Evolution of Insects

Peoria Riverfront Museum

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Why this title?

- Evolution is inherently about organisms responding to environmental change
- Insects have ruled this planet for the past 400 million years (at least in terrestrial environments)
- What is the most dangerous animal on the planet today?
  - Shark?
  - Mosquito?
  - Rat Flea?
  - Louse?

Agenda

Review of insect diversity and major localities for insect fossils

Discussion of Insect Origins

Overview/ evolution of major insect orders

Insect Diversity and Evolution

- About 1 million described species of insects
- Estimated total between 2.5 and 10 million species of insects alive today
- 4 orders account for 80% of all insects
  - Coleoptera
  - Lepidoptera
  - Hymenoptera
  - Diptera

Reasons for success

- "Big 4" orders all are holometabolous (egg > larva > pupa > adult)
- They also have wings
  - Insects, pterosaurs, birds, bats
  - Insects were first (by roughly 100 MY)
  - Permian – *Meganeuropsis permiana* – 27 inch wingspan

Systematics

- "The first part of knowledge is getting the names right" – Chinese proverb
- Most human cultures name the organisms they encounter
- Today, we rely on a structured scheme (originally proposed by Linnaeus - 1758)
- Species are grouped into genera, genera are grouped into families and so forth

What is a species?

- Consider this the fundamental unit of nature
- Mayr – "group of actually or potentially interbreeding populations, which are reproductively isolated from other such groups"
  - Biological species concept
- Grimaldi – "discrete group of individual organisms that can be diagnosed, or defined on the basis of certain specialized features, and that had a common ancestor and unique evolutionary history"
  - Evolutionary species concept

Recent insect species

Evolution

- Change in inherited traits in a population from one generation to next
- Processes involved
  - Variation
  - Reproduction
  - Selection
- Mechanisms that drive
  - Natural selection
  - Genetic drift

Evolution (2)

- Most unifying concept in biology
  - "Nothing makes sense in biology except in the light of evolution" – Theodosius Dobzhansky (1973)
- Evolution is inherently about organisms responding to environmental change

Paleontology

- Fossils provide information on 4 aspects of evolution
  - Documentation of extinct species (and lineages)
  - Actual and estimated ages of lineages
  - Phylogeny (relationships)
  - Biogeography (factors that contribute to present day distributions of organisms)

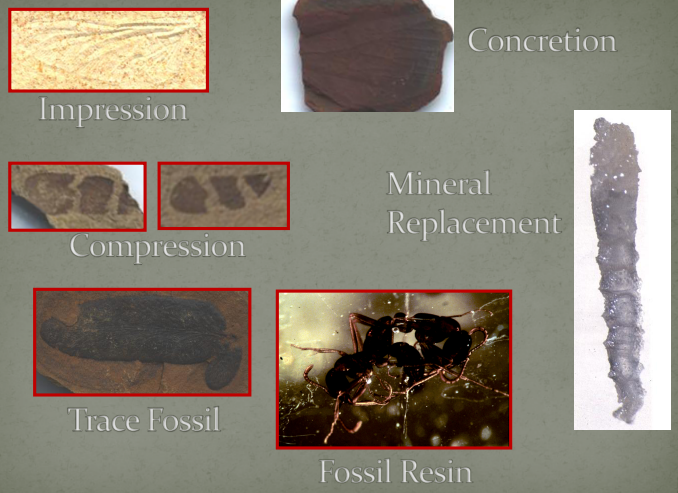
Fossilization

- Majority of insects (and other life forms) die, then decay leaving little or no trace
- Common insect fossils are from lake environments
  - Insects swept over the lake or deposited by a stream
  - Drowned and not eaten
  - Rapidly buried in lake sediments
  - Many are represented by wings (or wing fragments)
    - Many also have parts of body preserved (or impressions)
- There are exceptions to lake based fossils
  - Some are near shore marine environments
- Taphonomy – is the study of how organisms fossilize

Examples of "pre-fossils"

Types of preservation

- Impressions – like a cast or mold (no color from exoskeleton)
- Compressions – preserve remains of exoskeleton
- Concretions – minerals precipitated around decaying organism
- Mineral replication – complete (or partial) 3 dimensional replacement
- Amber/ copal inclusions – preserved tree resin
- Trace fossils (fossil burrows and nests)



Lagerstätten (age increasing down list)

- Exceptional fossil insect deposits (most specimens we examine will be from these deposits)
  - Amber (Dominican Republic) - Miocene
  - Florissant Formation (Colorado) - Oligocene
  - Green River Formation (Rocky Mtns) - Eocene
  - Santana Formation (Brasil) – Cretaceous limestone
  - Liaoning (China) – early Cretaceous
  - Solnhofen (Germany) – late Jurassic limestone
  - Elmo (Kansas) – Permian limestone
  - Mazon Creek - Francis Creek Shale (northern Illinois) – late Carboniferous

Fossil Resins

- Amber (> 2 Ma) vs. Copal (< 1.6 Ma, some very recent)
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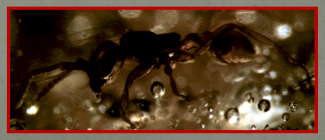
- 
- Drop of alcohol
  - Copal becomes sticky
  - Amber does not

Amber – Dominican Republic

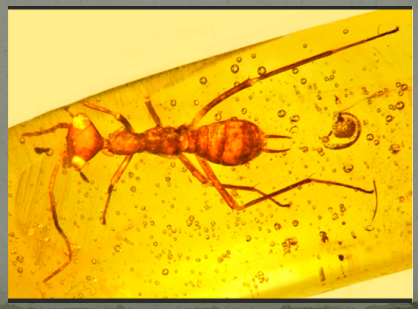
- Age – mid-Miocene (17 – 20 Ma)
- Over 400 families, 1,500 species of insects known
- Distinctly tropical environment
- Caribbean landmasses have complex history of drift, submergence, and land bridges
- These fossils provide insights into origins of modern ecosystems in the area
- Although most species are found in region, there are exceptions
  - Some species of ants and termites only known from Australia today

Baltic Amber

- Denmark, Sweden, Lithuania, Poland, Germany
- Formation runs about 45 m below the surface (and extends to about 5 m below sea level)
- Age – roughly middle Eocene (44 MYA)
- Several thousand species of insects known
- Gathered by humans for at least 13 centuries
- Amber room (above) was made from Baltic amber
- Cockroach (Lithuania)

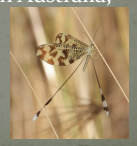
Burmese amber – Myanmar

- 2017 – new insect discovered – Cretaceous amber (100 Ma) - New insect order – Aethiocarenodea
- Single species - *Aethiocarenus burmanicus*

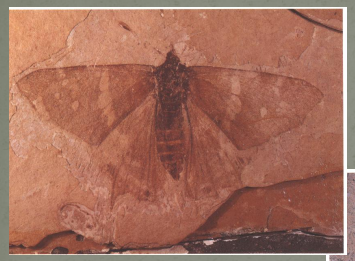


Florissant Formation (Colorado)

- Age – Late Eocene to Lower Oligocene (45 – 30 Ma)
- 200 families, 1,100 species of insects known
- Ancient Lake Florissant formed by volcanic mudflows that dammed up a river valley
- Over 1 – 2 million years – repeated volcanic eruptions blanketed area with ash
- Two insect groups no longer common in North America
  - Spoon winged lacewings (mostly Africa, some in Australia, South America, Asia)
  - Tsetse flies (only Africa today)
    - These were 2x the size of the recent species



Florissant Formation (Colorado)



Florissant Formation (reconstruction)

