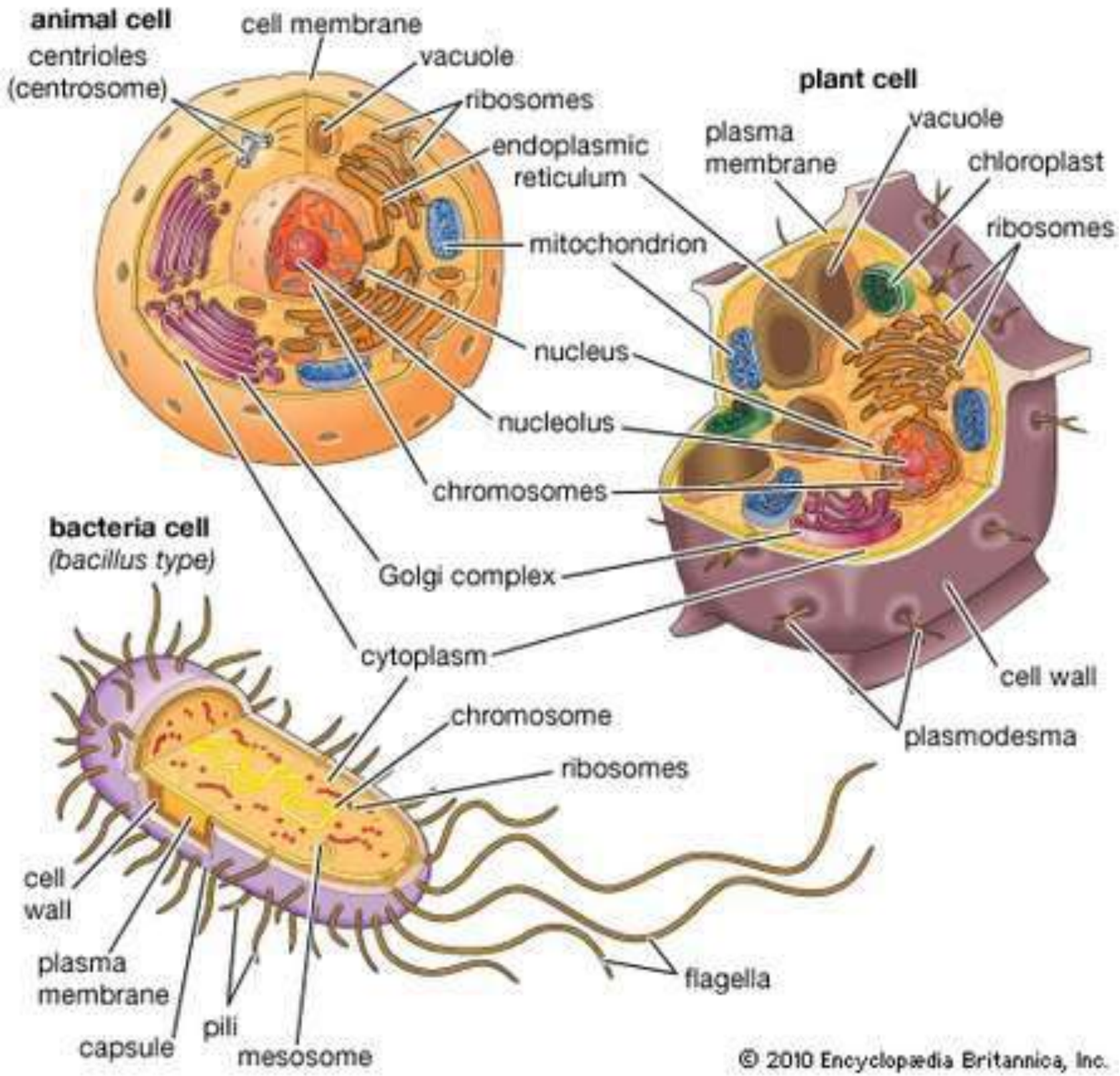
Shell model
or not?

Biomaterials have restricted composition and properties

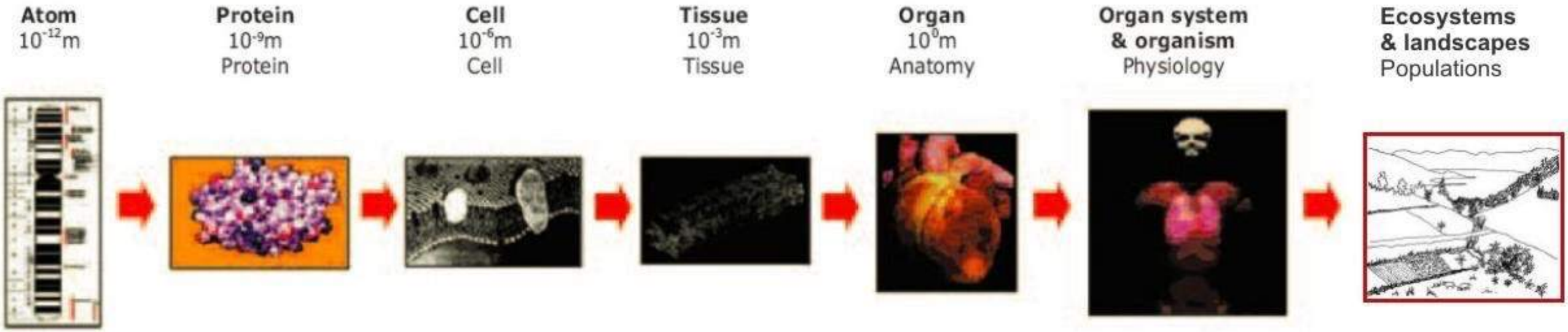


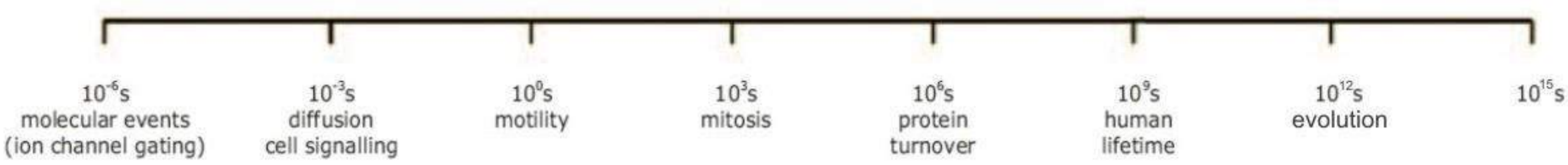
They are made of sugar, fat, and proteins

Some typical cells

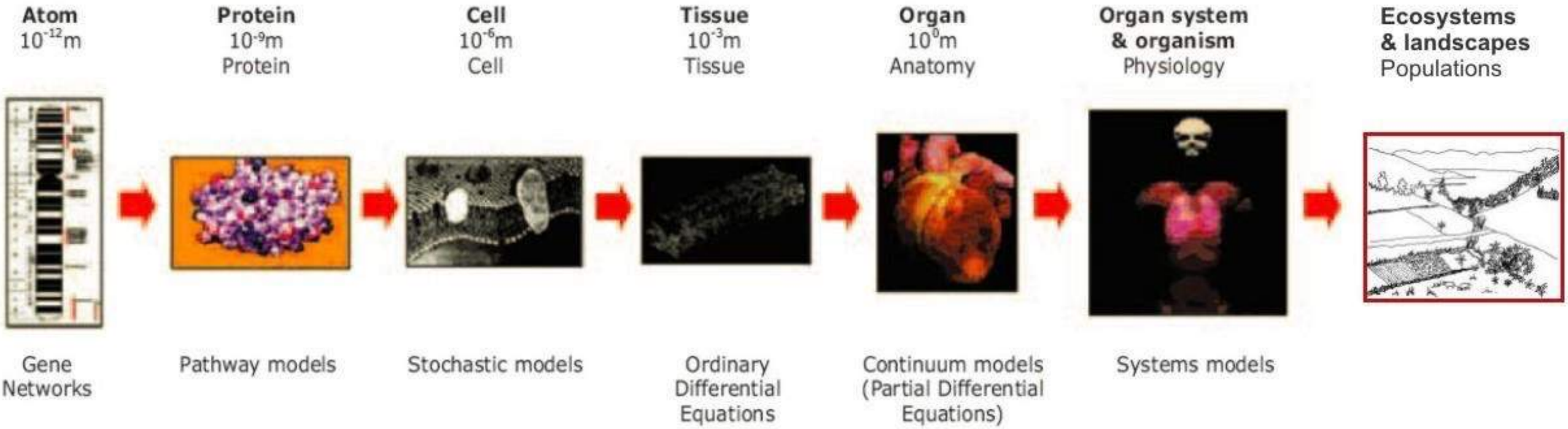


Scales of biological systems



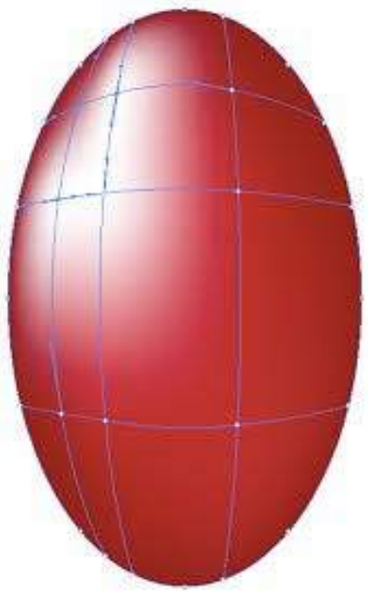


Scales of biological systems



Common geometries in organismal architecture

Zygote, etc.

