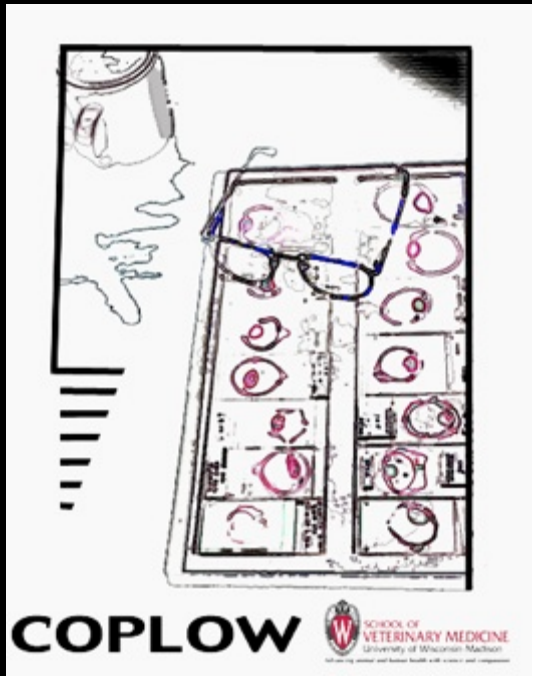
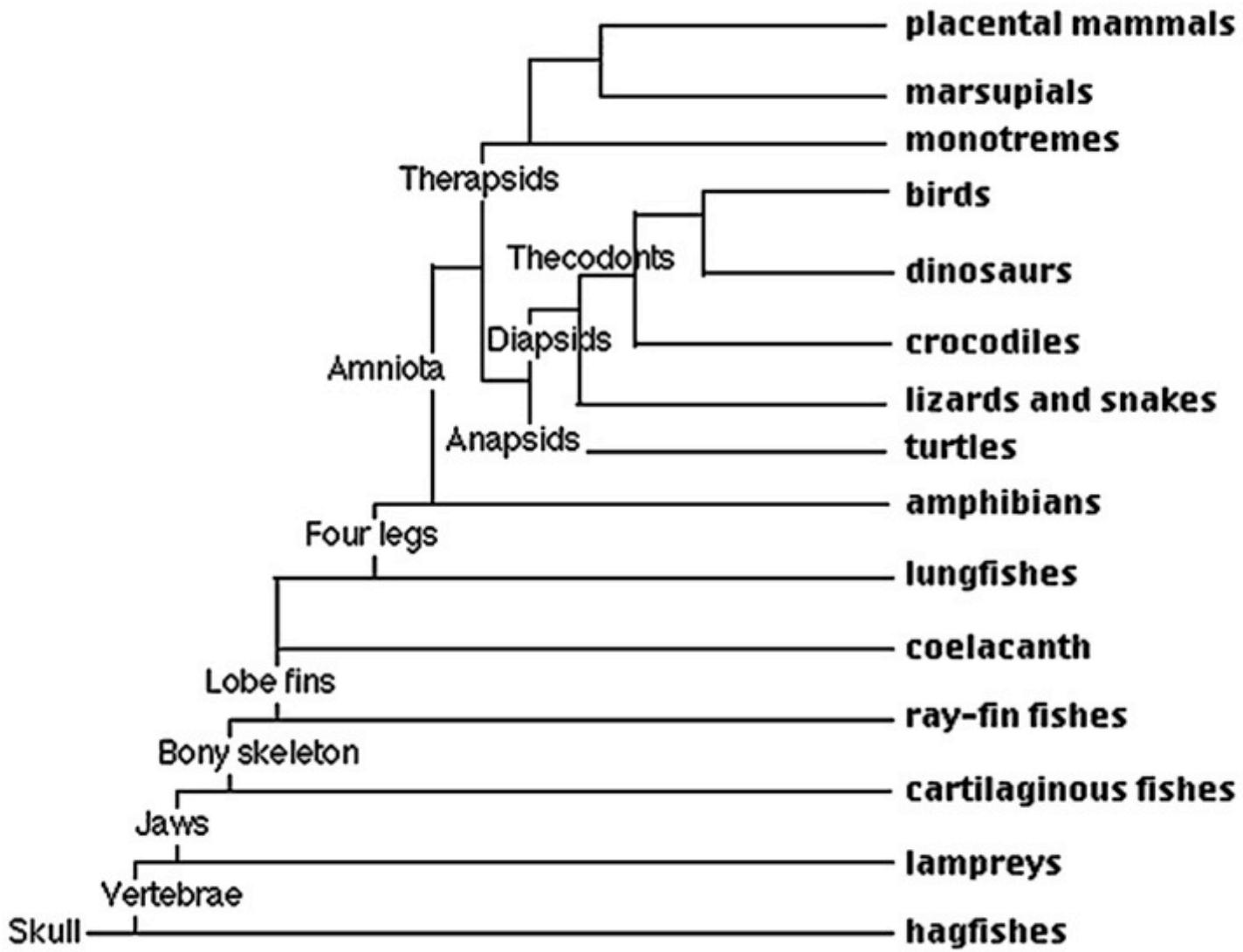
SCHOOL OF VETERINARY MEDICINE
University of Wisconsin-Madison
Advancing animal and human health with science and compassion

Comparative Anatomy of the Vertebrate Eye & Evolution

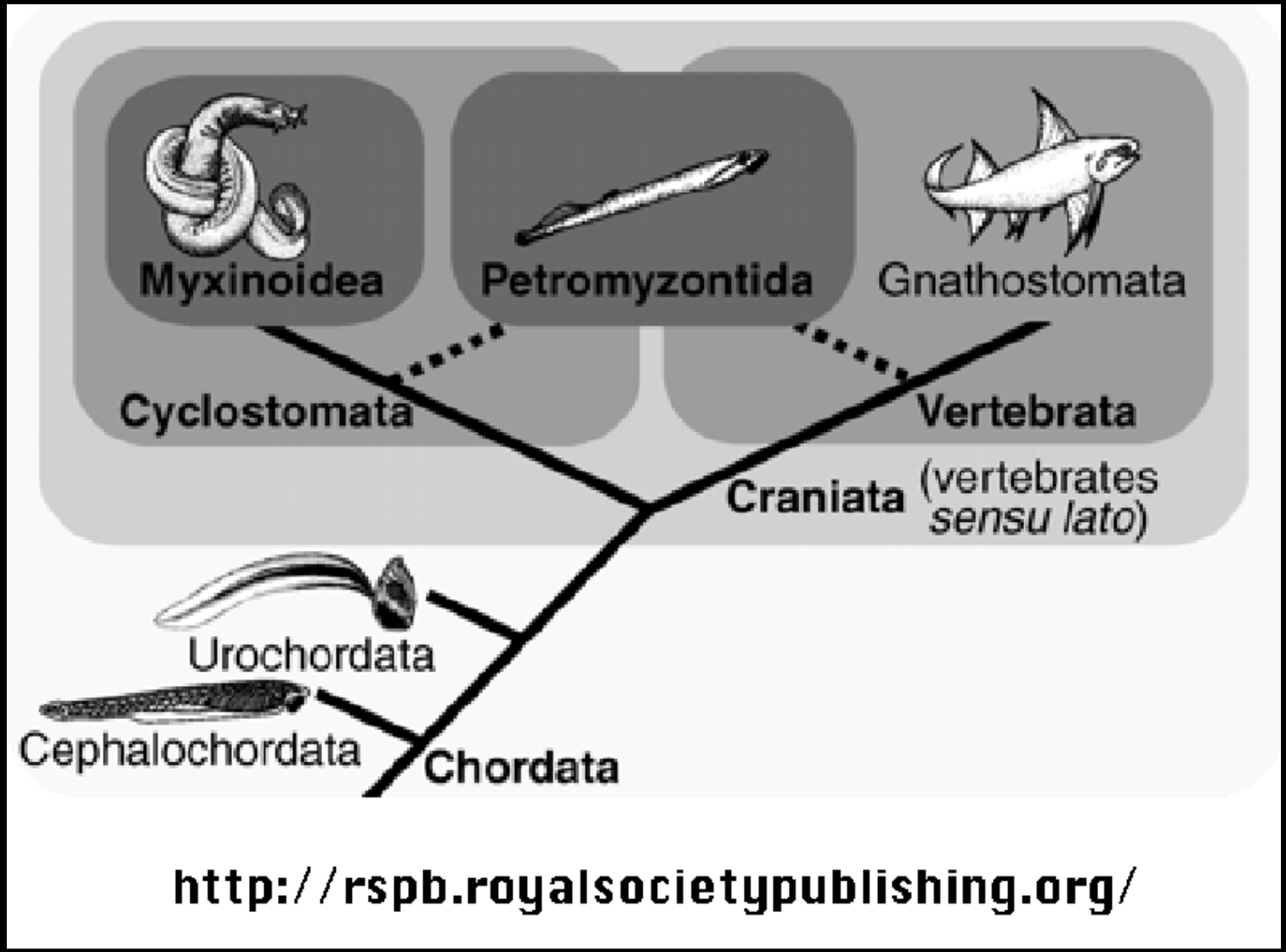
Dick Dubielzig



Vertebrate Evolution

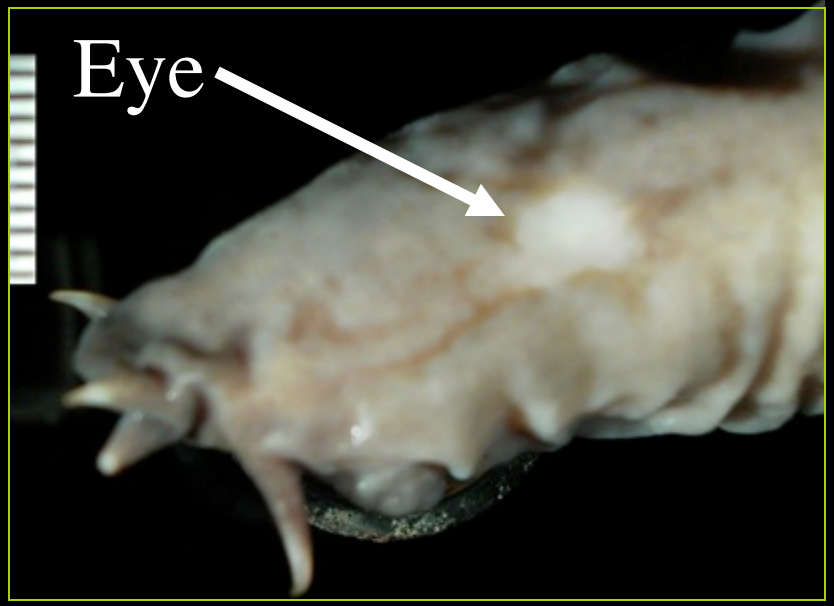


Hagfish & Lampreys



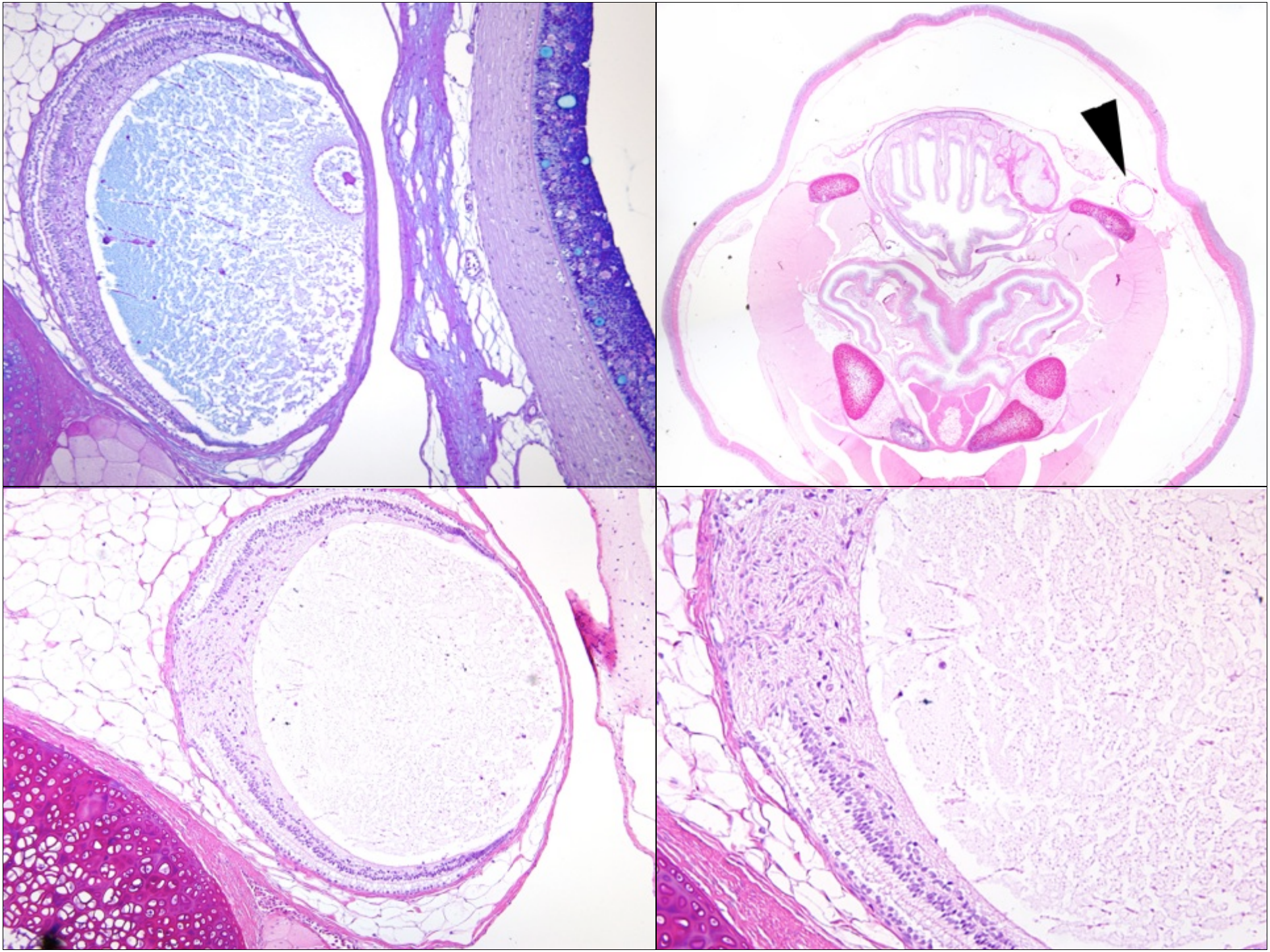
http://rspb.royalsocietypublishing.org/

Hagfish Eyes



- No cornea
- No lens
- 2-layered retina
- No melanin
- Wired to the brain like a pineal gland

Recommendation: You-Tube: “Eddie and the Hagfish”



Lamprey Eyes

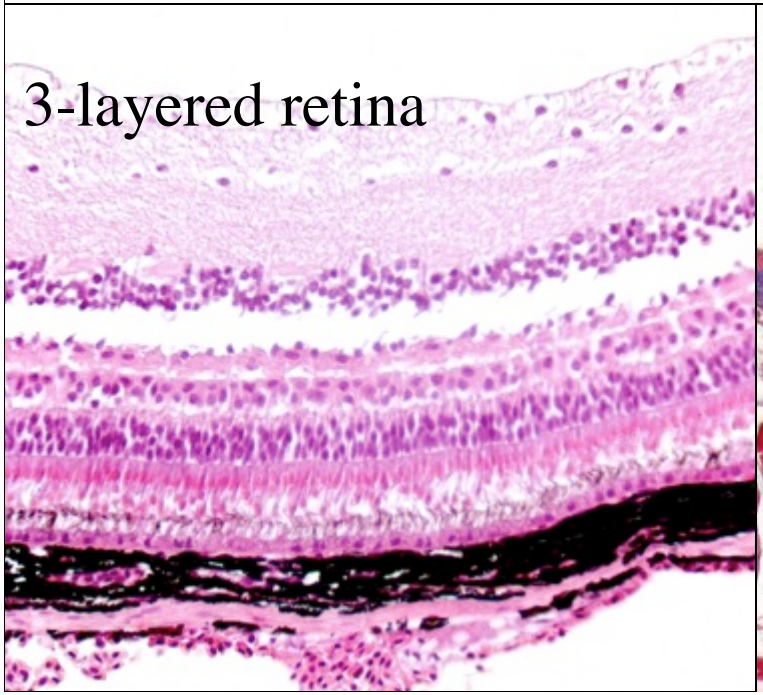
Adult

- Larval form and adult form
- Cornea largely continuous with the skin
- No muscles of accommodation
- Has most of the structures of the vertebrate eye
  - Lens
  - 3-layered retina
  - 4 Cone types
  - Extraocular muscles no intraocular muscles
  - Wired to brain like a visual eye
  - Melanin in Choroid and RPE

Larva

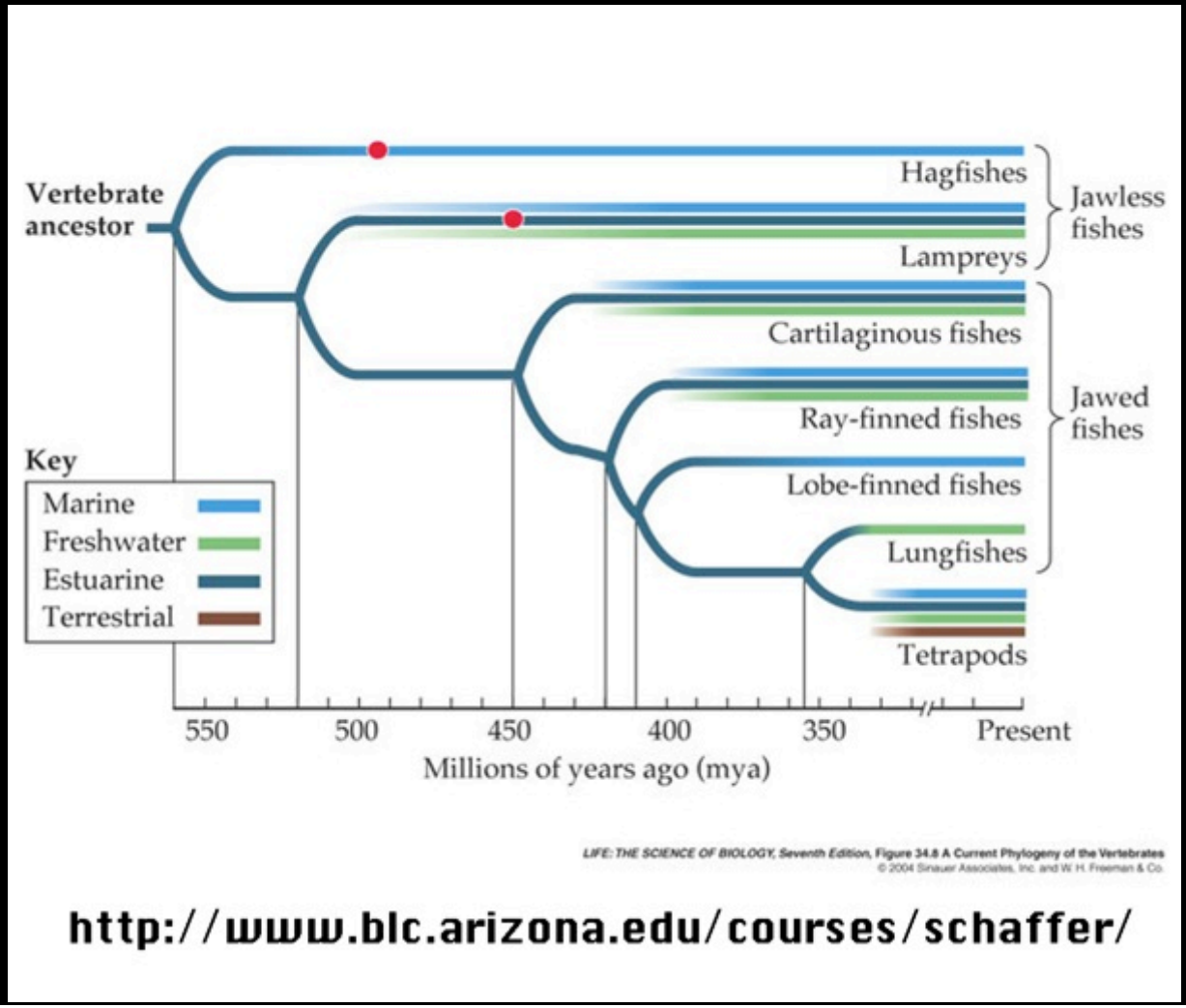

Larva


Adult


3-layered retina


Cornea continuous with skin

Vertebrate Evolution

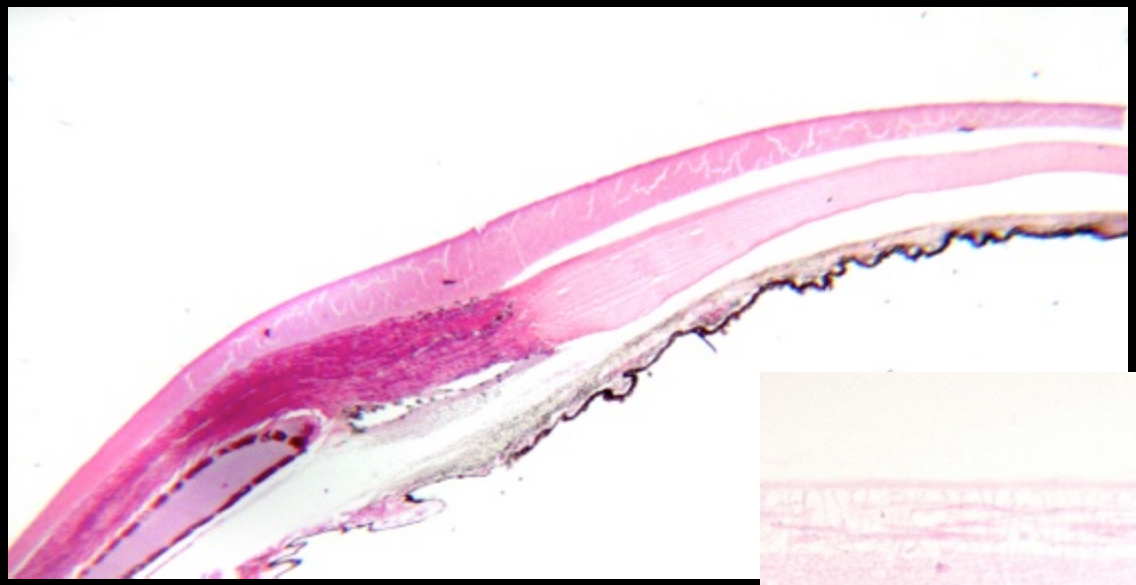


http://www.blc.arizona.edu/courses/schaffer/

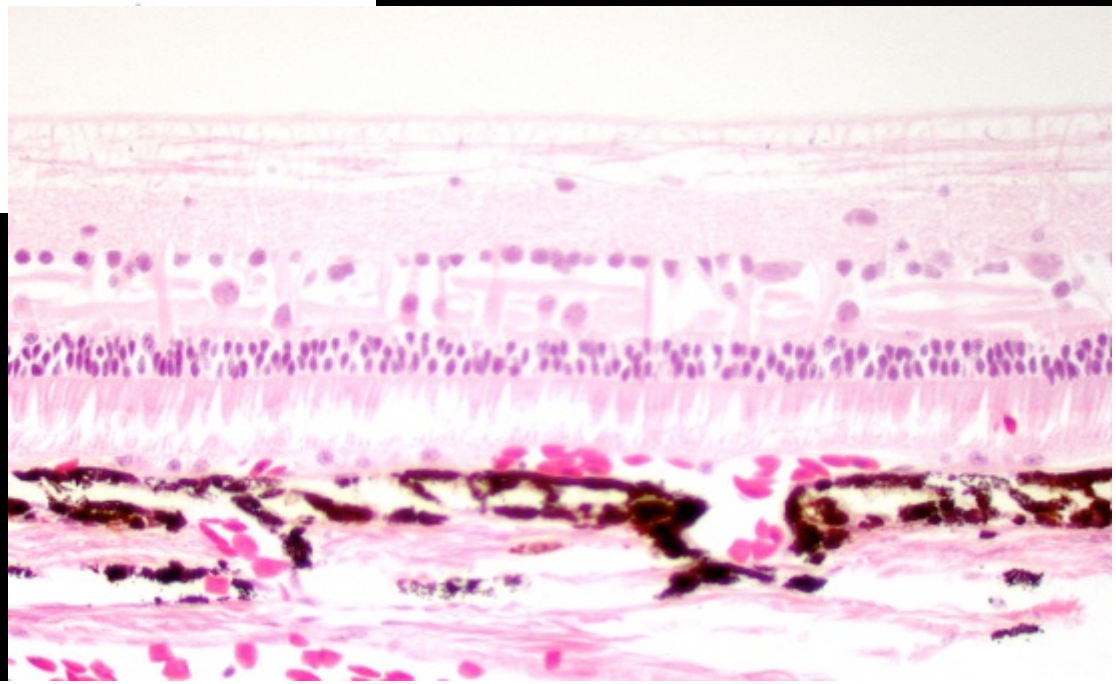
Shark & Ray Eyes

- Cartilaginous sclera, but no bone
- No muscle in the ciliary body
- Smooth muscle attached to the ventral lens
- Double cornea (scleral and skin)
- No shading of outer segments by the retinal pigment epithelium (RPE)

Sharks and Rays

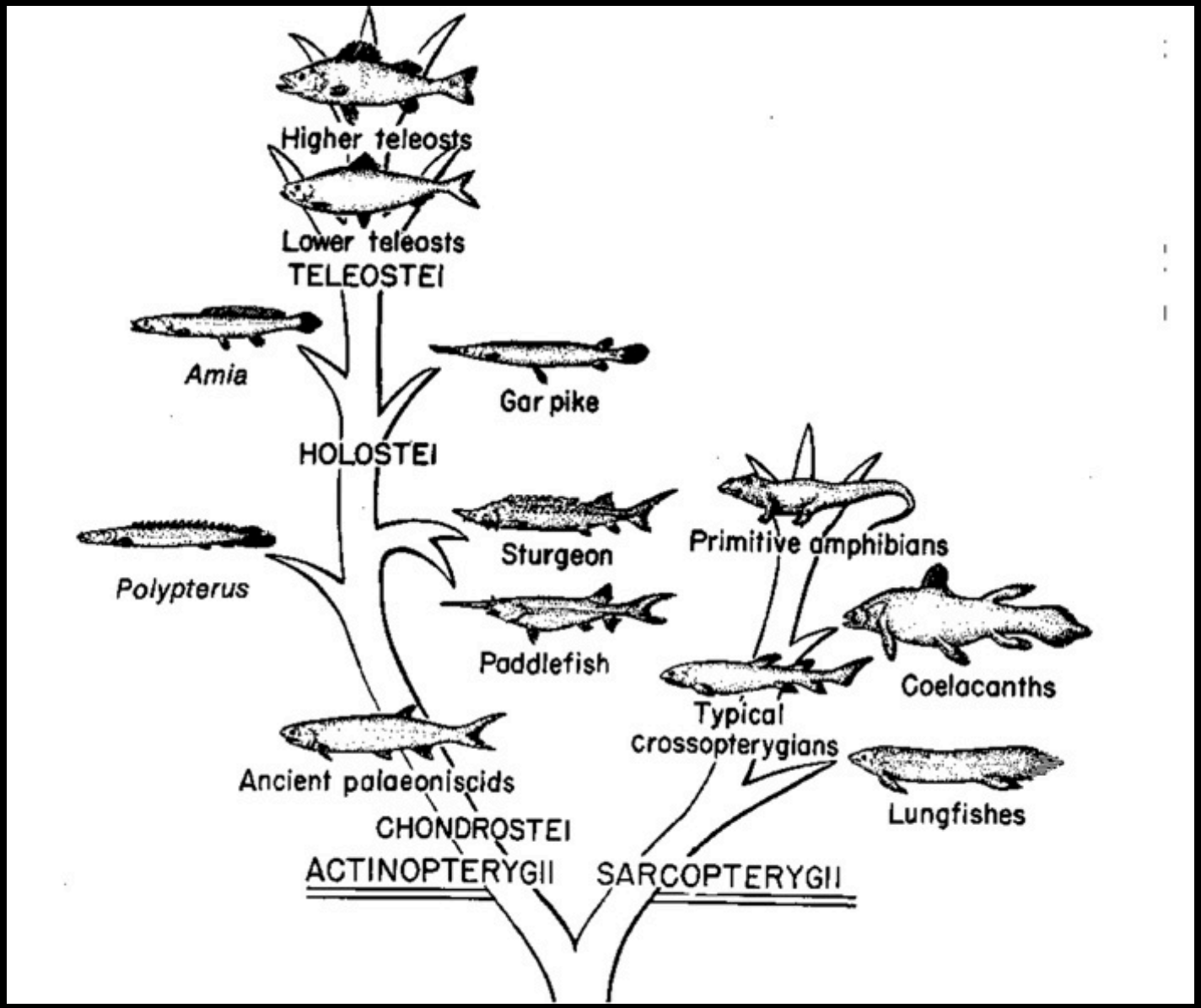


Double cornea



No shading of the photoreceptors by the RPE

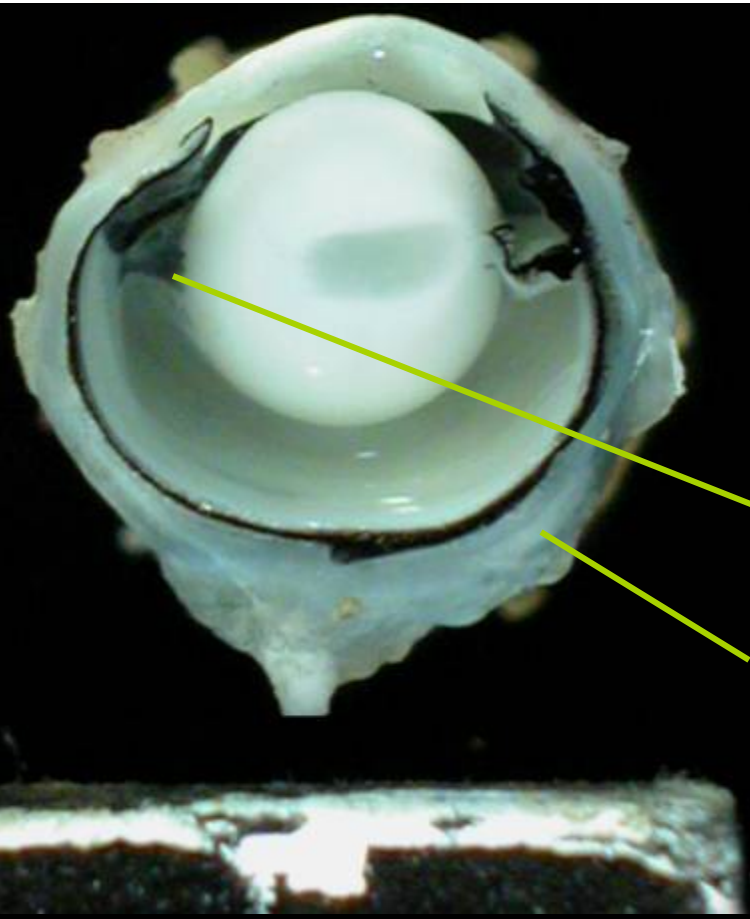
Evolution of the Fishes



Sturgeon Eyes

- Cartilaginous sclera, no bone
- No muscle in the ciliary body
- The lens is supported on a papilla, but no accommodation and no muscle are known
- Choroidal guanine tapetum lucidum
- Limited shading of the outer segments by the RPE