Green River Formation

- Age – Eocene (55 – 38 Ma)
- One of largest fossil lake systems in the world
  - 65,000 km²
  - Deposits roughly 600 m thick in places
- Climate warm temperate to sub-tropical
- 14 orders, 100 families, 300 species of insects known

Santana Formation (Brazil)

- Age – Cretaceous (120 Ma)
- Near shore deposit
- Insects are preserved as permineralized replicas
- 18 orders, 100 families, 300 species known

Liaoning (China)

- Age – early Cretaceous (130 Ma)
- Array of feathered dinosaurs (dromeosaurs)
- Vast diversity of insects

Solnhofen (Germany)

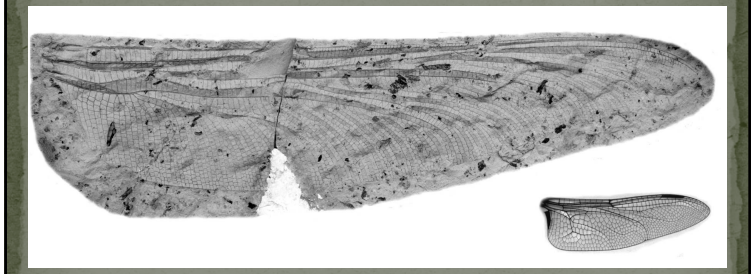
- Age – Jurassic
- Most famous for *Archaeopteryx lithographica* (6 specimens)
  - Transition form between raptor dinosaurs and birds
- Fine grained layered limestone (initially quarried by Romans)
- Fossils preserved in mud of isolated lagoons
- 12 orders, 50 genera of insects known (many dragonflies)

Elmo, Kansas

- Age – Permian (267 Ma)
- Most insect fossils found in lenses
- These are thought to be lakes (some fresh water, some playas)
- Coastal region – tropical climate
- 15,500 specimens, 17 orders, 150 species known
- Largest insect ever is known from this formation (Wellington)
  - Roughly 27 inch wingspan

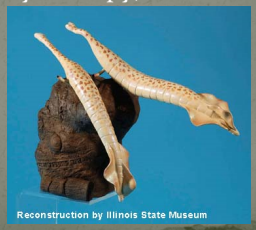
Elmo, Kansas

- Fossil and modern "dragonfly" wings



Mazon Creek

- Age – Upper Carboniferous – (300 Ma)
- Mostly Will and Grundy Counties (Illinois)
- Specimens preserved in iron stone nodules
- Typically exposed in strip mining operations
- Environment tropical (and very swampy)
- Illinois state fossil
  Tullimonstrum gregarium



Mazon Creek

- Paleodictyoptera

- Protorthoptera

Mazon Creek Reconstruction

- Illinois straddled the equator
- Illinois State Museum reconstruction

Defining features of insects

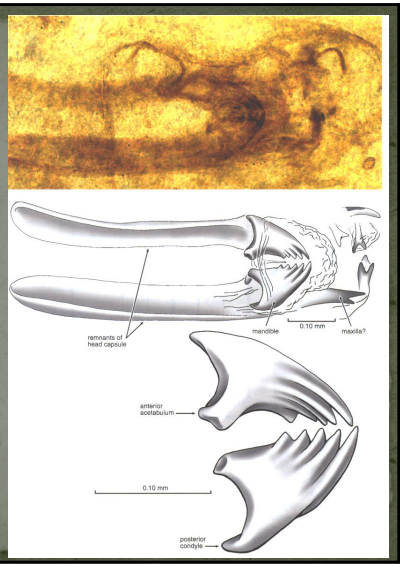
- Obviously 6 legs… (but immature chiggers have 6 legs)
- Specifically…
  - Loss of musculature in the antenna beyond the scape
  - Presence of chordontal organ (Johnston's organ) in the antennal pedicel
  - Development of posterior tentorium into a transverse bar
  - Loss of articulation between coxae and sterna
  - Subsegmentation of tarsus into tarsomeres
  - Articulation of pretarsal claws with apical most tarsomere
  - Presence in females of ovipositor (formed by outgrowths of 8th and 9th abdominal segments)
  - Presence (primitively) of long terminal filament on dorsum of 11th abdominal segment

Origins of Insects

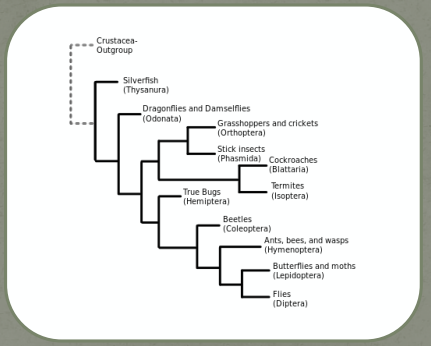
- Insects are principally terrestrial organisms
- Earliest terrestrial relatives (springtails)
  - *Rhyniella hirsti* – Rhynie Chert (Scotland) – Devonian (360 – 400 Ma)
  - Also known from Gaspé fossil beds of Quebec
  - Bristletails (modern example from Tree of Life project)
  - http://tolweb.org/Archaeognatha
  - Nocturnal, hide in crevices in day, loose bark or stones

Rhyniella

- Rhynie Chert (Scotland)
- Devonian (360 – 400 Ma)
- Mandibles are more representative of winged insects than primitive groups
- This has lead some to suspect origin of insects is Silurian
- Recent molecular study placed origin (of insects) in Ordovician



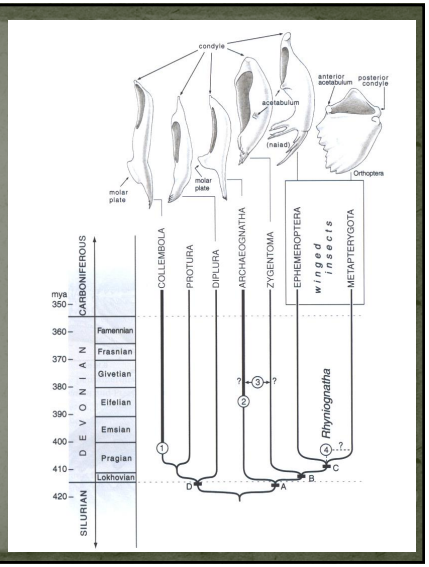
Relationship of common orders

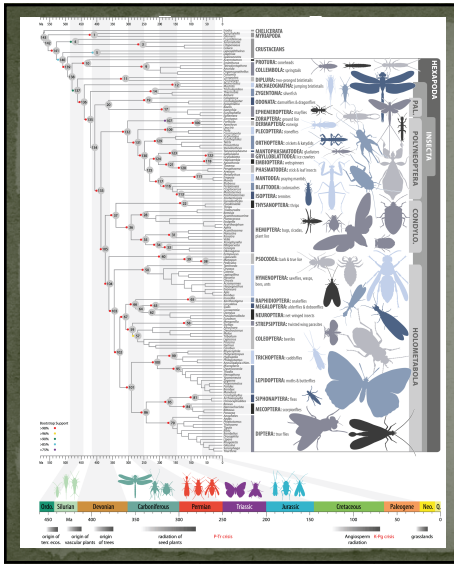


Source: https://en.wikipedia.org/wiki/Evolution_of_insects

Origins

- Numbers represent various fossils
- Letters
  - A – insectan
  - B – dicondylic mandibles
  - C – wings
  - D – entognathus mouthparts





2014 study based on:

- 1478 protein coding genes
- 413,459 amino acid sites
- 2,5 gigabases of cDNA from 103 species

Origin:

479 Ma (Ordovician)

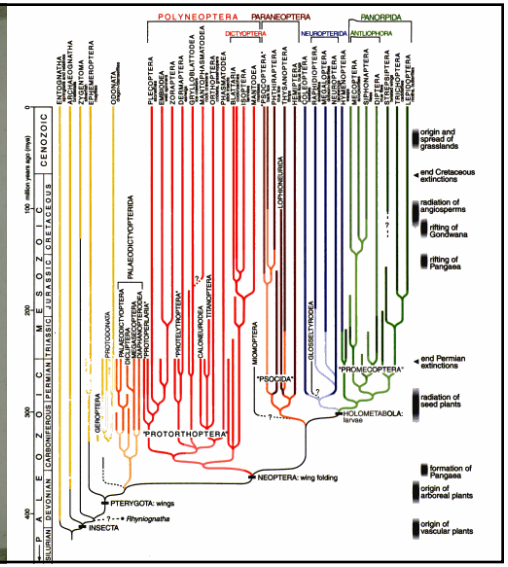
Flight:
406 Ma (Devonian)

Major extant lineages
345 Ma (Mississippian)

Source: http://science.sciencemag.org/content/346/6210/763

Phylogeny

- From previous origins…
- Major groupings of insects (extant and extinct)



Why so many species of insects?

- Age – earliest known fossil insect from early Devonian
  - Probably evolved in Ordovician (> 479 Ma)
  - As terrestrial ecosystems evolved, insects were present and readily exploited new resources
- Design – cascade of innovations
  - Exoskeleton – physical protection
  - Segmentation (and repetition) allows specialization of some appendages while retaining original functions of others
  - Flight – escape from predators, disperse to new areas
  - Larval stage – exploit different diets from adults

Why so many species of insects? (2)

- Capacity for high rates of speciation – consider
  - Lepidoptera and plant eating beetles
  - Roughly 250,000 species (majority feed on angiosperms)
  - Angiosperms have been around at best 100 million years
  - Short generation time (life span)
  - Coupled with high reproductive rates
  - Consider – *Drosophila melanogaster* (fruit fly)
    - Suppose 1 female lays 100 viable eggs
    - Half of these produce viable females that do the same
    - At the end of 25 generations – mass would be larger than the earth itself

Why so many species of insects? (3)

- Low rates of natural extinction
  - Consider Cretaceous extinctions
  - Dinosaurs, many oceanic organisms when extinct
  - Negligible effect on insects
- Permian extinctions – only 3 major groups went extinct
  - Paleodictyopterida, Caloneurodea, Miomoptera
  - Yet roughly 95% of life vanished (trilobites and a whole lot more)
- Today – experiencing another great extinction spasms
  - Likely insects will remain long after humans

Origin of insect wings

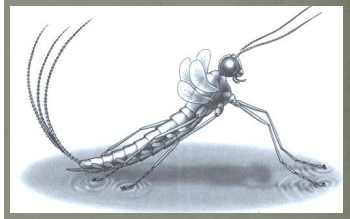
- Insects the only group of invertebrates to achieve powered flight (at least 90 MY before winged vertebrates) [Most recent estimate – early Devonian 406 Ma]
  - Improved dispersal capabilities
  - Quick retreat from predators
  - Improved capabilities of finding a mate
- Function of insect wings
  - For most – lower pressure on upper surface creates lift (Bernoulli's principle)
    - Indirect (up to 1,000 cycles per second) or direct flight muscles
  - For some (minute species) – flight is like swimming through a vat of melted chocolate

Origin of insect wings (2)

- Single origin for all insects now accepted (Pterygota)
  - Ephemeroptera (mayflies)
  - Paleodictyopterida (extinct beaked insects)
  - Odonatoptera (dragonflies, damselflies and extinct relatives)
  - Neoptera (all remaining winged insects) – flex wings over abdomen while at rest
- 2 current/ contrasting theories about origin of insect wings
  - Paranotal lobes – fixed extensions of thorax – initially gliding
  - Gill theory – arose from modified gills on thorax
- Estimated origin in Devonian
  - Paranotal lobes theory has more supporters
  - Still lacking an insect equivalent of *Archaeopteryx*

Origin of insect wings (3)

Paranotal Lobes



Gill Theory

Evolution of Major Insect Orders

- Mayflies
- Extinct Beaked Insects
- Dragonflies (and relatives)
- Grasshoppers (and relatives)
- Sucking insects
- Lacewings (and relatives)
- Beetles
- Ants, Bees, Wasps (and relatives)
- Flies
- Caddisflies
- Butterflies and moths

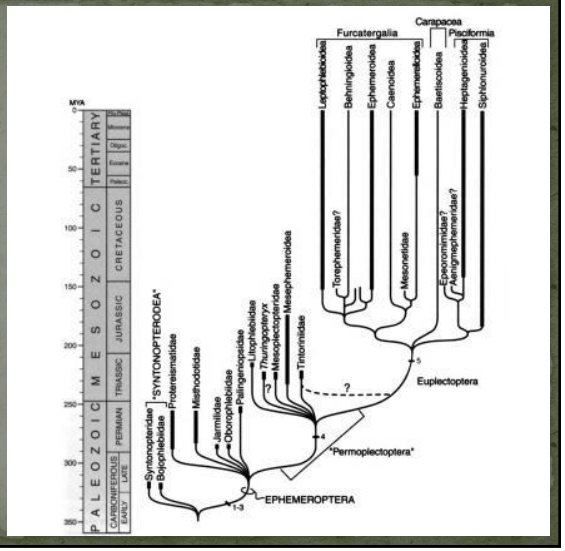
Mayflies (Ephemeroptera)

- Greek – ephemeros = "short-lived"
- Greek – pteron = "wing"
- Roughly 2,500 species alive today (worldwide)
- Egg > Nymph > Sub-Adult > Adult
  - Sub-adult is unique among living insects
    - Winged, but sexually immature stage
- Nymphs typically live in freshwater (up to several years)
- Adults live from a few minutes to a few days

Mayflies (2)

- Most fossil specimens are immature
  - These are from Liaoning formation
  - Earliest definitive mayflies – Permian
  - Some adults known from amber

Mayflies

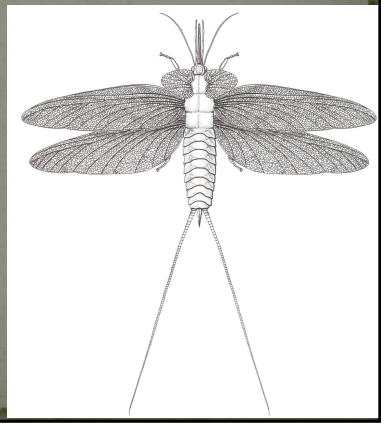


Mayflies

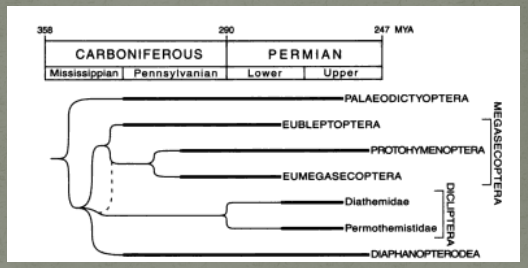
- Key fossils
  - *Lithoneura lameerei*
  - Carboniferous
  - Mazon Creek, Illinois
  - Very early mayfly
  - Width of specimen 65 mm

Extinct Beaked Orders

- Paleodictyoptera (this one reconstructed from Carboniferous of France)
- Most common insects of Paleozoic
- Note prothoracic paranotal lobes
- Mouthparts designed for piercing/ sucking
- Some quite large (up to 22 inches)
- Most likely herbivorous