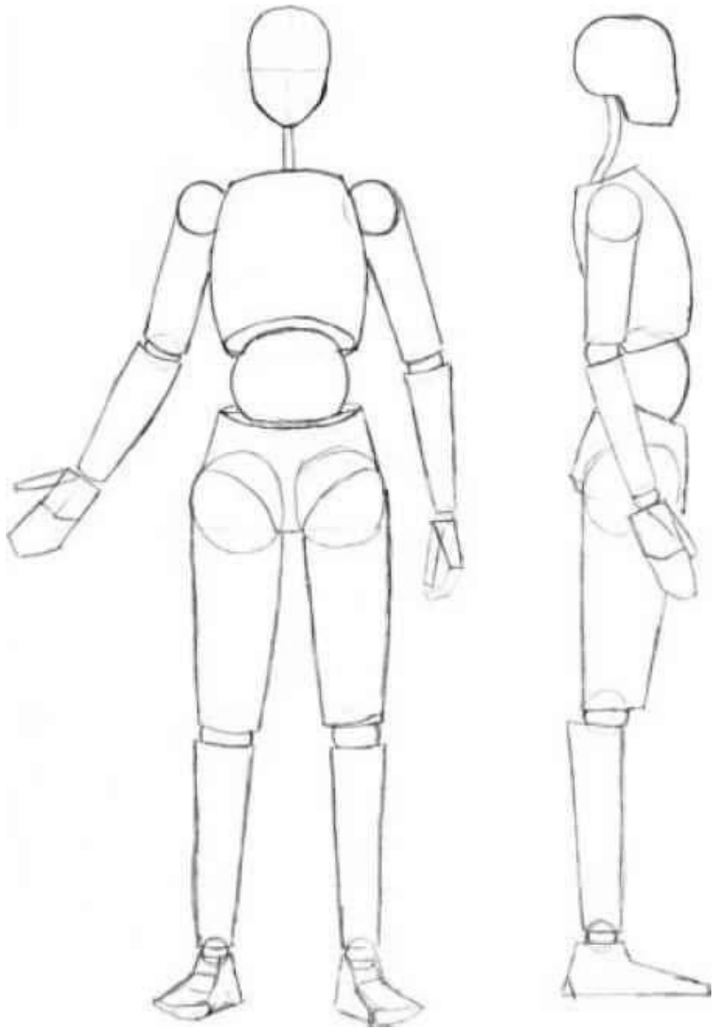


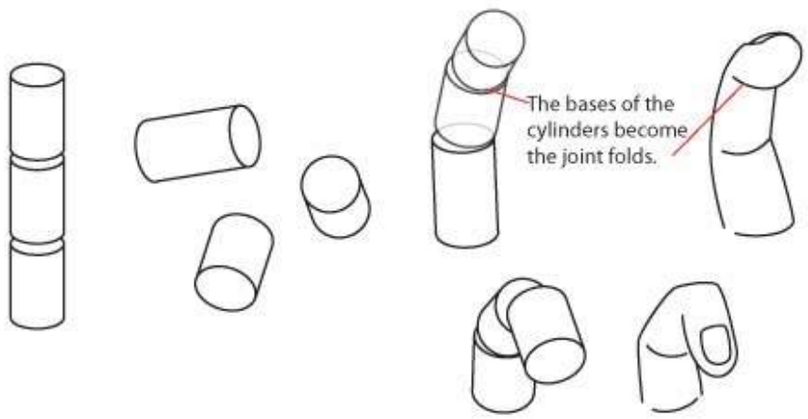
Bacterial cells, sperm, seeds, etc.

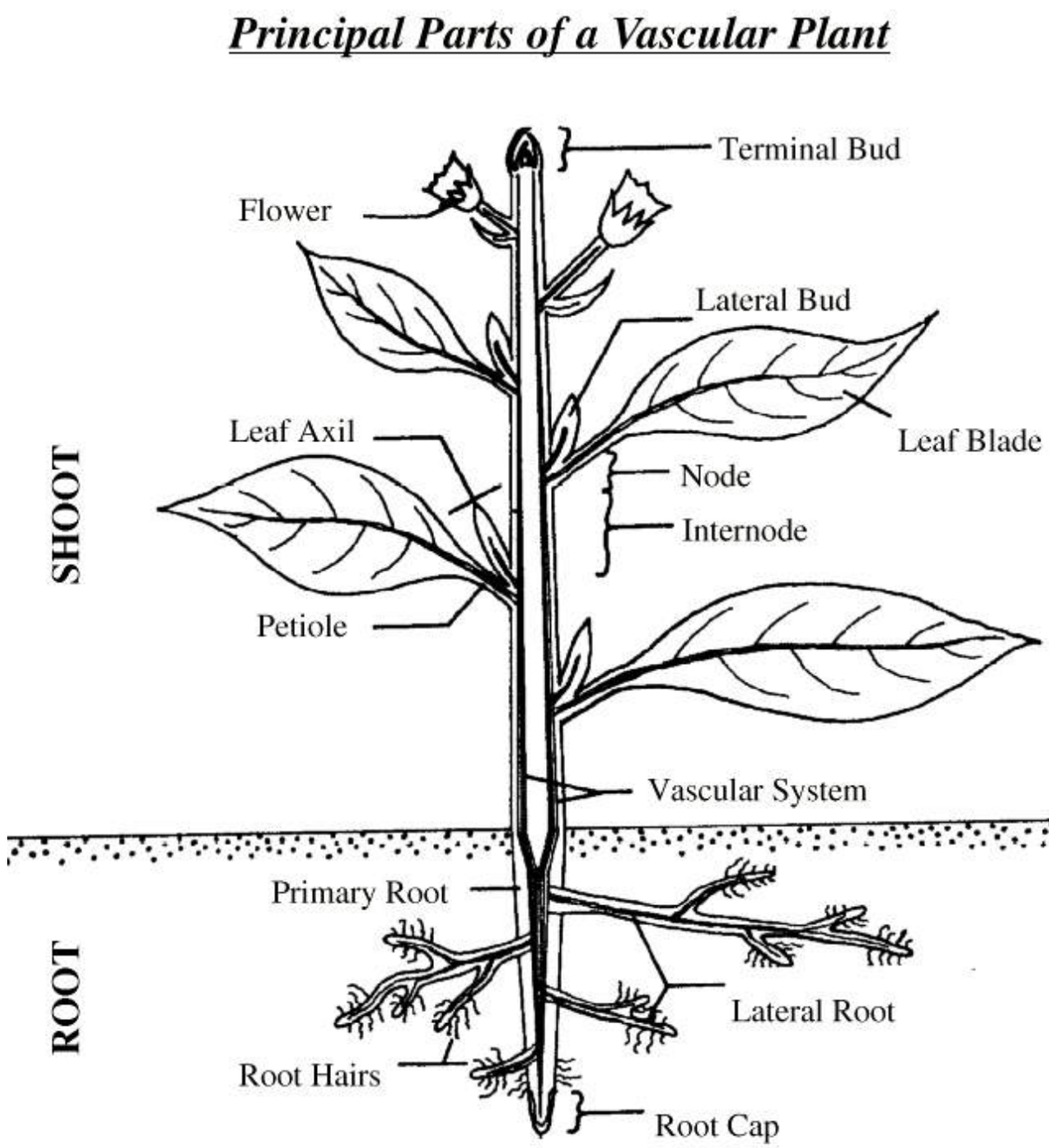
Most lateral organs, main torso, stems, branches, etc.

Hairs, antennae, whiskers, roots, etc.

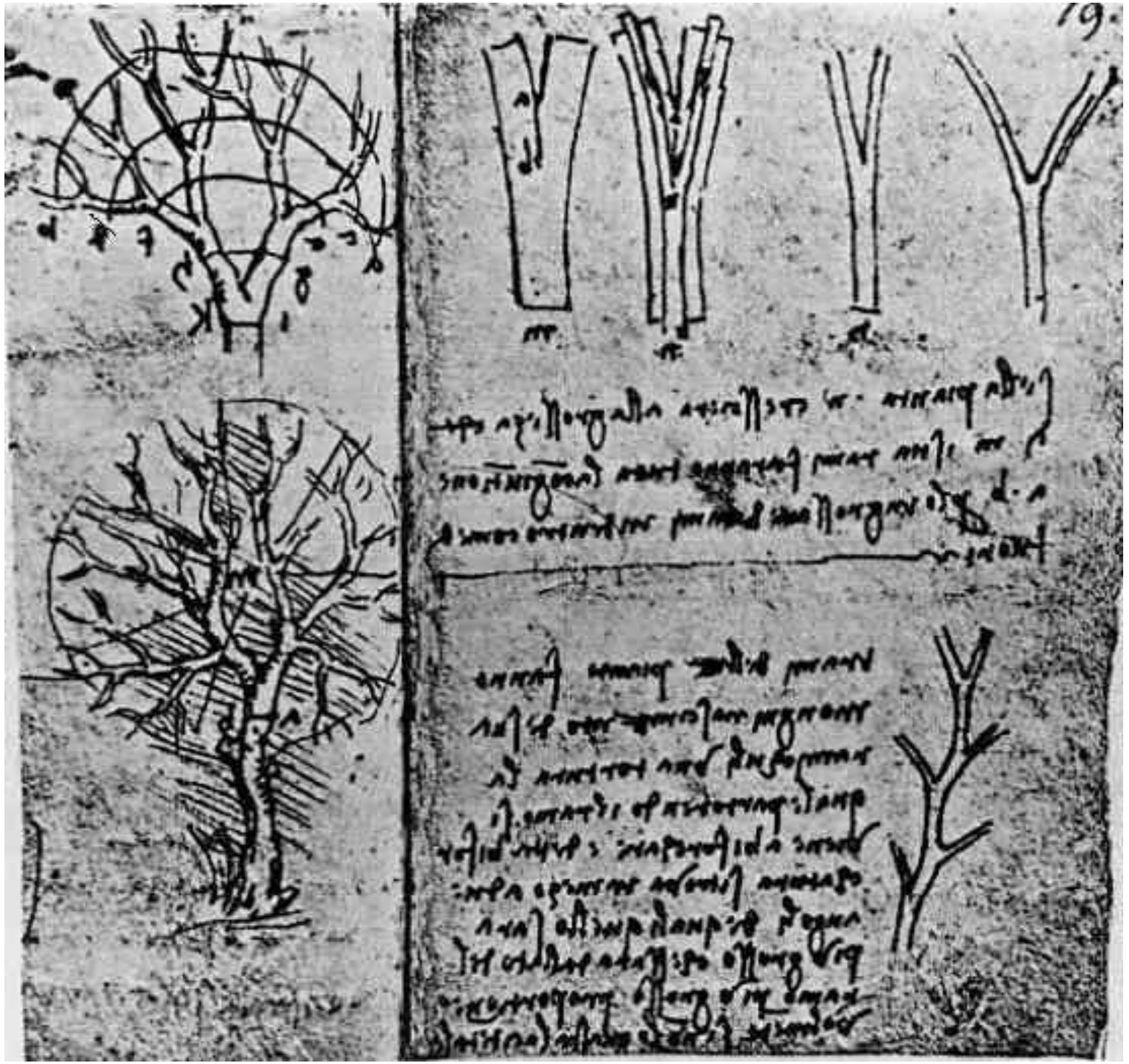
Organismal bodies are made of cylindrical or cone-shaped parts





