Evolution

BIOZONE

Evolution Series: **Set 3**

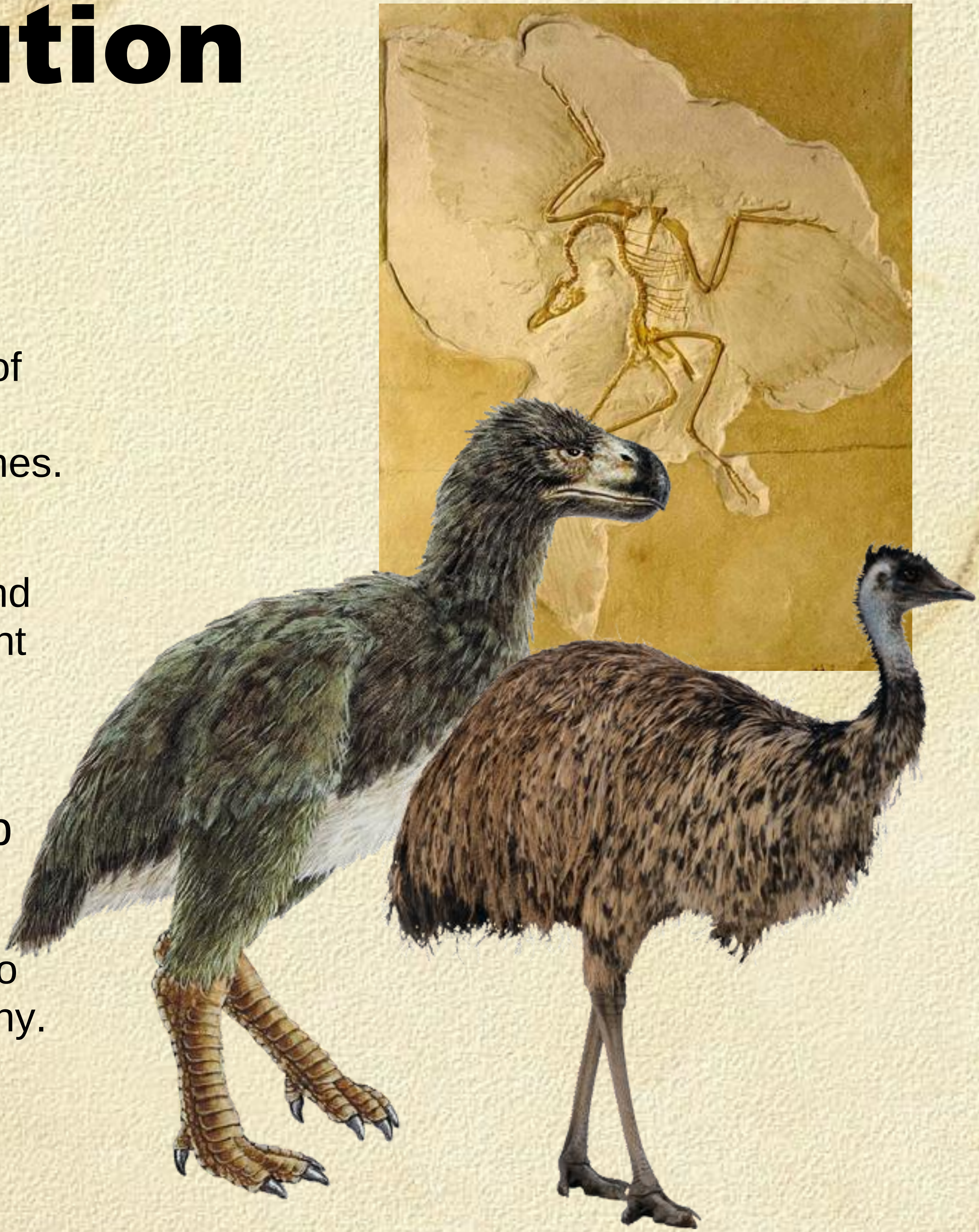
Version: 2.0

What is Evolution?

- **What is evolution?**
  - Evolution refers to the permanent genetic change (change in gene frequencies) in population of individuals.
  - It does not refer to changes occurring to individuals within their own lifetimes. Populations evolve, not individuals.
- **Microevolution** describes the small-scale changes within gene pools over generations.
- **Macroevolution** is the term used to describe large scale changes in form, as viewed in the fossil record, involving whole groups of species and genera.