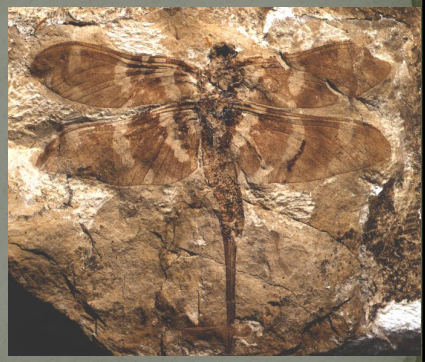


Extinct Beaked Orders



Extinct Beaked Orders

- Key fossils
  - *Dunbaria fascipennis*
  - Permian
  - Elmo, KS
  - Note striking patterns on this paleodictyopteran

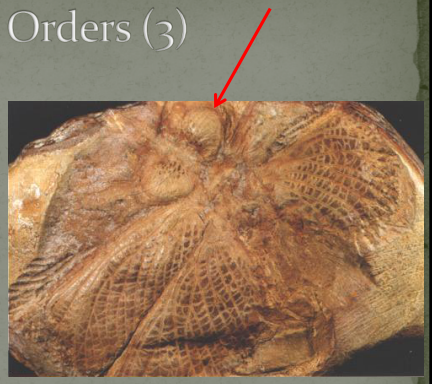


Extinct Beaked Orders (2)

- Key fossils
  - *Moravia grandis*
  - Permian
  - Midco, OK
  - Some paleodictyopteran were large
    - This hindwing measures 73 mm wide

Extinct Beaked Orders (3)

- Key fossils
  - *Lithomantis carbonarius*
  - Late Carboniferous
  - Scotland
  - Note large paranotal lobes on first thoracic segment



Extinct Beaked Orders (4)

- Key fossils
  - *Pseudohymen sp.*
  - Early Permian
  - Ural Mountains
  - Megasecoptera

Dragonflies (and damselflies and griffenflies)

- Greek – odon = "tooth"
- Roughly 6,500 species alive today (worldwide)
- Egg > Nymph > Adult
- Nymphs typically live in freshwater (up to several years) and are predators
  - Some species in Hawaii live in moist leaf litter
- Adults are predators
  - Common names include: "mosquito hawks," "devil's darning needles," and "snake doctors"
- Some species are estimated to fly at over 55 kph

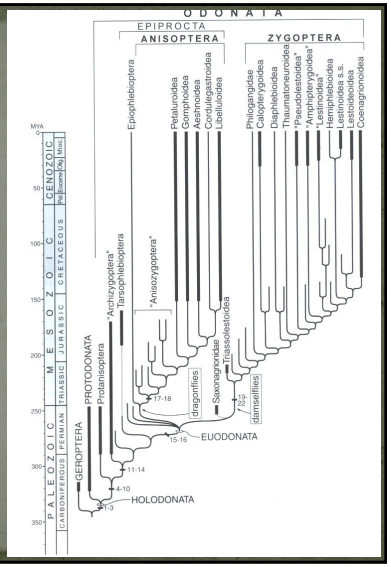
Dragonflies and damselflies

- Order Odonata



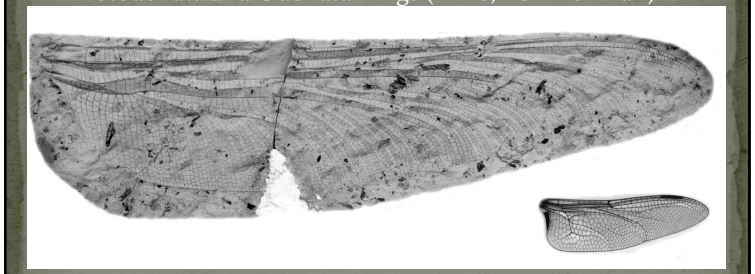

Dragonflies (and relatives)

- 3 main groups
  - Geroptera (late Carboniferous of Argentina)
  - Protodonata (griffenflies – up to 28 inch wingspans)
  - Odonata (dragonflies and damselflies)



Dragonflies (and relatives)

- Protodonata and Odonata wings (Elmo, KS – Permian)



- Although most Protodonata are preserved only as wings, some fossils show large toothed mandibles, large compound eyes and stout legs with spines (similar habits to modern day Odonata)

Dragonflies (and relatives) (2)

- Key fossils
  - *Arctotypus sinuatus*
  - Permian
  - Russia

Dragonflies (and relatives) (3)

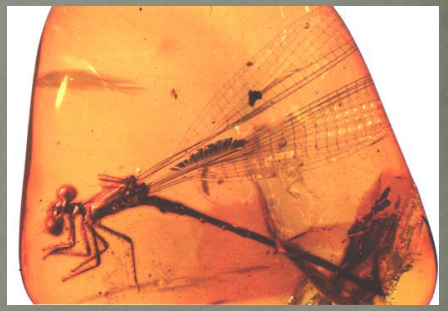
- Key fossils
  - *Eoprotoneura hyperstigma*
  - Early Cretaceous
  - Santana Formation, Brazil
  - Damselfly

Dragonflies (and relatives) (4)

- Key fossils
  - *Pseudomacromia sensibilis*
  - Early Cretaceous
  - Santana Formation, Brazil
  - Dragonfly nymph
    - Long antenna may have helped detect prey in dense aquatic vegetation

Dragonflies (and relatives) (5)

- Key fossils
  - Modern Damselfly
  - Miocene amber
  - Dominican Republic



Grasshoppers (and relatives)

- Greek – orthos = "straight"
- Greek – pteron = "wing"
- Roughly 37,000 species alive today (worldwide)
- Egg > Nymph > Adult
- Grasshoppers, crickets and locusts
- Several smaller orders
- Many produce sound (via stridulation)

Grasshoppers (and relatives)


Plecoptera


Embioptera


Zoraptera


Dermaptera


Grylloblattodea


Mantophasmatodea


Isoptera


Phasmatodea


Orthoptera


Blattodea


Mantodea

Order Notoptera/ a.k.a Grylloblattodea

- Grylloblattidae (ice crawlers)
- 5 genera, 34 species
- optimal living temperature is between 1-4 °C (33.8-39.2 °F)
- Feed mostly on dead arthropods
- Found under stones at high elevations

Notoptera in baltic amber

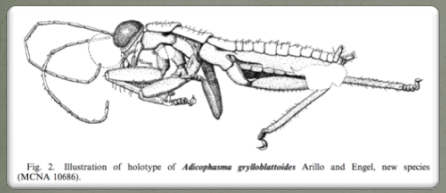
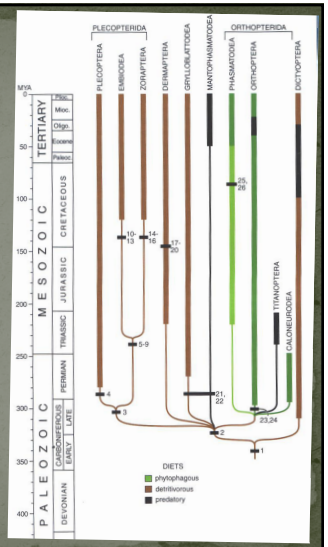


Fig. 2. Illustration of holotype of *Adicophasma grylloblattoides* Arillo and Engel, new species (MCNA 10686).