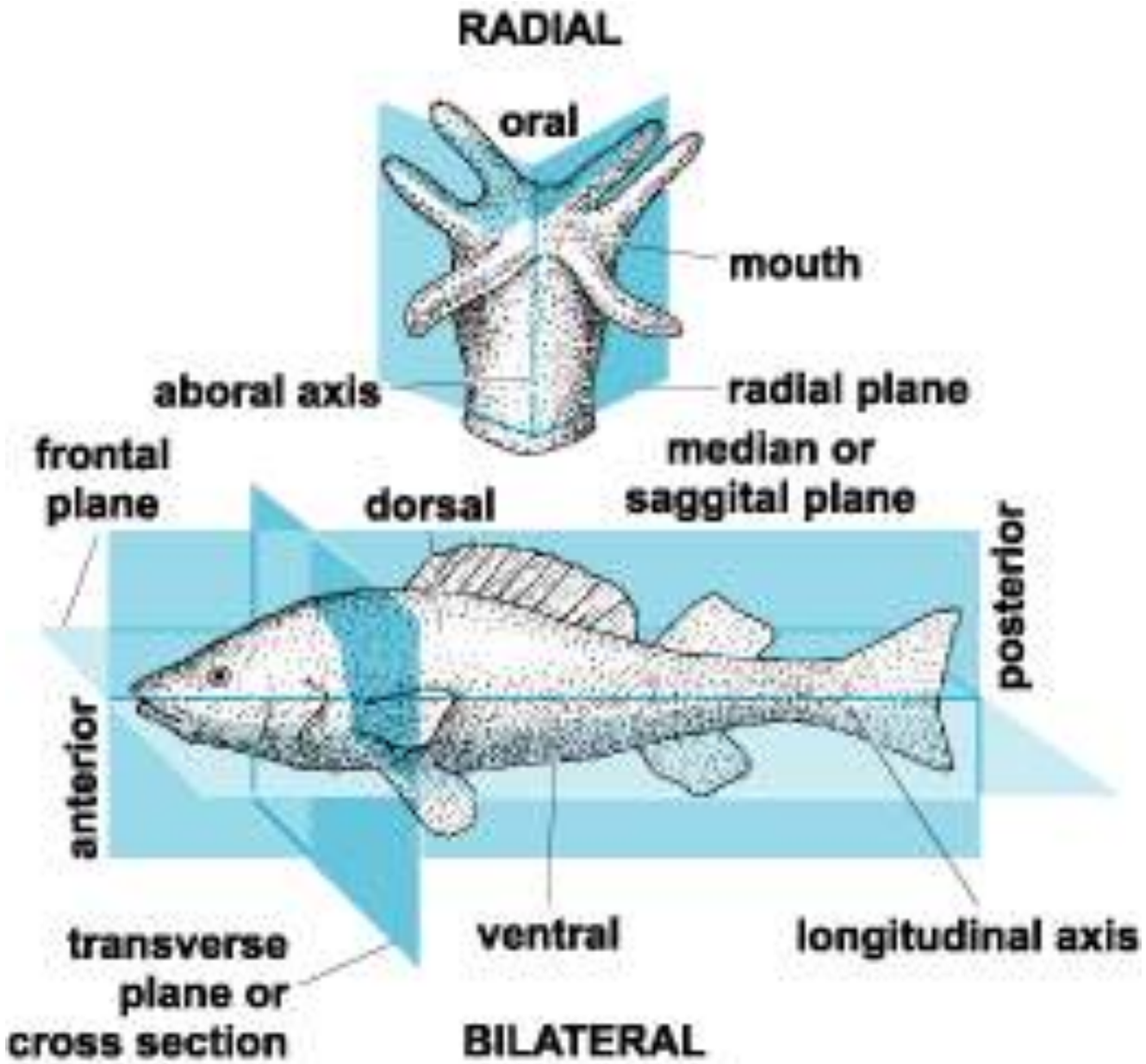


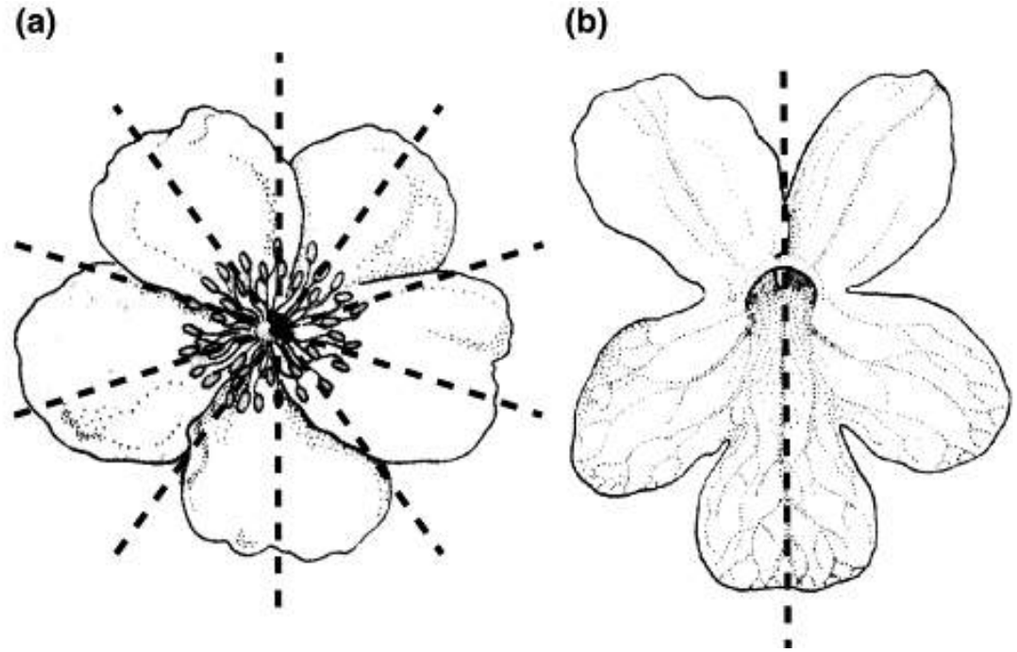
Branching



Increasing surface area and spread

Symmetry





Decreases gradually in evolution

Diversity of forms along the developmental axis

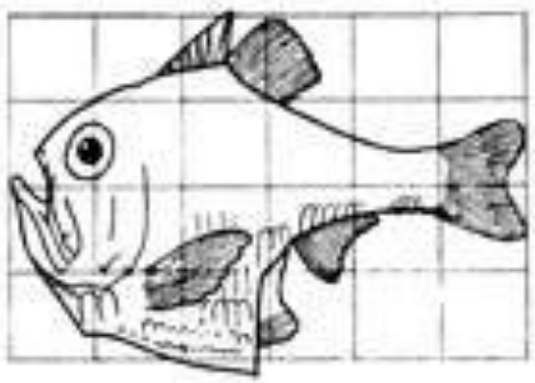


Fig. 146. *Argyropelecus olfersi.*

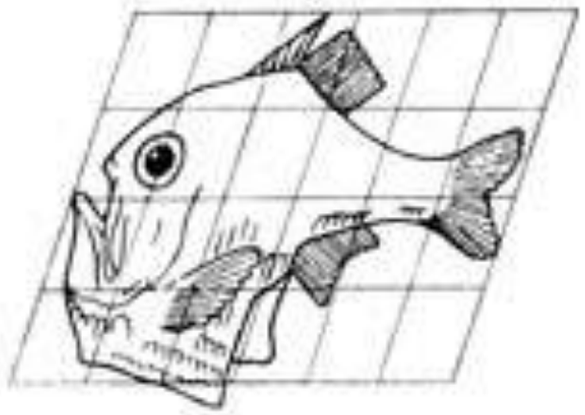


Fig. 147. *Sternoptyx diaphana.*

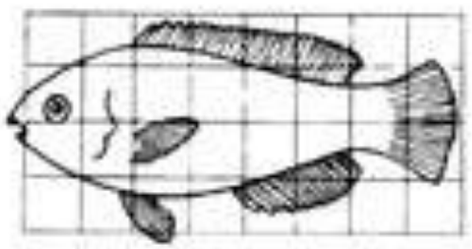


Fig. 148. *Scarus* sp.