Macroevolution

- **Macroevolution includes**:
  - **Adaptive radiation** of groups of species into different environments and different niches.
  - The origin of **evolutionary novelties** such as the wings and feathers of birds, and the upright posture of humans.
- The evolutionary history of a species or taxonomic group is called its **phylogeny**.
  - Classification of species aims to accurately reflect their phylogeny.

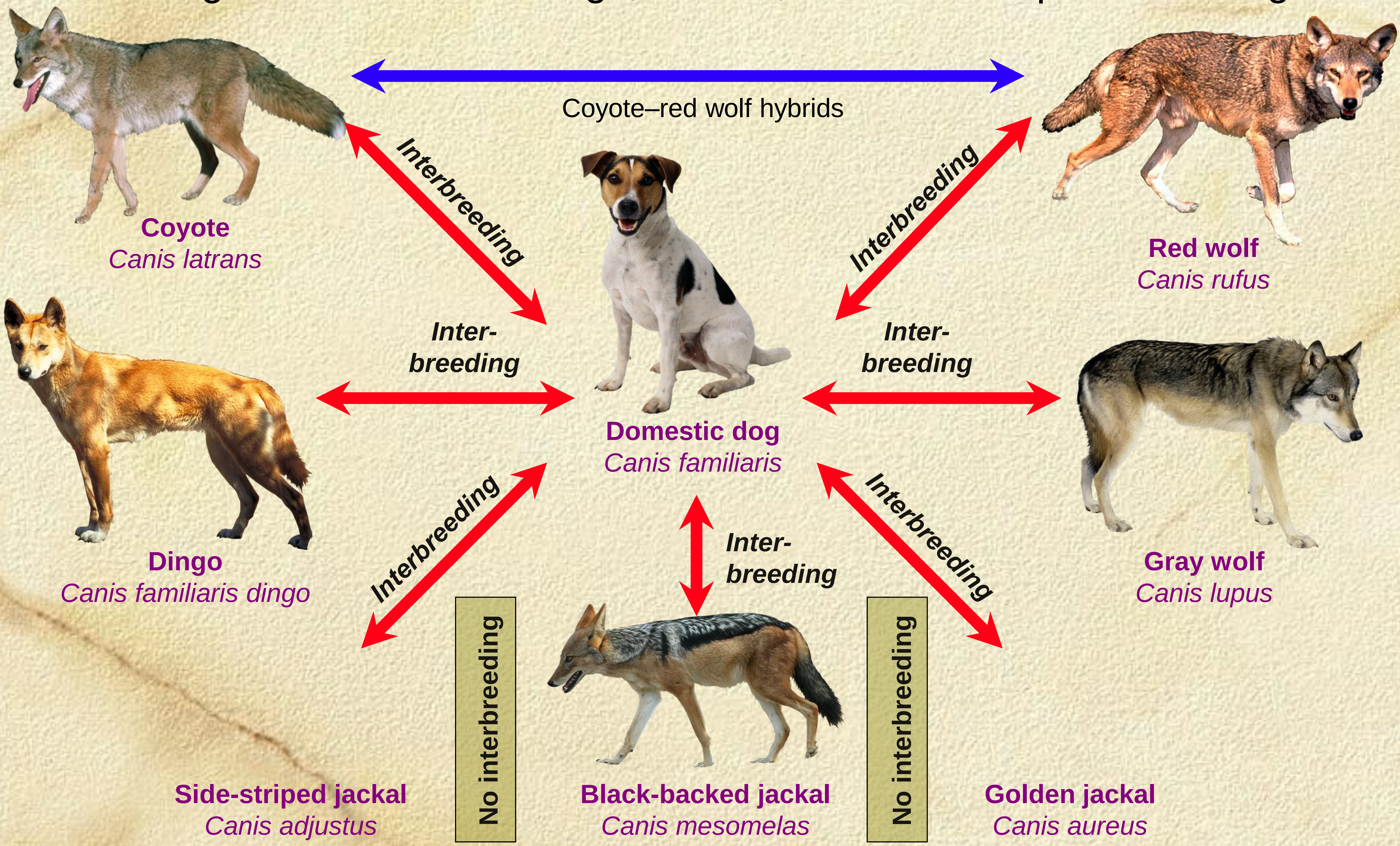


Species

- A biological species is:
  a group of interbreeding (or potentially interbreeding) individuals, reproductively isolated from other such groups.
- Species are often composed of different populations (often in different habitats) that are quite distinct.
- These are often called **subspecies**, **races**, and **varieties** depending on the degree of reproductive isolation.