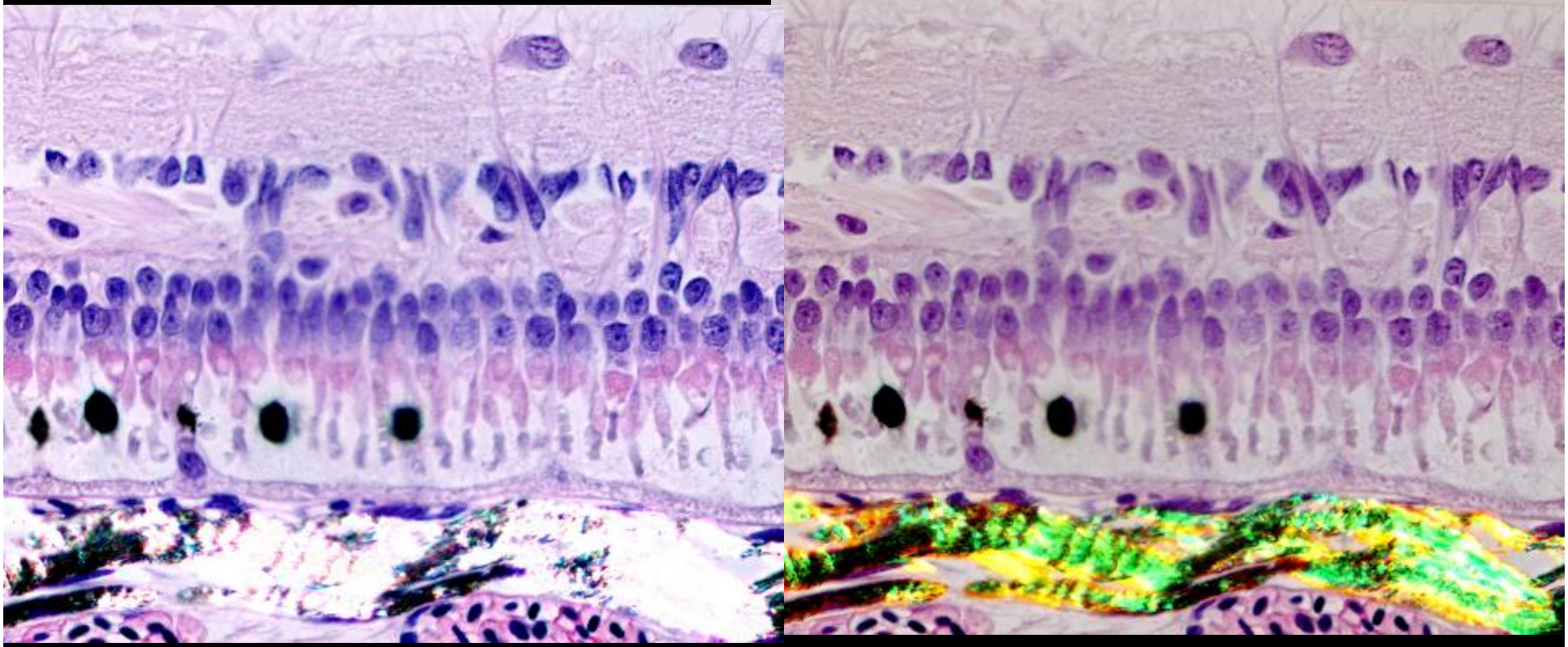
Juvenile Sturgeon Eye



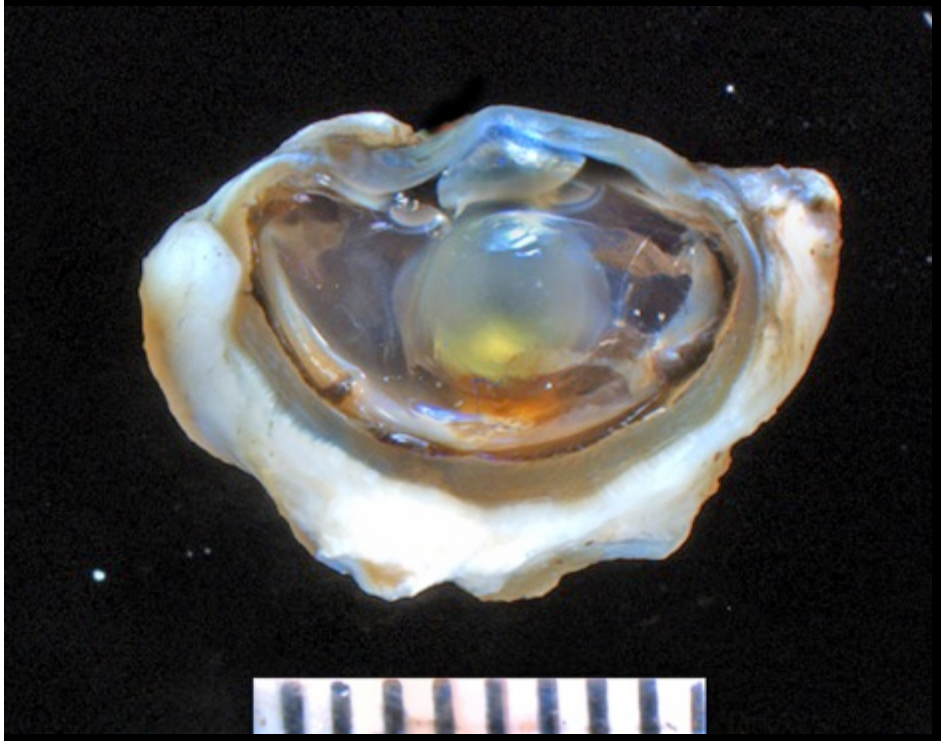
Papilla

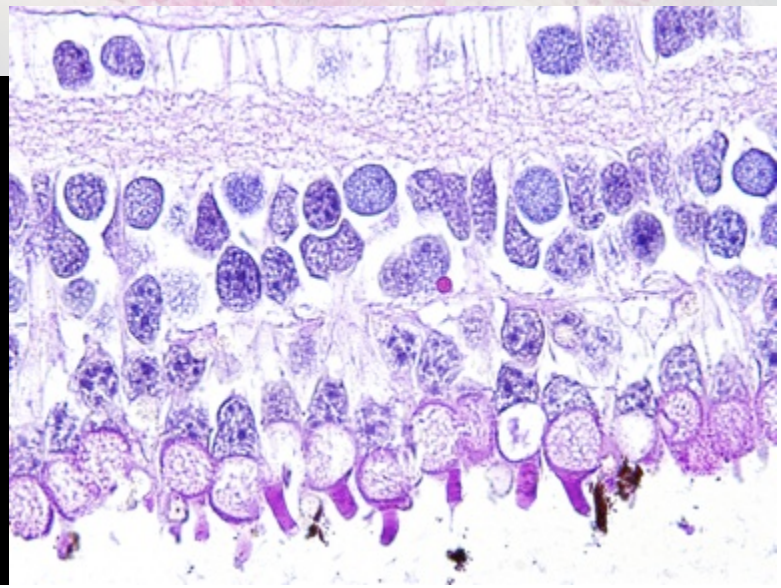
Cartilaginous sclera

Sturgeon Eye Guanine Tapetum



Lungfish





- No Choroidal Rete
- No retractor lentis muscle
- Limited shading of outer segments

Higher Teleosts

- Cartilage and sometimes bone in sclera
- Retractor lentis muscle (smooth muscle) accommodation
- Vascular rete called “choroidal gland”
- RPE melanin has photomechanical movement
- Some fish have a retinal fovea
- Trichromatic vision
- Double cornea (skin and scleral)
- Papillary process supplies blood to the retina

Higher Teleosts

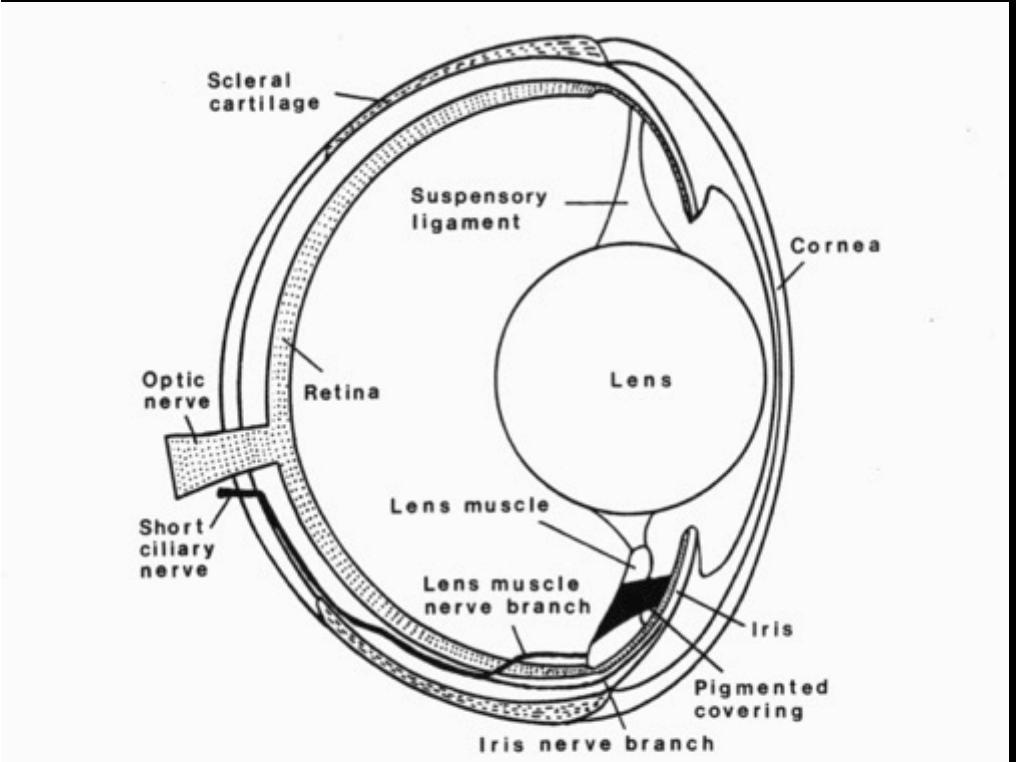
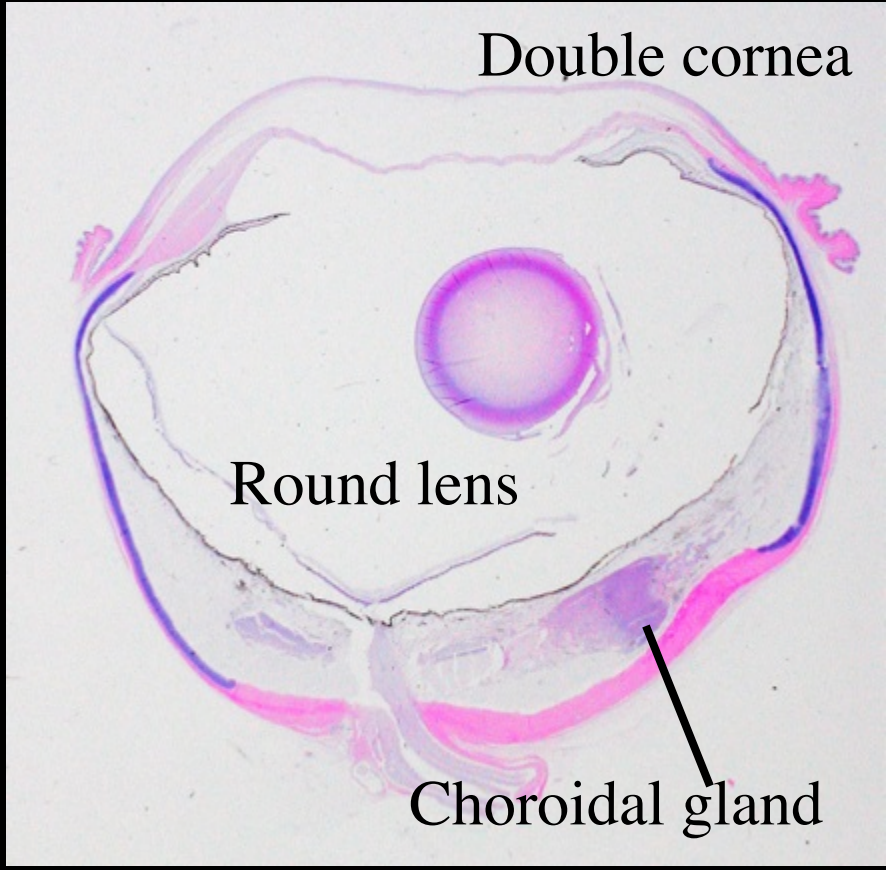
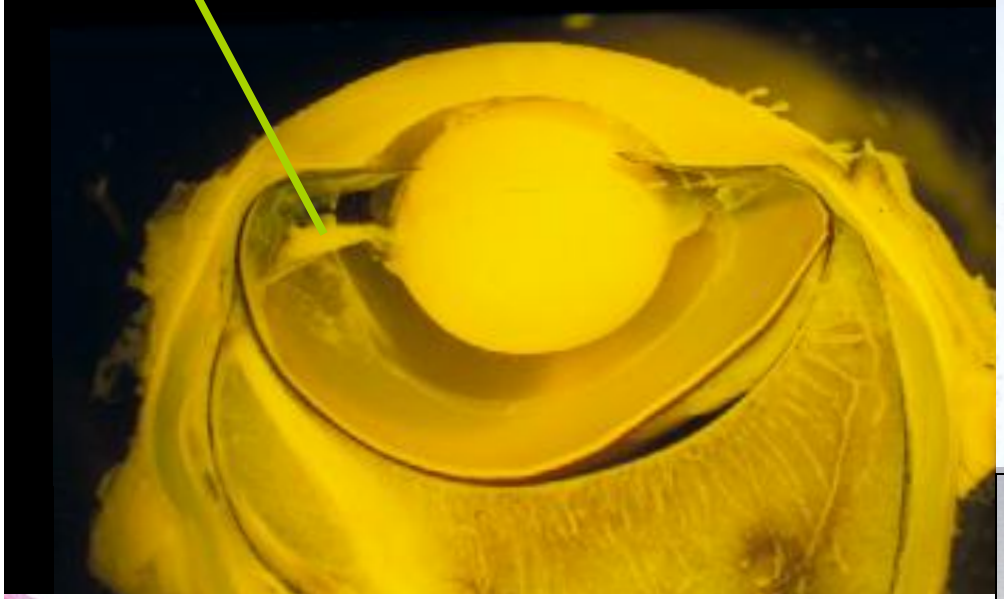


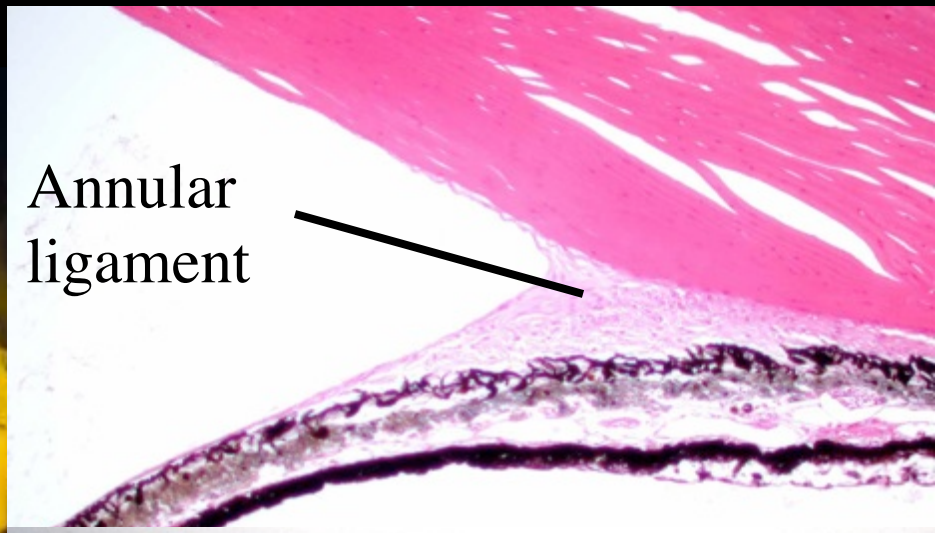
Fig. 7.7. Vertical section of the eye in a bass showing the lens muscle and its nerve supply (from Somiya 1987).

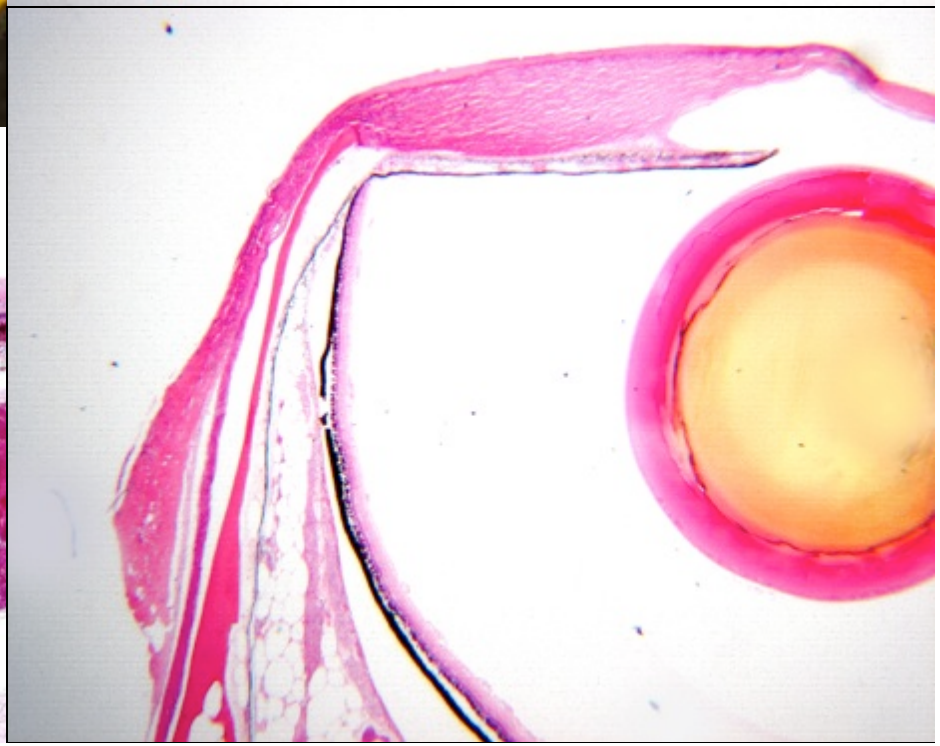


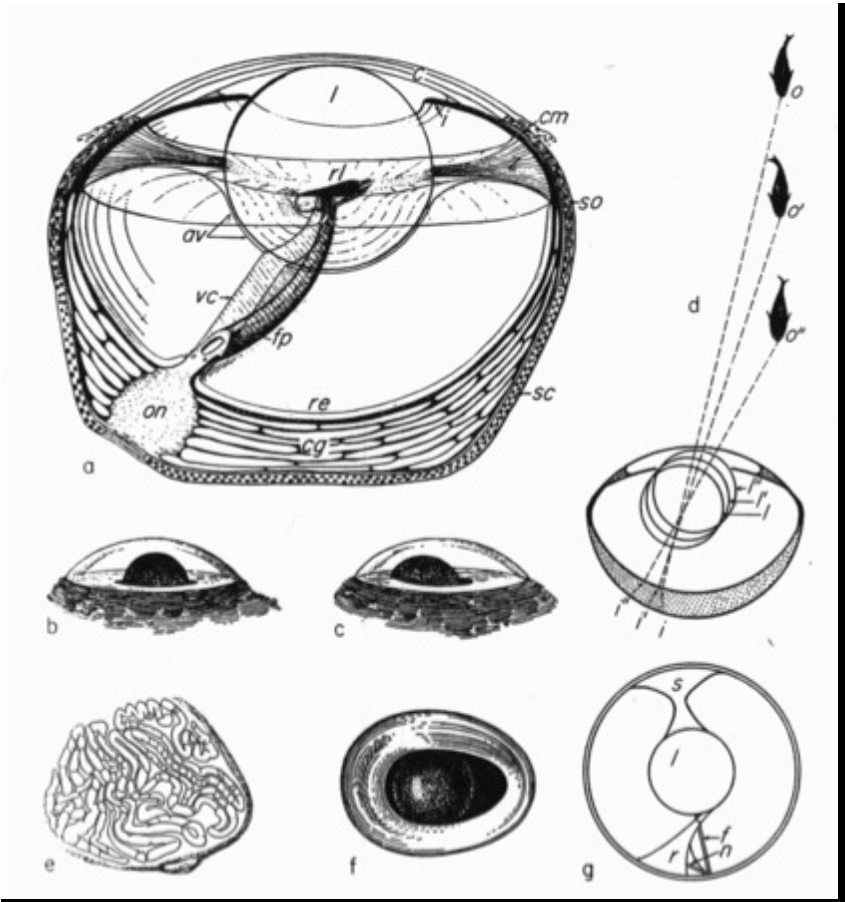
Walls. *The Vertebrate Eye and its Adaptive Radiation*. 1942.

Higher Teleosts



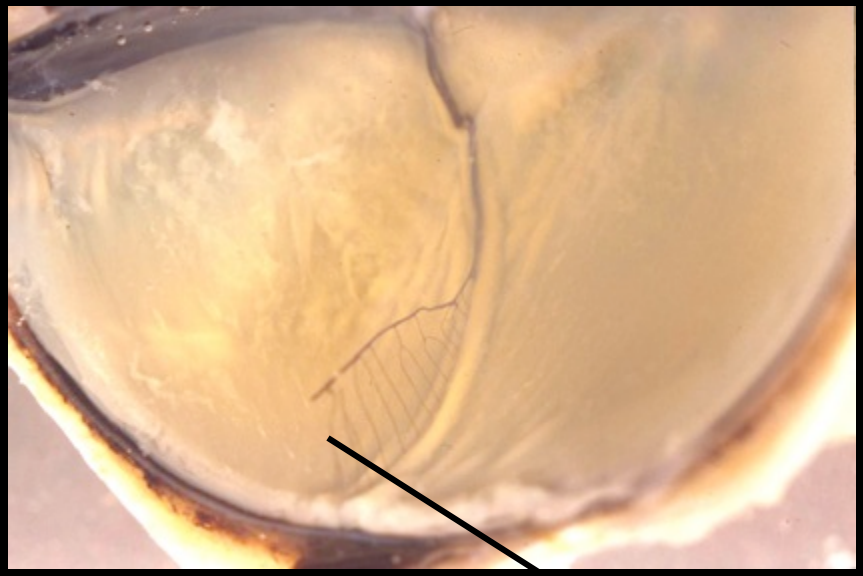




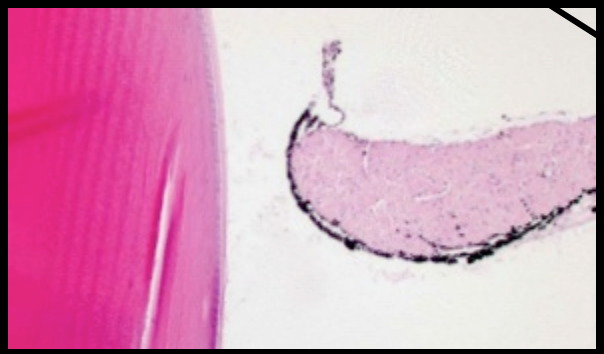


Higher Teleosts

Falciform process & accommodation



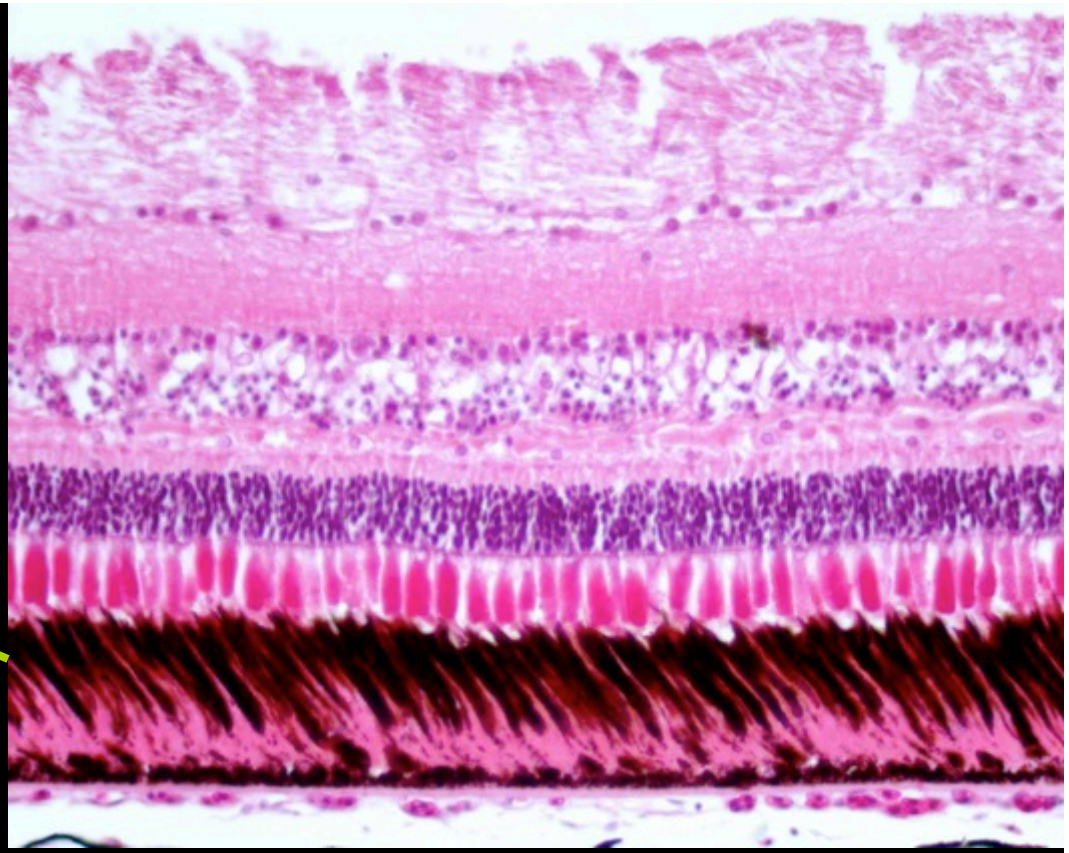
Walls. *The Vertebrate Eye and its Adaptive Radiation*. 1942.



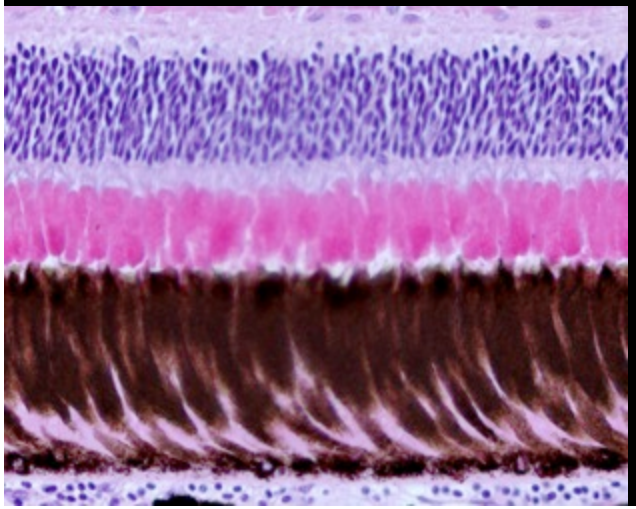
Retractor lentis muscle

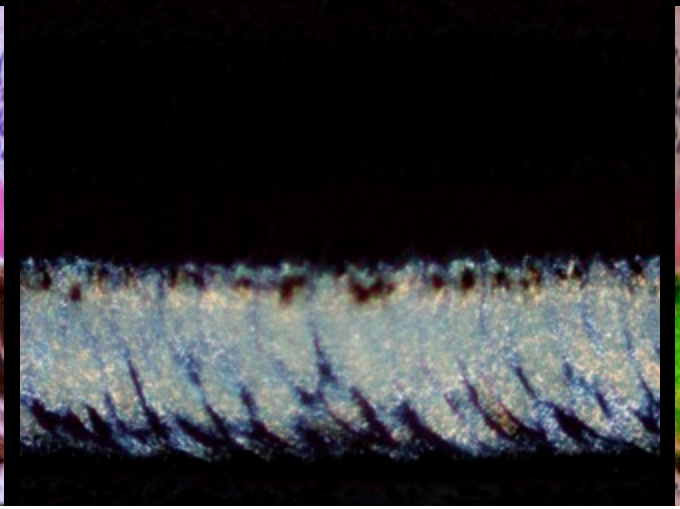
Higher Teleosts
Retinal Variations

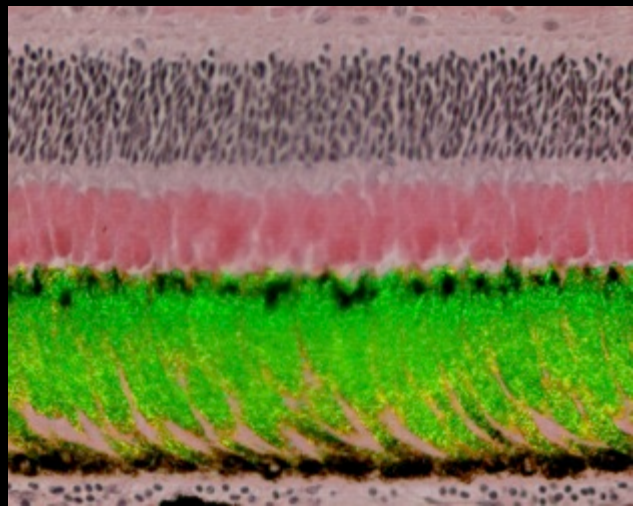
Photomechanical Movement



Guanine in the Retinal Tapetum of the Walleye







Amphibian Eyes

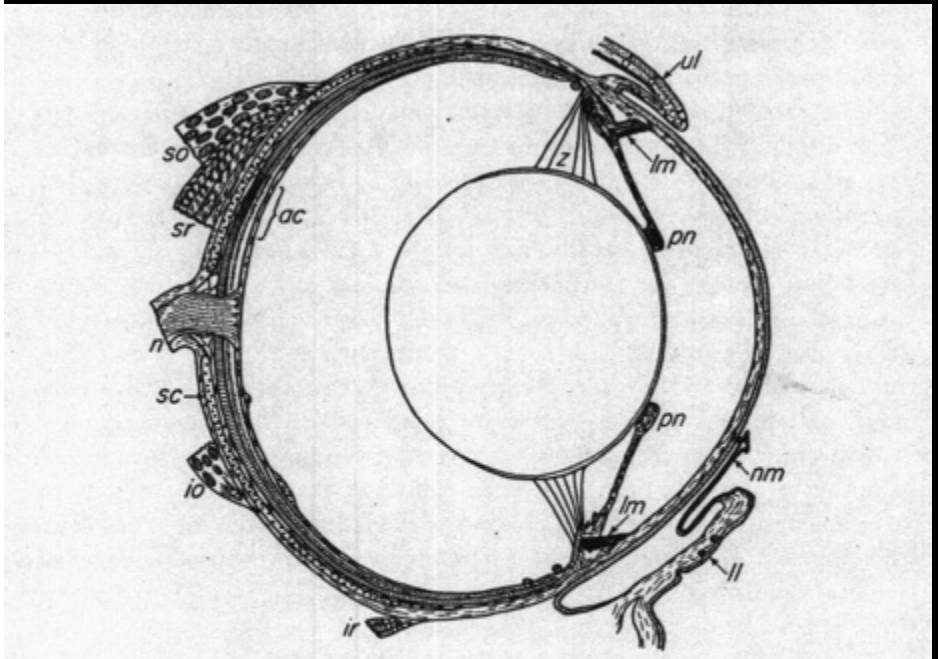
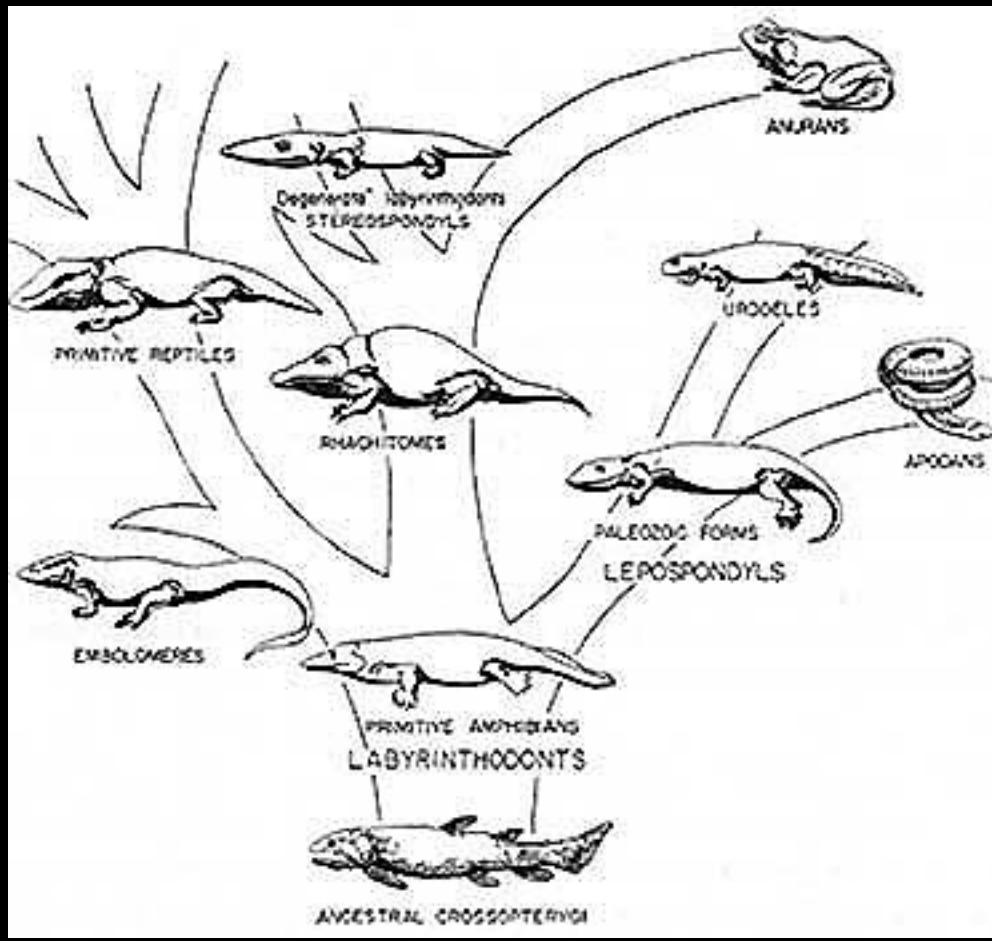


Fig. 172—The anuran eye in vertical section; semi-diagrammatic; based largely upon the leopard frog, *Rana pipiens*. ×11½.

ac- area centralis; *io*- inferior oblique; *ir*- inferior rectus; *ll*- lower lid; *lm, lm*- lens muscles (*cf*. Fig. 173); *n*- optic nerve; *nm*- 'nictitating membrane'; *pn, pn*- pupillary nodules; *sc*- scleral cartilage; *so*- superior oblique; *sr*- superior rectus; *ul*- upper lid; *z*- zonule.