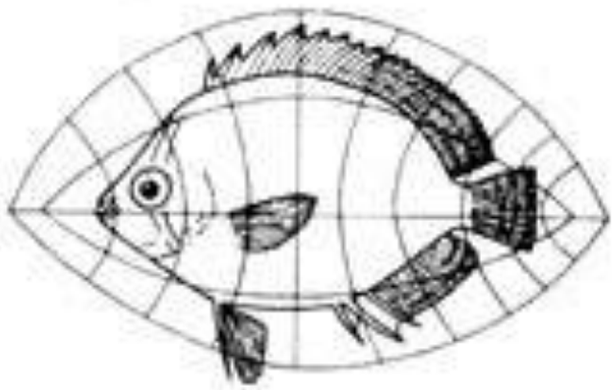


Fig. 149. *Pomacanthus.*

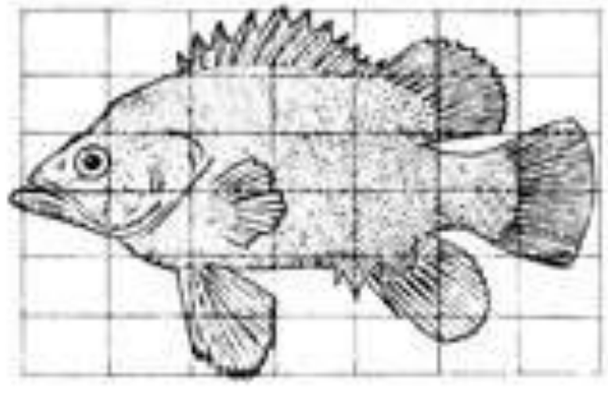


Fig. 150. *Polyprion.*

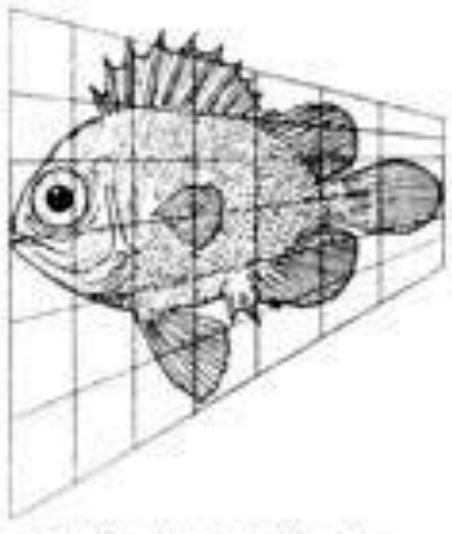
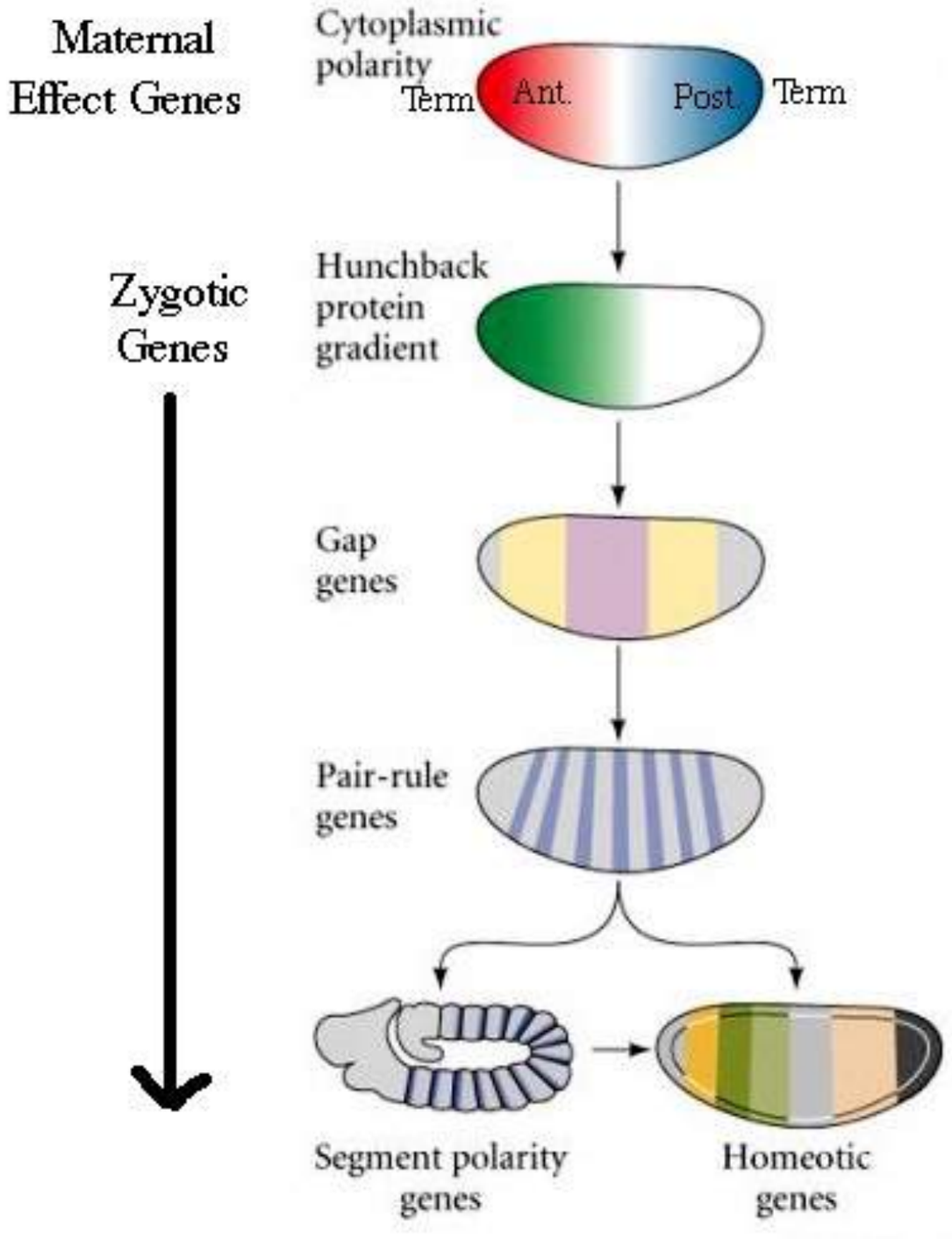


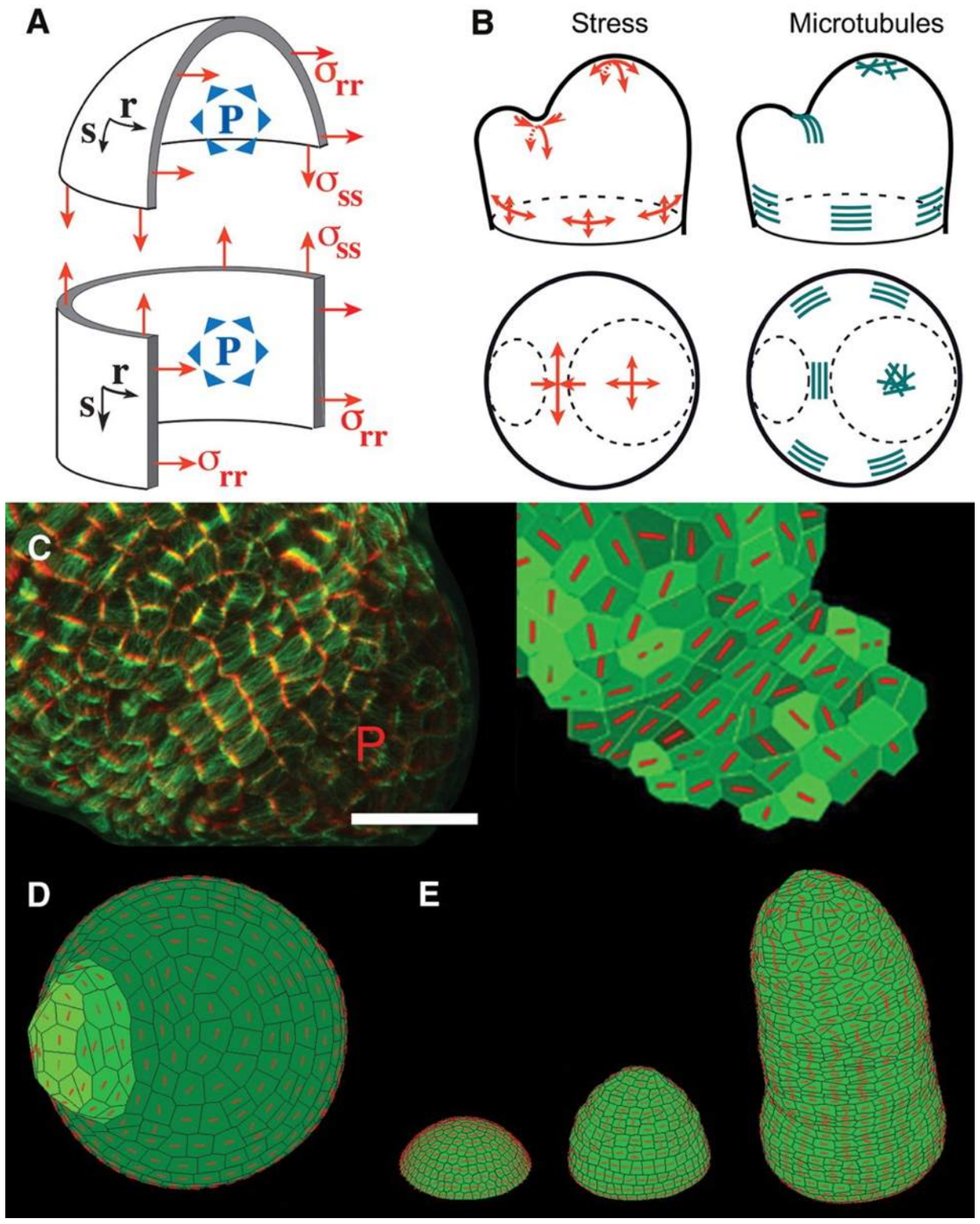
Fig. 151. *Pseudopriacanthus altus.*

D’Arcy Thompson (1917) On Growth and Form.

Morphogens
= chemical agents for developmental patterning



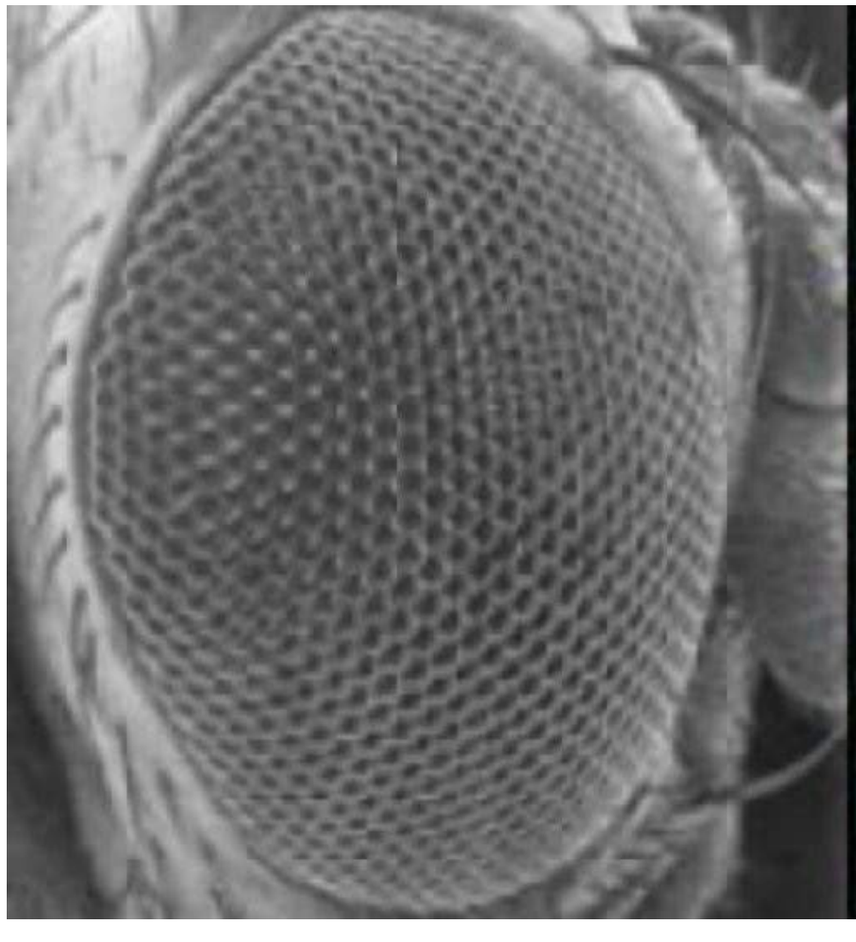
Mechanical stress-dependent morphogenesis