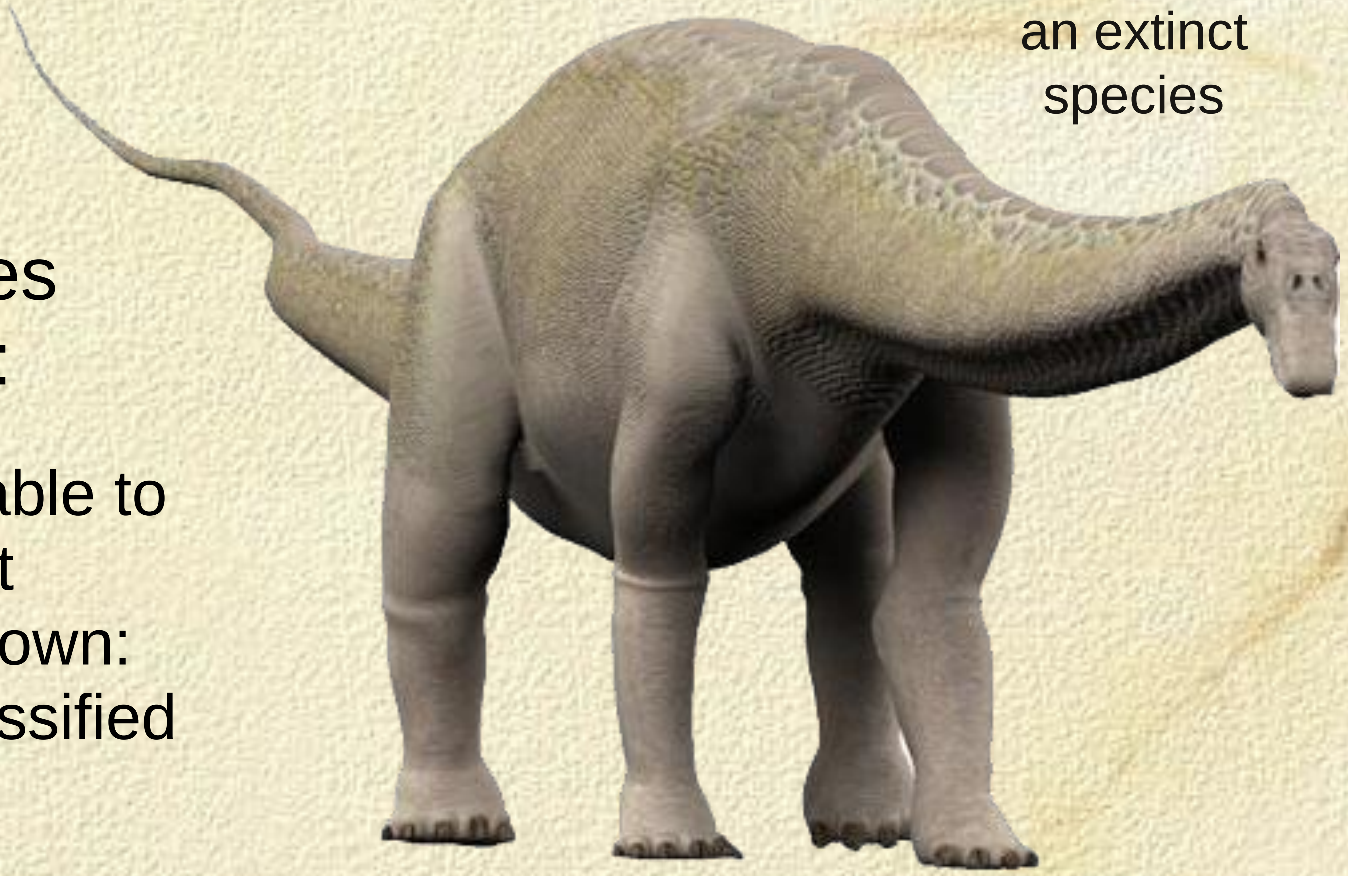
Species

- The boundaries of a species gene pool can be sometimes unclear, such as the genus to which all dogs, wolves, and related species belong:

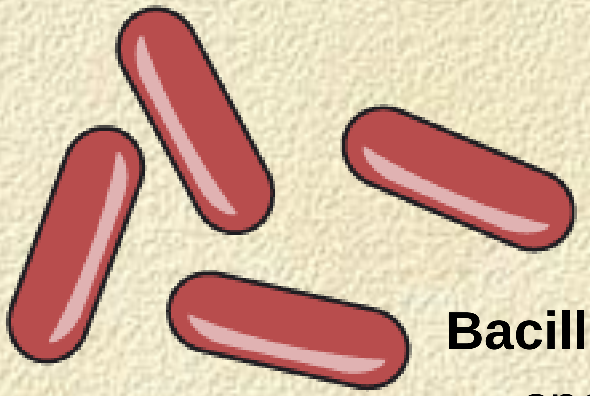


Limitations of the Species Concept

- Definition of a biological species does not apply in all situations:
  - The concept of a species being able to interbreed cannot apply to extinct populations because this is unknown: extinct forms must usually be classified on morphological grounds.
  - Asexually reproducing organisms do not breed with each other and so are assigned to species on the basis of appearance or biochemical similarities.



Apatosaurus, an extinct species



Bacillus bacteria, species that reproduce asexually

Reproductive Isolating Mechanisms

- **Reproductive isolating mechanisms** (**RIMs**) prevent successful breeding between different species. They are **barriers** to **gene flow**.
- A single barrier may not completely isolate a gene pool, but most species have more than one isolating mechanism operating to maintain a distinct gene pool.
- **Geographical barriers** prevent species interbreeding but **are not considered to be RIMs** because they are not operating through the organisms themselves.

Geographical Barriers

- **Geographical barriers** isolate species and prevent interbreeding.
- Geographical barriers include mountains, rivers, and oceans. Geographical features that may be barriers to some species may not be barriers to others.
  - In the USA, two species of antelope squirrels occupy different ranges either side of the Grand Canyon.
  - Their separation is both geographical and ecological. They are separated by the canyon and by the different habitat preferences in the regions they occupy.

Although they are in the same region, the white tailed antelope squirrel inhabits desert to the north of the canyon, while Harris's antelope squirrel (above) has a more limited range to the south.

Reproductive Isolating Mechanisms

- Reproductive isolating mechanisms can be categorized according to when and how they operate:
  - **Prezygotic** (pre-fertilization) mechanisms include:
    - habitat preference
    - behavioral incompatibility
    - structural incompatibility
    - physiological incompatibility
  - **Postzygotic** (post-fertilization) mechanisms include:
    - zygote mortality
    - poor hybrid fitness
    - hybrid sterility