- Arillo, A and M. Engel. 2006. Rock Crawlers in Baltic Amber(Notoptera: Mantophasmatodea). American Museum Novitates # 3539

Grasshoppers (and relatives)

- Plecopterida
  - Each order lacks clear affinities to other orders
  - Each order is remnant of ancient lineage
- Orthopterida
  - 2 living orders and extinct forms
- Dictyoptera
  - Mantodea, Isoptera, Blattodea
  - Modern roaches appeared in Cretaceous
  - Paleozoic "roaches" had large external ovipositor
  - Isoptera is only major order of insects without any extinct families



Termite origins

- "Some primal termite knocked on wood
  And tasted it and found it good
  And that is why your cousin May
  Fell through the parlor floor today."
  - - Ogden Nash
- Most termite radiation occurred within a 50 million year span in the early Cretaceous
- Roach – *Cryptocercus* (Appalachian Mountains) also contains similar Protozoa

Grasshoppers (and relatives)

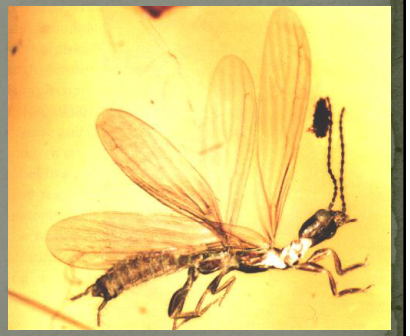
- Key fossils
  - *Chresmoda aquatica*
  - Early Cretaceous
  - Spain
  - Resemble modern water striders (Heteroptera: Gerridae), but these were relatives of Orthoptera and Phasmatodea

Grasshoppers (and relatives) (2)

- Key fossils
  - *Lemmatophora typa*
  - Early Permian
  - Elmo, KS
  - Primitive relative of modern stoneflies

Grasshoppers (and relatives) (3)

- Key fossils
  - Embioptera
  - Miocene amber
  - Dominican Republic
  - Resembles modern species



Grasshoppers (and relatives) (4)

- Key fossils
  - *Zorotypus nascimbenei*
  - Cretaceous amber
  - Burma
  - Resembles modern species

Grasshoppers (and relatives) (5)

- Key fossils
  - Katydid like
  - Early Cretaceous
  - Brazil
  - Resembles modern species
  - Note long, thin ovipositor

Grasshoppers (and relatives) (6)

- Key fossils
  - *Clatrotitan andersoni*
  - Triassic
  - Australia
  - Titanopteran
  - Note stridulatory apparatus on wing
  - Length 139 mm

Grasshoppers (and relatives) (7)

- Key fossils
  - Earwig
  - Miocene amber
  - Dominican Republic
  - Resembles modern species

Grasshoppers (and relatives) (8)

- Key fossils
  - *Tillyardembia antennaeplana*
  - Permian
  - Russia
  - Early relative of Grylloblatodea (rock crawlers)

Grasshoppers (and relatives) (9)

- Key fossils
  - *Phylloblatta gallica*
  - Late Carboniferous
  - France
  - Closely resemble modern roaches, but have large ovipositor

Grasshoppers (and relatives) (10)

- Key fossils
  - *Karataublatta longicaudata*
  - Late Jurassic
  - Kazakhstan
  - Closely resemble modern roaches, but have large ovipositor
  - One of last times "roachoids" appear in fossil record

Grasshoppers (and relatives) (11)

- Key fossils
  - Blatellidae
  - Early Cretaceous
  - Brazil
  - Ootheca (egg case) still lodged in terminalia

Grasshoppers (and relatives) (12)

- Key fossils
  - *Santanmantis axelrodi*
  - Cretaceous
  - Brazil
  - Primitive mantis

Sucking insects

- Roughly 102,000 species alive today (worldwide)
- Egg > Nymph > Adult
- Bark lice, true lice, thrips, aphids, cicadas, true bugs
- Some produce ultrasound (communicate via plant sap)
- Some produce sound (cicadas)
- Many species are easily overlooked (small in size, secretive)

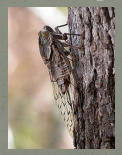
Sucking Insects

Psocodea: Psocoptera

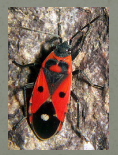
Psocodea: Phthiraptera

Thysanoptera

Hemiptera: Sternorryncha



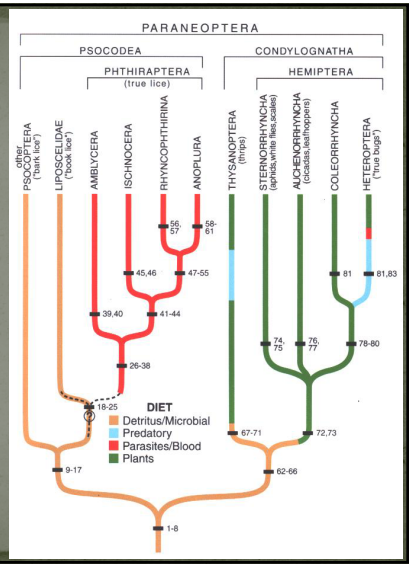
Hemiptera: Auchenorryncha



Hemiptera: Heteroptera

Sucking Insects

- Note lack of time scale
- Some groups have much better fossil records than others
  - Psocoptera – late Jurassic
  - Anoplura – Eocene
  - Thysanoptera – Triassic
  - Heteroptera - Permian

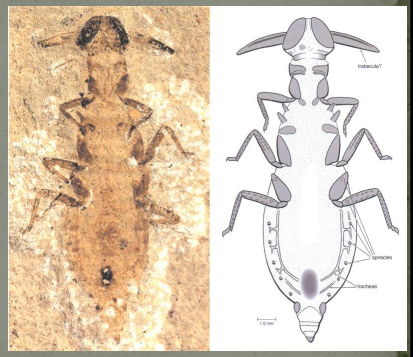


Sucking Insects

- Key fossils
  - Psocoptera
  - Cretaceous amber
  - Lebanon
  - Bark lice – Family Prionoglariidae
    - 5 species alive today
    - Inhabit caves in Eurasia

Sucking Insects (2)

- Key fossils
  - *Saurodectes vrsanskyi*
  - Cretaceous
  - Siberia
  - Mesozoic louse?
    - Large eyes
    - 17 mm long
    - Size of louse and host typically correlated
    - Perhaps louse had a huge host?
  - Reconstruction



Sucking Insects (3)

- Key fossils
  - *Cretothrips antiquus*
  - Cretaceous amber
  - New Jersey
  - Very similar to living *Cycadothrips* from Australia
  - Many primitive features (for thrips)

Sucking Insects (4)

- Key fossils
  - Whitefly
  - Cretaceous amber
  - Lebanon

Sucking Insects (5)

- Key fossils
  - Aphid
  - Cretaceous amber
  - Burma

Sucking Insects (6)

- Key fossils
  - Scale insect
  - Miocene amber
  - Dominican Republic
  - *Acropyga* queen ant carrying scale insect (she takes one or more when founding a new ant colony)

Sucking Insects (7)

- Key fossils
  - *Fletcheriana triassica*
  - Late Triassic
  - Australia
  - Large cicada like insects which may have fed on ginkgos
  - Note color patterns preserved in wings

Sucking Insects (8)

- Key fossils
  - *Platypedia primigenia*
  - Late Eocene
  - Florissant, CO
  - Cicada

Sucking Insects (9)

- Key fossils
  - Cercopidae (spittlebug)
  - Late Eocene
  - Florissant, CO
  - Nymphs of living species typically live in protective mass of spittle

Sucking Insects (10)

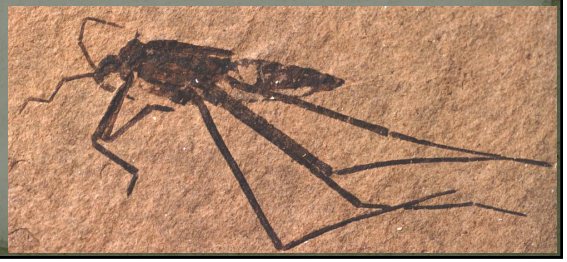
- Key fossils
  - Enicocephalidae
  - Early Cretaceous amber
  - Lebanon
  - Most primitive "true bugs"
  - Sister group to rest of Heteroptera