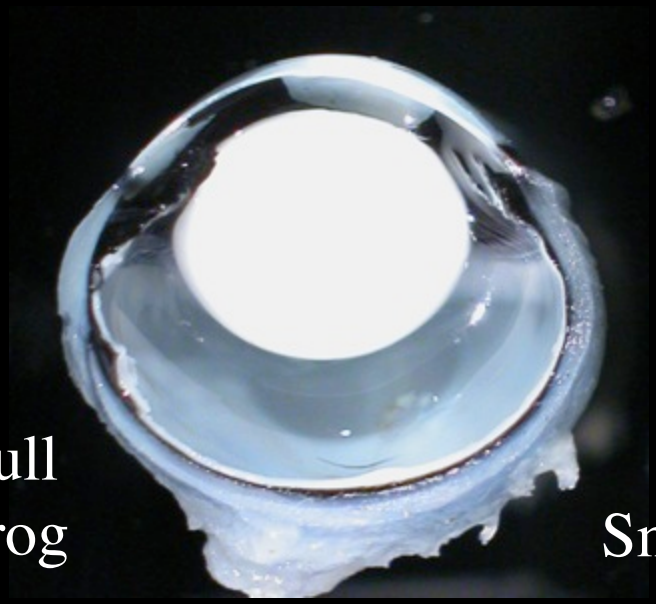
Walls

Features of Amphibian Eyes

- Cartilaginous sclera, but no bone
- Trichromatic vision
- Photomechanical motion in the RPE
- Minimal amount of accommodation with smooth muscle
- Double cornea only in the tadpole
- No annular pad in lens
- Retractor bulbi muscle and eyelids

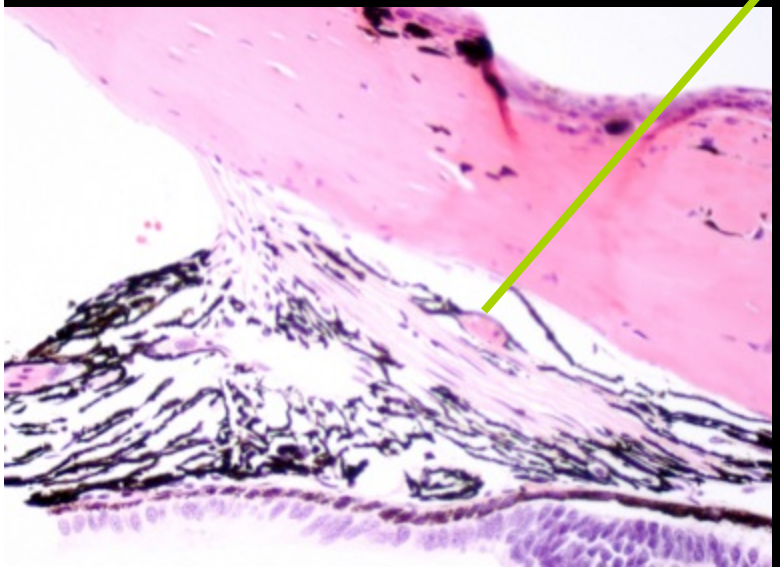
Features of Amphibian Eyes

Frogs and Toads



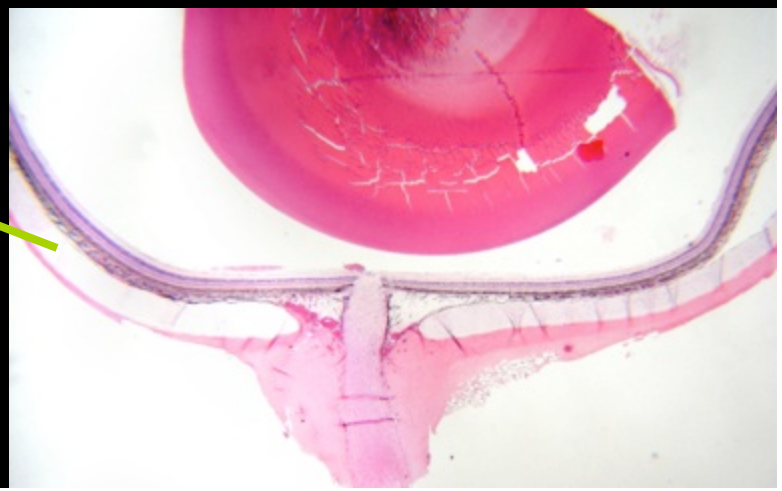
Bull Frog

Smooth Muscle



Cartilage

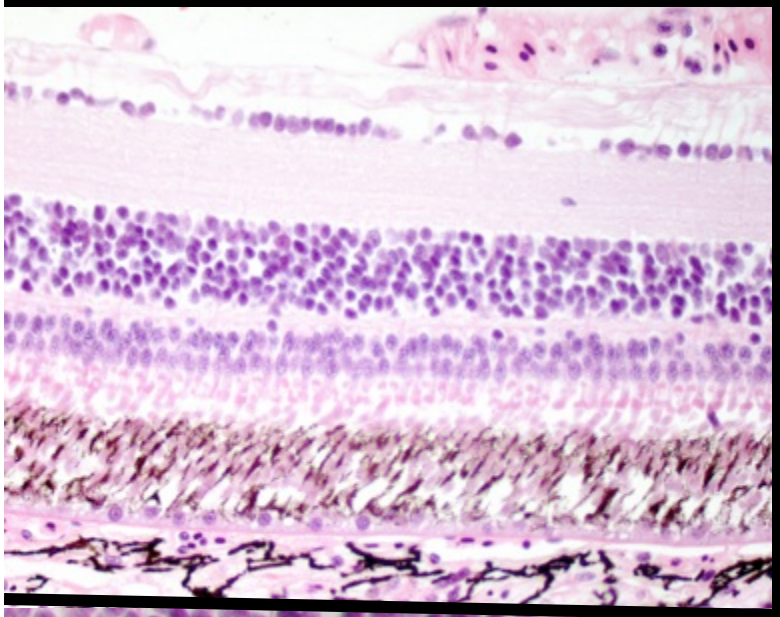
Cornea

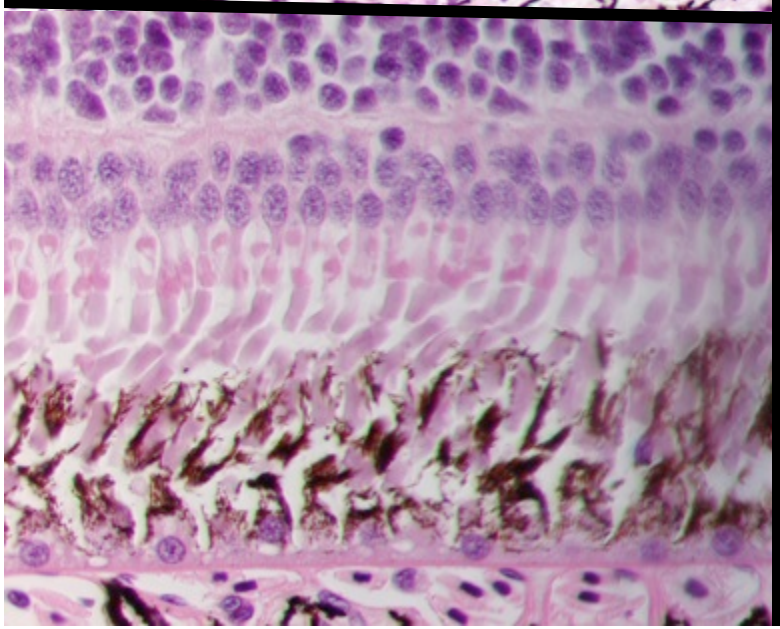


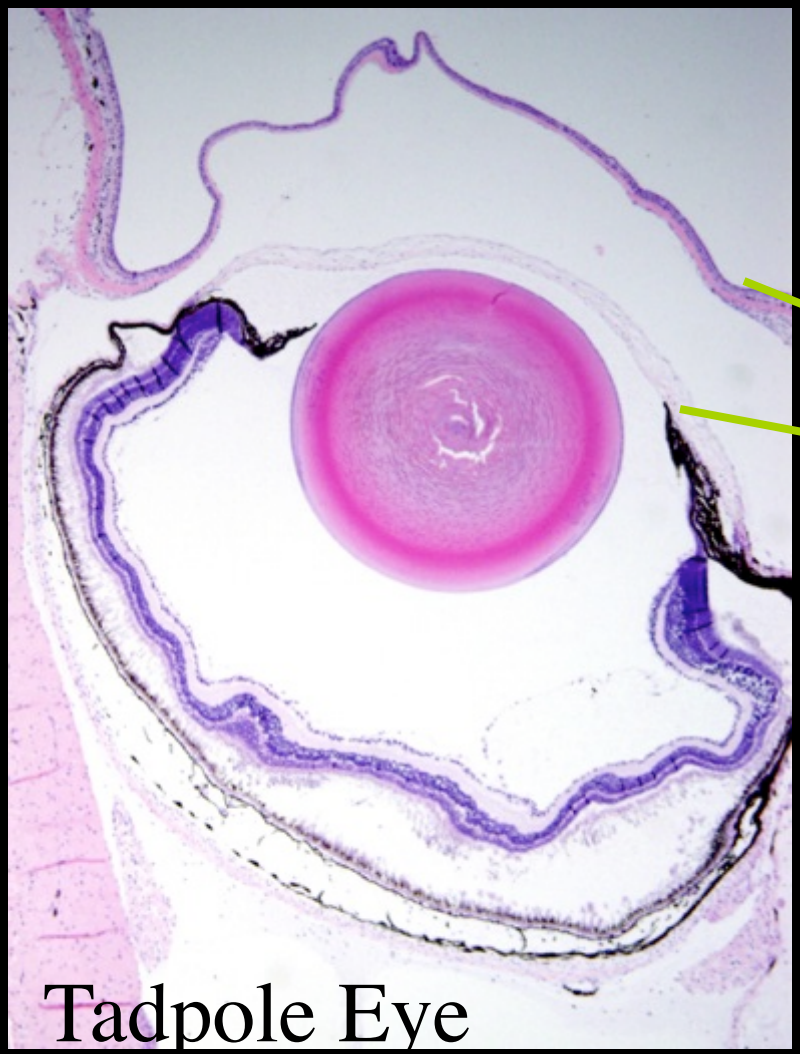
Features of Amphibian Eyes

Frogs and Toads

Retina



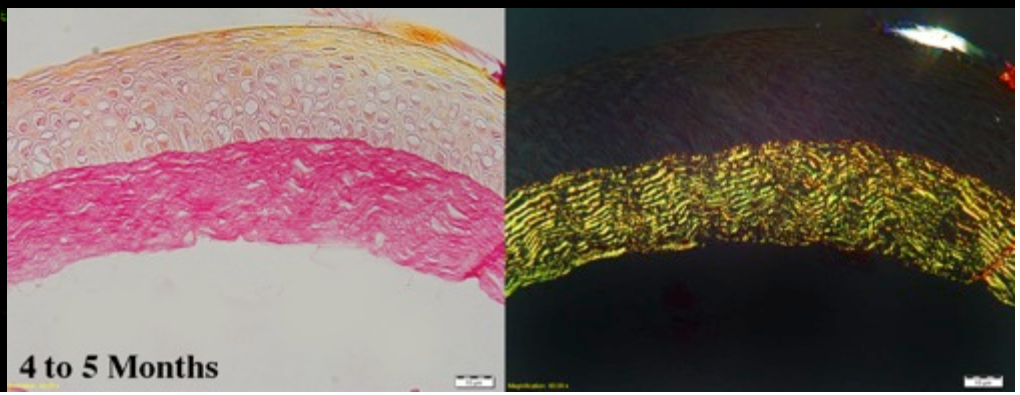




Tadpole Eye

Xenopus Tadpole

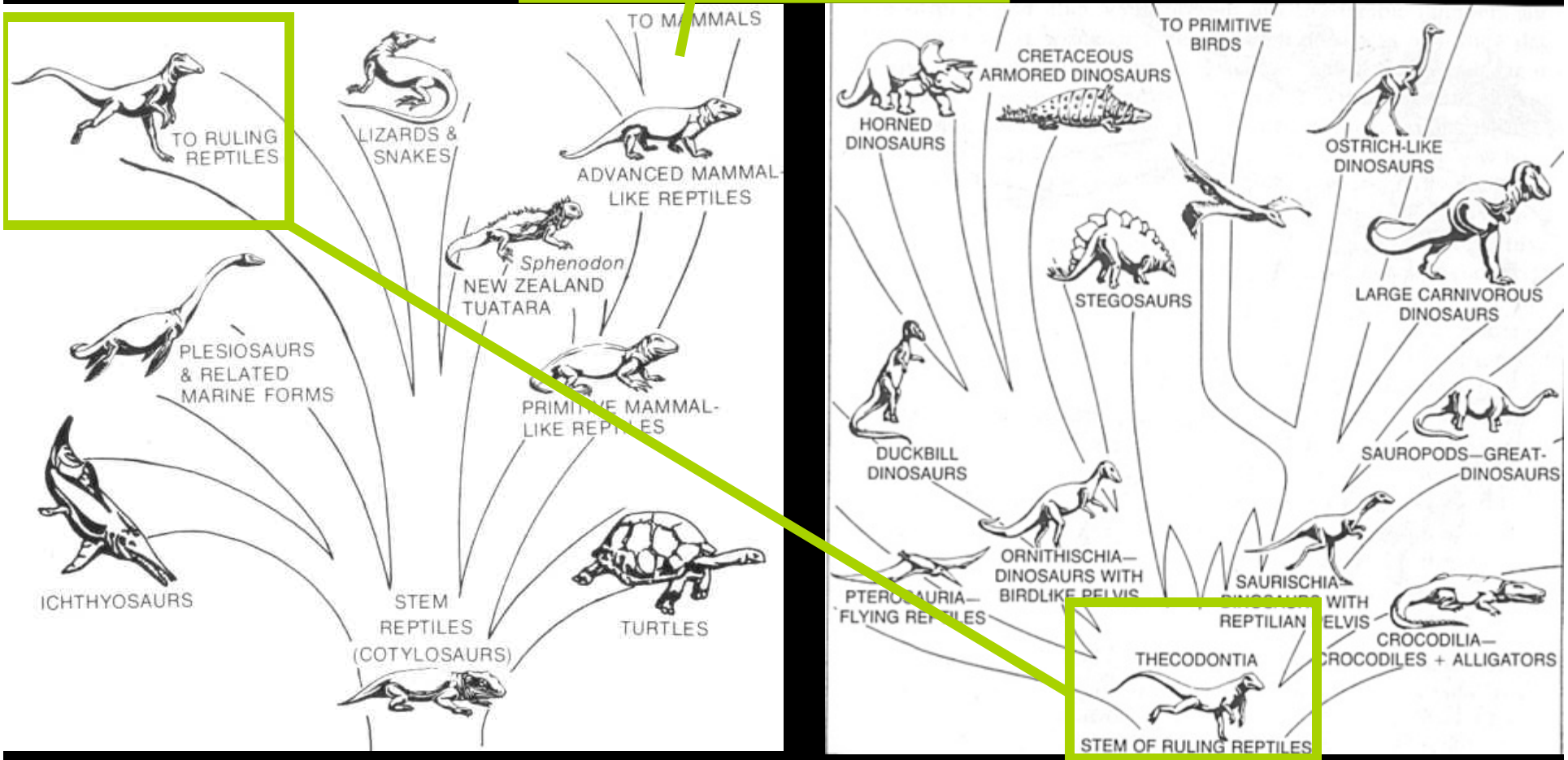
Xenopus Tadpole



The Rise of Reptiles

Duck-billed Platypus
Monotreme

Birds

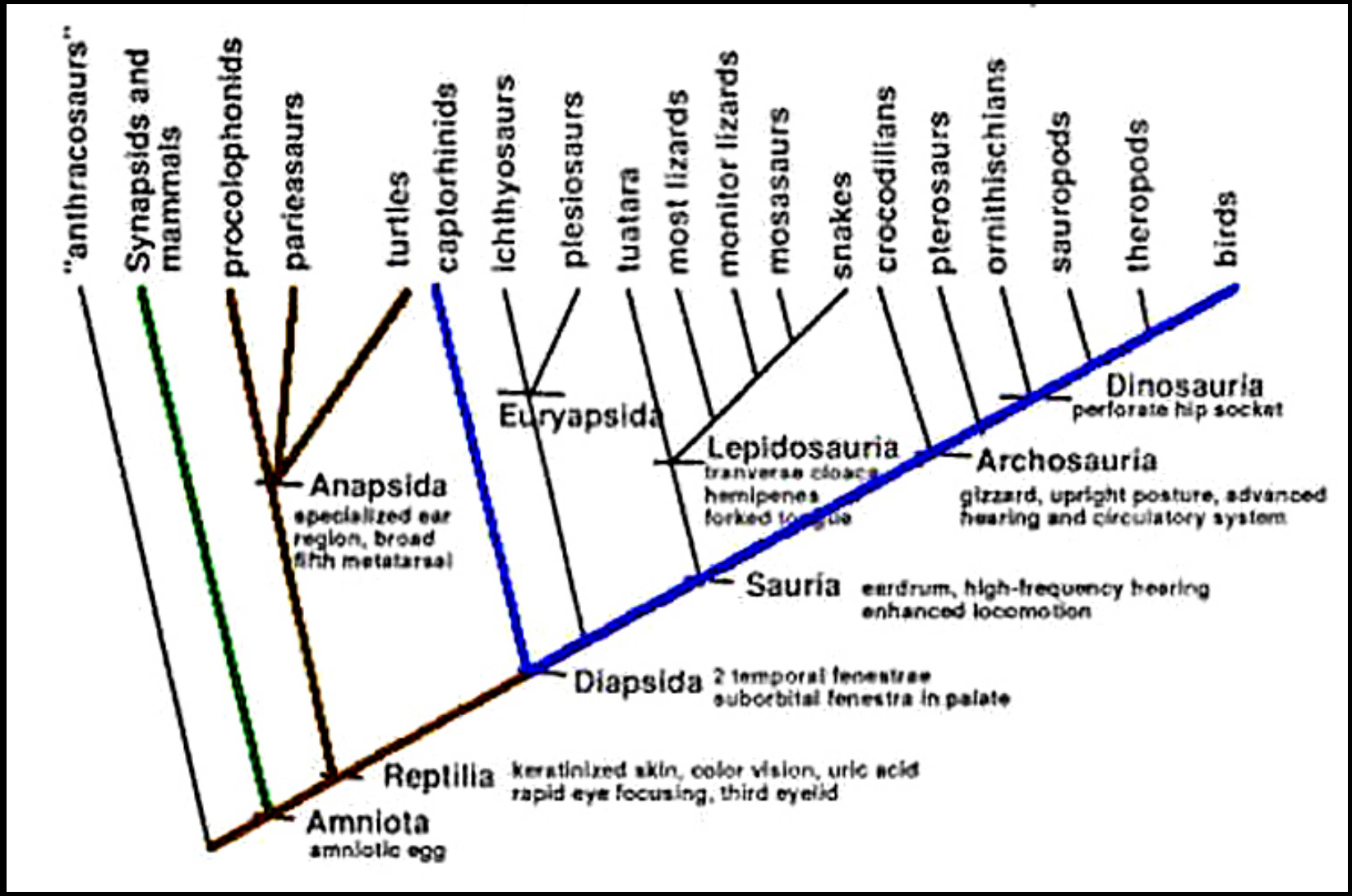


Amphibians

Contrasting Features

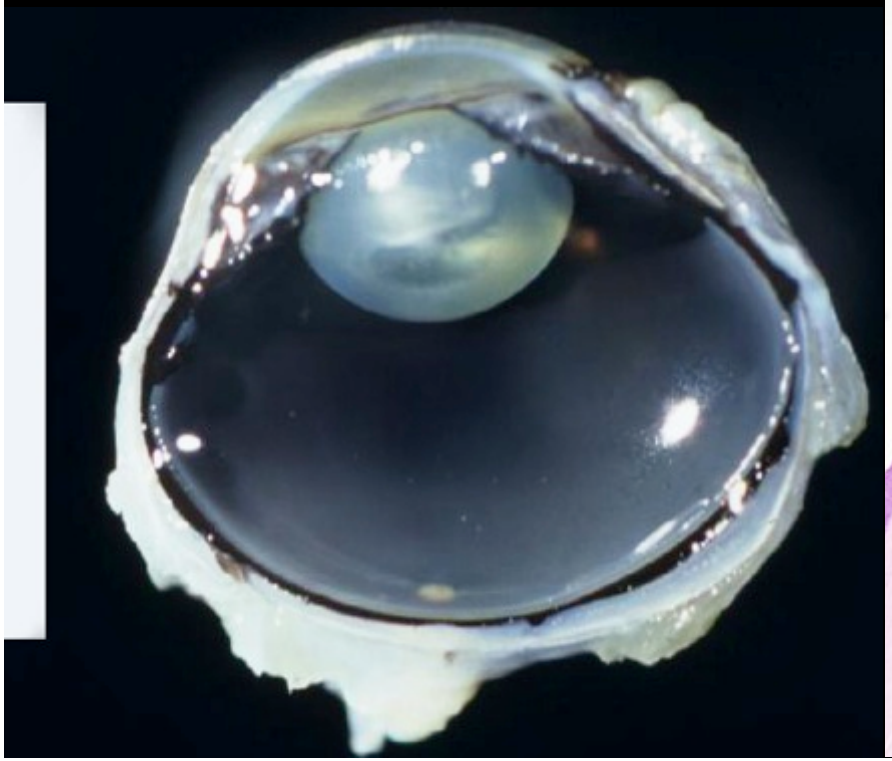
Amphibian	Platypus	Placental Mammal	Turtle
Cartilage, no bone	Cartilage, no bone	No bone or cartilage	Cartilage and bone
Uveal muscle is smooth muscle	No uveal muscle	Uveal muscle is smooth muscle	Uveal muscle is skeletal muscle
Photomechanical movement	Photomechanical movement	No photomechanical movement	Photomechanical movement
No annular lens pad	No annular lens pad	No annular lens pad	Small annular pad

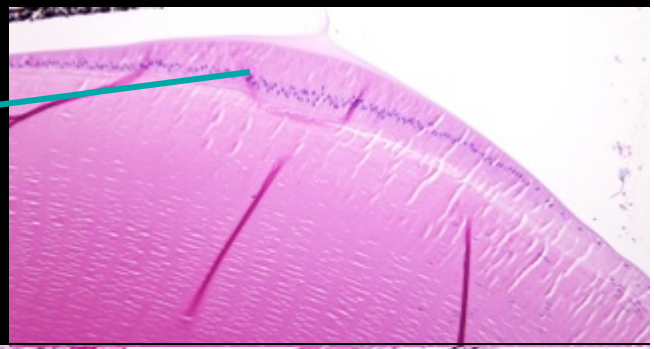
Reptiles

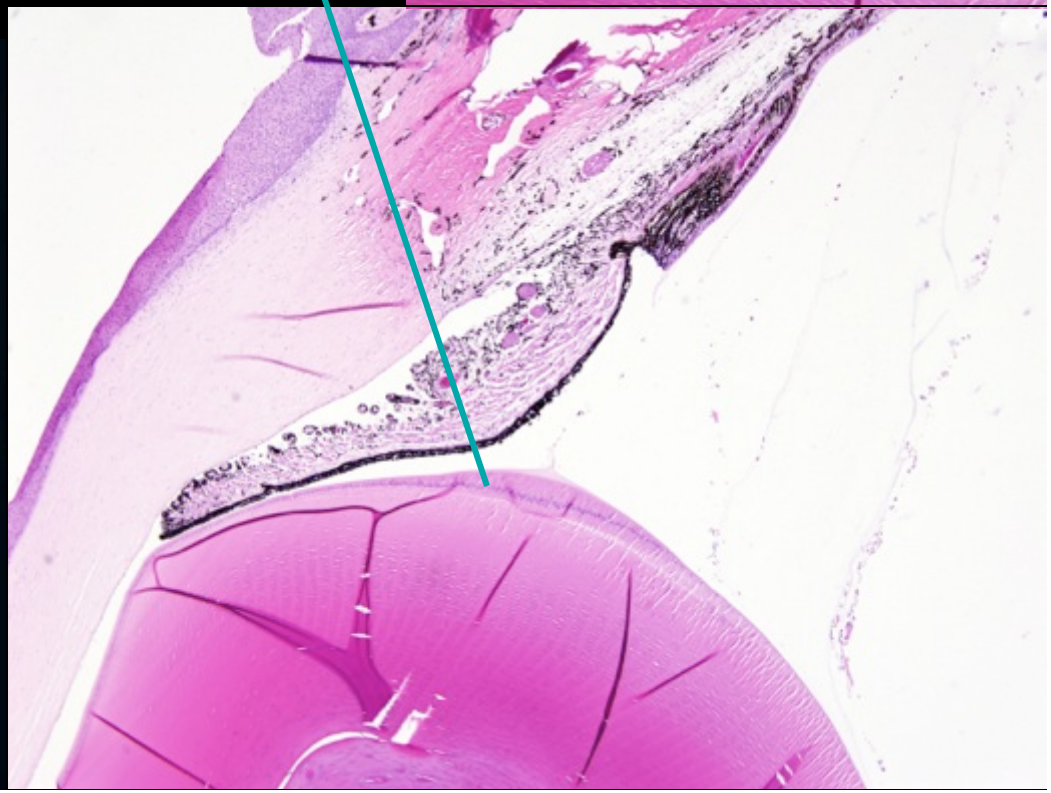

"anthracosaurs"
Synapsids and mammals
procolophonids
parieasaurs
turtles
captorhinids
ichthyosaurs
plesiosaurs
tuatara
most lizards
monitor lizards
mosasaurs
snakes
crocodilians
pterosaurs
ornithischians
sauropods
theropods
birds
Dinosauria
perforate hip socket
Euryapsida
Lepidosauria
Archosauria
gizzard, upright posture, advanced hearing and circulatory system
Anapsida
specialized ear region, broad fifth metatarsal
Sauria
eardrum, high-frequency hearing enhanced locomotion
Diapsida
2 temporal fenestrae suborbital fenestra in palate
Reptilia
keratinized skin, color vision, uric acid rapid eye focusing, third eyelid
Amniota
amniotic egg