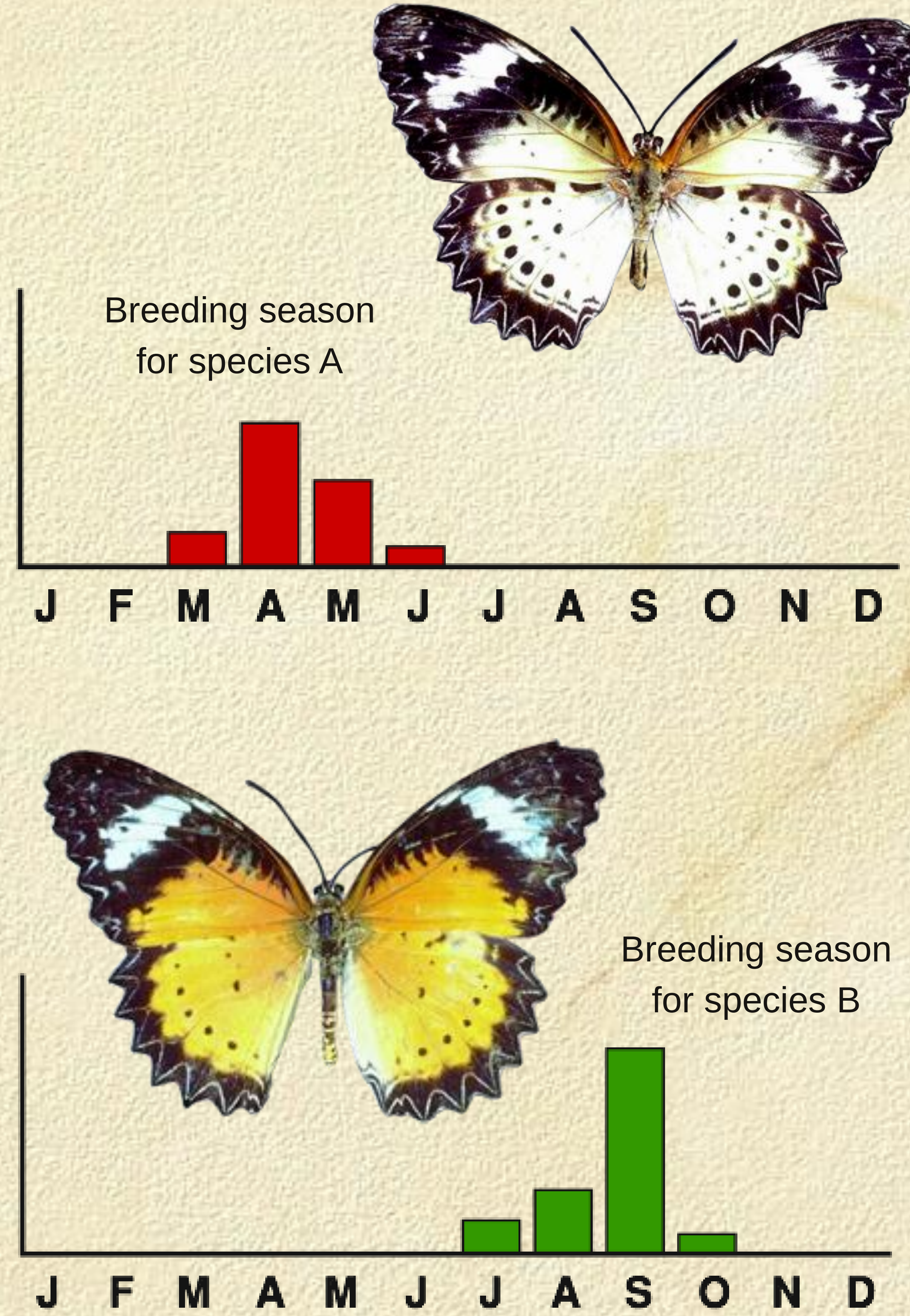
Prezygotic Isolating Mechanisms

- **Prezygotic isolating mechanisms** act before fertilization to prevent successful reproduction.
- **Ecological** or **habitat**:
  - Different species may occupy different habitats within the same geographical area, e.g. desert and coastal species, ground or tree dwelling.
  - In New Zealand, Hochstetter's and Archey's frogs occur in the same relatively restricted region but occupy different habitats within that range.

Archey's frog (top) has no webbing between the toes and is found in forested areas away from water. Hochstetter's frog (bottom) has partial toe webbing and can be found in stream margins.

Prezygotic Isolating Mechanisms

- **Temporal** (time-based):
  - Species may have different activity patterns; they may be nocturnal or diurnal, or breed at different seasons.
  - In this hypothetical example, the two species of butterfly will never mate because they are sexually active at different times of the year.

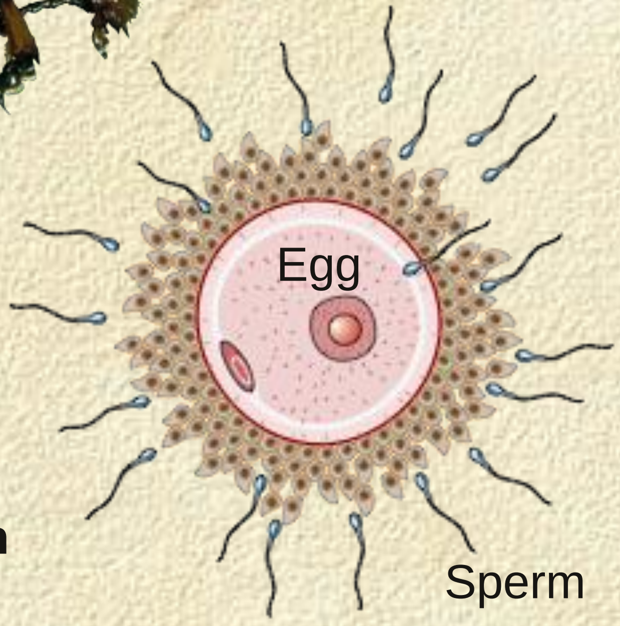


Prezygotic Isolating Mechanisms

- **Behavioral**:
  - Species may have specific calls, rituals, postures etc. that enable them to recognize potential mates (many bird species have elaborate behaviors).
- **Structural**:
  - For successful mating, species must have compatible copulatory apparatuses, appearance, and chemical make-up (odor, chemical attractants).
- **Gamete mortality**:
  - If sperm and egg fail to unite, fertilization will be unsuccessful.