Sucking Insects (11)

- Key fossils
  - *Duncanovelia extensa*
  - Early Cretaceous
  - Australia
  - Example of fossil Heteroptera

Sucking Insects (12)

- Key fossils
  - *Limnoporus sp.*
  - Eocene
  - British Columbia
  - Water strider (Gerridae)



Sucking Insects (13)

- Key fossils
  - Belostomatidae
  - Early Cretaceous
  - Brazil
  - Giant Water Bugs have the best fossil record of all Heteroptera

Origins of "complete" metamorphosis

- All groups discussed to this point have similar development
  - Egg > Nymph > Adult
- Groups we will cover next have a different development
  - Egg > Larva > Pupa > Adult
- Two theories
  - Pupa developed as intermediate form as young and adults increasingly differed
  - Preferred – larvae are essentially free living embryos
    - Most hemimatabolous insects have a brief pronymph stage (between hatching from egg and first instar)

Lacewings (and relatives)

- Roughly 25,000 species alive today (worldwide)
- Egg > Larva > Pupa > Adult
- Neuroptera, Megaloptera, Raphidioptera
  - These three are a sister group of the beetles

Lacewings (and relatives)

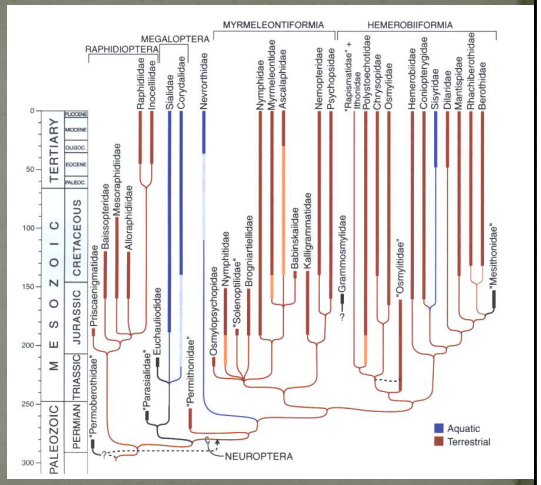
Neuroptera

Raphidioptera

Megaloptera

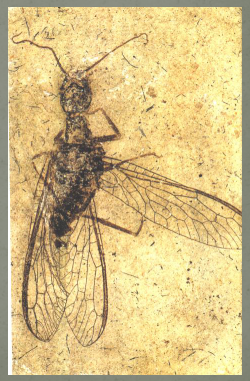
Lacewings (and relatives)

- Raphidoptera is base – early Jurassic
- Megaloptera – late Permian (Russia)



Lacewings (and relatives)

- Key fossils
  - *Mesoraphidia pterostigmalis*
  - Late Jurassic
  - Kazakhstan
  - Mesozoic snakefly

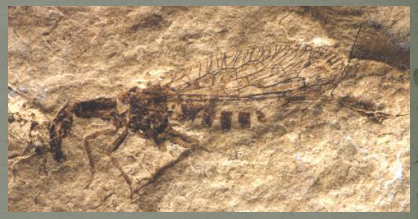


Lacewings (and relatives) (2)

- Key fossils
  - *Baissoptera brasiliansis*
  - Early Cretaceous
  - Brasil
  - Mesozoic snakefly
  - Today, snakeflies are extinct in the southern hemisphere

Lacewings (and relatives) (3)

- Key fossils
  - *Raphidia funerata*
  - Oligocene - Eocene
  - Florissant, CO
  - Tertiary snakefly



Lacewings (and relatives) (4)

- Key fossils
  - *Petropsychops superba*
  - Triassic
  - Australia
  - Mesozoic lacewing

Lacewings (and relatives) (5)

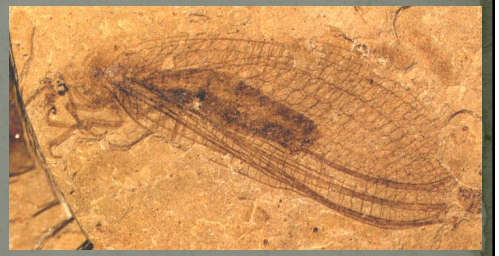
- Key fossils
  - *Marquettia americana*
  - Oligocene - Eocene
  - Florissant, CO
  - Tertiary Nemopteridae (presently found in Europe & Africa)

Lacewings (and relatives) (6)

- Key fossils
  - *Meioneurites spectabilis*
  - Late Jurassic
  - Kazakhstan
  - Giant lacewing – convergent with butterflies

Lacewings (and relatives) (7)

- Key fossils
  - *Chrysopa sp.*
  - Eocene
  - British Columbia
  - Lacewing



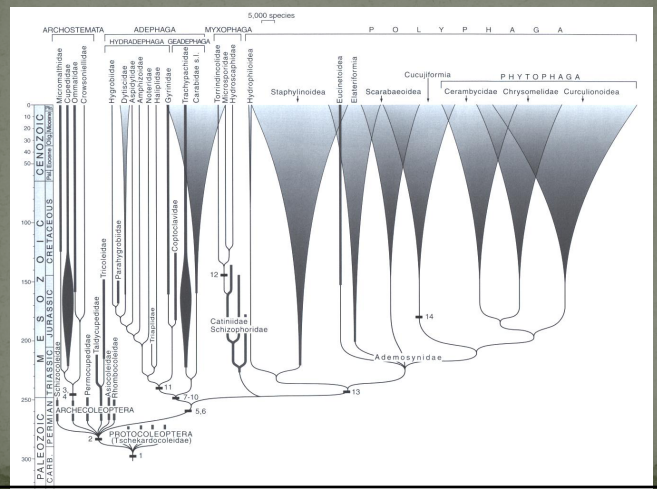
Beetles (Coleoptera)

- Greek – koleos= "sheath"
- Greek – pteron = "wing"
- Roughly 350,000 species alive today (worldwide)
  - Every one in four animals is a beetle
  - Most of diversity achieved by late Jurassic
- Egg > Larva > Pupa > Adult
- Strepsiptera is a sister group (small, parasitic)

Beetles

- Examples of some diversity
- Major groups
  - Archostemata (35 extant species – most ancient)
  - Myxophaga (65 extant species)
  - Adephaga (10% of all beetle species – ground and aquatic beetles)
    - Mostly predators
  - Polyphaga (90% of all beetle species)
    - Highly varied diets

Beetles



Beetles

- Key fossils
  - Cupedidae
  - Early Cretaceous
  - Spain
  - Group was diverse throughout early Mesozoic, but declined in Cretaceous

Beetles (2)

- Key fossils
  - *Coptoclava longipoda*
  - Early Cretaceous
  - Siberia
  - Extinct predatory beetle
  - Swam using paddle shaped mid and hind legs

Beetles (3)

- Key fossils
  - Carabidae
  - Late Triassic
  - Virginia
  - About 40,000 living species of ground beetles

Beetles (4)

- Key fossils
  - Staphylinidae
  - Late Triassic
  - Virginia
  - Oldest known member of this family
  - 47,000 extant species (probably many more undescribed)

Beetles (5)

- Key fossils
  - Dryopidae
  - Cretaceous
  - Santana Formation, Brazil

Beetles (6)