Turtle Eyes

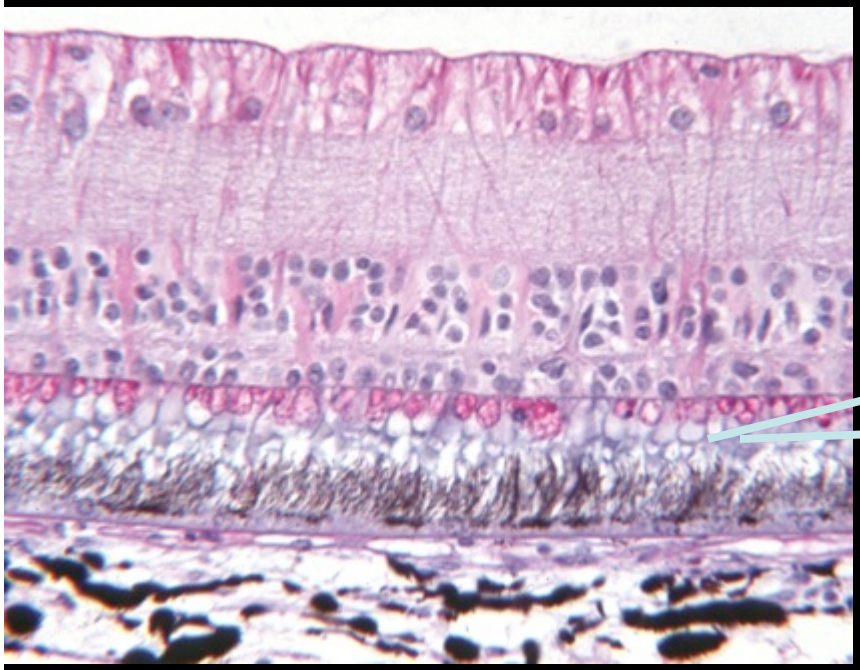
Annular Lens Pad

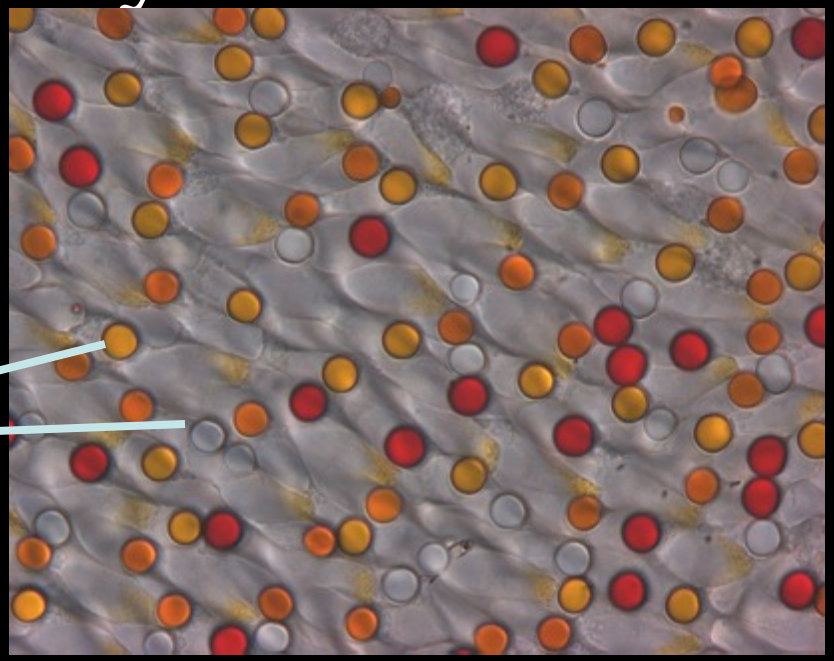




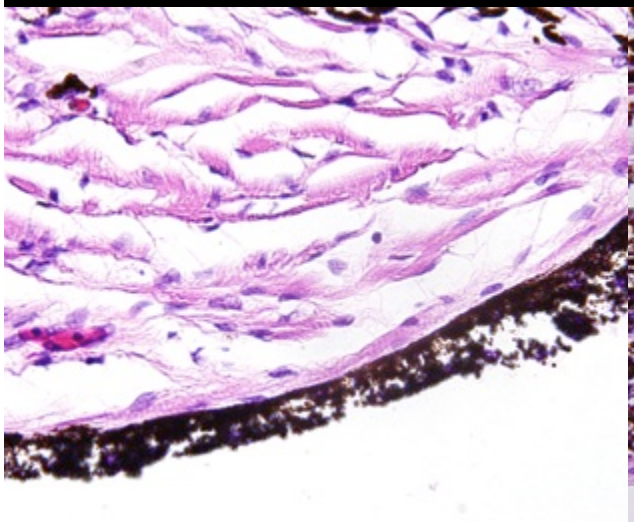


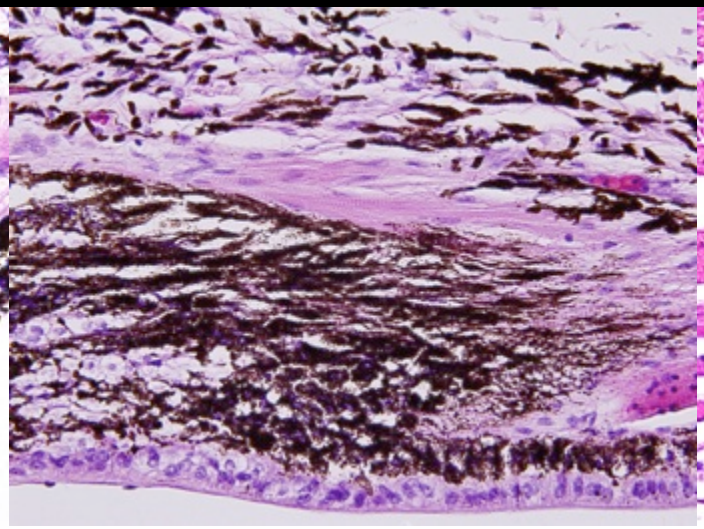
Turtle Eye

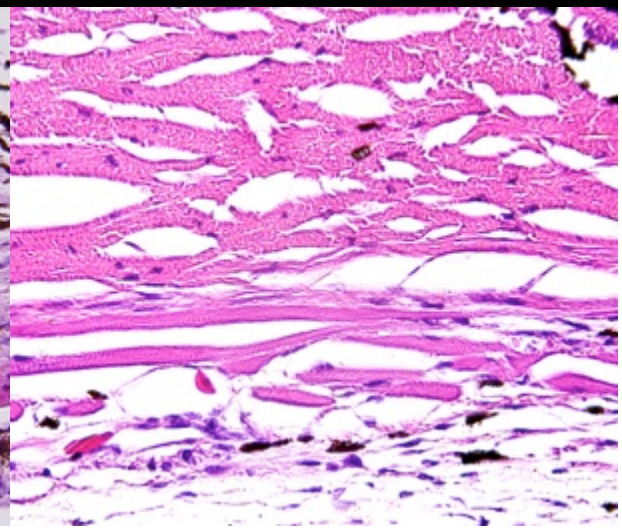




Skeletal Muscle



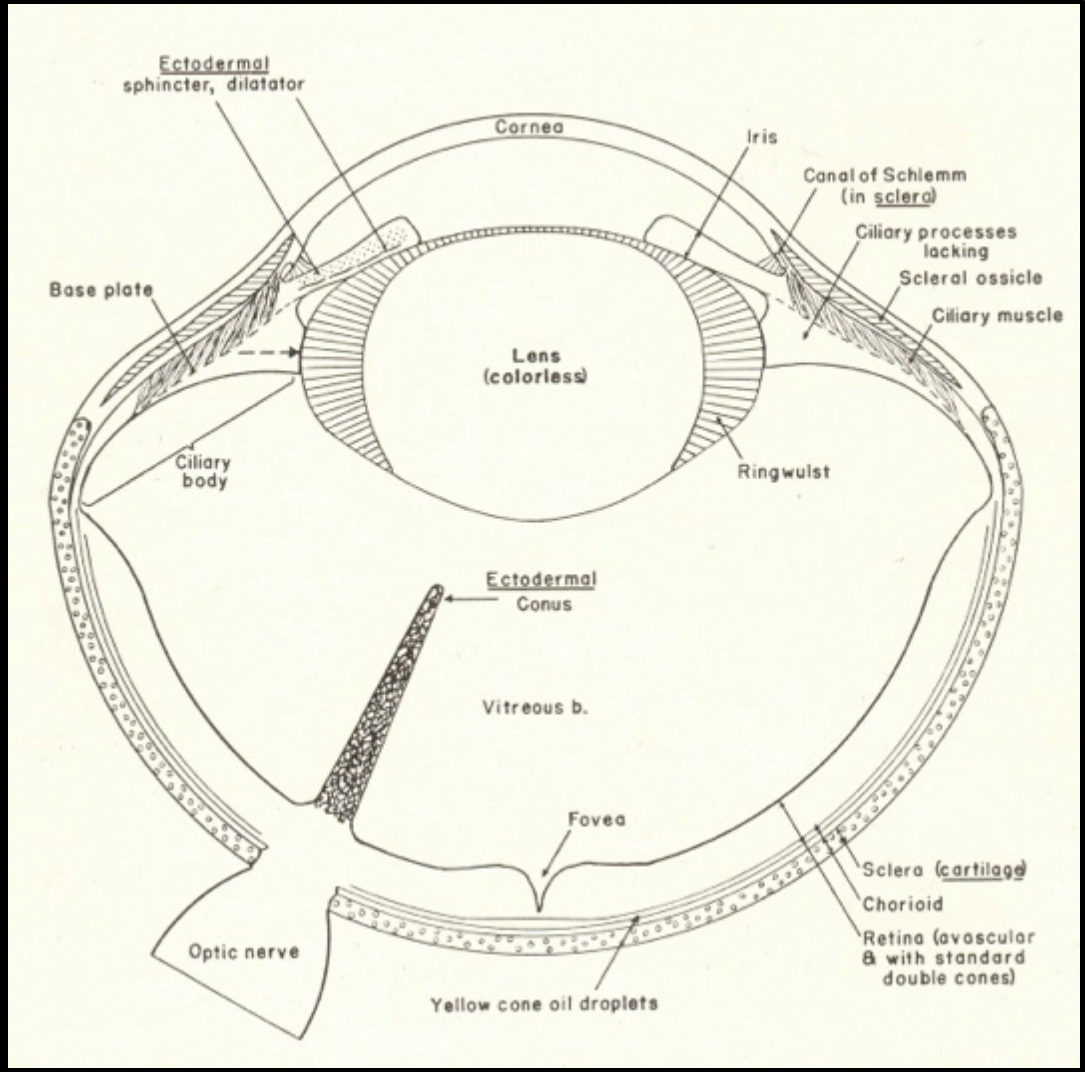




Lizards

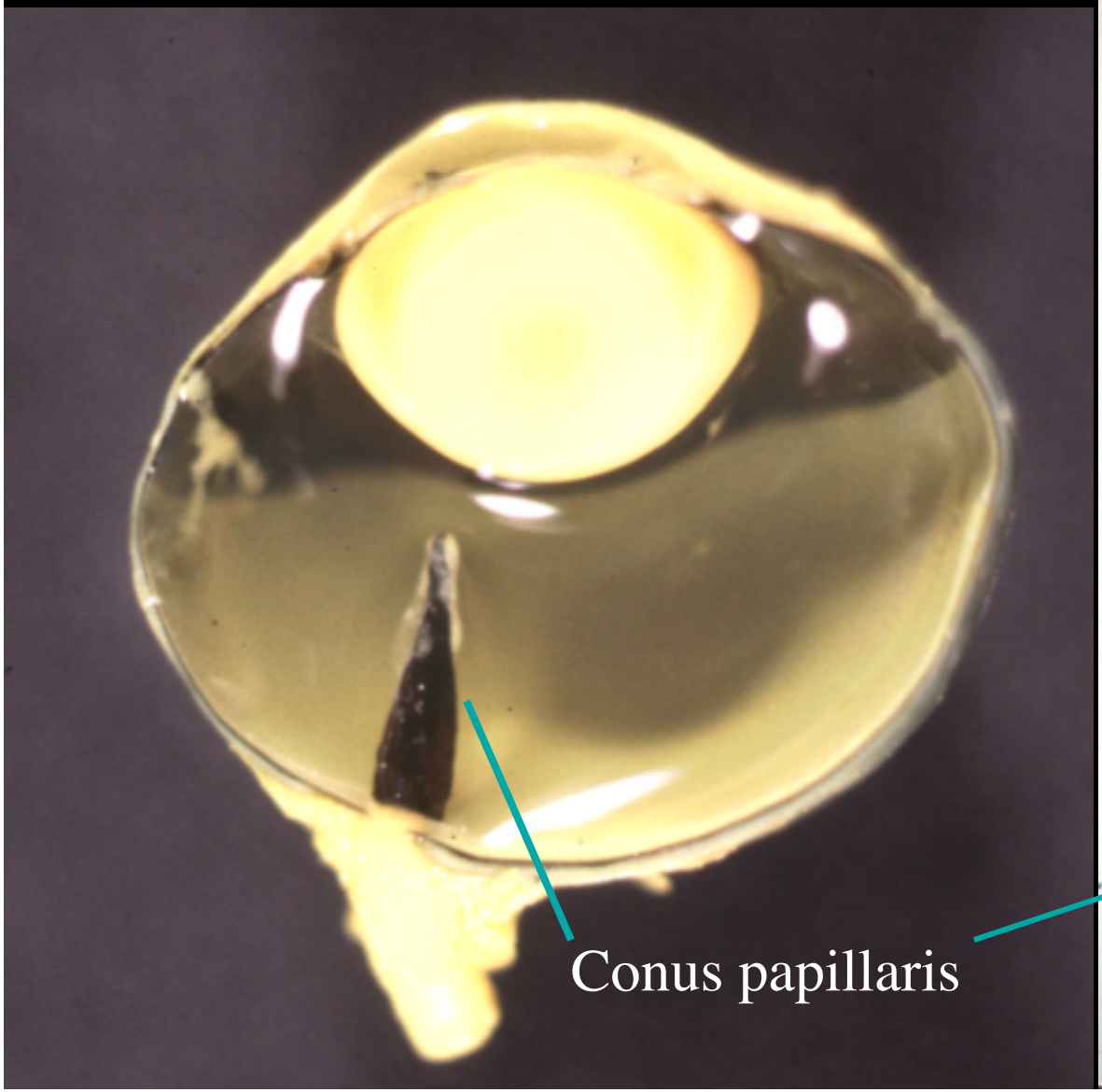
- General features of lizard eyes
  - Scleral bone and cartilage
  - Annular pad in lens
  - Skeletal muscles for accommodation
  - Trichromatic vision or more
  - Fovea
  - Avascular retina with special adaptations for blood supply
  - Special considerations by group
    - Tuatara, the most primitive of the extant lizards
      - Lacks a conus papillaris
    - Iguana, Chameleons, Monitors
    - Gecko
      - Ecdysis
      - Spectacle
    - Snakes are treated separately

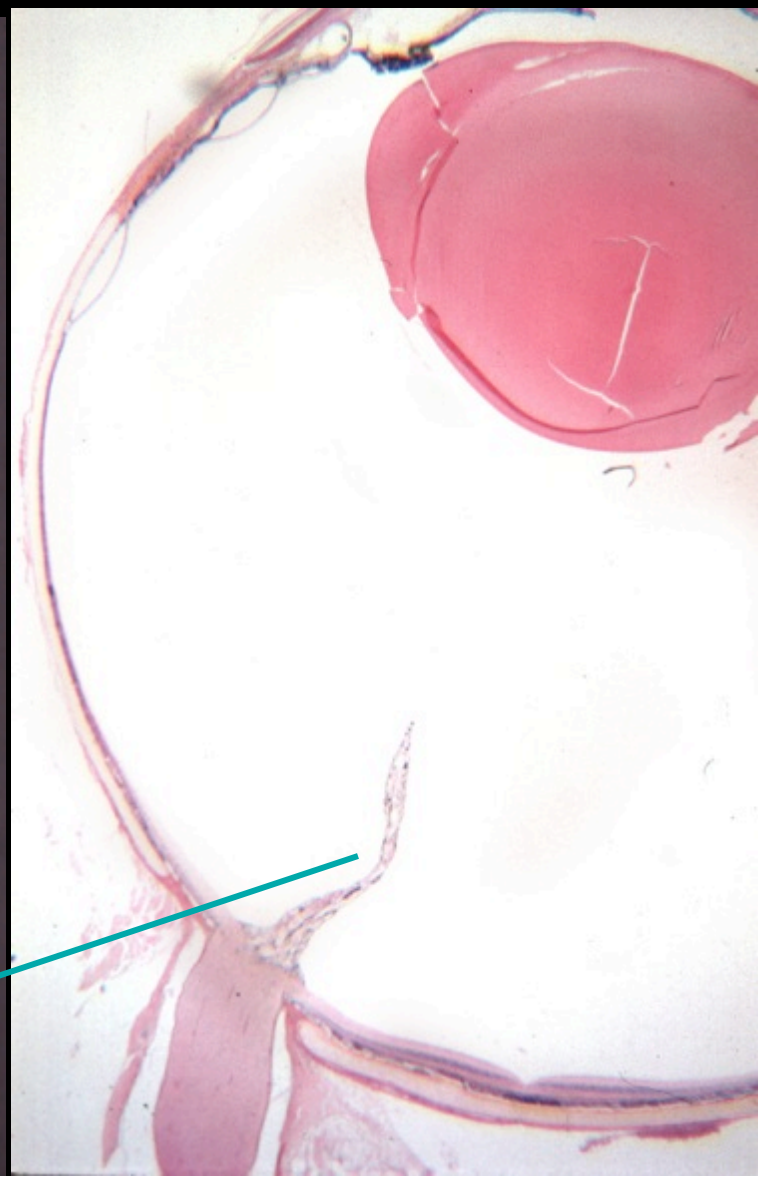
General Features of Lizard Eyes



Walls

Features of Lizard Eyes

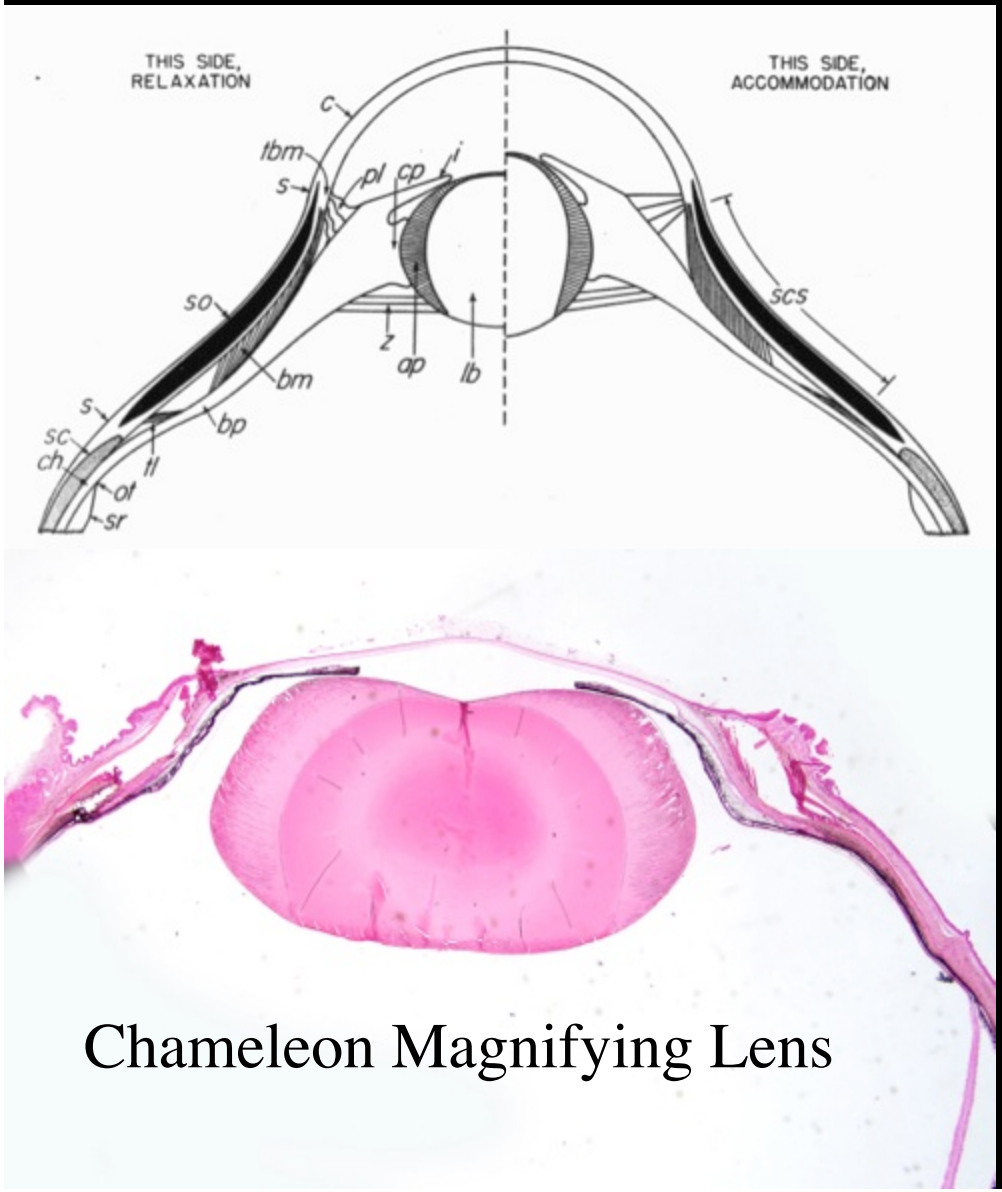




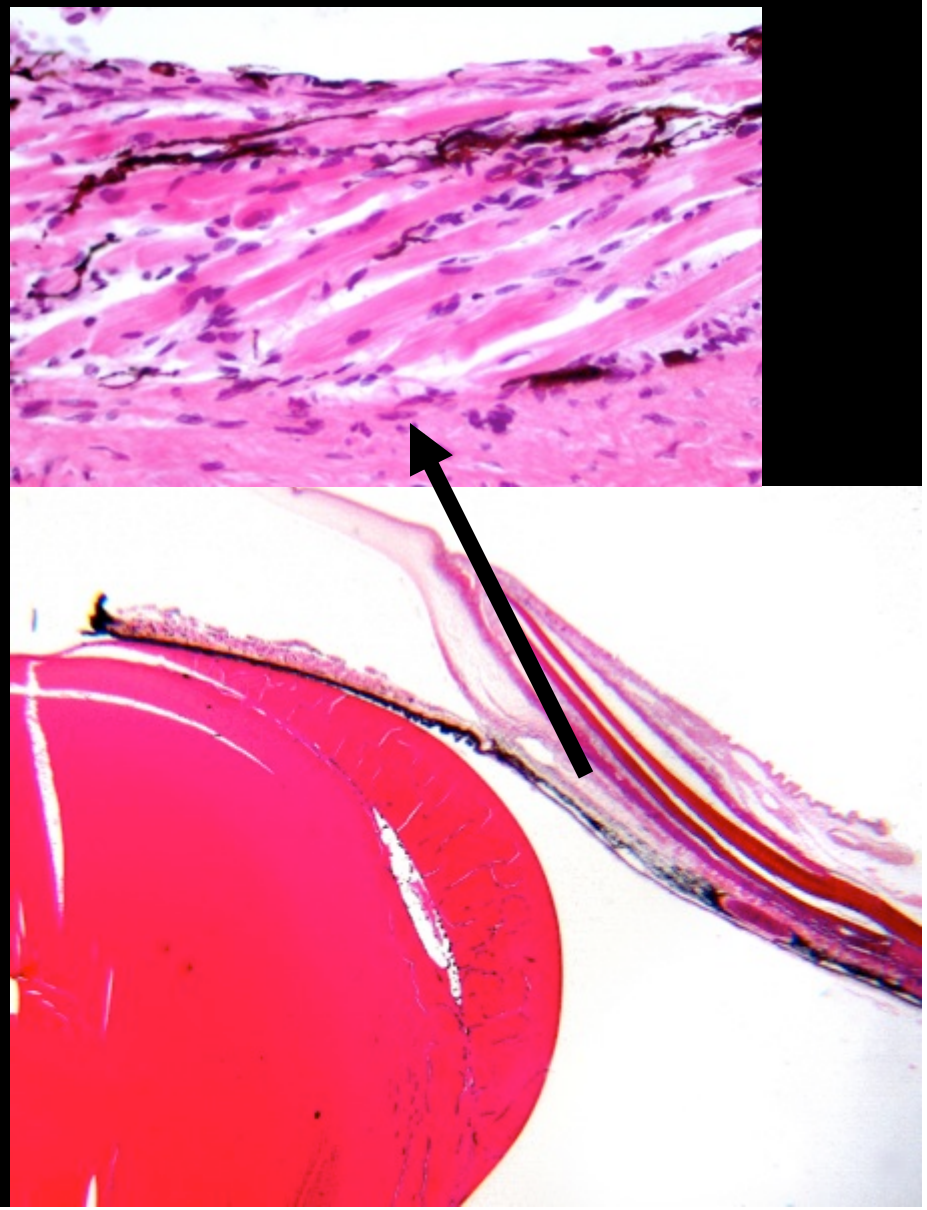
Conus papillaris

Features of Lizard Eyes

Accommodation

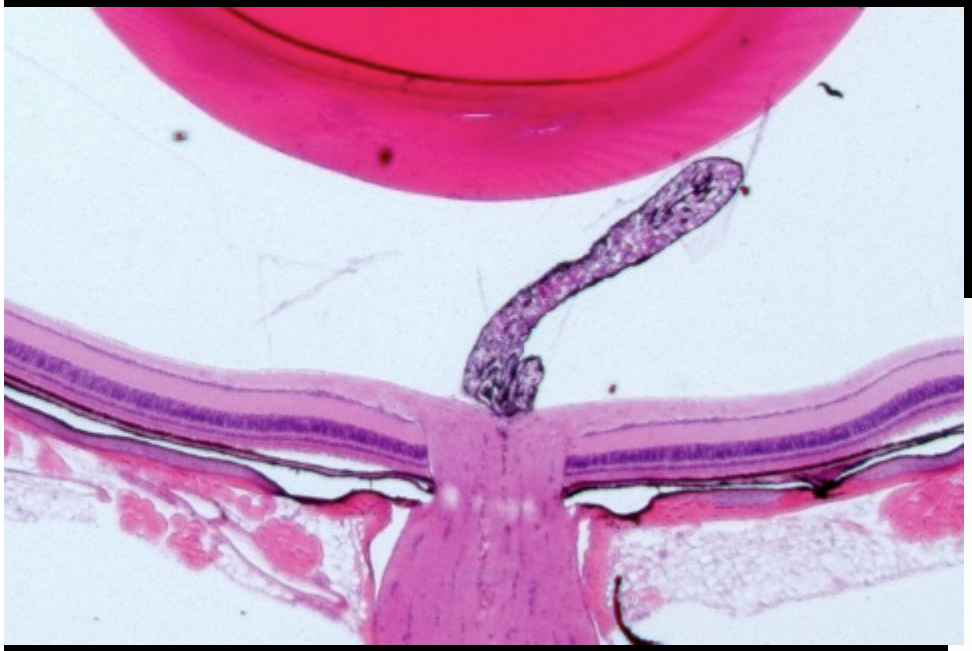


Chameleon Magnifying Lens

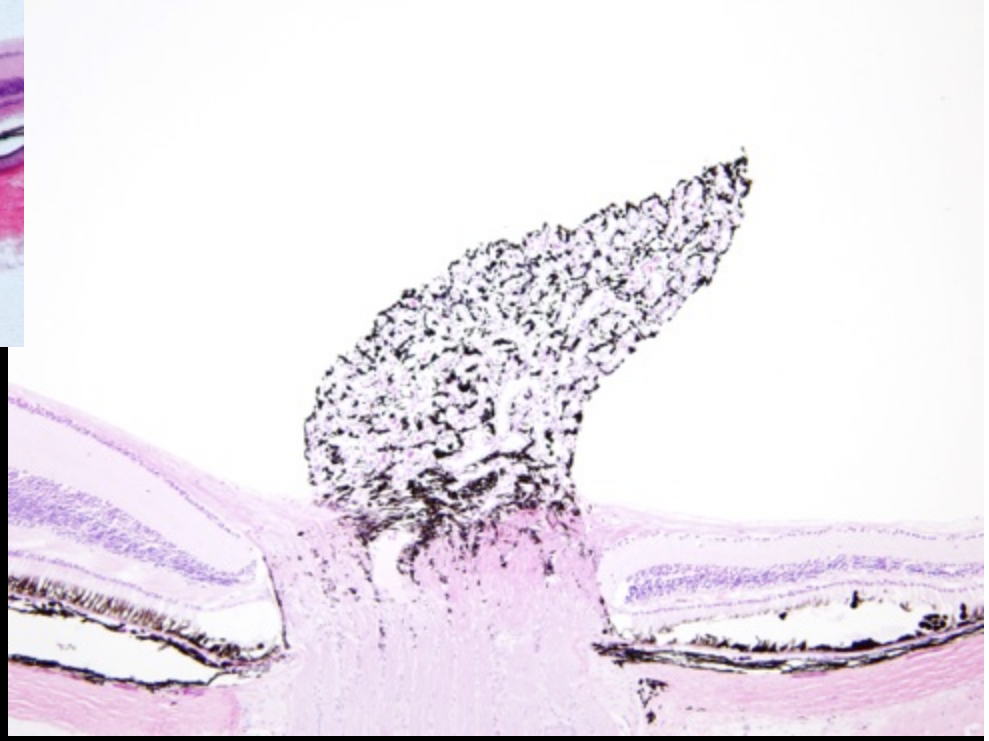


Features of Lizard Eyes

Conus Papillaris



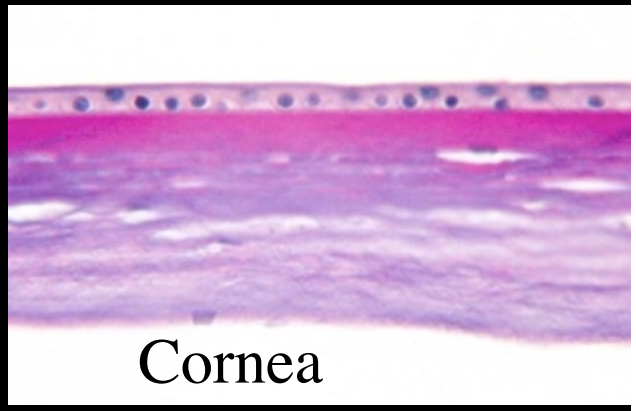
Gecko



Chameleon

Features of Lizard Eyes

Retina & Cornea



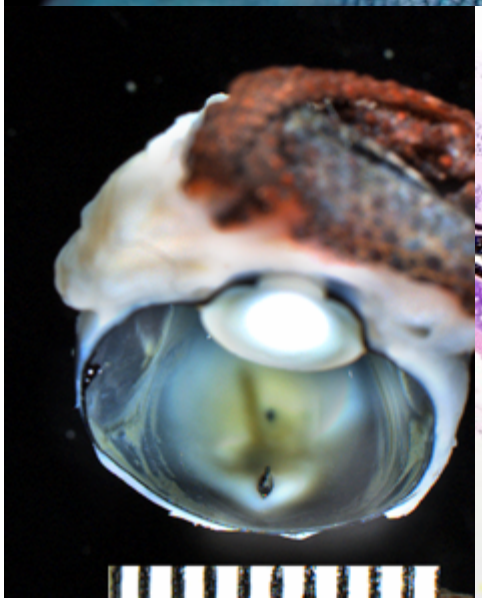
Cornea

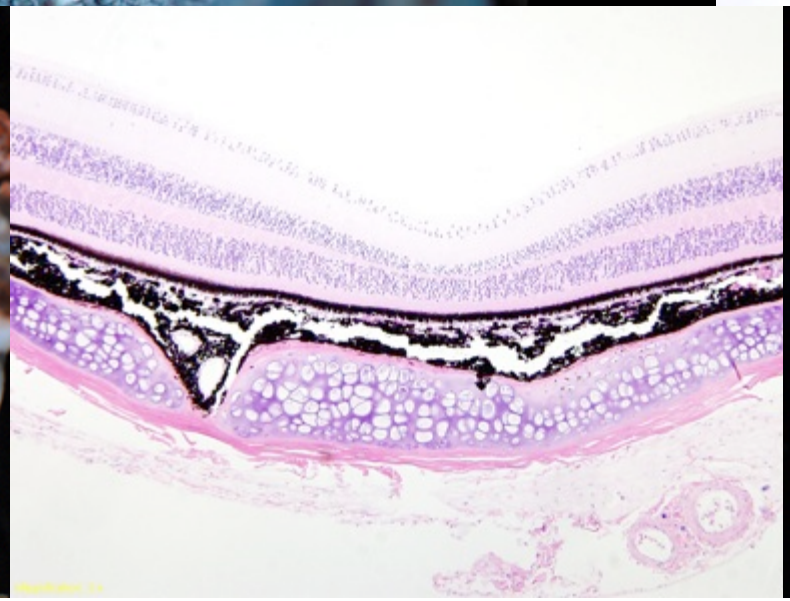
Iguana Shallow Fovea

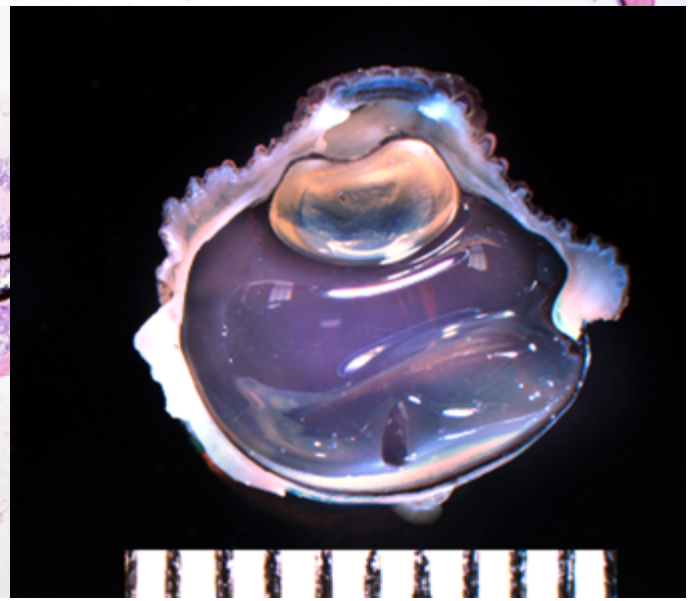
Gecko Shallow Fovea

Gecko Cone-rich Retina

Chameleon Eyes







Features of Snake Eyes

- Snakes are closely related to the lizards and are thought to have lost ocular features in a degenerative process
- No cartilage or bone
- No annular lens pad
- Smooth muscle in iris, none in ciliary body
- Vessels on the inner surface of the retina
- Some snakes have a conus papillaris
- Photomechanical movement in the RPE
- Spectacle in front of cornea

Features of Snake Eyes

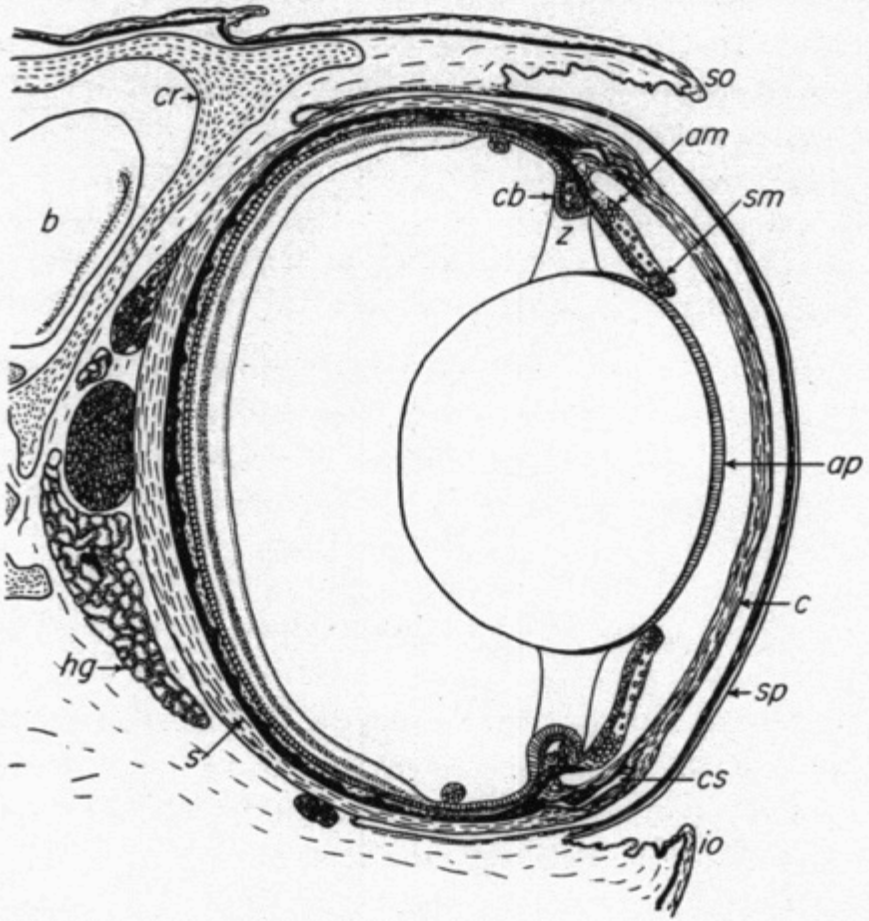
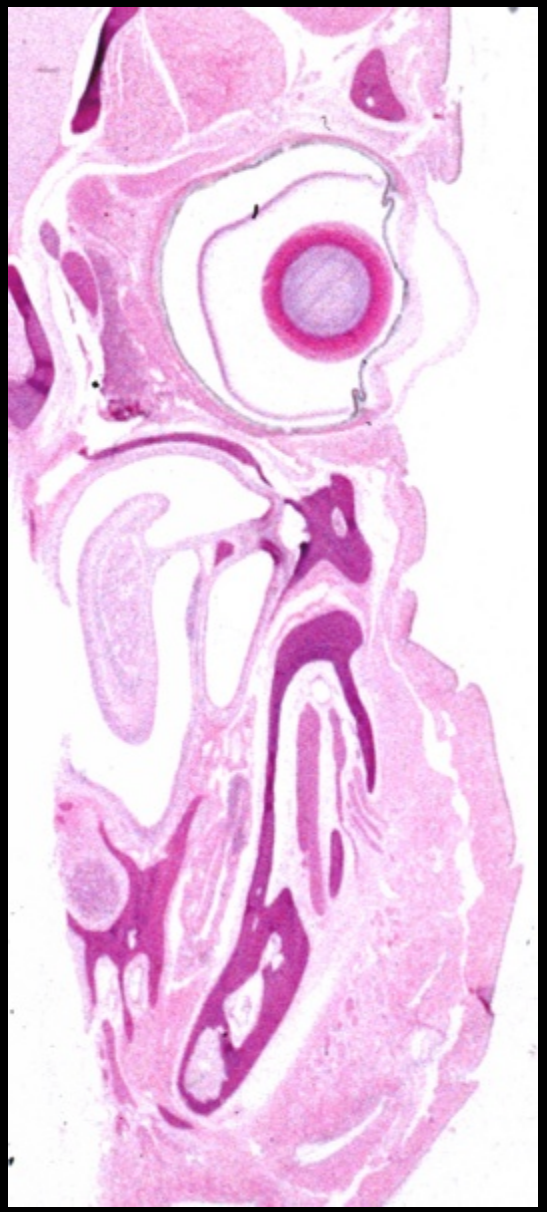
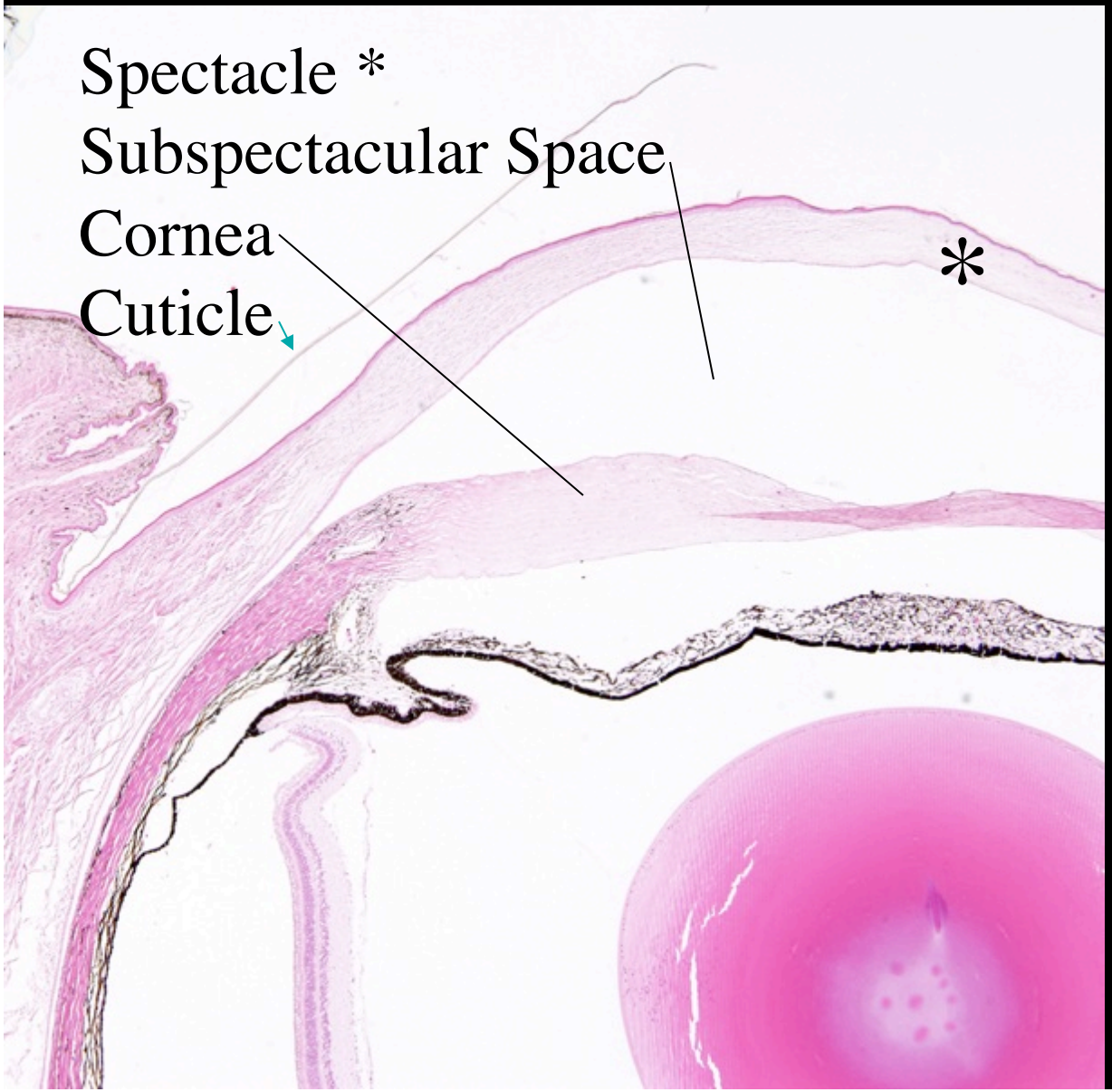


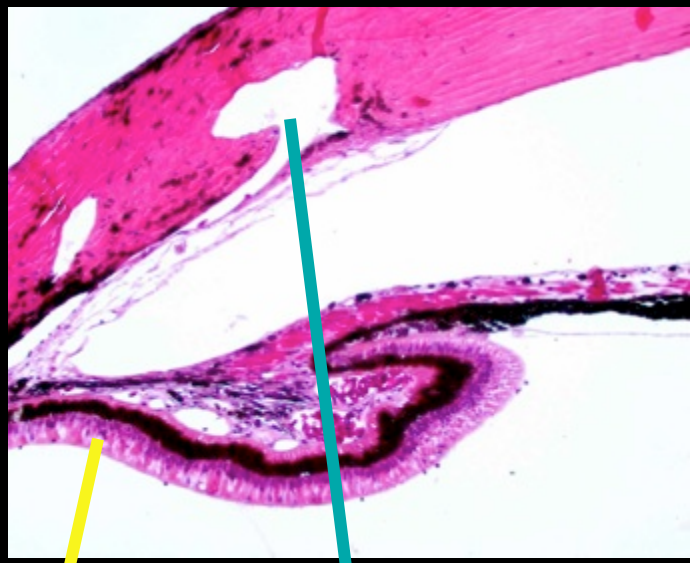
Fig. 181—The ophidian eye in vertical section: *Natrix natrix*. ×22. Redrawn from Schwarz-Karsten, modified from original preparations.

am- accommodatory muscle; *ap*- anterior pad of lens; *b*- brain; *c*- cornea; *cb*- ciliary body (main portion, the ciliary roll; note cross-section of hyaloid vein lying on orbiculus behind it; the very small vessels of the hyaloid plexus, lying on the inner surface of the retina, are omitted from the drawing); *cr*- cranium; *cs*- canal of Schlemm; *hg*- Harderian gland; *io*- infraocular scale; *s*- sclera; *sm*- sphincter muscle; *so*- supraocular scale; *sp*- spectacle; *z*- zonule (collapsed; see text).