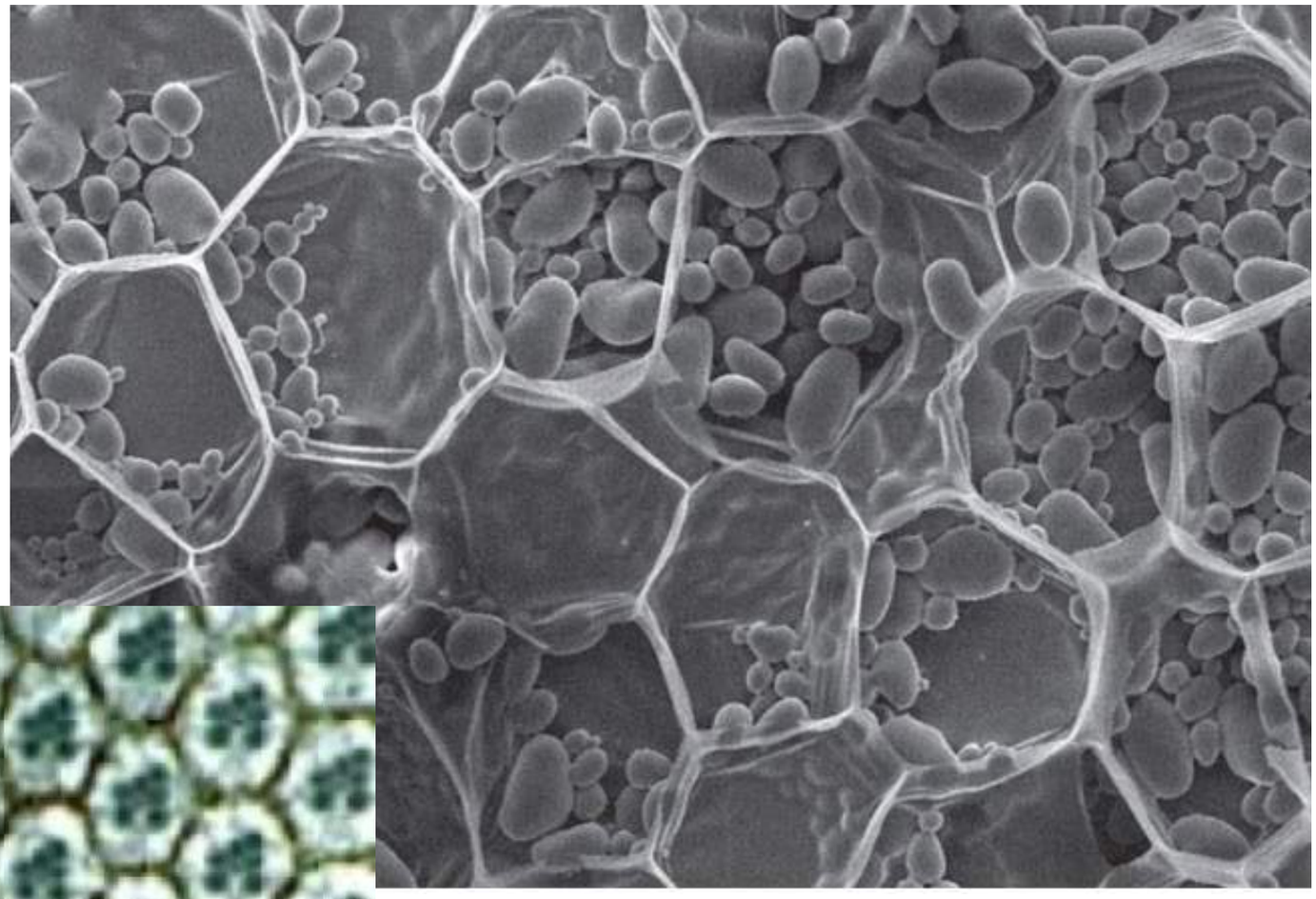


Hamant et al. (2008) Science.

Hexagonal cells

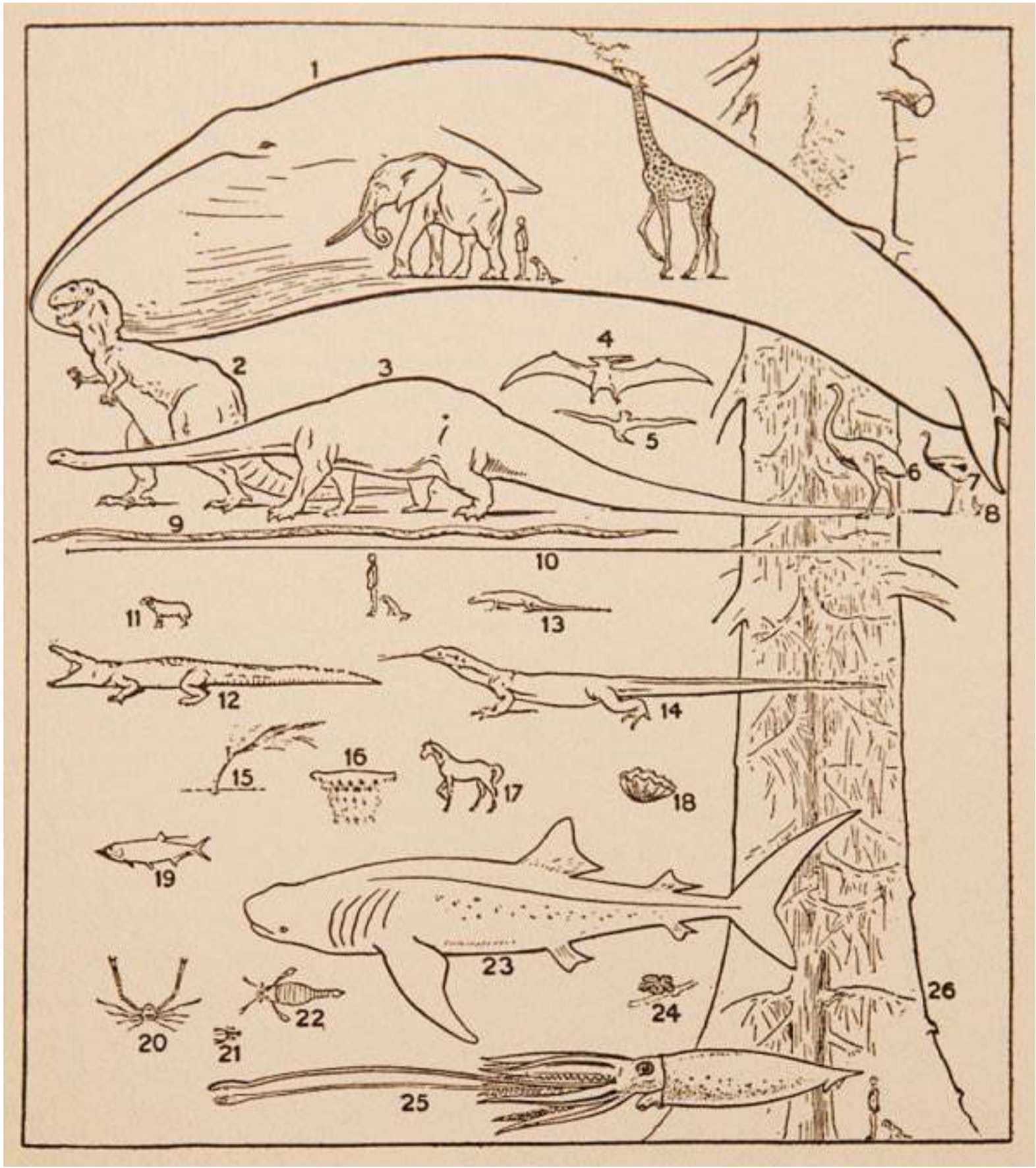
Optimal structural cost for strength





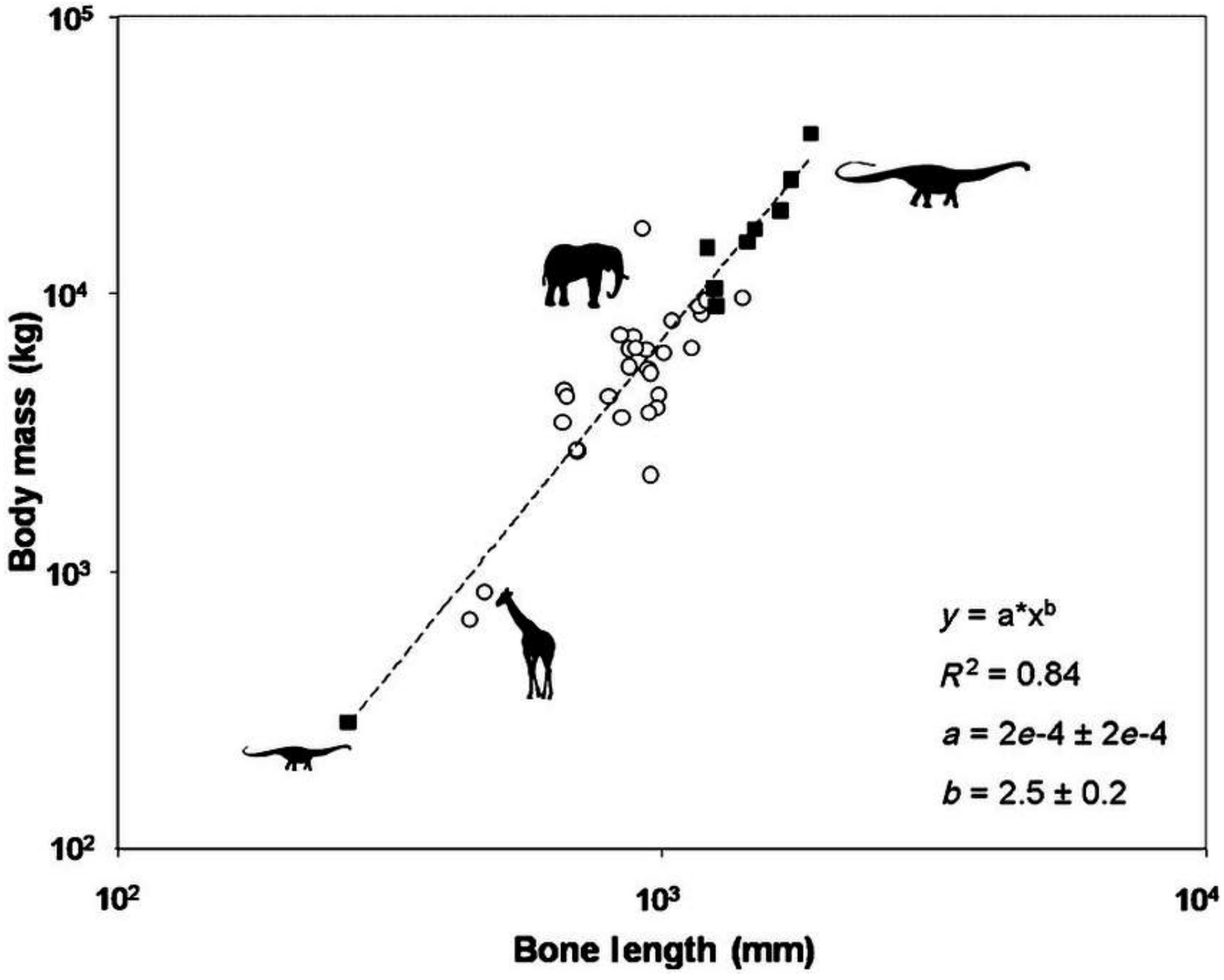
Size variation

Largest organisms on Earth



HG Wells et al. (1931) Science of Life.