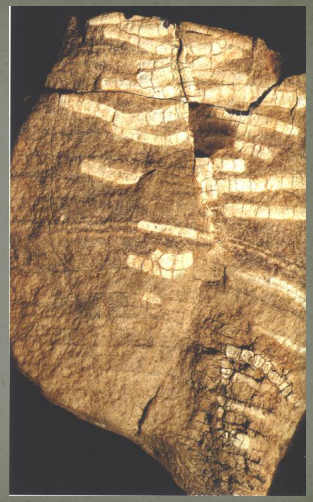
- Key fossils
  - Platypodine beetle
  - Miocene amber
  - Dominican Republic
  - Their feeding damage may have produced resin defenses from *Hymanea* trees

Beetles (7)

- Key fossils
  - Weevil
  - Miocene amber
  - Dominican Republic
  - There are more species of weevils alive today than species of vertebrates

Beetles (8)

- Key fossils
  - Beetle galleries
  - Cretaceous
  - Siberia
  - Attributed to scolytine beetles

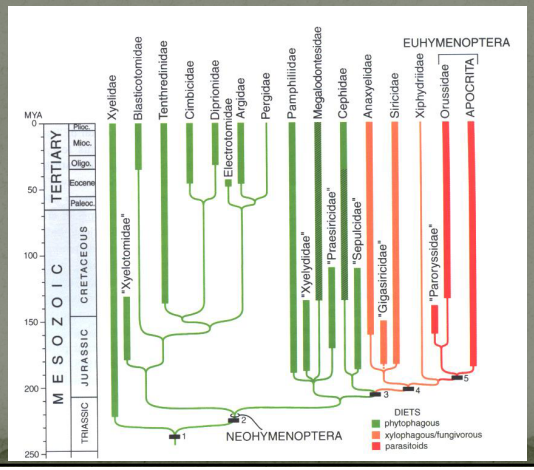


Ants (and relatives)

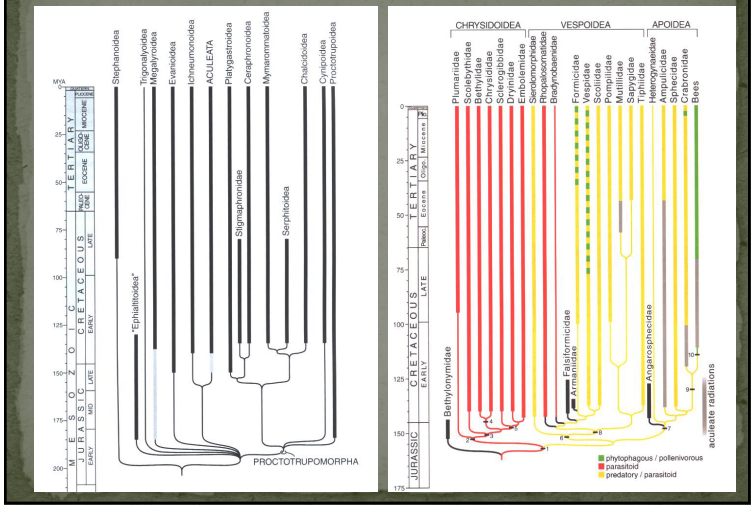
- Greek – hymen = "membrane"
- Greek – pteron = "wing"
- Roughly 125,000 species alive today (worldwide)
  - Estimated there may be up to 1,200,000 species when fully studied
- Egg > Larva > Pupa > Adult
- Outside of termites, most of the social insects belong to this group (ants, bees, wasps)

Ants (and relatives)

Ants (and relatives)



Ants (and relatives)



Hymenoptera

- Key fossils
  - Xyelidae
  - Triassic
  - Australia
  - Earliest Hymenoptera
  - This family is sister group to all other Hymenoptera

Hymenoptera (2)

- Key fossils
  - *Stephanogaster magna*
  - Late Jurassic
  - Kazakhstan
  - Common in Jurassic and early Cretaceous
  - Long ovipositor indicates possibly parasitoids of wood boring larvae

Hymenoptera (3)

- Key fossils
  - Ensign wasp
  - Miocene amber
  - Dominican Republic
  - Modern members of Evaniidae are parasitoids of cockroach ootheca

Hymenoptera (4)

- Key fossils
  - *Architiphia rasnitsyni*
  - Early Cretaceous
  - Brazil
  - Earliest known tiphiiform wasp

Hymenoptera (5)

- Key fossils
  - *Zacryptocerus sp.*
  - Miocene amber
  - Dominican Republic
  - Many ants are known from amber inclusions

Hymenoptera (6)

- Key fossils
  - *Armania robusta*
  - Mid-Cretaceous
  - Central Asia
  - Early close relative of ants

Hymenoptera (7)

- Key fossils
  - *Cariridris bipetiolata*
  - Early Cretaceous
  - Santana Formation, Brazil
  - Possible ant (also attributed to Ampulicidae)

Hymenoptera (8)

- Key fossils
  - *Brownimecia clavata*
  - Cretaceous amber
  - New Jersey
  - Early ant (90 Ma)

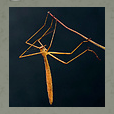
Hymenoptera (9)

- Key fossils
  - *Apis henshawi*
  - Oligocene
  - Germany
  - Primitive honey bee

Flies (Diptera)

- Greek – di= "two"
- Greek – pteron = "wing"
- Roughly 120,000 species alive today (worldwide)
  - Estimated at least that many more species waiting to be described
- Egg > Larva > Pupa > Adult
- Group contains most dangerous animals on earth
  - Vectors of malaria, plague, yellow fever, dengue fever, encephalitis, West Nile virus (and a host of other diseases)

Flies (Diptera) (and relatives)



Mecoptera

Siphonaptera

Diptera



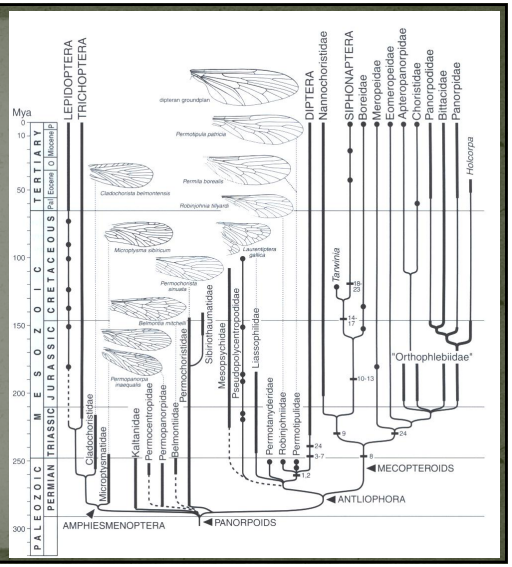






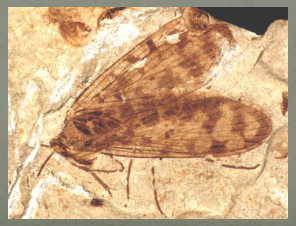


Flies



Flies (and relatives)

- Key fossils
  - Mecopteroid insects
  - Early Cretaceous
  - Yixian Formation, China
  - Examples of scorpionflies



Flies (and relatives) (2)

- Key fossils
  - *Strashila incredibilis*
  - Late Jurassic
  - Siberia
  - Apparently ectoparasitic mecopteroid
  - Hind legs probably used for grasping host
  - Function of abdominal lobes unknown

Flies (and relatives) (3)

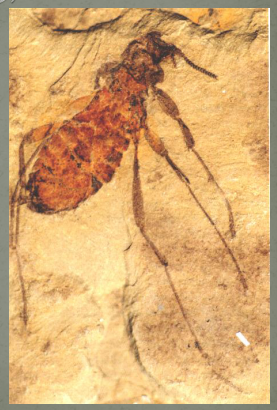
- Key fossils
  - *Holcorpa maculosa*
  - Oligocene
  - Florissant, CO
  - Note genitalia at end of very long folded stalk