Features of Snake Eyes

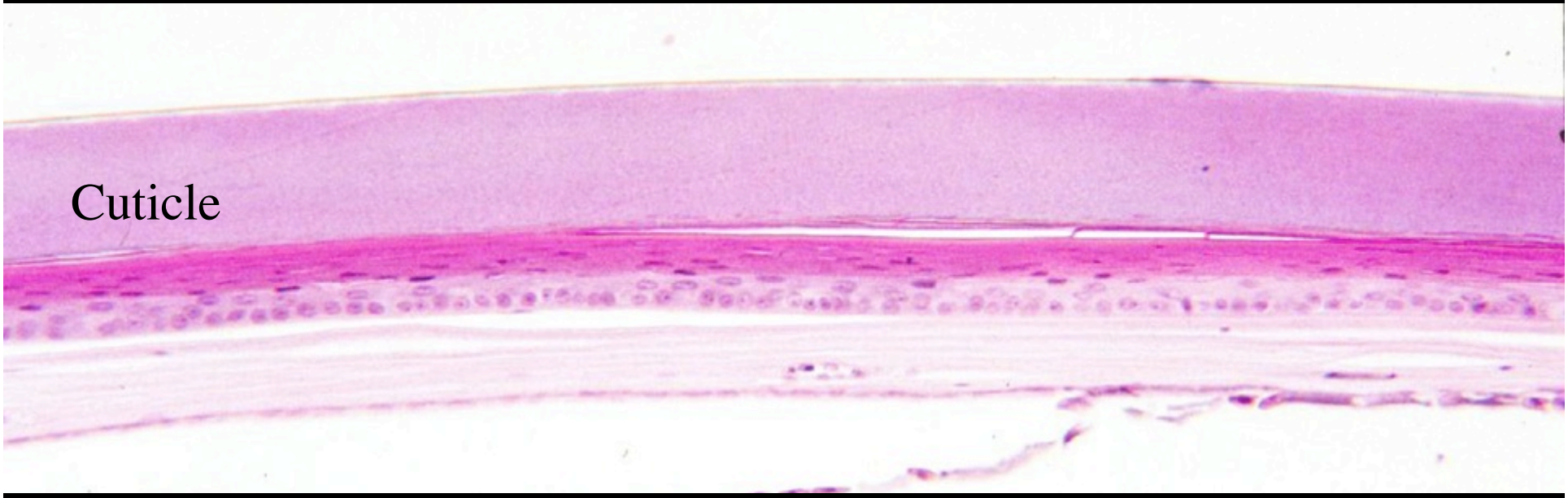


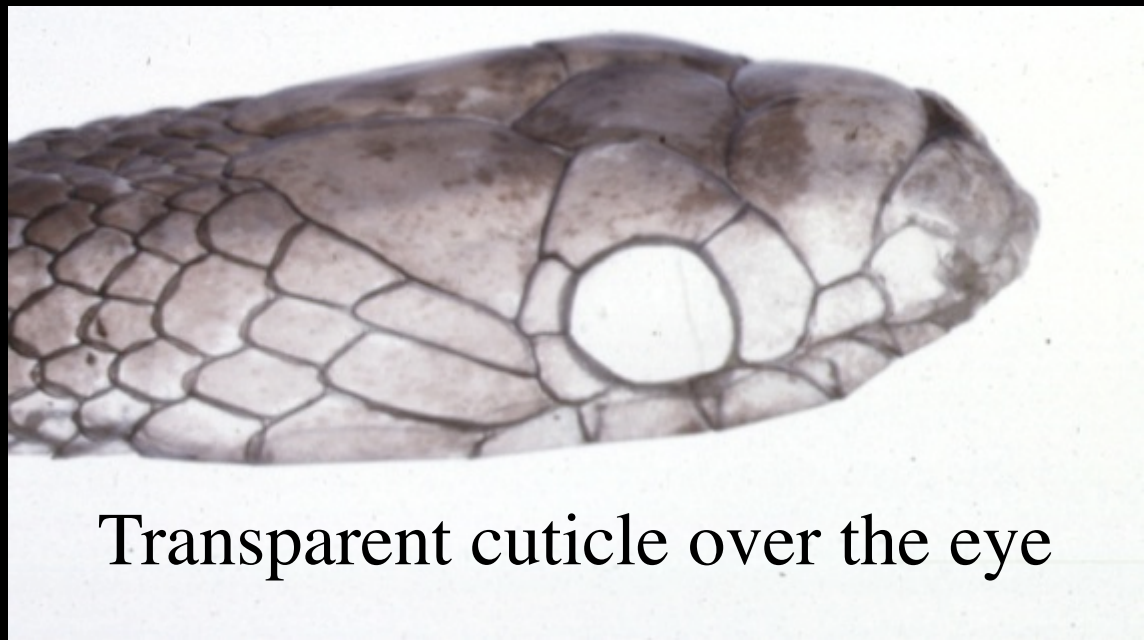


Schlemm's canal

Ciliary roll

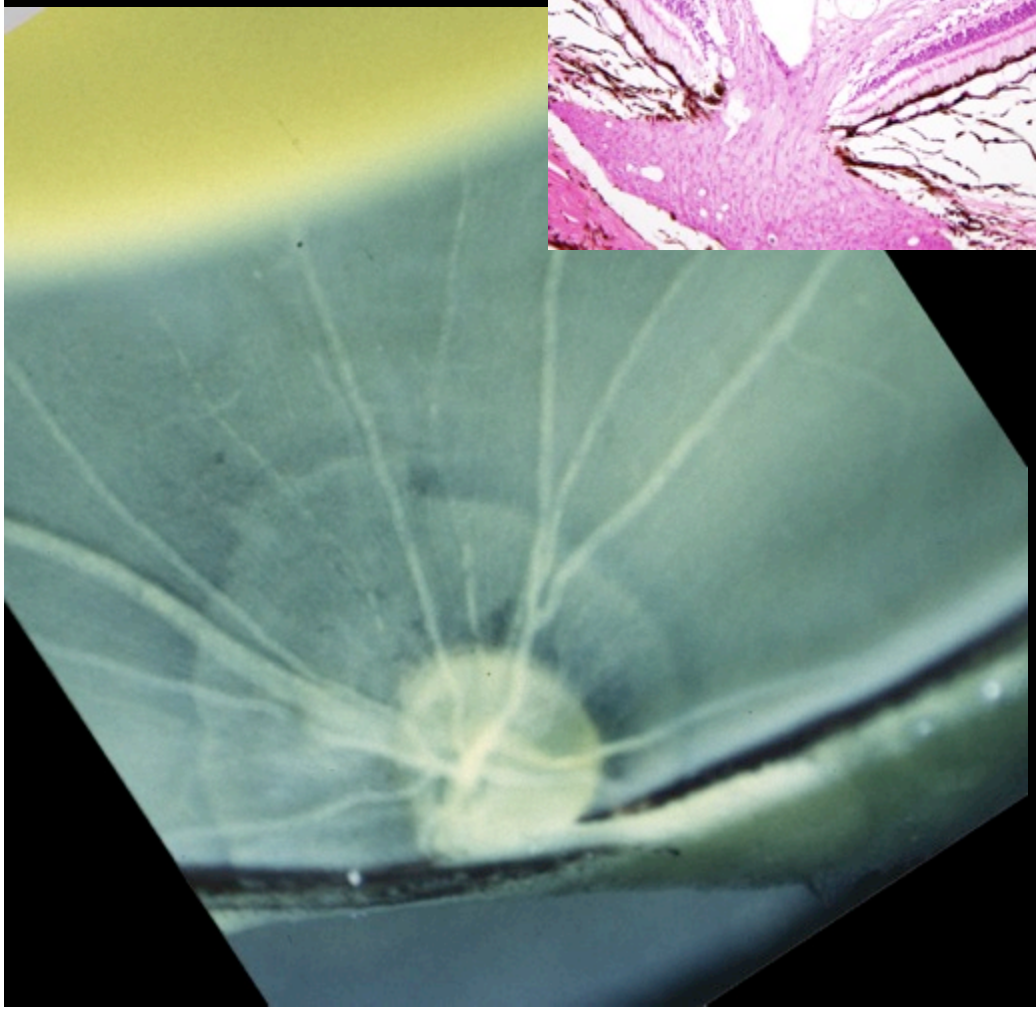
Ecdysis

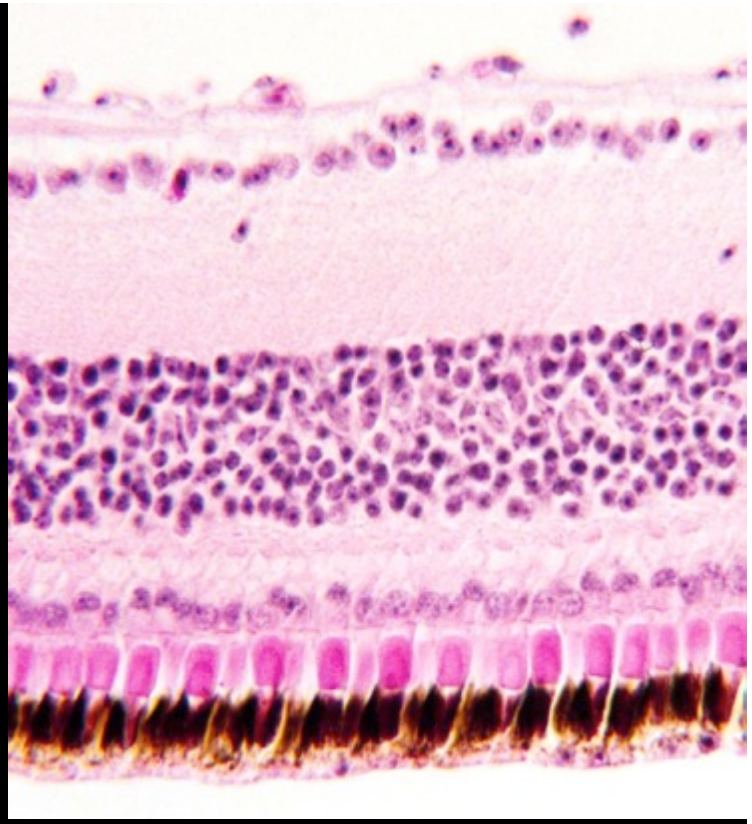


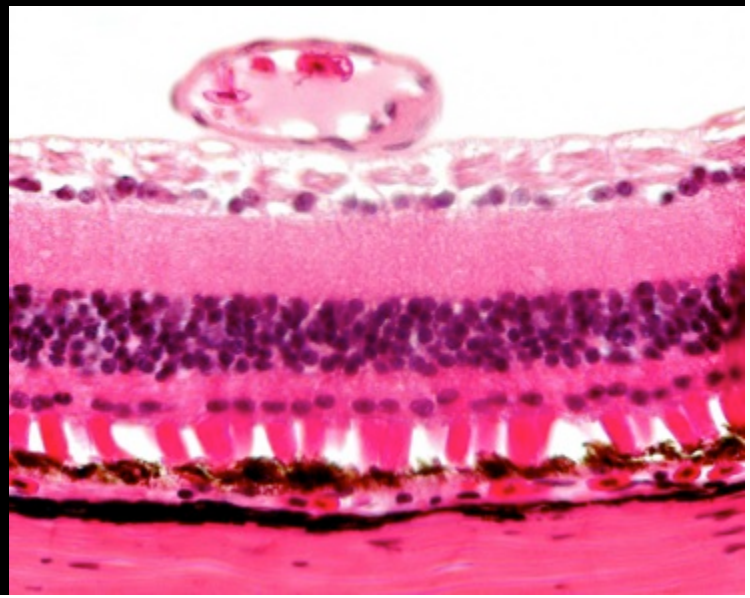


Transparent cuticle over the eye

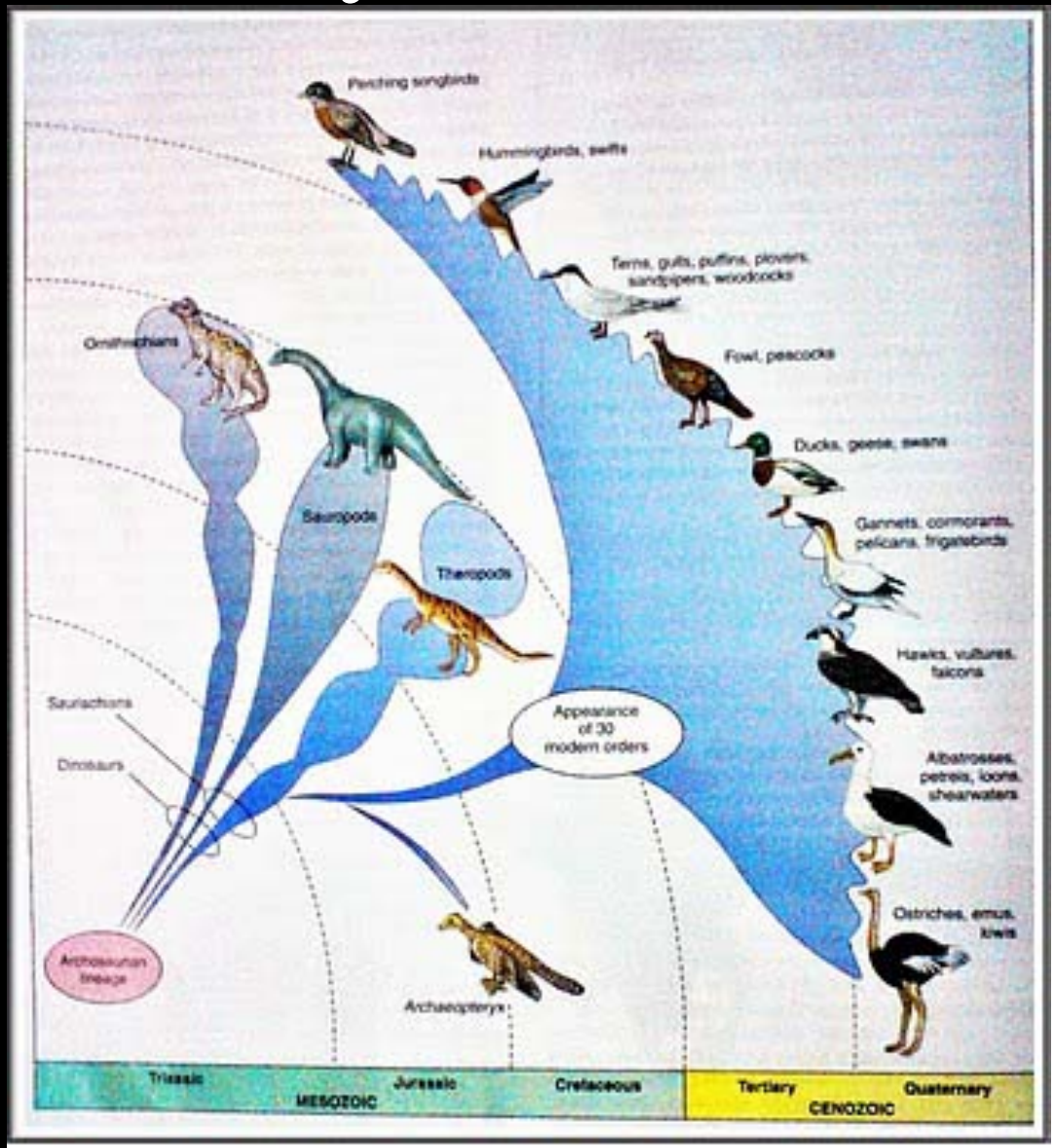
Snake Retina







Avian Eyes



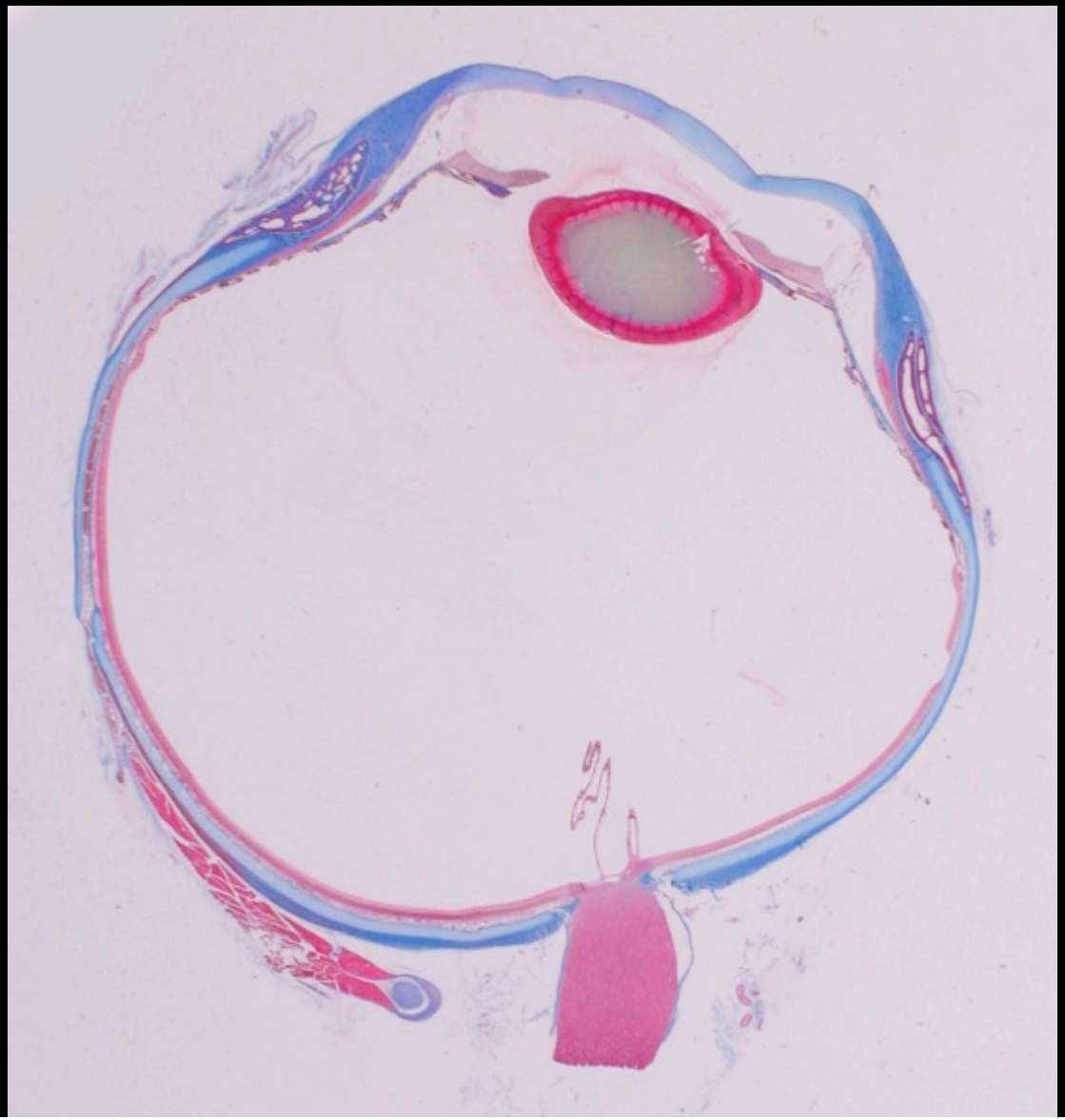
http://avesbirds.blogspot.com/2010/03/birds-cladogram.html

Features of Bird Eyes

- Cartilage and well-developed ossicle
  - Some birds have a tubular eye shape
- Skeletal muscle in iris and ciliary body
- Annular lens pad
- Photomechanical movement in the RPE
- Pecten oculi
- Fovea common - some birds have two fovea
- Corneal accommodation
- Trichromatic vision or more