Strength $\propto$ Size(=weight)$^{2/3}$

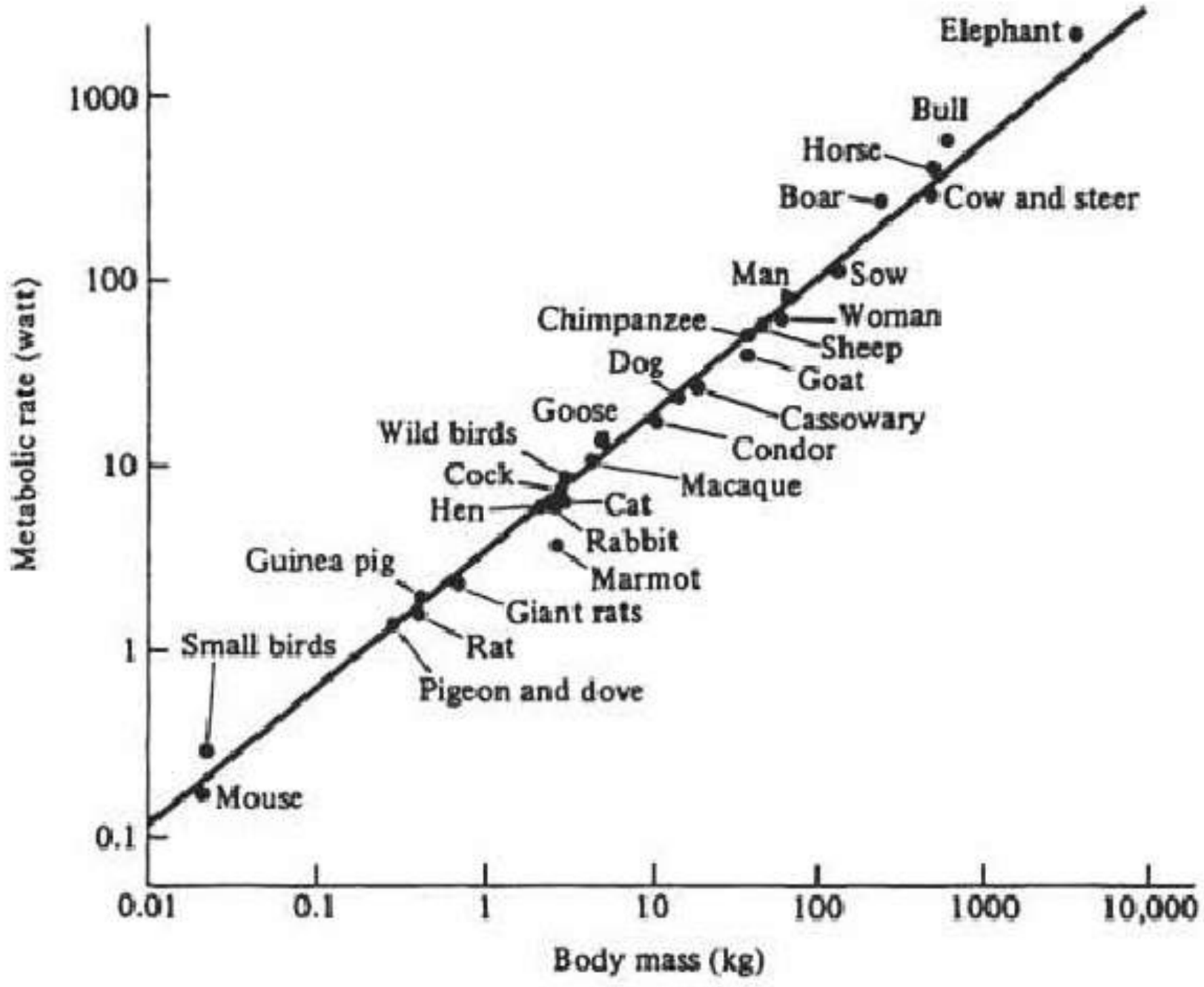


Dumont M. et al. (2014) RS Biol. J.,112:782.

Surface $\propto$ Weight$^{2/3}$

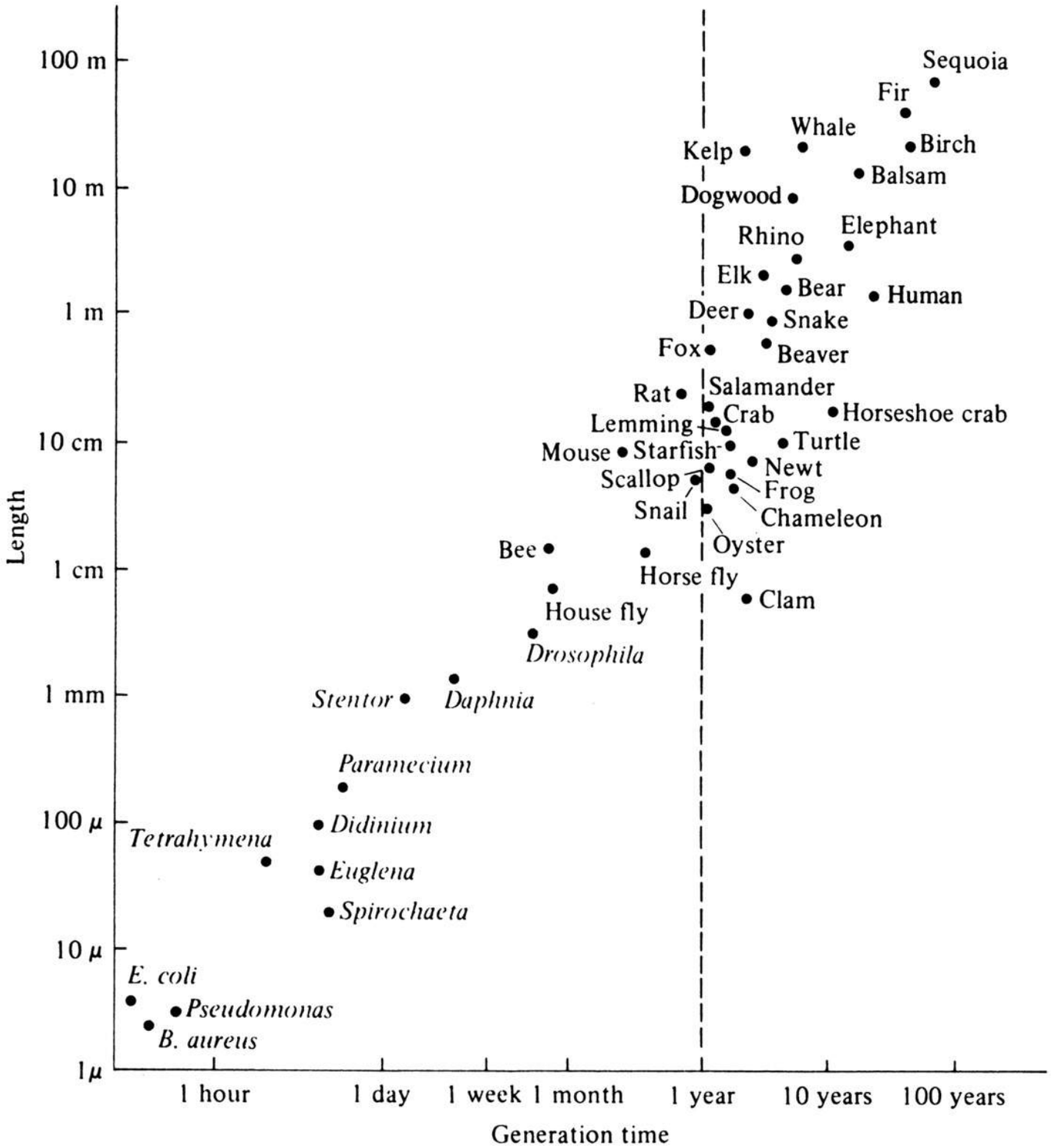
For gas exchange,
interaction with the environment

Size ∝ Metabolic rate



Bonner JT. (1965) Size and Cycle: An Essay on the Structure of Biology.

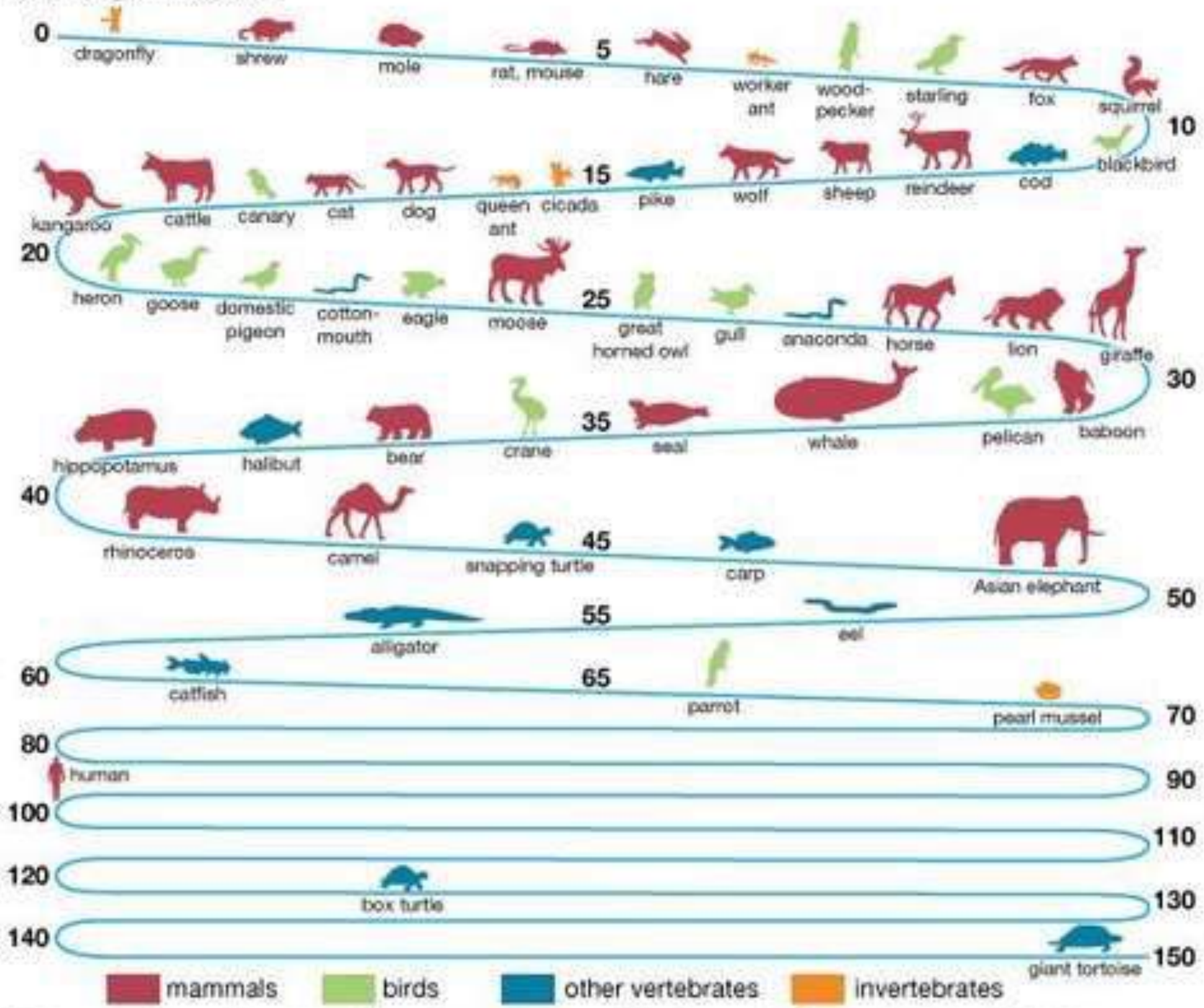
Size ∝ Generation time



Log-log plot of organism length against generation time for a wide variety of organisms.