Flies (and relatives) (4)

- Key fossils
  - Rhopalopsyllidae
  - Miocene amber
  - Dominican Republic
  - Modern members of this family feed on rodents

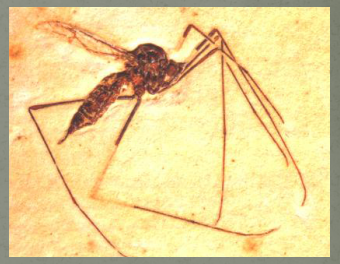
Flies (and relatives) (5)

- Key fossils
  - *Tarwinia australis*
  - Early Cretaceous
  - Australia
  - Likely an early relative of fleas (has some, but not all features of modern fleas)



Flies (and relatives) (6)

- Key fossils
  - Tipuloidae: Limoniidae
  - Early Cretaceous
  - Brazil
  - Tipulids are considered to be most "primitive" of living flies



Flies (and relatives) (7)

- Key fossils
  - Procramptonomyiidae
  - Jurassic
  - Kazakhstan
  - Extinct close relative of Bibionid flies

Flies (and relatives) (8)

- Key fossils
  - *Araripogon axelrodi*
  - Early Cretaceous
  - Brazil
  - Robber fly (Asilidae)
  - Modern family contains over 5,000 species
  - Adults are all predators

Flies (and relatives) (9)

- Key fossils
  - Horsefly (Tabanidae)
  - Oligocene
  - Florissant, CO
  - Note well preserved large proboscis

Flies (and relatives) (10)

- Key fossils
  - *Glossina oligocena*
  - Oligocene
  - Florissant, CO
  - Tsetse flies now restricted to sub-Saharan Africa
  - This species was twice as large as modern forms

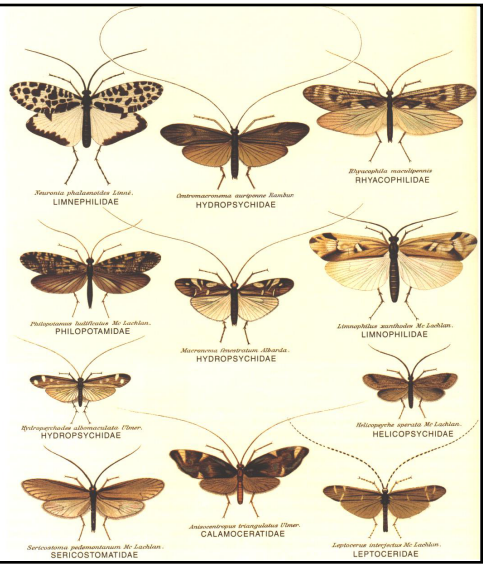
Flies (and relatives) (11)

- Key fossils
  - *Prosphyracephala sp.*
  - Eocene
  - Baltic amber
  - Similar to modern species of stalk eyed flies

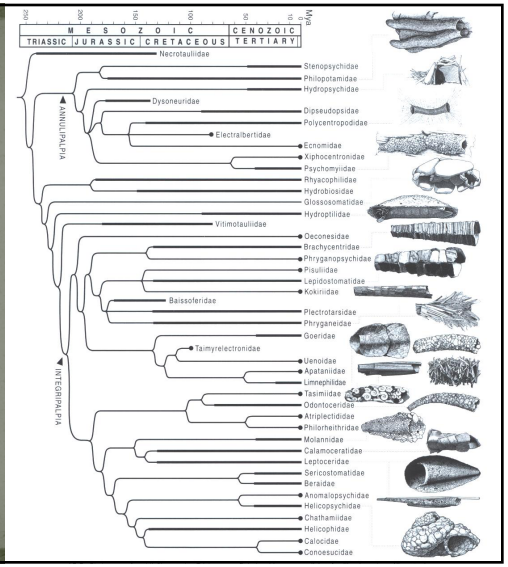
Caddisflies (Trichoptera)

- Greek – trich = "hair"
- Greek – pteron = "wing"
- Roughly 11,500 species alive today (worldwide)
- Egg > Larva > Pupa > Adult
  - Larvae are aquatic (many live in cases they build)
- Only group (besides midges) where some larvae develop in seawater - Chathamiidae – Australia and New Zealand)
- Oldest definitive Trichoptera – Early Jurassic (Germany)

Caddisflies



Caddisflies



Caddisflies

- Key fossils
  - *Terrindusia sp.*
  - Cretaceous
  - Aurasia
  - Fossil caddisfly case made of pebbles

Caddisflies (2)

- Key fossils
  - *Folindusia kemaensis*
  - Oligocene
  - Far Eastern Russia
  - Fossil caddisfly case made of trimmed plant fragments

Caddisflies (3)

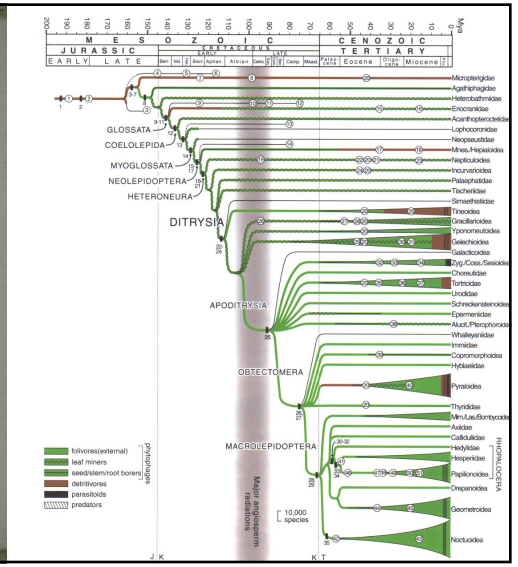
- Key fossils
  - Cretaceous amber
  - New Jersey
  - Fossil caddisfly

Butterflies and Moths (Lepidoptera)

- Greek – lepidos = "scale"
- Greek – pteron = "wing"
- Roughly 180,000 species alive today (worldwide)
- Egg > Larva > Pupa > Adult
  - Some larvae are economic pests
  - Largest lineage of plant feeding organisms
- Fossil record is rather sparse
- Likely arose in Jurassic and diversified significantly in Cretaceous and early Tertiary

Butterflies and Moths

Butterflies and Moths



Butterflies and Moths

- Key fossils
  - *Protodryas persephone*
  - Eocene
  - Florissant, CO
  - Butterfly shown to Frank Carpenter by Samuel Scudder
    - Inspired Frank Carpenter to spend 70 years studying fossil insects at Harvard

Butterflies and Moths (2)

- Key fossils
  - Primitive moth
  - Early Cretaceous
  - Brazil

Butterflies and Moths (3)

- Key fossils
  - *Chlorippe wilmattae*
  - Eocene
  - Florissant, CO

Butterflies and Moths (4)

- Key fossils
  - Rhiodinidae
  - Miocene amber
  - Dominican Republic

What we covered

Review of insect diversity and major localities for insect fossils

Discussion of Insect Origins

Overview/ evolution of major insect orders

Resources

- If you want to learn more…

More Resources

- Websites
  - http://tolweb.org/tree/
  - http://tolweb.org/Insecta
  - http://www.yale.edu/ypmip/locations/florissant/index.html
    - http://www.nps.gov/archive/flfo/online_museum/index.html
  - http://www.3dotstudio.com/amberhome.html
  - http://www.espd.com/amber/index.htm
- Many other resources – use your favorite search engine

Evolution of Insects

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