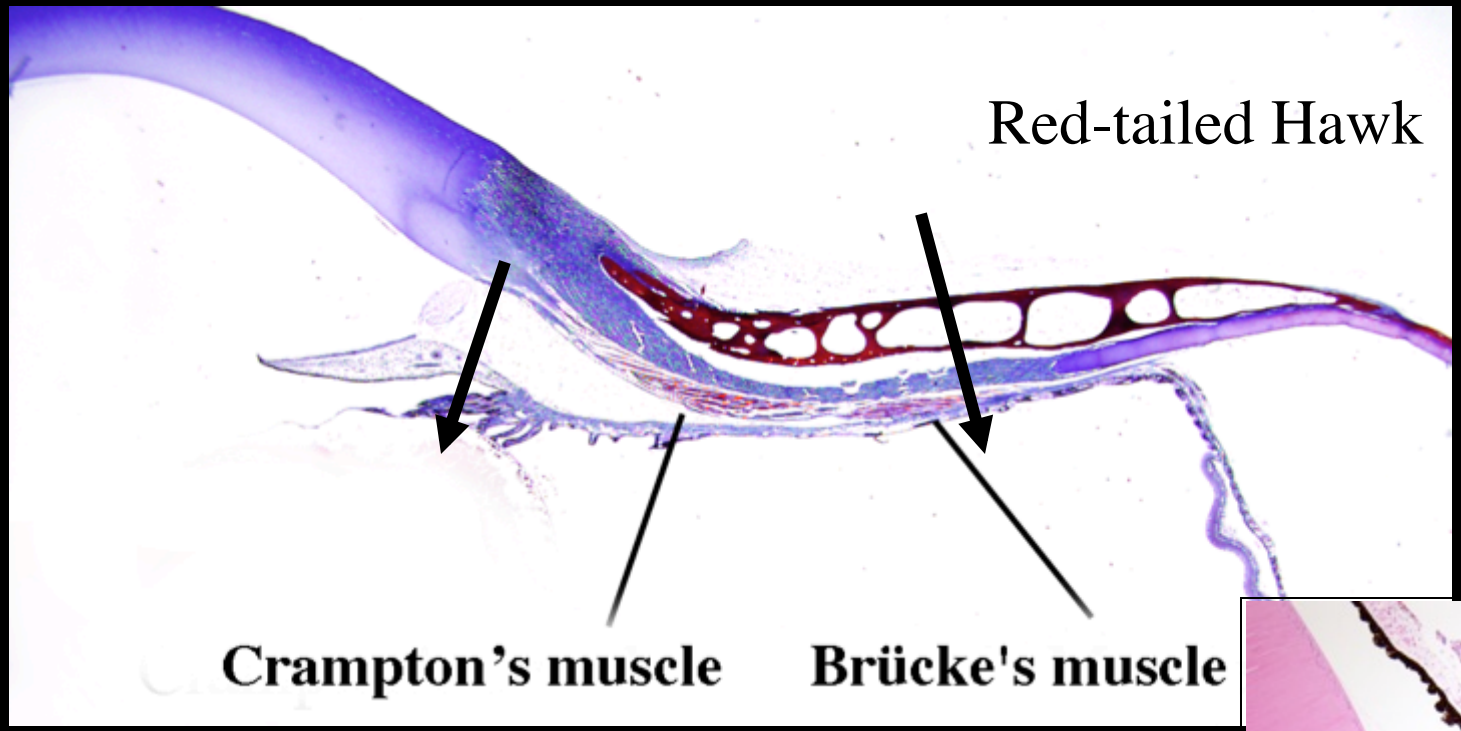
Features of Bird Eyes

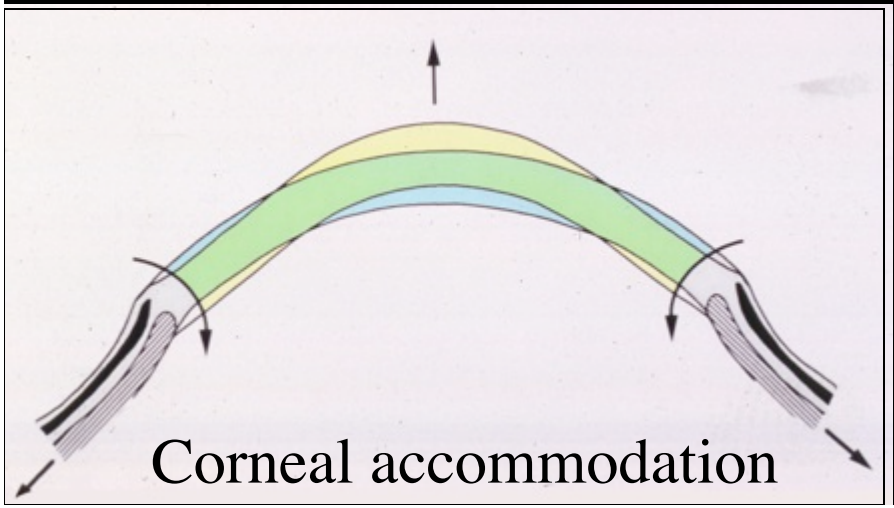
Ferry Bird

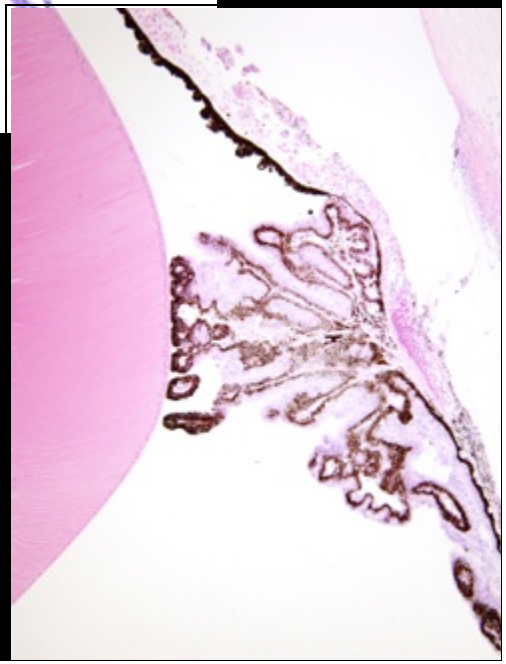


Loon Eye

Avian Accommodation







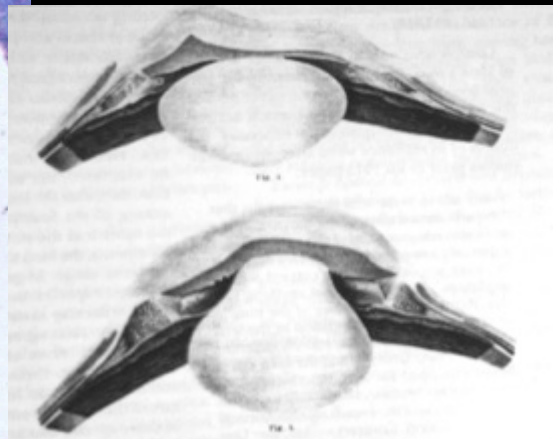
Accommodation in Diving Birds

Loons, Puffins, Penguins, Cormorants

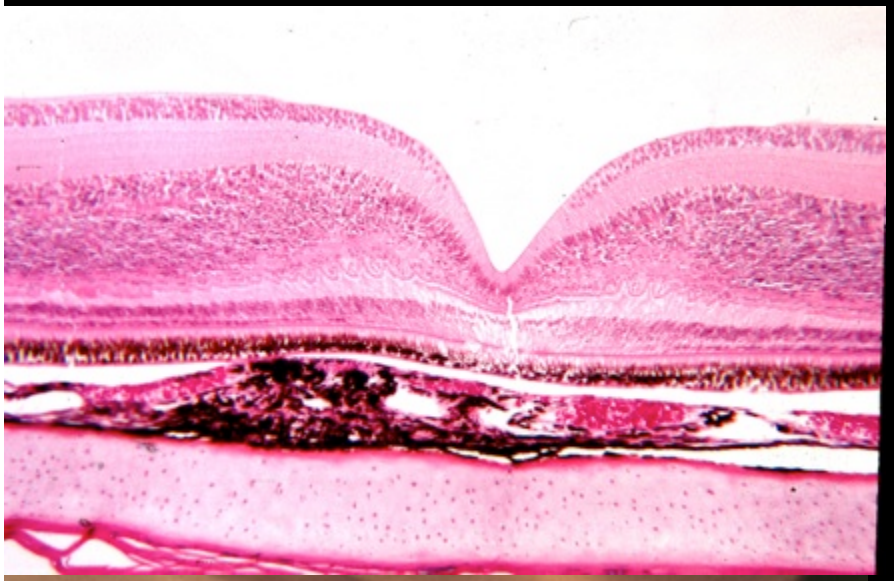
Otter Iris

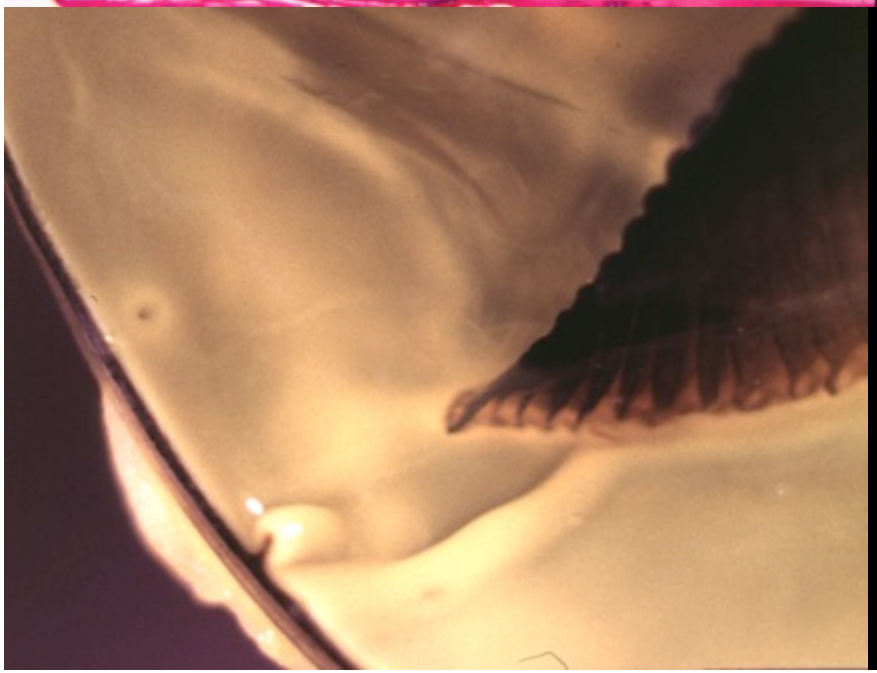
Muscular Iris

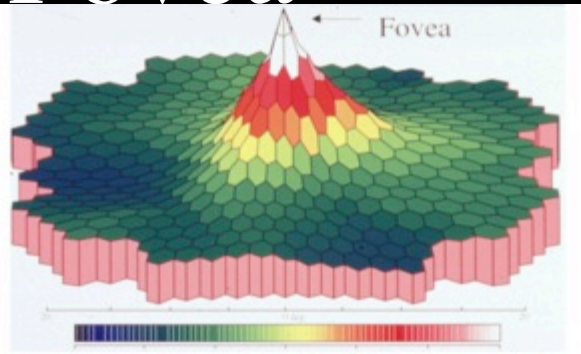
Anterior Attachment
of Ciliary Process



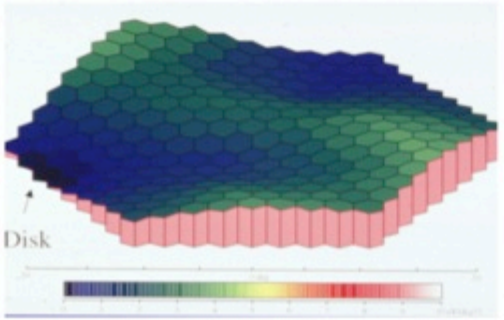
The Double Fovea



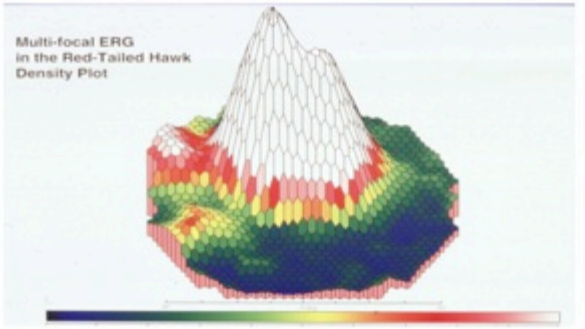




Human mERG



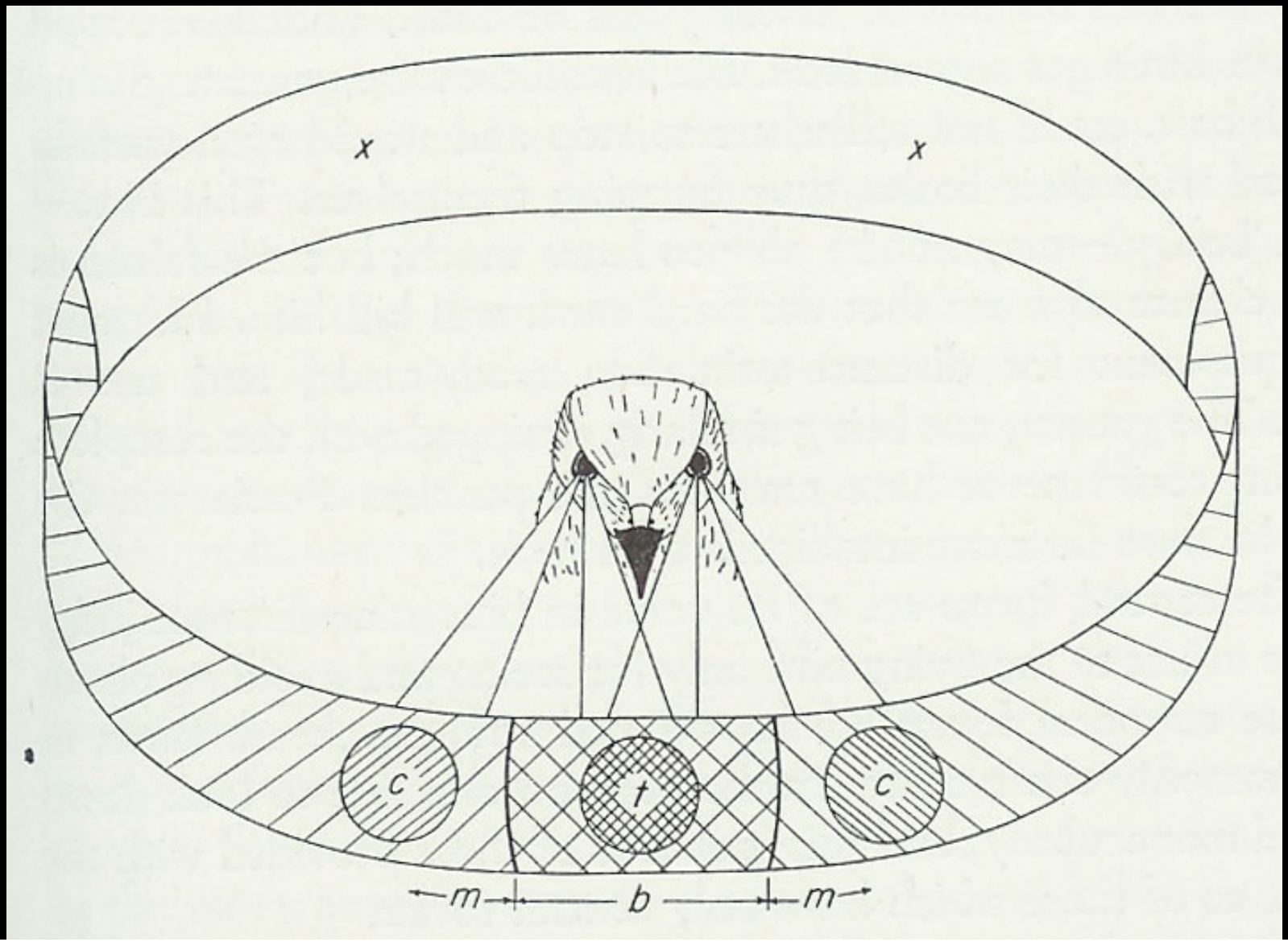
Equine mERG



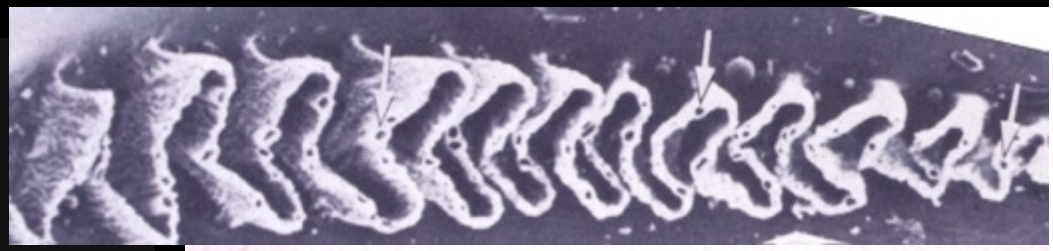
Red Tailed Hawk mERG

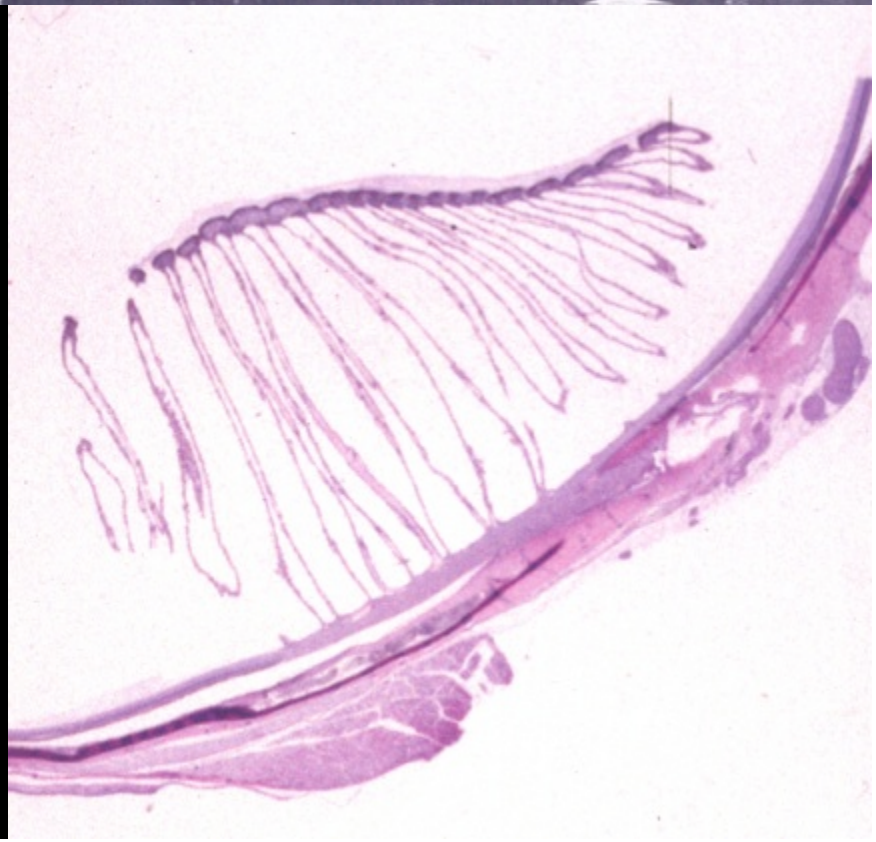
Dr Jim Ver Hoeve

The temporal fovea is bilateral vision
The central fovea is used by just one eye



Pecten Oculi



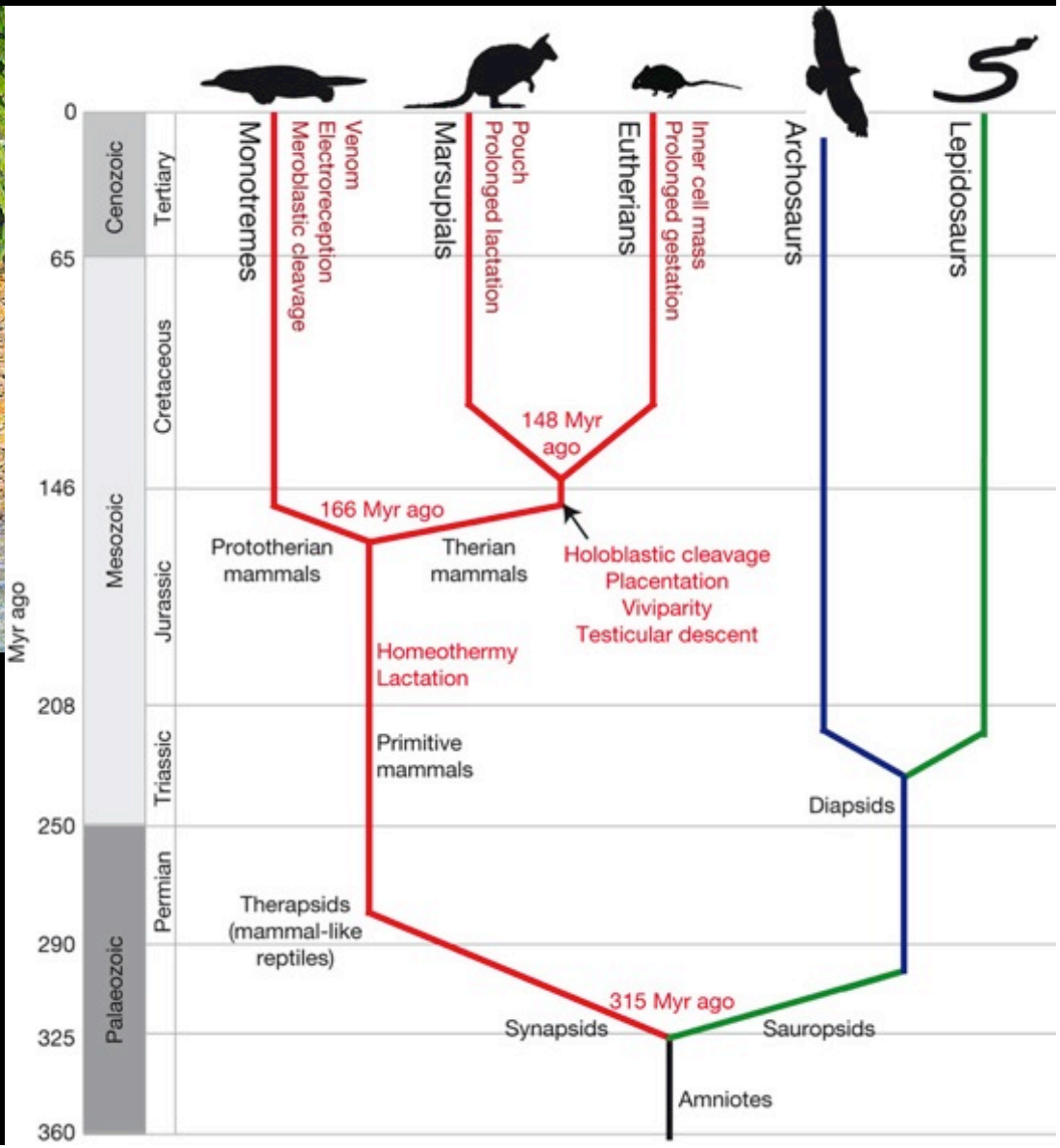


The Monotreme Eye

Duck-billed Platypus

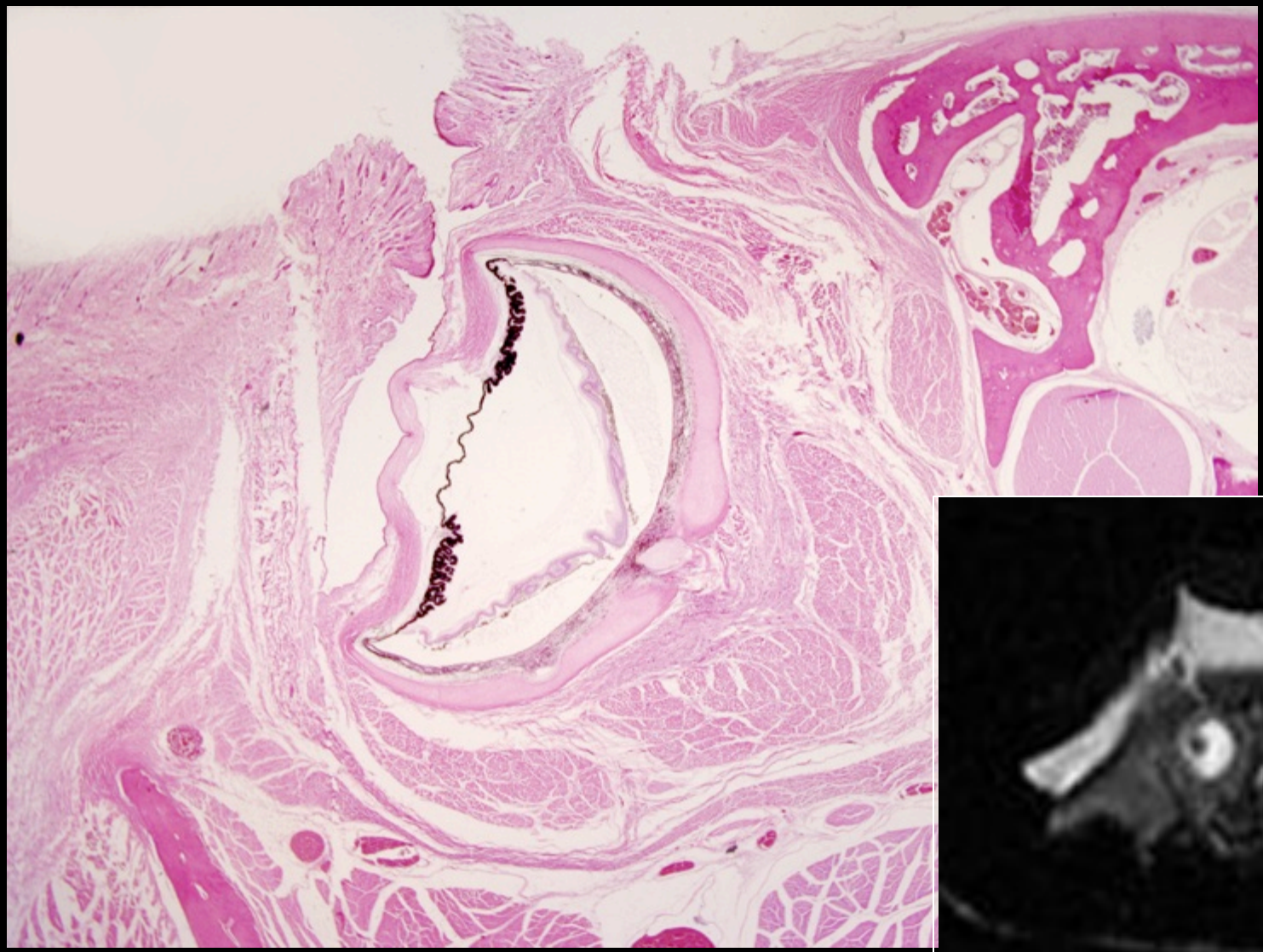
Lost Features

- 4 cone types
- Double cones (Some Marsupials)
- Oil droplets (Some Marsupials)
- Shading or outer segments
- Cartillage



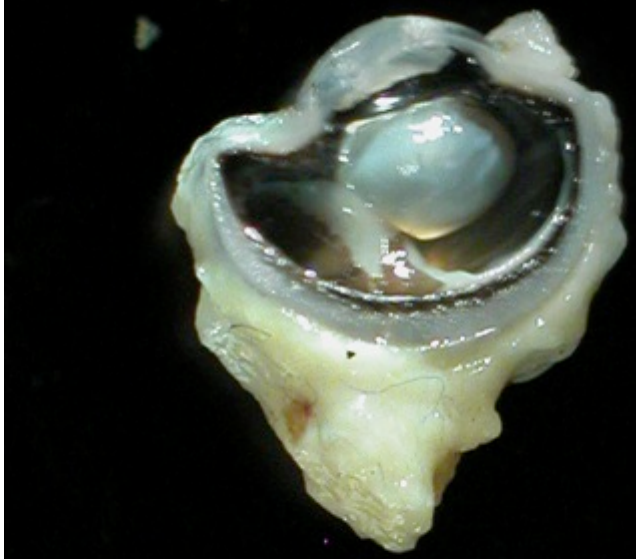
The Monotreme Eye

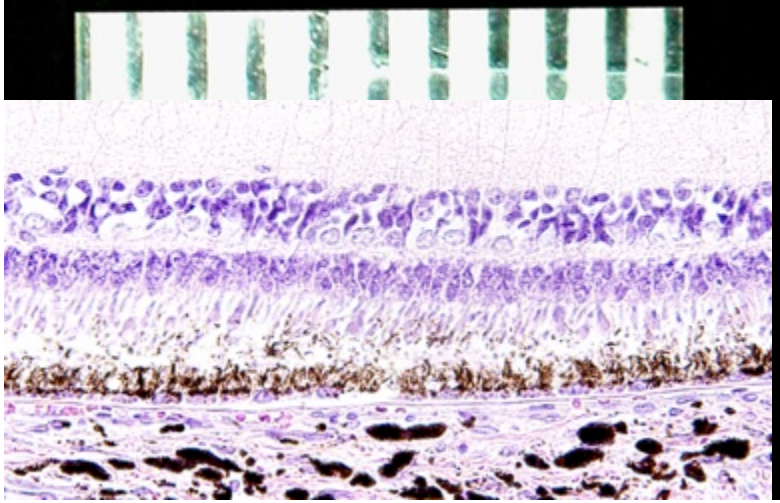
Duck-billed Platypus

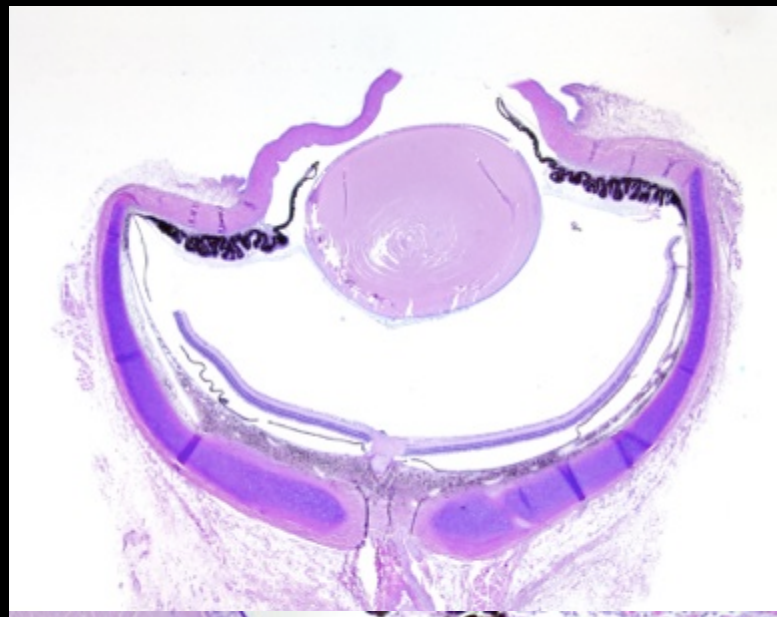


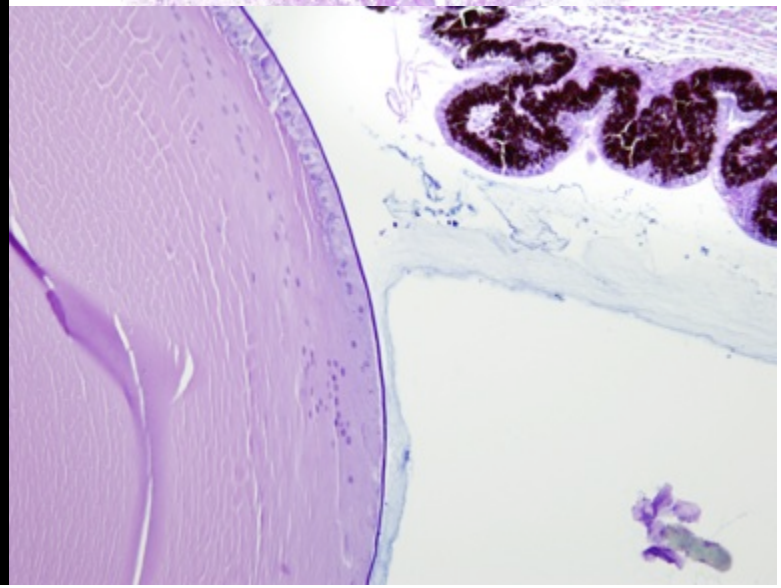
The Monotreme Eye

Duck-billed Platypus









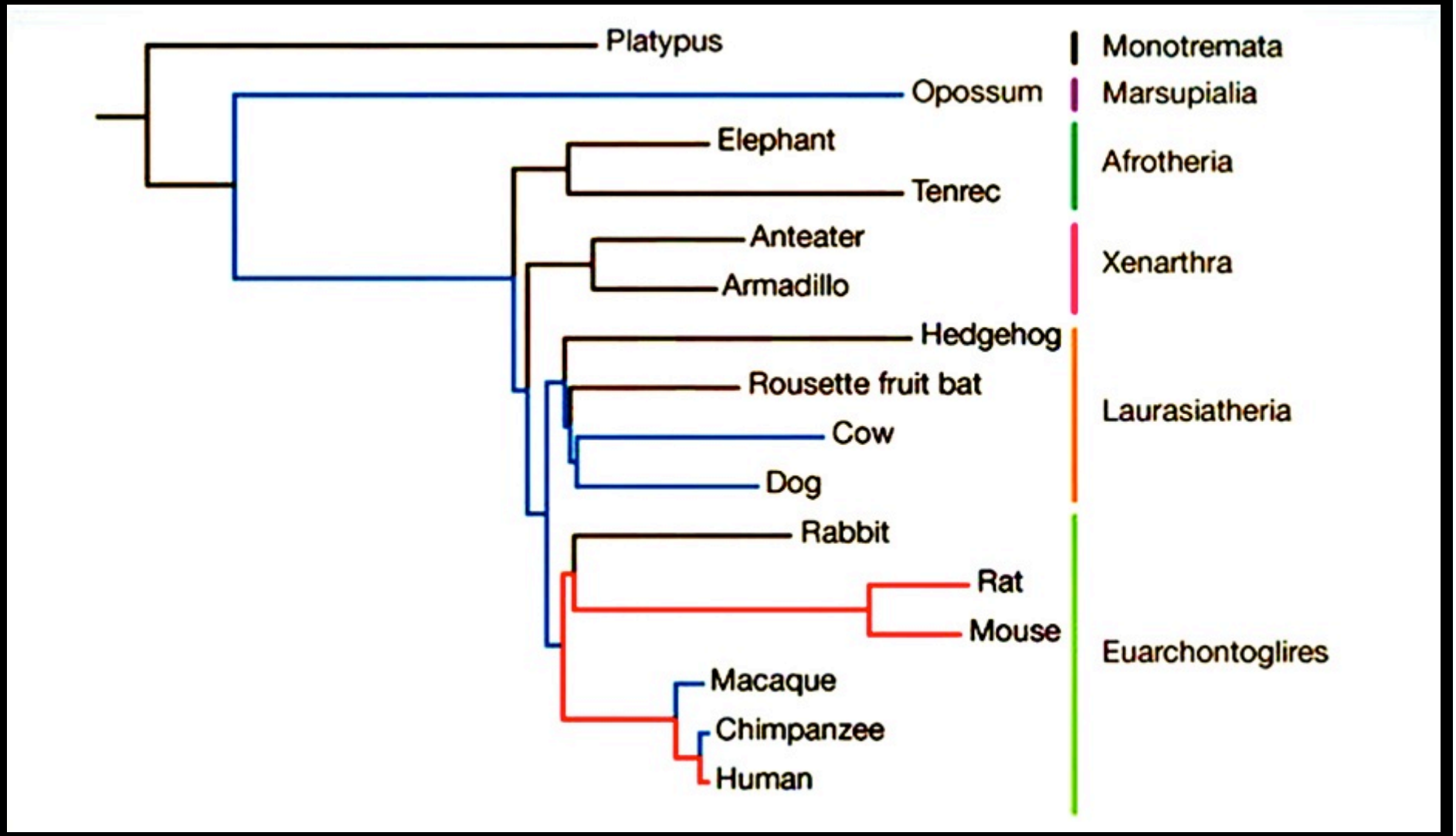
Features of Mammalian Eyes

Marsupials and Placental Mammals

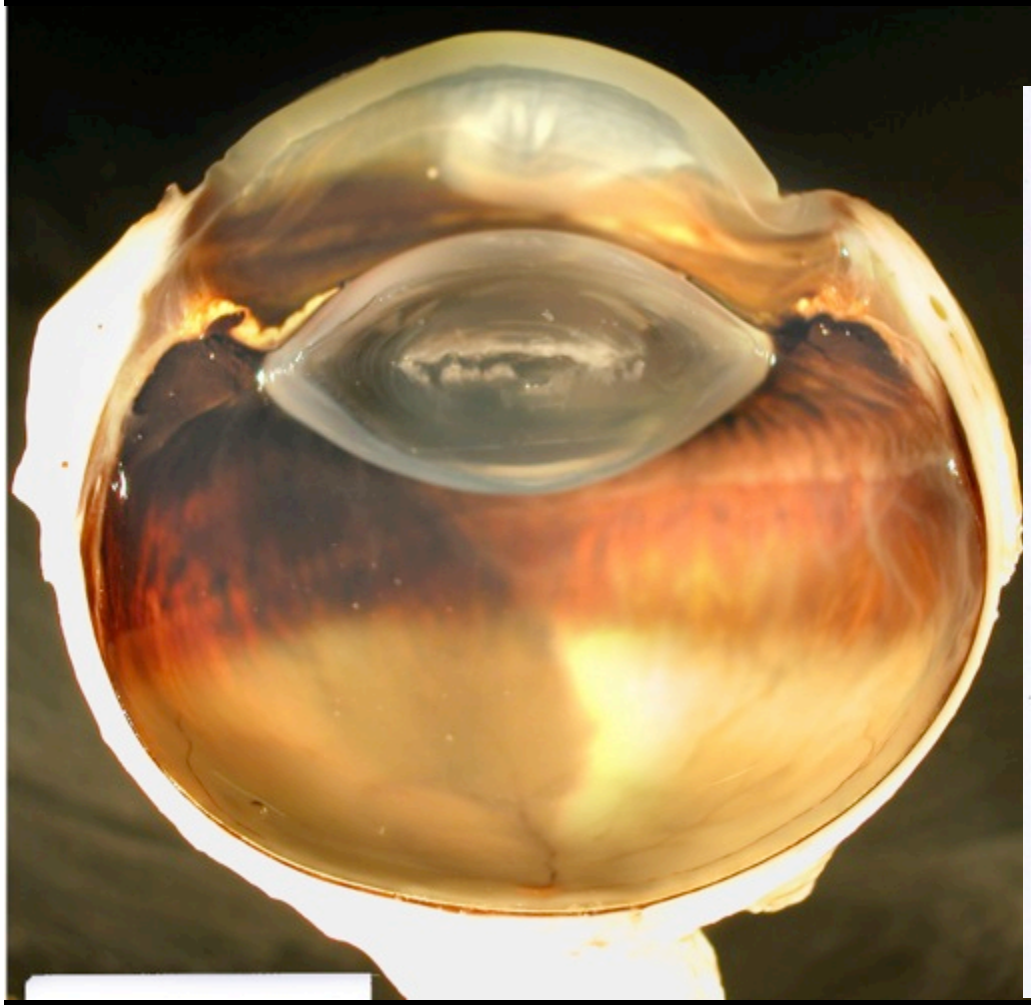
- No bone or cartilage in sclera
- No skeletal muscle
- Iris dilator muscle
- No photomechanical movement in RPE
- Dichromatic vision (except Old World primates)
- No fovea (except Old World primates)
- Most have blood vessels within the retina
- Accommodation limited by passive action of lens capsule on lens

Phylogeny of Mammalian Eyes

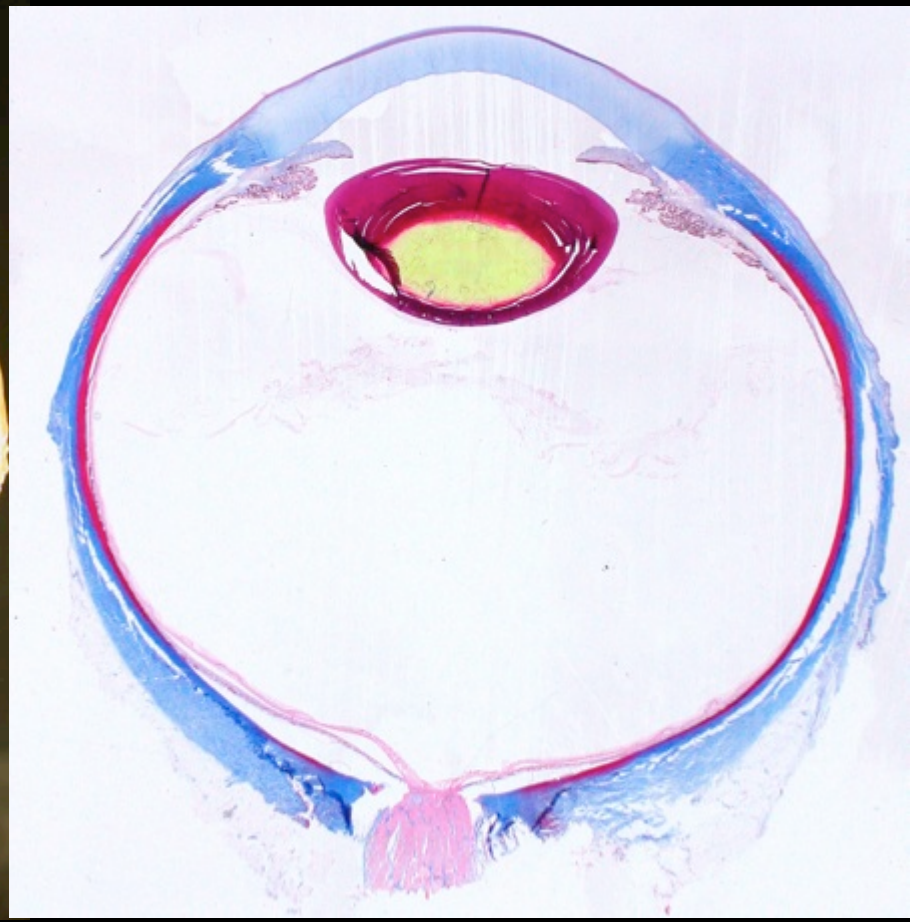
Marsupials and Placental Mammals



Features of the Mammalian Eye



Lion Eye



Rhinoceros Eye

The Nocturnal Eye
from Walls

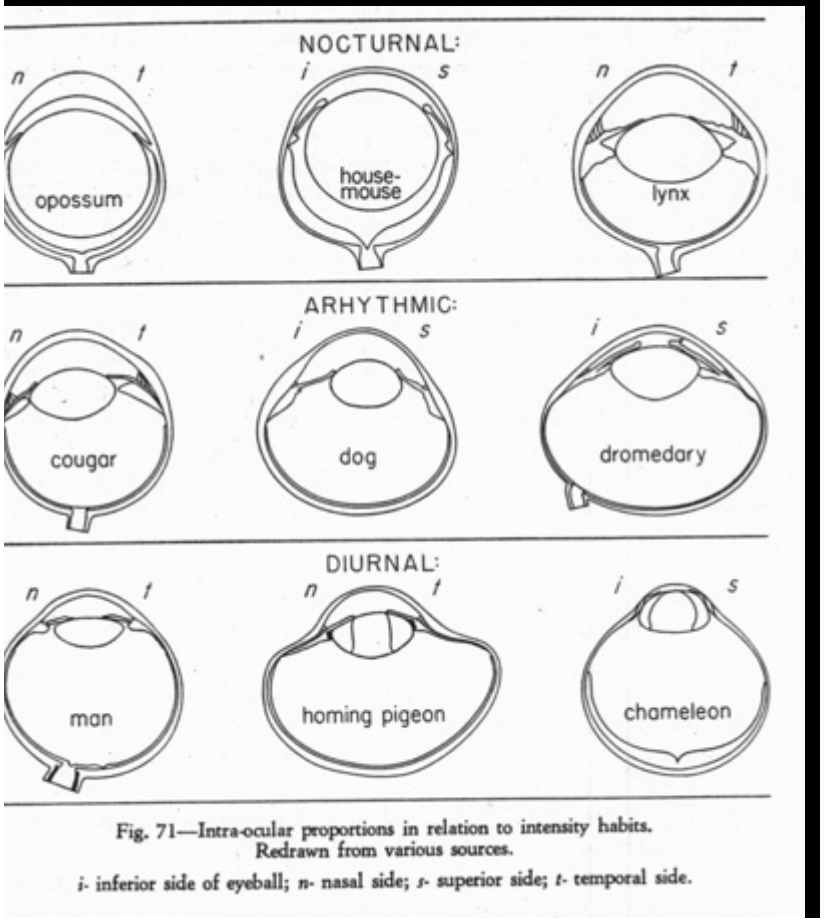


Fig. 71—Intra-ocular proportions in relation to intensity habits. Redrawn from various sources.

i- inferior side of eyeball; *n*- nasal side; *s*- superior side; *t*- temporal side.