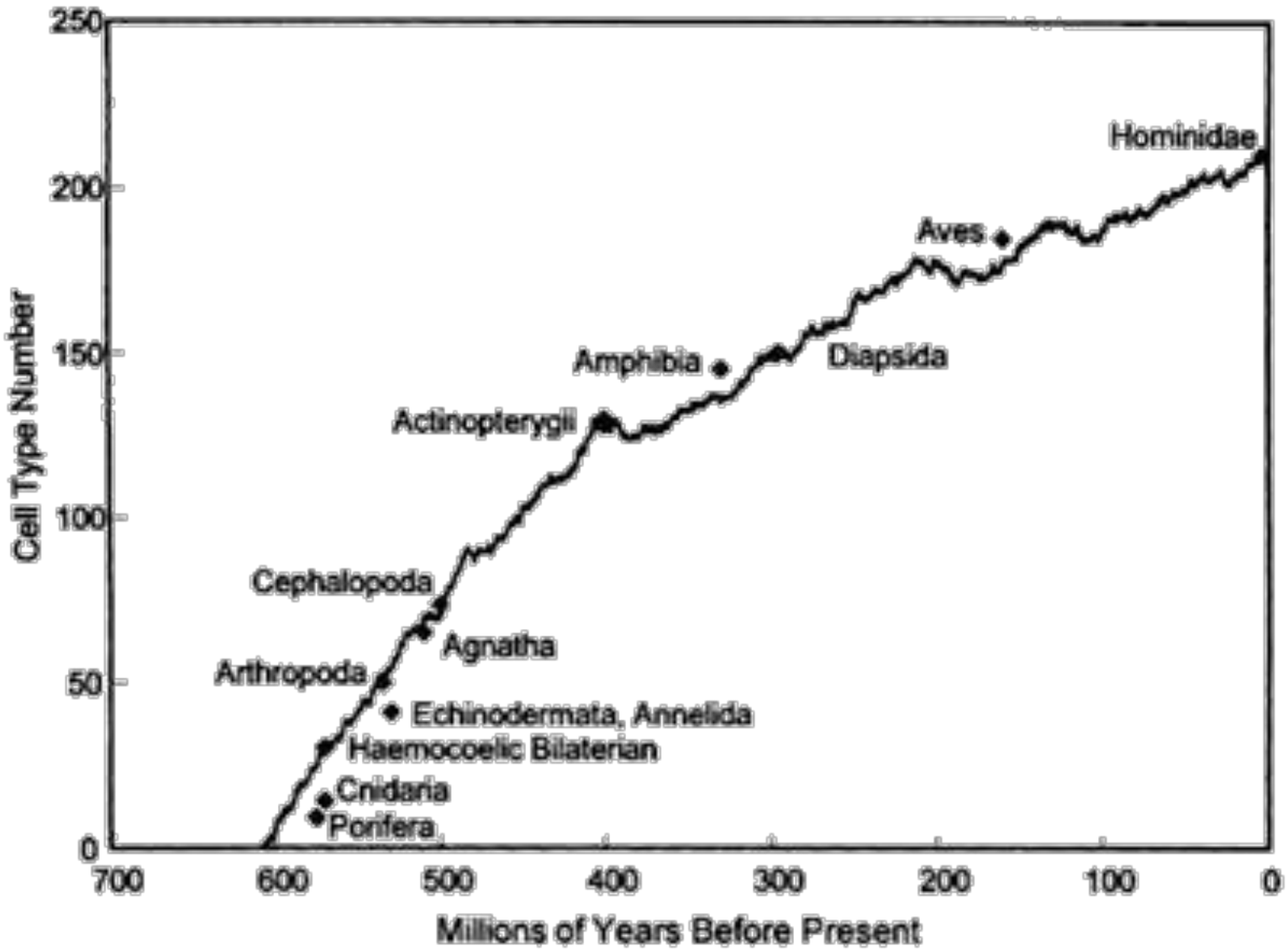
Bonner JT. (1965) Size and Cycle: An Essay on the Structure of Biology.

How long animals live



Maximum ages, in years, that certain animals may be expected to reach, based on reports of zoos and estimates of biologists.
(Data from S.S. Flower, "The Duration of Life in Animals," in *Proceedings of the London Zoological Society*.)

Size $\propto$ complexity (degree of division of labor)

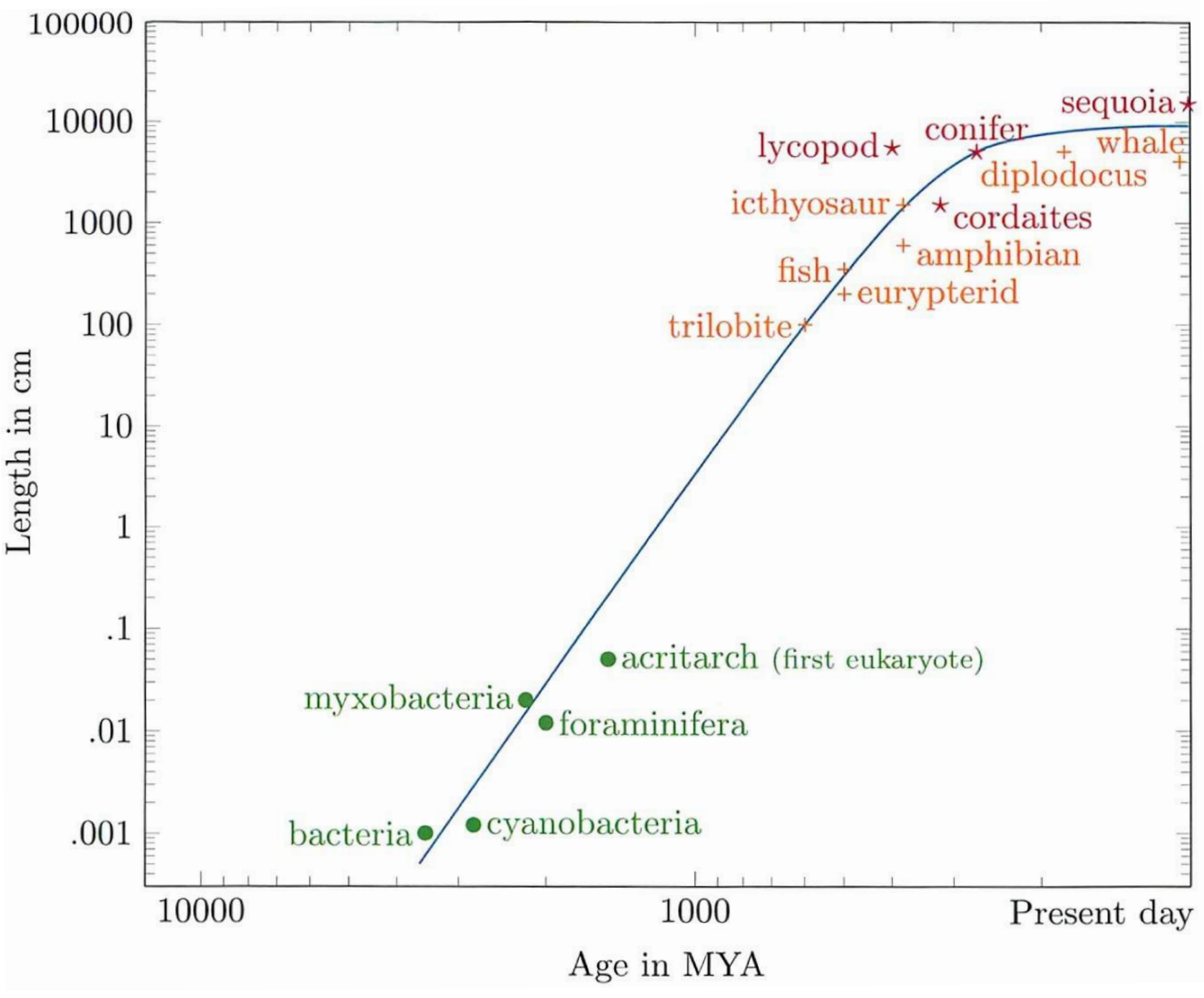


Consider the different cell types of an organism: What are their functions?

