Origin of Tetrapods
and life in the Carboniferous and Permian

Reading: Benton
Chapters 4 and 5

Eurypos, early Permian temnospondyl (painting by Douglas Henderson, 1990)
Phylogeny of Bony Fish

Tetrapoda: vertebrates more closely related to living amphibians and amniotes than to their nearest living relatives

Synapomorphies

- muscular pectoral and pelvic limbs with substantial limb bones
- one or more squamosal bones
- one or more splenial bones
- flattened head
- enlarged ribs
- humerus with anterior keel for muscle attachment
- carpus and tarsus
- up to eight digits
- broad contact between jugal and quadratojugal
- reduction to five digits
Transformation of the limb during origin of Tetrapoda

Transformation of early tetrapod limb involves modification of bones, loss of some bones, addition of other bones

Formation and growth of these bones is regulated by gene expression during development. Changes in the regulation result in evolutionary changes in the adult.

In earliest development, the precursors of the bones are similar in tetrapods and their closest relatives.

Developmental biology (ontogeny) is an important aid to paleontologists for identifying or confirming homologies in radically transformed groups.
Skeletal transformations in early tetrapods

Lobe-fin bones include humerus, radius and ulna. These are transformed into weight bearing limbs.

Hyomandibula attaches hyoid arch (the support skeleton between jaws and gill arches) to neurocranium. Transformed into massive stapes at otic region of braincase.

Challenges for a fish out of water

**Respiration.** Fine structure of gills collapse in air, reducing surface area and inhibiting gas exchange. *Solution:* cutaneous respiration, lung respiration.

**Support against gravity.** Original vertebrate skeleton not really evolved for supporting the body off the ground. *Solution:* derived limbs and vertebral column.

**Sensory perception.** Ever see a fish with ears? *Solution:* transformation of hyomandibula to stapes, reorganization of skull for lateral sight, improvements to olfactory system.

**Reproduction 1.** Fish typically spawn. *Solution:* internal fertilization.


**Communication.** Ever hear a fish scream? *Solution:* vocalizations in conjunction with hearing, new olfactory chemical signals, new visual signals.

**Food.** Fish are typically predatory and have prey capture strategies that often involve sucking prey into mouth with water. *Solution:* reorganization of jaws, neck, new dietary types.
Phylogeny of basal tetrapods

Structure of the tetrapod middle ear

Inner ear housed in prootic and opisthotic bones of braincase

Hymandibula transformed into stapes, which connects opening in wall of braincase to tympanum in skin

Early vertebral development

Vertebrae are modeled around notochord from somite tissue

Each vertebra develops between somites, receiving tissue from one in front and one behind

Directly related to evolutionary transformations in vertebrae of early tetrapods
Vertebral evolution in early tetrapods

Lissamphibians retain intercentrum, amniotes retain pleurocentrum

Neural arch  
Intercentrum  
Pleurocentrum

Temnospondyls

Close relatives to crown-group Amphibians

Long-lived group, Early Carboniferous (ca. 330 mya) to Early Cretaceous (ca. 120 mya)

Origin of crown-group amphibia associated with stereospondyls

Possess stereospondylyous form of vertebrae, with the body composed of the intercentrum like in living amphibians

Amniota and skull fenestrae

Names of fenestrae:
- Temporal fenestra
- Suprtemporal fenestra
- Infratemporal fenestra
- Antorbital fenestra
- Mandibular fenestration

Living Mammals  
Living Lizards and Snakes  
Living Crocodiles and Alligators

Diapsida  
Amniota  
Synapsida  
Reptilia  
ANAPSID  
ANAPSID  
MODIFIED DIAPSID  
MODIFIED SYNAPSID  
SYNAPSID

Living Birds  
Aves  
Ornithischian  
Saurischian  
Dinosauria  
Crurotarsi

Bird-hipped dinosaurs  
Lizard-hipped dinosaurs

Reptilia

Lepidosauria  
Archosauria  
Diapsida

Living Lizards  
Living Crocodiles

Living Birds  
Aves
Non-amniote tetrapod skull: *Proterogyrinus*

*Proterogyrinus scheelei*
*Embolomere anthracosaur*
*Late Mississippian*
*Namurian A, (Serpukhovian)*
*Greer, West Virginia*
Amniote Skull: Early Anapsid Reptile
Cladogram of selected amniotes and outgroups

Outgroups to Amniota:
- Diadectes
- Protagyrinus

Diapsida:
- Synapsida
  - 1. Single temporal fenestra not bounded by quadratojugal
- Amniota

Diapsida synapomorphies:
1. Supratemporal fenestra
2. Infratemporal fenestra

Amniota:
- Edmontosaurus
- Kuhneosaurus
- Youngina
- Diadectes
- Protagyrinus
- Titanophonus
- Dimetrodon
- Captorhinus

Outgroups to Amniota:
- Archaeopteryx
- Aves
- Archosauria
- Dinosauria
- Lepidosauria
- Synapsida
- Lepidosauria
- Archosauria
Amniota

Reduction or loss of the posterior bones of the cranium associated with origin of the neck: tabular, postparietal, supratemporal, infratemporal.