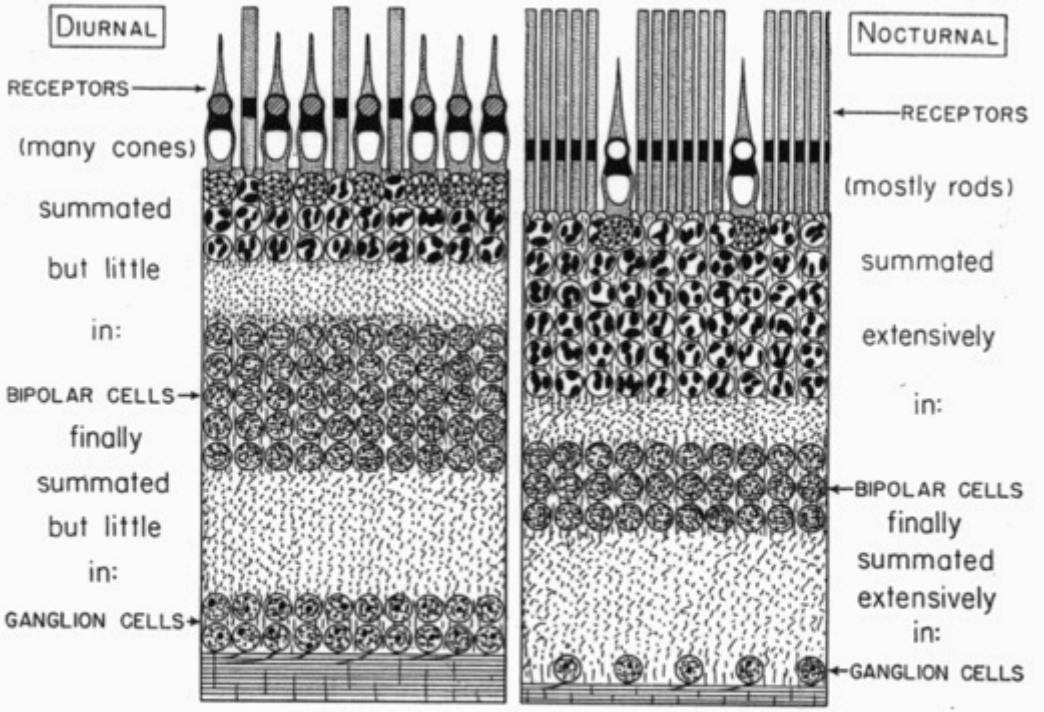
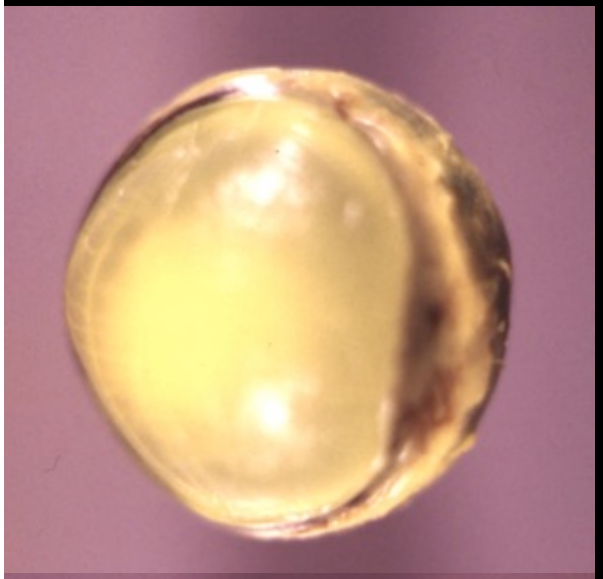
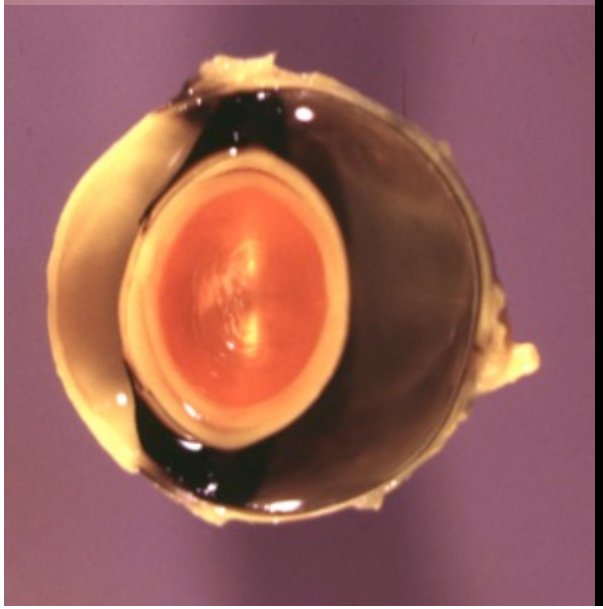


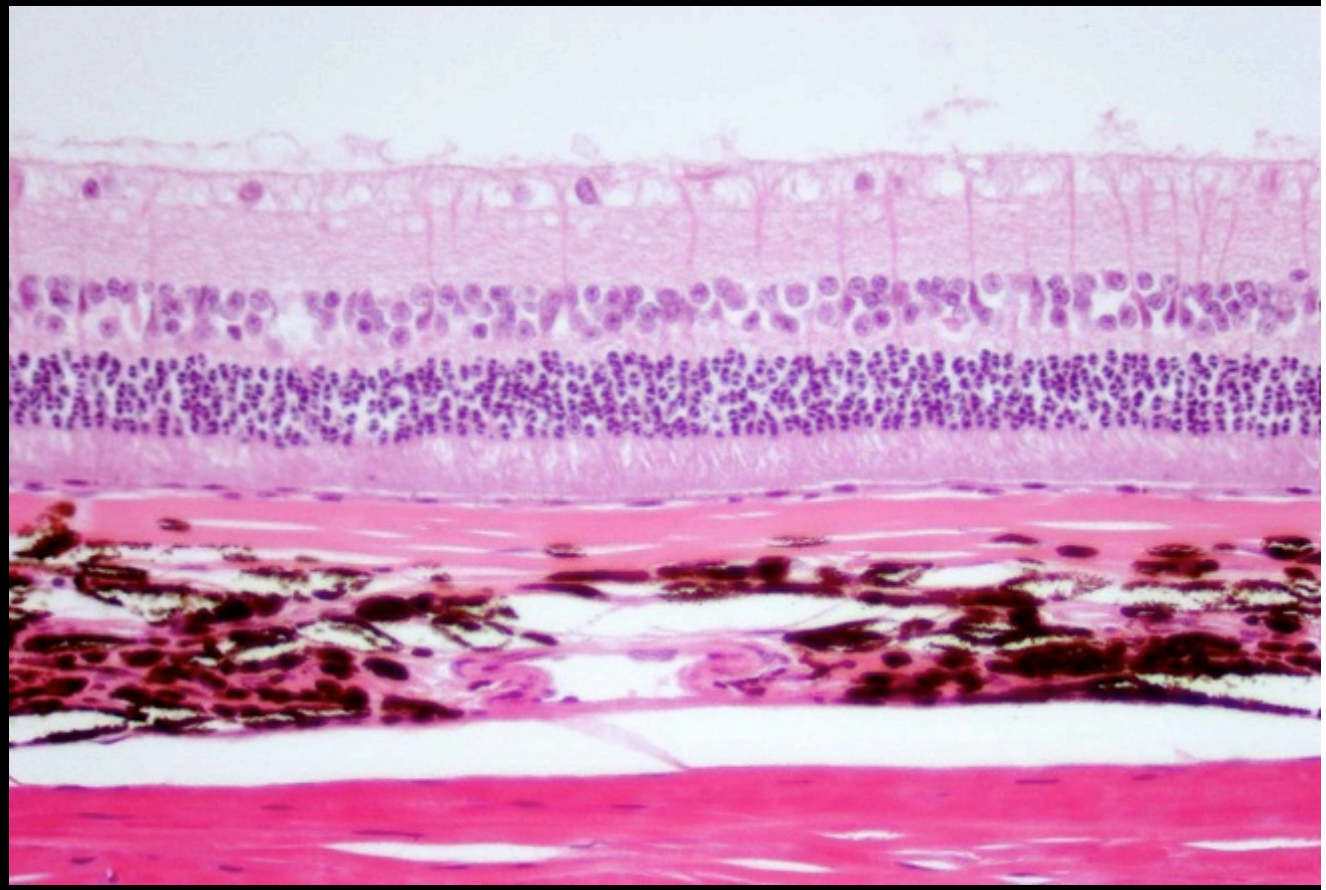
Fig. 72—Diurnal and nocturnal retinæ contrasted.

The diagrams represent two related species, one of which is diurnal and the other nocturnal. The characteristic differences in the relative thickness of the nuclear layers are the result of the visual-cell patterns and the differing extents of summation in optic nerve fibers.