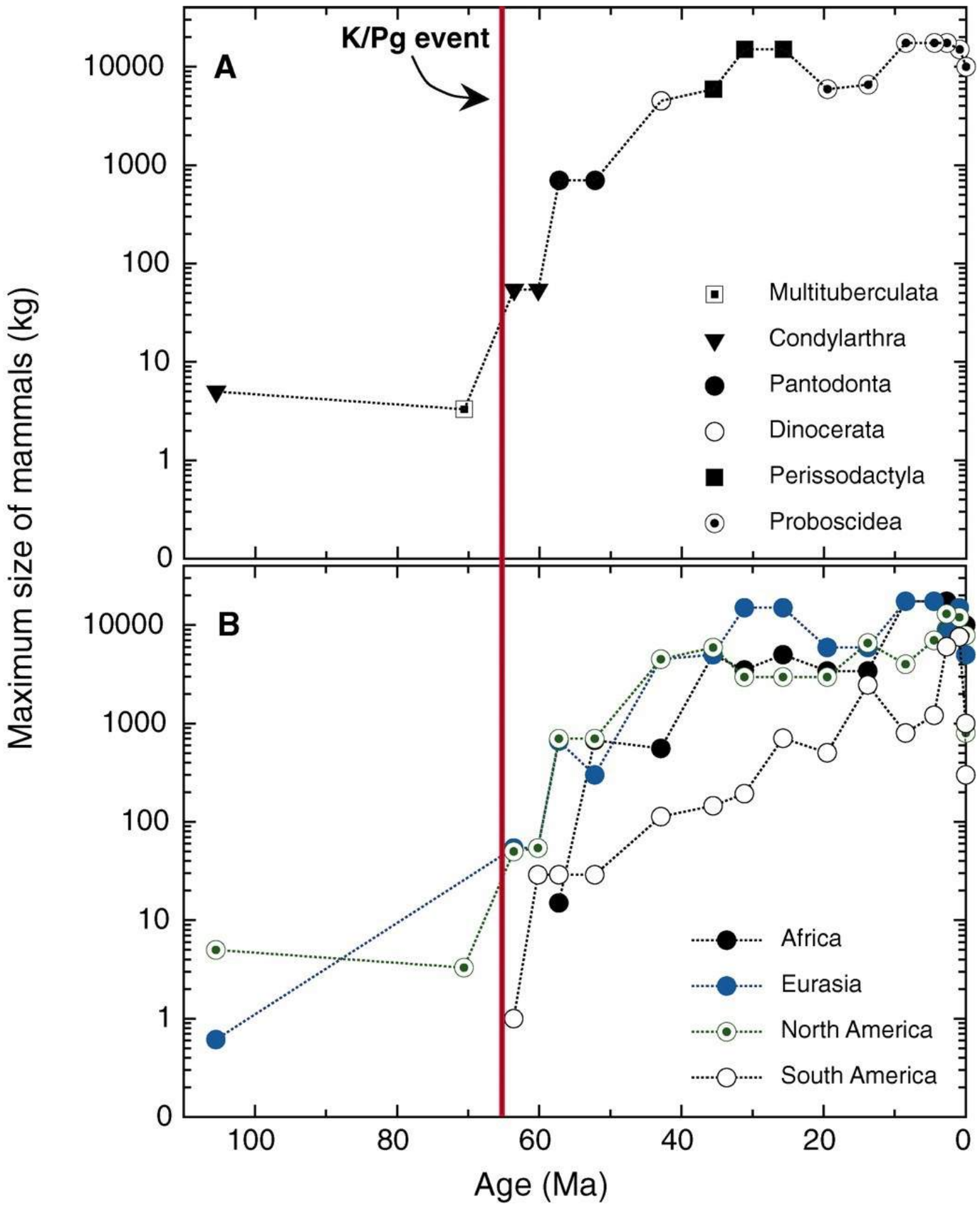
Note: the number of cell types are hard to define

Valentine, JW, et al. (1994) Paleobiology 20(2):131-142.

Size increase over evolutionary time



The maximum sizes of organisms at different periods of life on Earth.
Adapted from Bonner (1988).

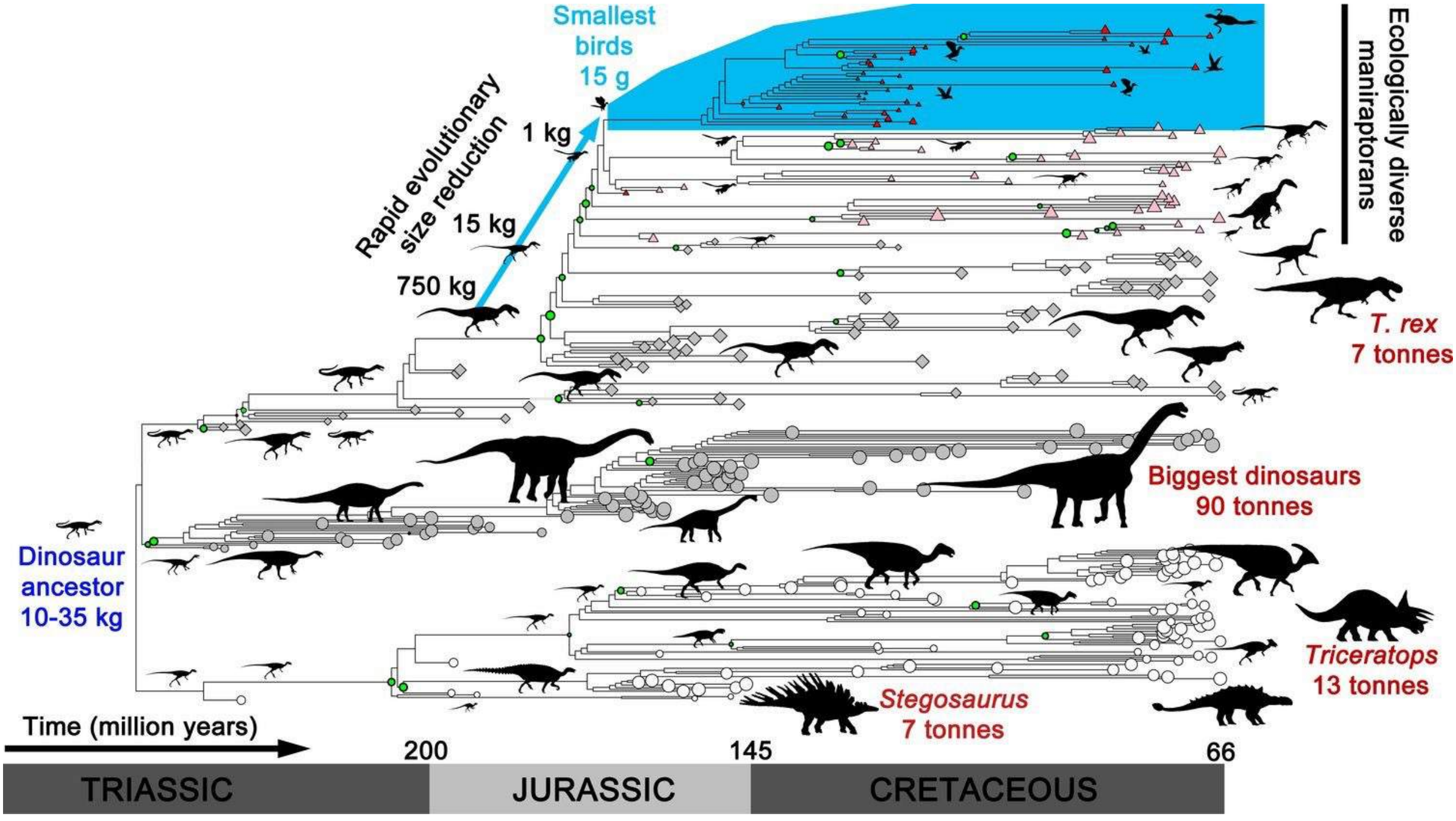


Smith FA et al. (2010) Science. 330:1216.

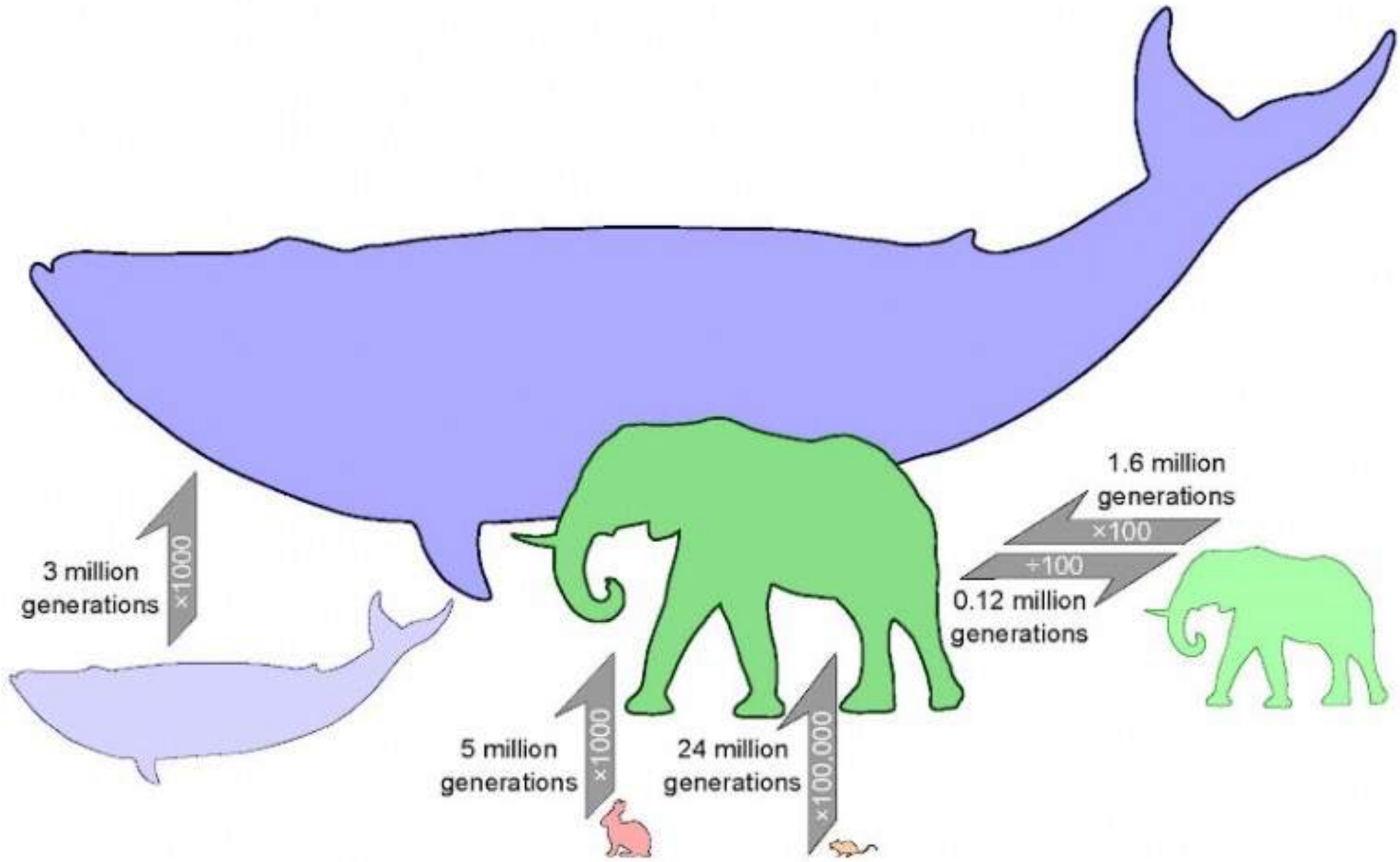
Maximum body mass of terrestrial mammals over time and space.

(B) Maximum body mass over time examined globally at the sub-epoch level over the past 110 million years.

(C) Maximum body mass for the largest continents (South America, North America, Africa, and Eurasia) over the same time interval.



Benson RBJ, et al. (2014) PLoS Biol 12(5): e1001853



Evans AR, et al. (2012) PNAS. 109:4187.

Question: describe the typical architectural features of the organisms living in the given habitat

1. A pond that suddenly turned acidic due to a pollution about 10 years ago

2. An open field, where very fast and hungry predators looms dairy

3. A poor land, with little access from humans, where some light and water are available