Outgroup state: large tabular, postparietal, supratemporal, infratemporal

Ingroup state: small or absent tabular, postparietal, supratemporal, infratemporal, often positioned on posterior of cranium
Synapsida

Opening of the synapsid fenestra between the jugal, squamosal and post-orbital bones, not bounded by quadratojugal. (Note is in a different place than in diapsids).

Surangular, articular, and quadratojugal reduced in size.

Outgroup state: No opening exclusively between squamosal, jugal, and postorbital. Surangular and quadratojugal major parts of skull.

Ingroup state: Opening between postorbital, squamosal and jugal. Quadratojugal and surangular reduced and moved posteriorly.
Synapsid Amniote

Single temporal fenestra bounded by postorbital, jugal, and squamosal

(from Romer, 1966, Vertebrate Paleontology)
Synapsid Amniote

T. potens
Late Permian
Russia

(from Romer, 1966, Vertebrate Paleontology)
Synapsids - dominant land vertebrates of the Permian

“Pelycosaurs”

Romer, 1966, Vertebrate Paleontology
Derived synapsids


Romer, 1966, Vertebrate Paleontology.
Transformations of the middle ear in synapsids

Quadrate and articular become smaller as muscular focus shifts anteriorly to dentary

Quadrate and articular join the stapes (formerly hyomandibula) as small bones in the middle ear

Angular bone holds tympanum, becomes tympanic annulus
Diapsida

Opening of temporal fenestra between jugal, quadratojugal, and squamosal (postorbital sometimes involved).

Opening of second fenestra between parietal, postfrontal, and squamosal (postorbital sometimes involved).

Outgroup state: No fenestrae in diapsid positions.

Ingroup state: two temporal fenestrae, one between jugal, quadratojugal and squamosal, one between parietal, postfrontal and squamosal.

Non-diapsids

Diapsids

Protogyrinus

Diadectes

Captorhinus

Titanophoneus

Diapsida

Edmontosaurus

Archaeopteryx

Kuhneosaurus

Youngina

Dimetrodon

Edmontosaurus

Archaeopteryx

Kuhneosaurus

Youngina

Dimetrodon
Early Diapsid Amniote

Double temporal fenestra: top bounded by parietal, postfrontal, postorbital, and squamosal; bottom bounded by postorbital, jugal, quadratojugal, and squamosal (postorbital sometimes inserts between, as in this skull)

Youngina capensis
Late Permian, Karoo Red Beds
South Africa

(from Romer, 1966, Vertebrate Paleontology)
Lepidosaur Diapsid

Loss of quadratojugal opens lower temporal fenestra on inferior side (allows for more mobility in lower jaw)

Kuehneosaurus
Late Triassic
United Kingdom

(from Romer, 1966, Vertebrate Paleontology)
Ornithischian Dinosaurs

Edmontosaurus regalis
Late Cretaceous
North America

Triceratops horridus
Late Cretaceous
North America

(from Romer, 1966, Vertebrate Paleontology)
Avian Theropod Dinosaur

(from Romer, 1966, *Vertebrate Paleontology*)
Pangea
the Late Permian
(260 mya)
Single continent
Massive global extinction

Reconstruction by Ron Blakey
http://jan.ucc.nau.edu/~rcb7/index.html
Permo-Triassic extinction
ca. 251 million years ago

Nearly 95% of the Earth’s species became extinct.

Eruption of Siberian traps peaked 251 mya, covering at least 1.6 million square km, an area the size of Europe, with 400 to 3000 m of flood basalt, lasting 600,000 years.

Oxygen isotope data suggest rapid global rise in temperature of 6°C, which combined with Pangea continent configuration, reduces ocean circulation and dissolved oxygen to create anoxic conditions on the floor.

Carbon isotope excursions indicate that CO2 increased in atmosphere through production by the Siberian Traps, which raised global temperature enough to melt gas hydrate deposits, which further increased atmospheric CO2 and temperature... “runaway greenhouse effect”.

Tetrapods hard hit, with the dicyodont Lystrosaurus being one of the few found in fossil record for millions of years after extinction. Forest communities absent until Middle Triassic.
Scientific papers for further reading