The Nocturnal Mammal

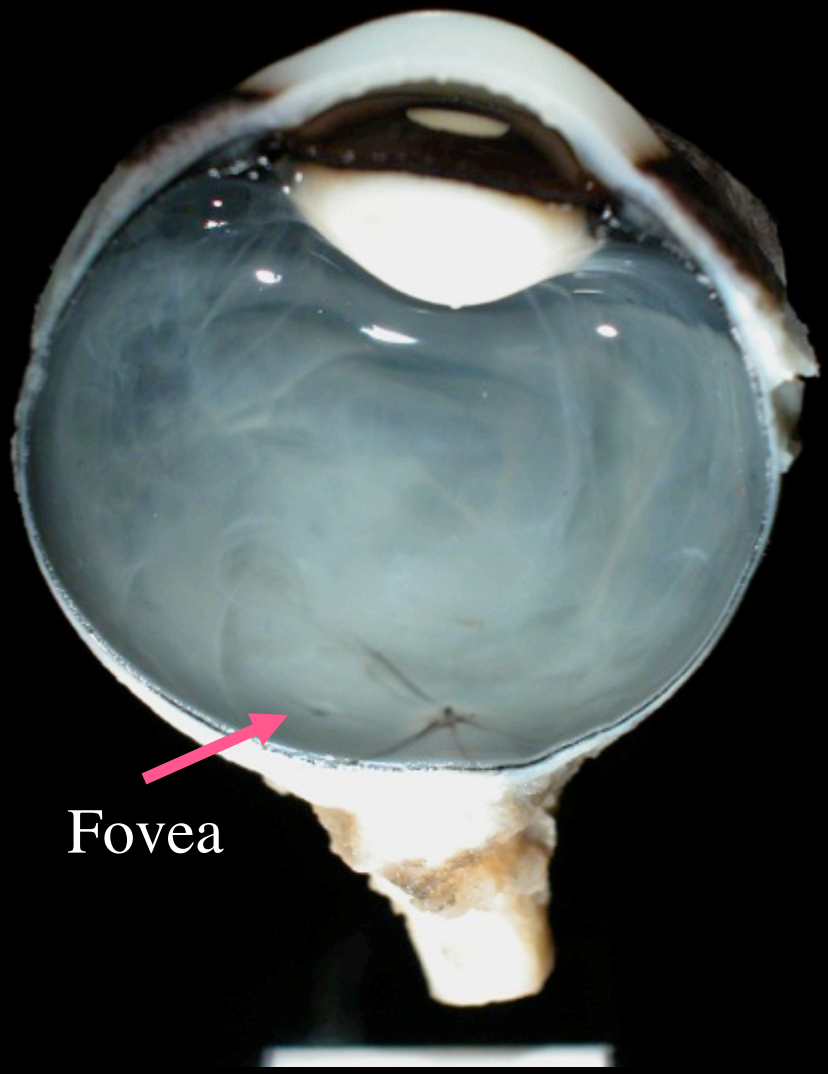




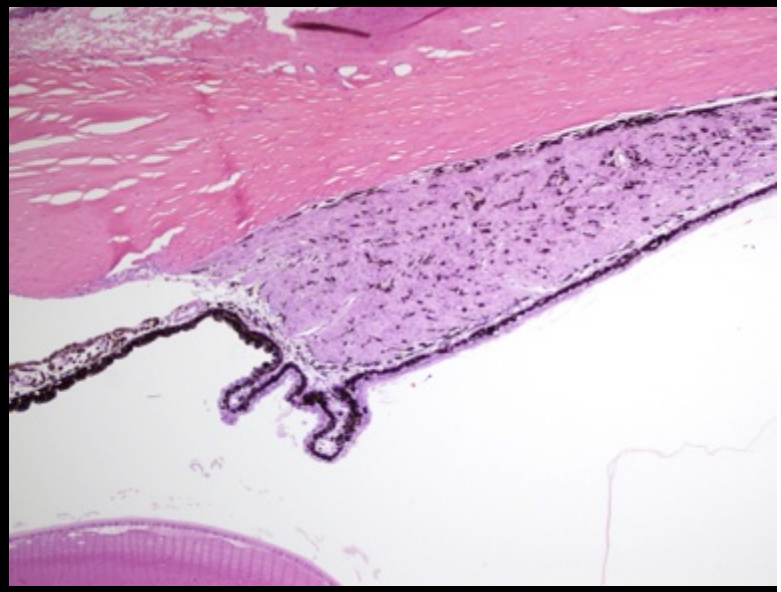


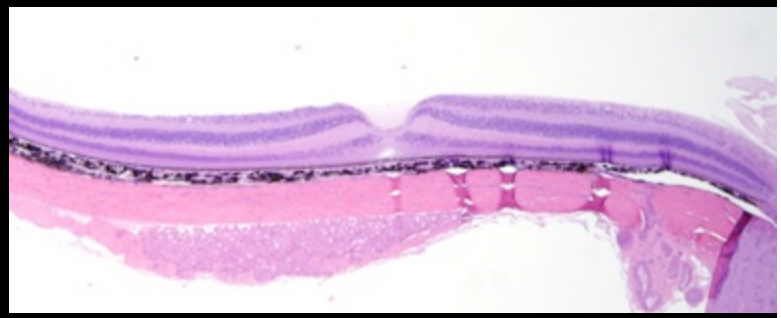
Springhaas

The Diurnal Eye



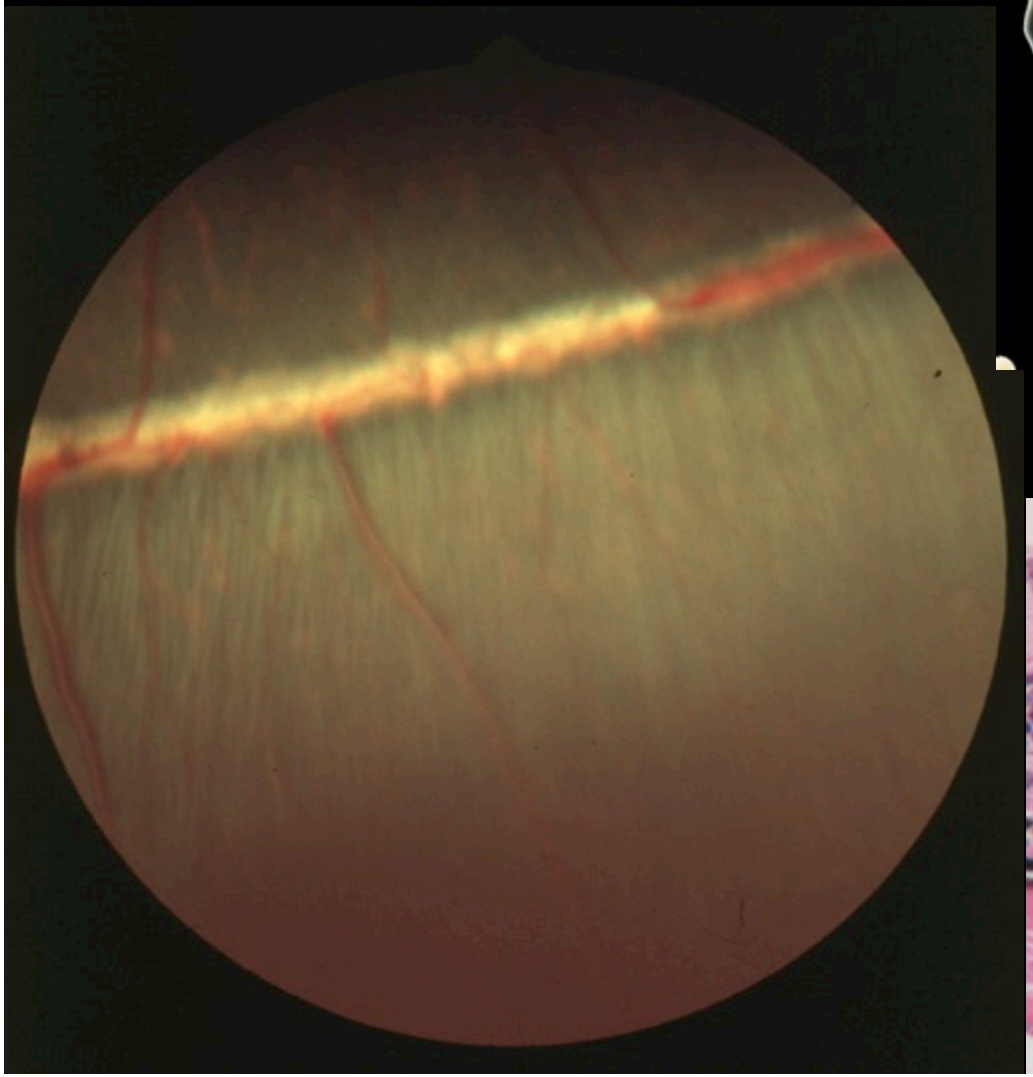
Orangutan

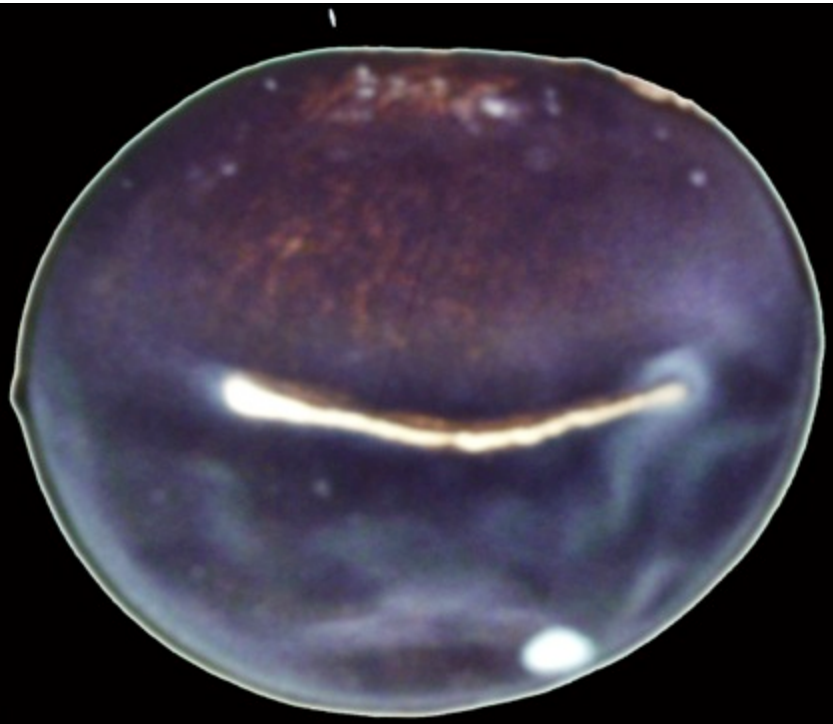




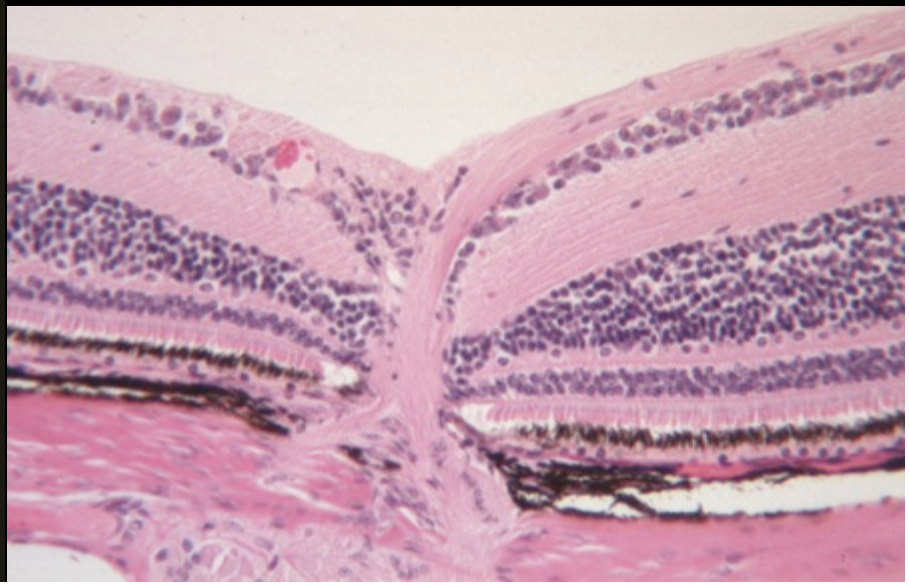
Diurnal Eye

Ground Squirrel

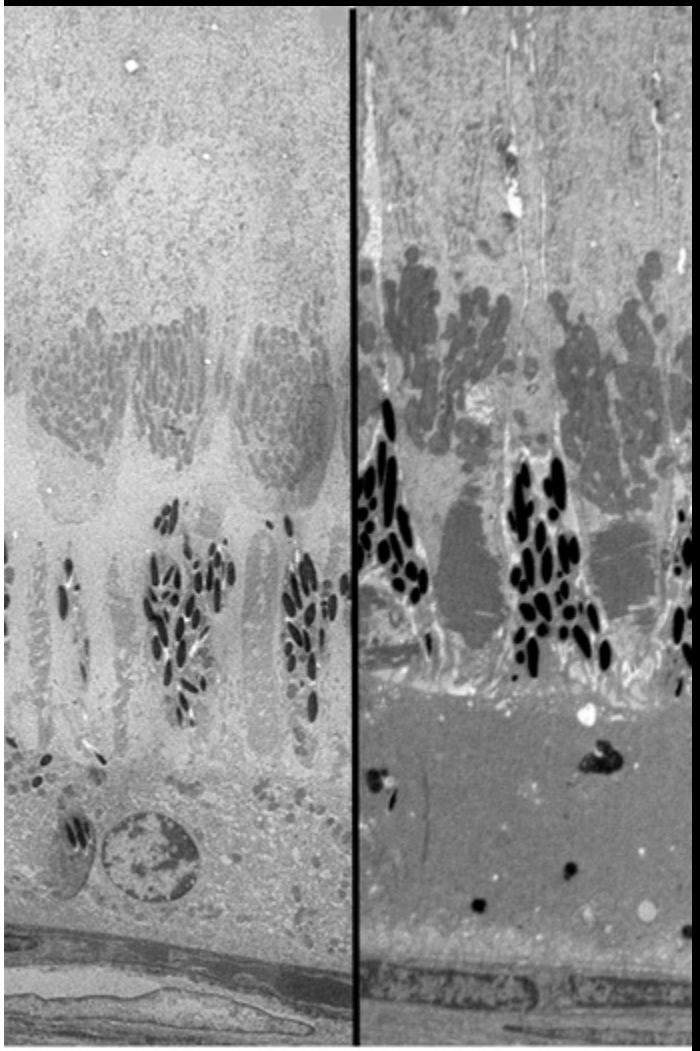




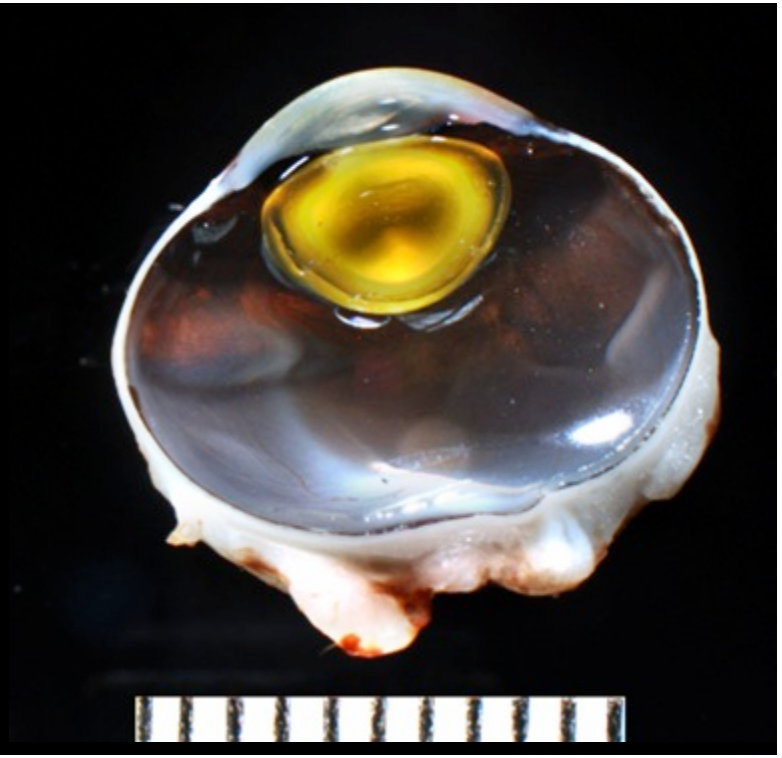
Woodchuck

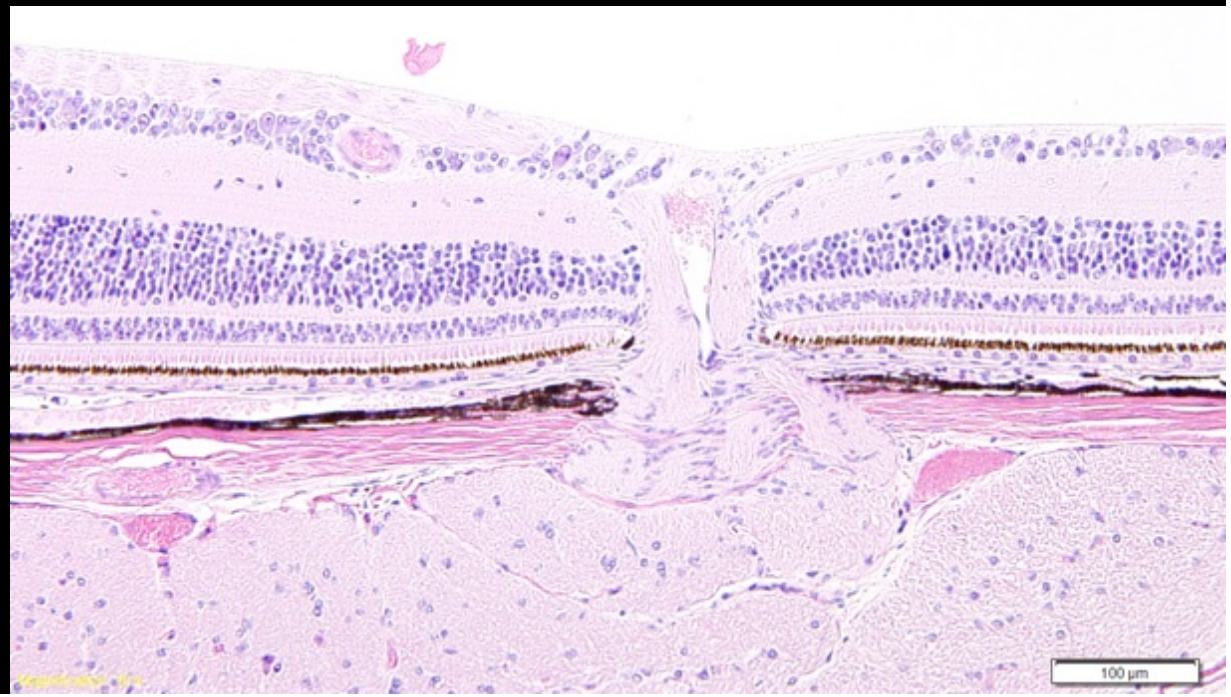


Diurnal Eye
Ground Squirrel



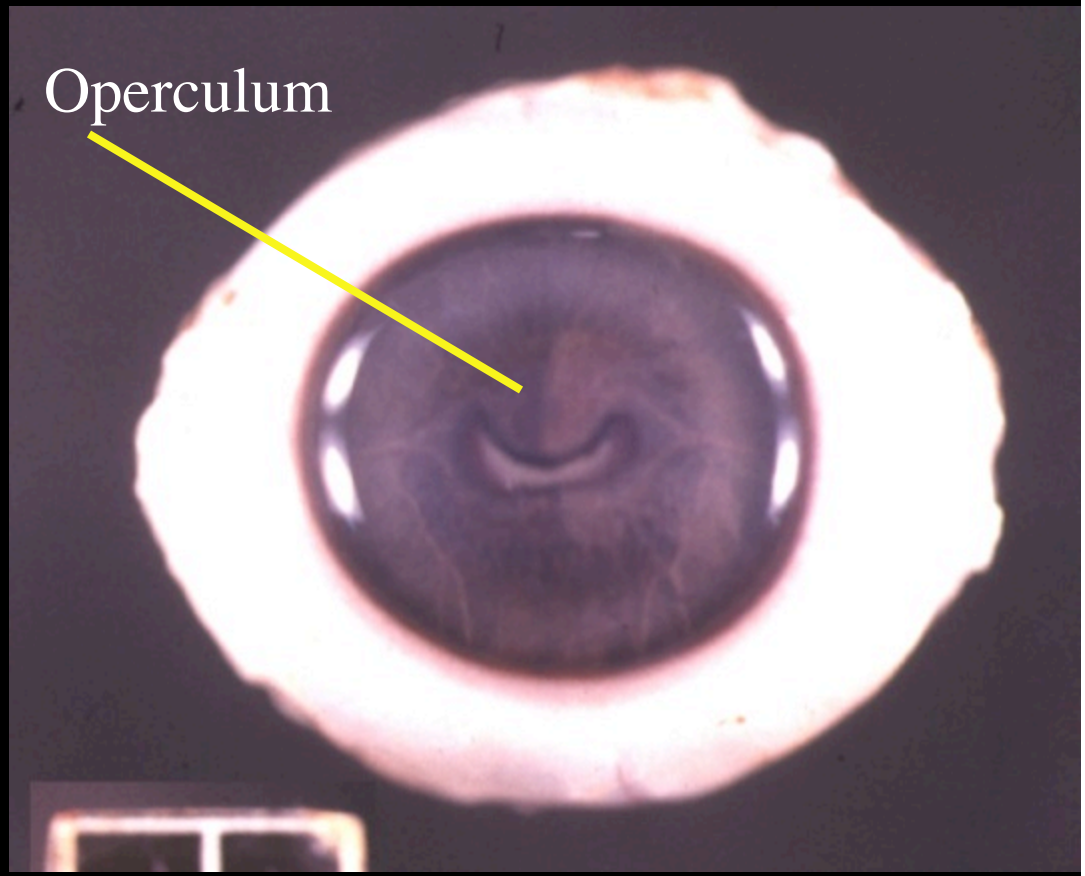
Summer Winter





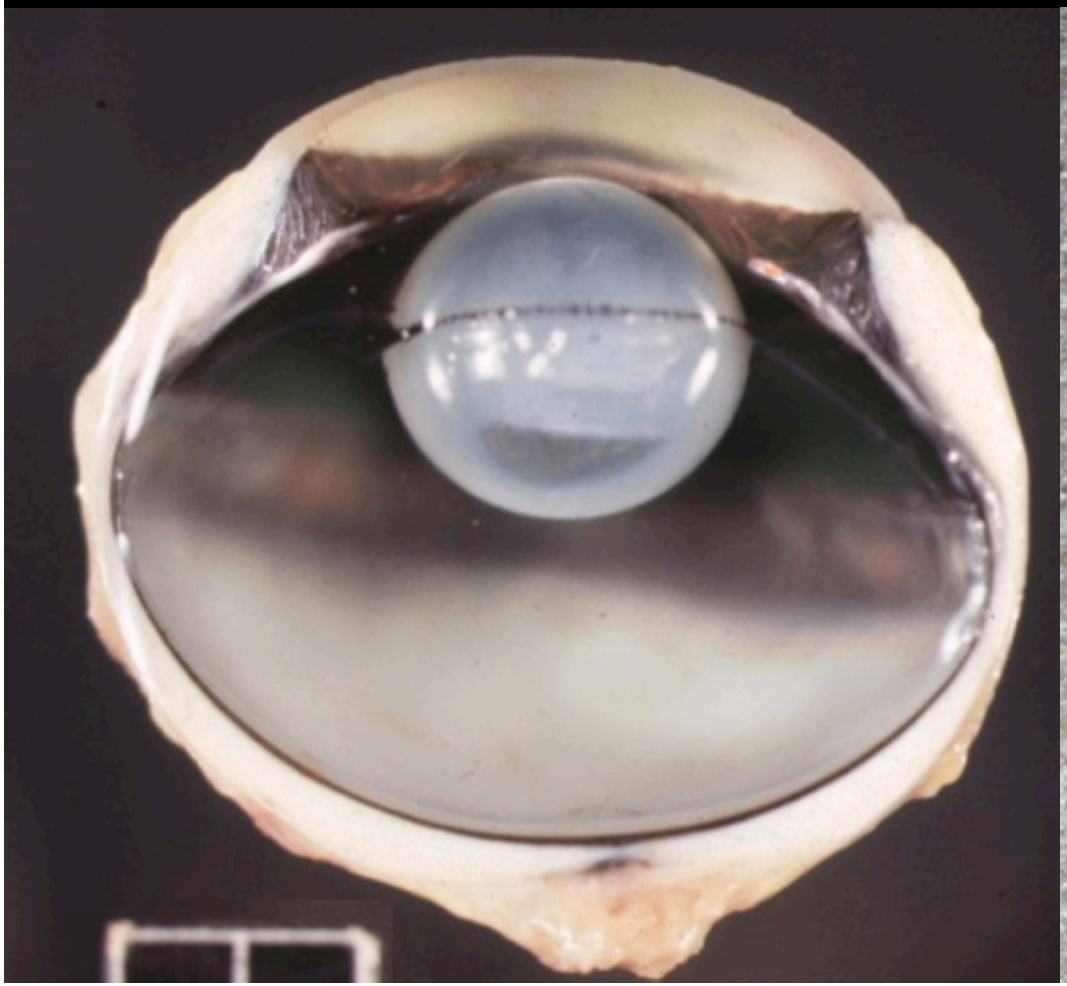
Underwater Eye

Cetacean

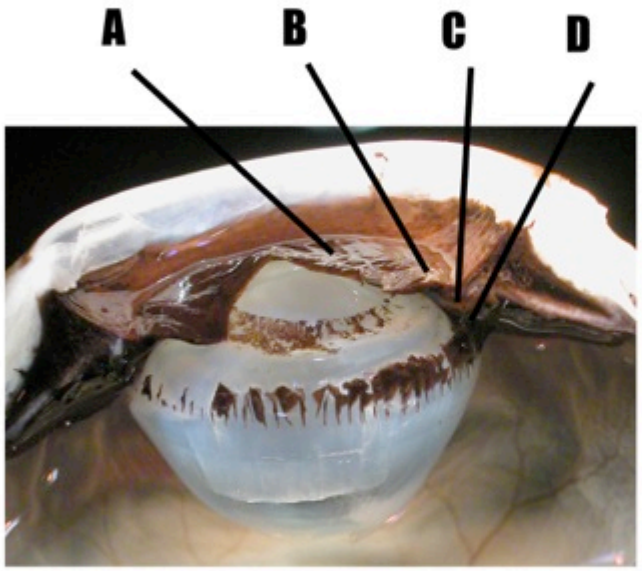


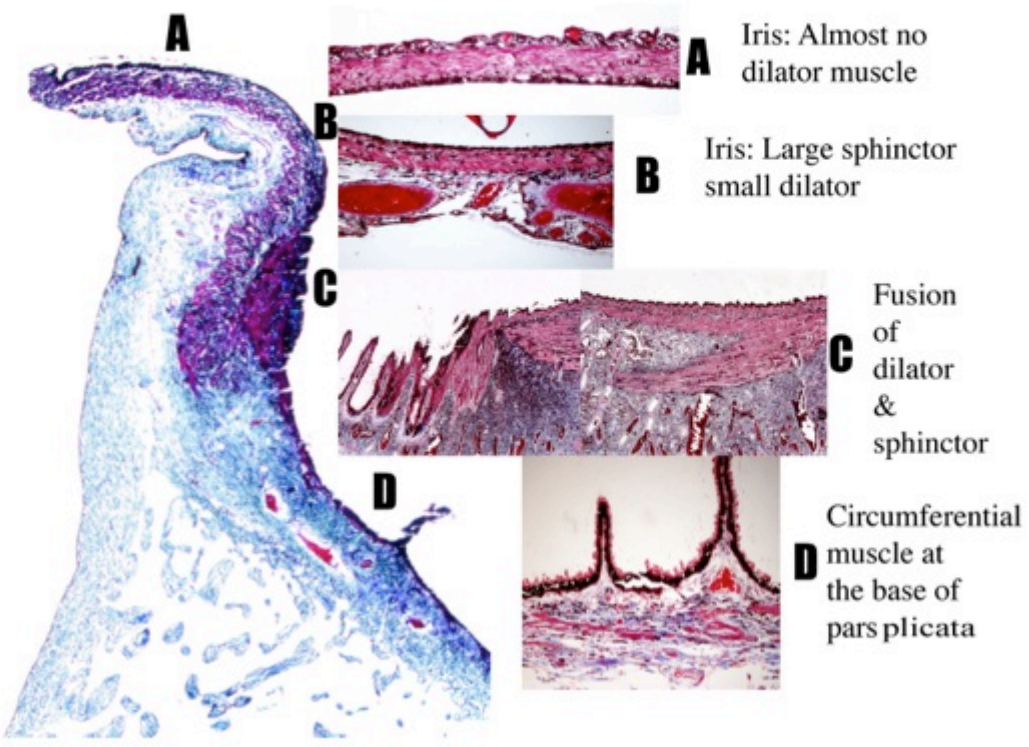
Dolphin

Underwater Eye
Pinniped



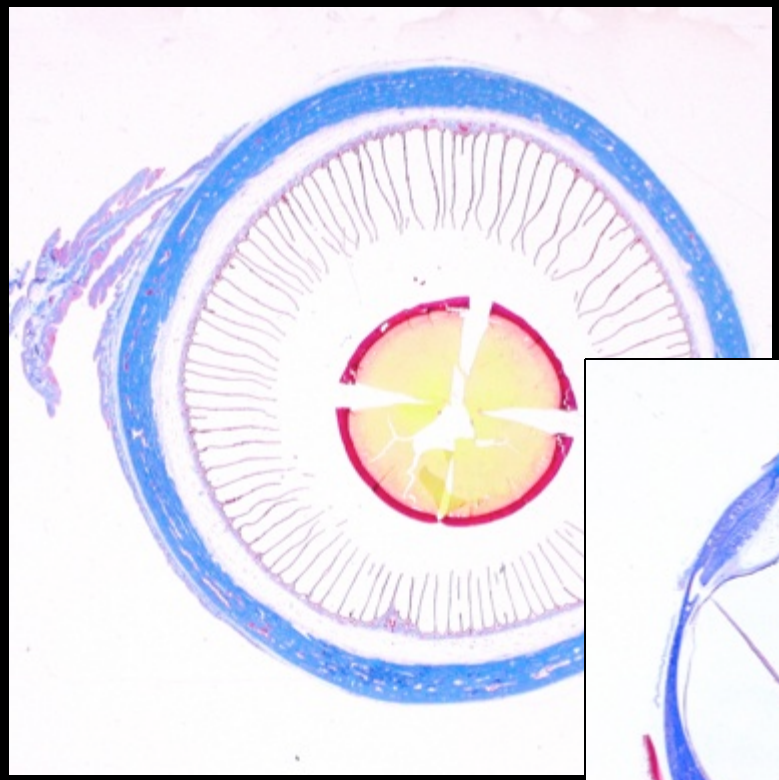
Underwater Eye
Pinniped

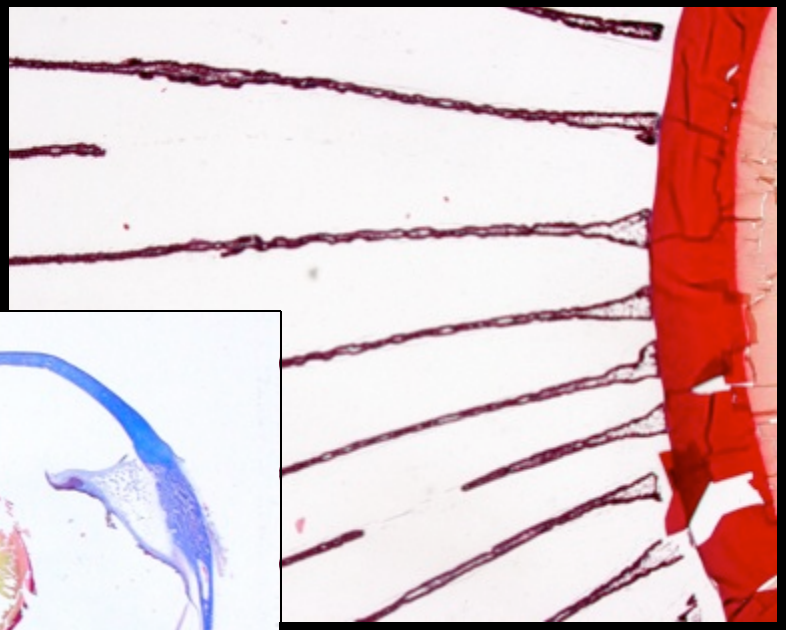


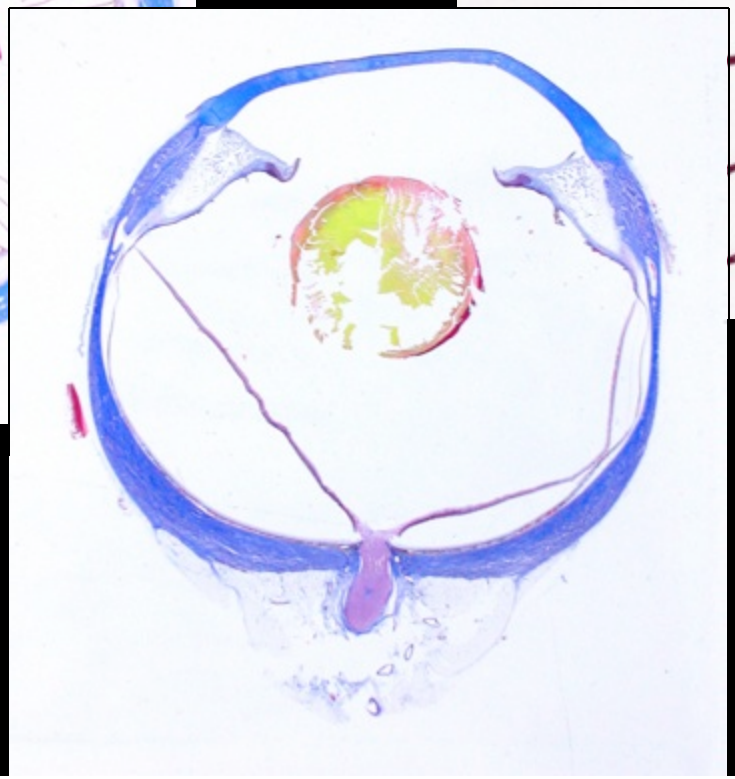


Underwater Eye

Pinniped

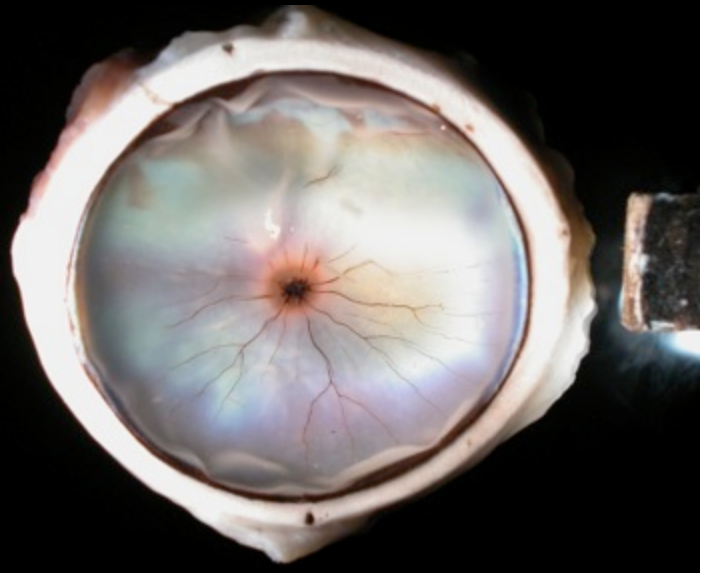






The Tapetum Lucidum

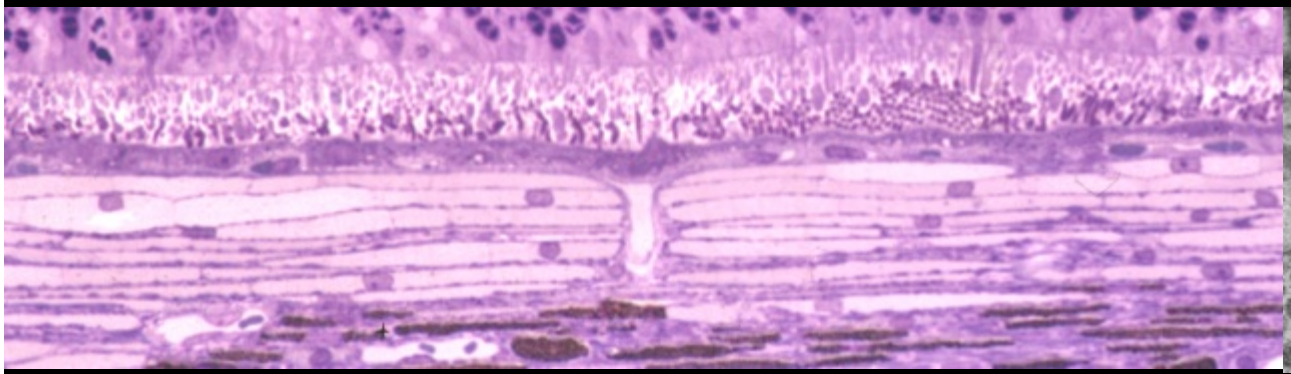
- Fibrous Tapetum: Herbivore
  - Equine/Tapir/Hippo
  - Ruminant: not Camelid
  - Cetacean
- Cellular Tapetum: Carnivore
  - Canine type
    - Mustelids
    - Pinniped
    - Bears
  - Feline type
    - Hyena
- Fibrous Tapetum in other groups
  - Springhaas: Rodent
- Cellular Tapetum in other groups
  - Fat-tailed Lemur: Primate
- Retinal Tapetum: American Opossum

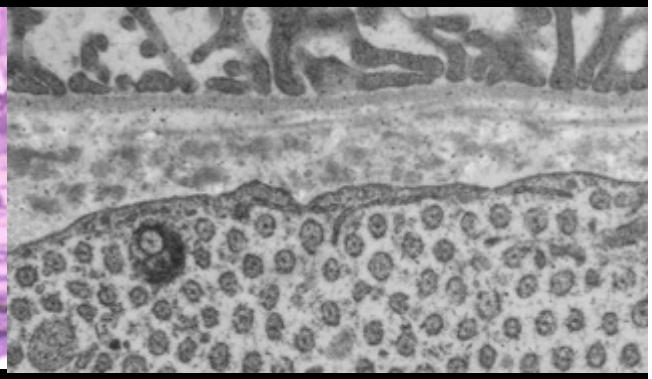


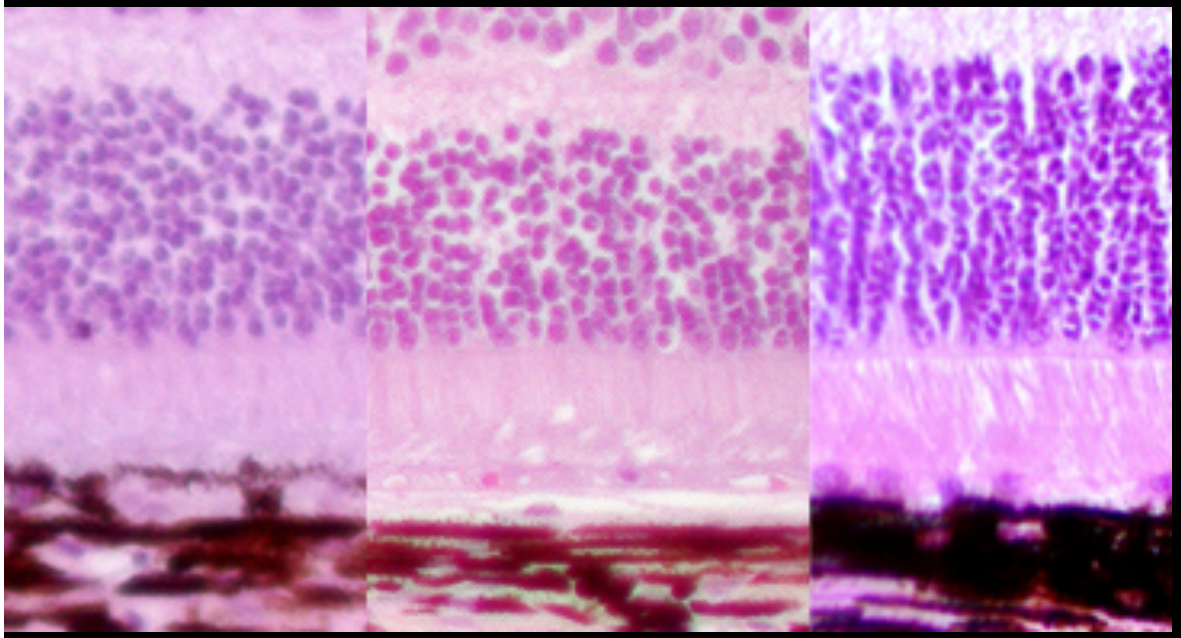
Dolphin Fibrous Tapetum

Cellular Tapetum Lucidum

Carnivore



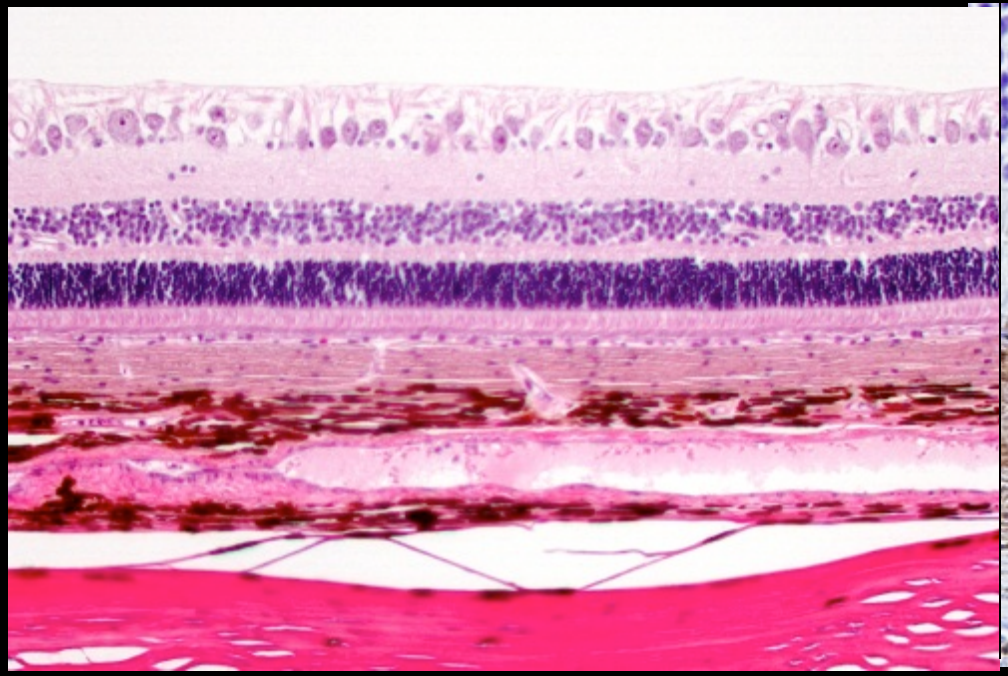


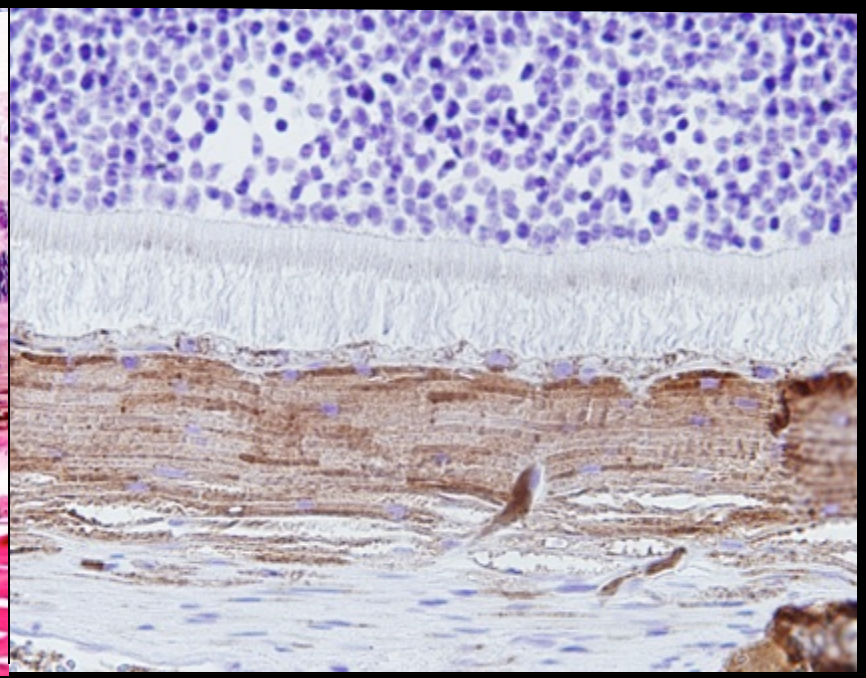


Nontapetal Tapetal Tapetal

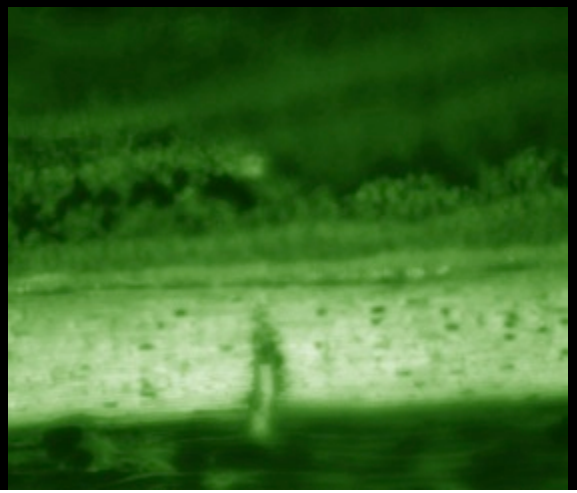
Cellular Tapetum Lucidum

Feline





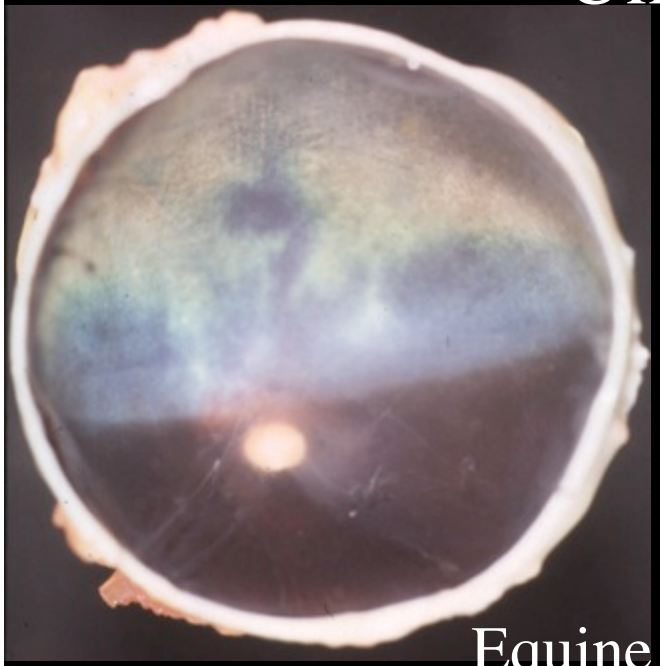
Melan-A



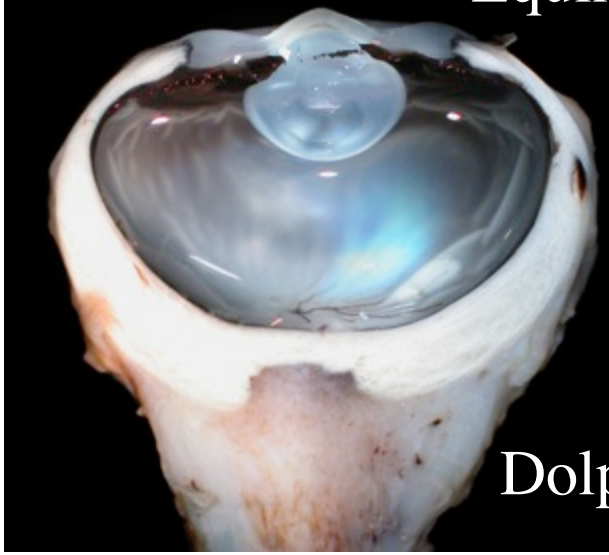
Autofluorescent

Fibrous Tapetum Lucidum

Ungulates & Cetaceans

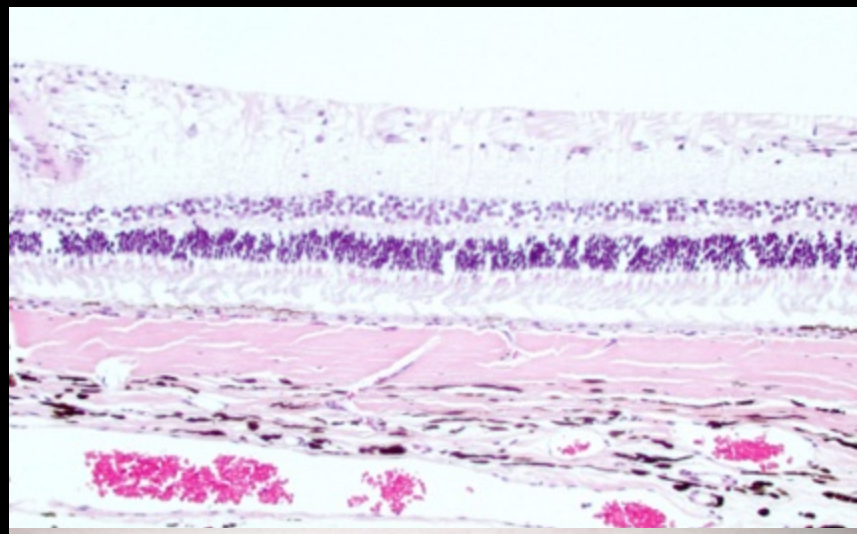


Equine

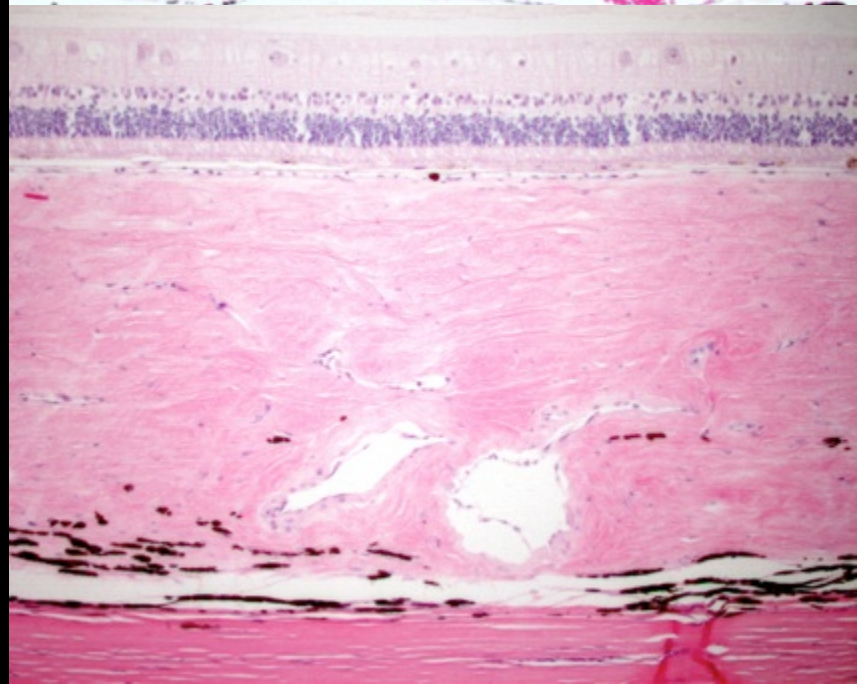


Dolphin

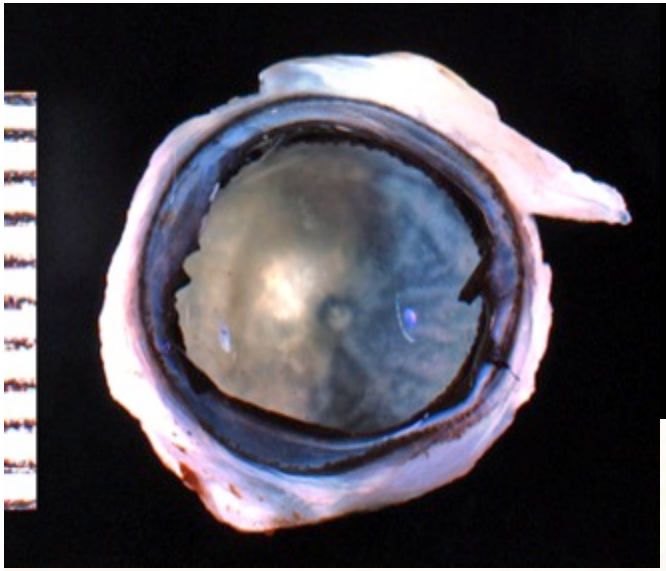
Impala

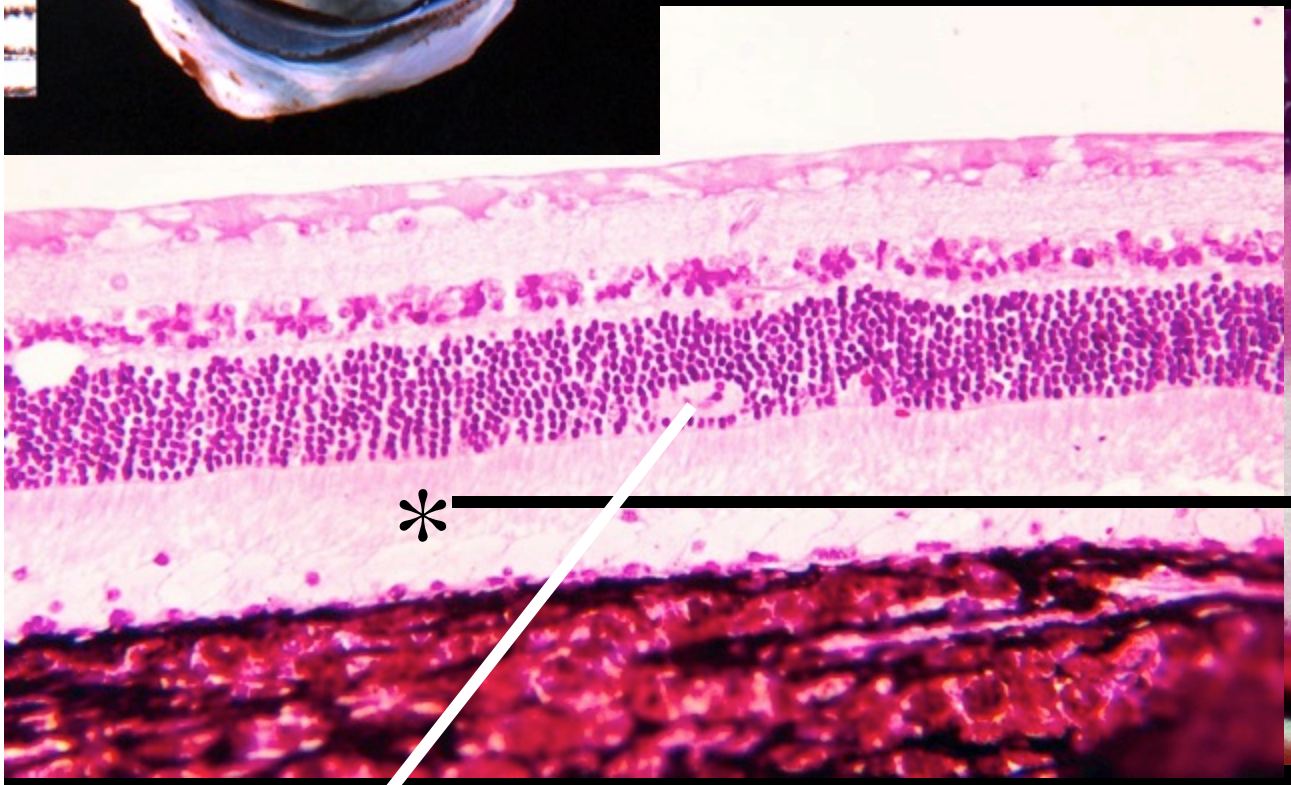


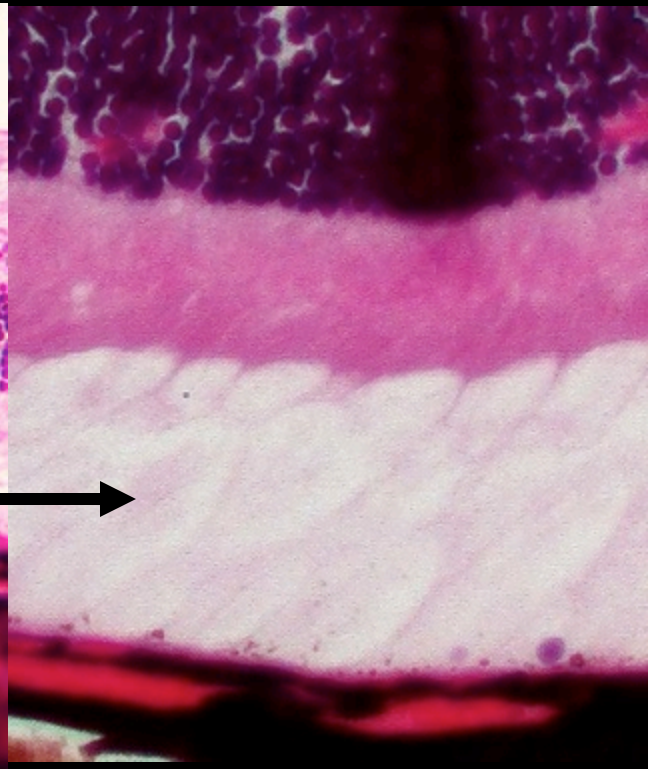
Tapir
or
Hippo



Retinal Tapetum
North American Opossum







Capillary blood vessels in the ourter nuclear layer