Peacock

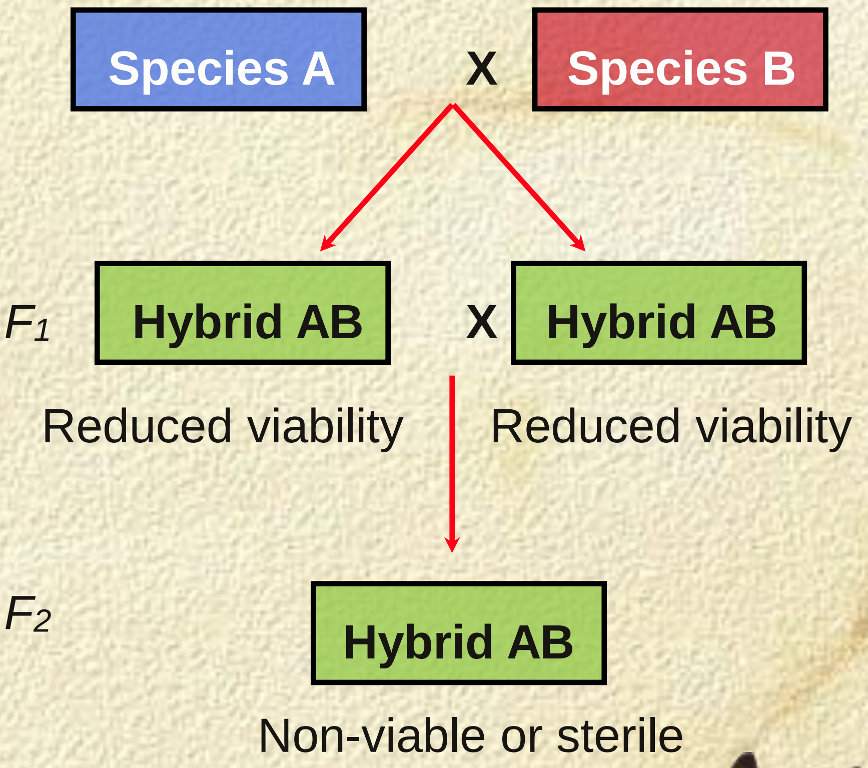
Insects have very specific copulatory organs which act like a lock and key

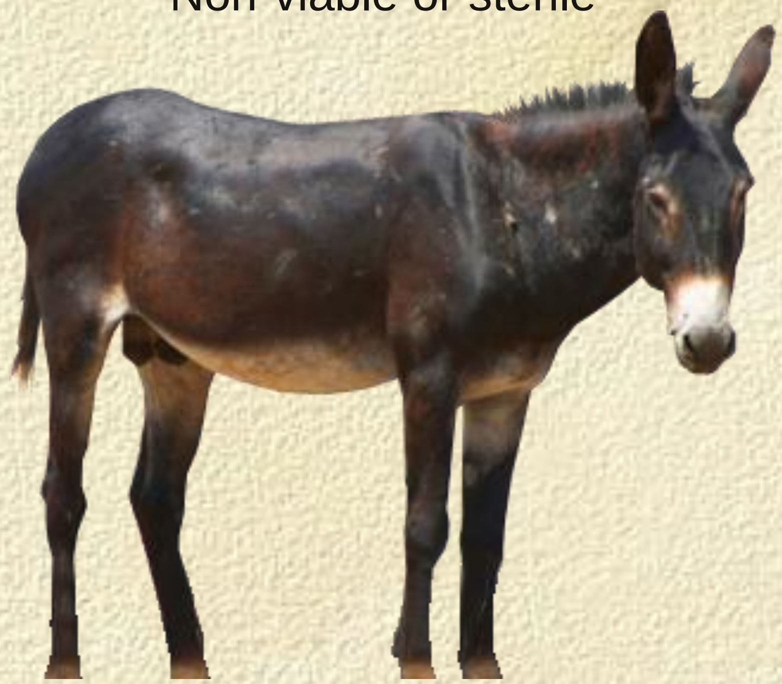


Attempted fertilization

Postzygotic Isolating Mechanisms

- Postzygotic isolating mechanisms act **after fertilization** to prevent successful reproduction.
- **Hybrid inviability**:
  - The fertilized egg may fail to develop properly
  - Fewer young may be produced and they may have a low viability (survivability).
- **Hybrid sterility**:
  - The hybrid of two species may be **viable** but **sterile**, unable to breed (e.g. the mule).
- **Hybrid breakdown**:
  - The first generation may be fertile but subsequent generations are infertile or non-viable.





This mule is a hybrid between a horse and a donkey

Hybrids in the Horse Family

- Sterile hybrids are common among the horse family.
- The chromosomes of the zebra and donkey parents differ in number and structure, producing a sterile **zebronkey**.

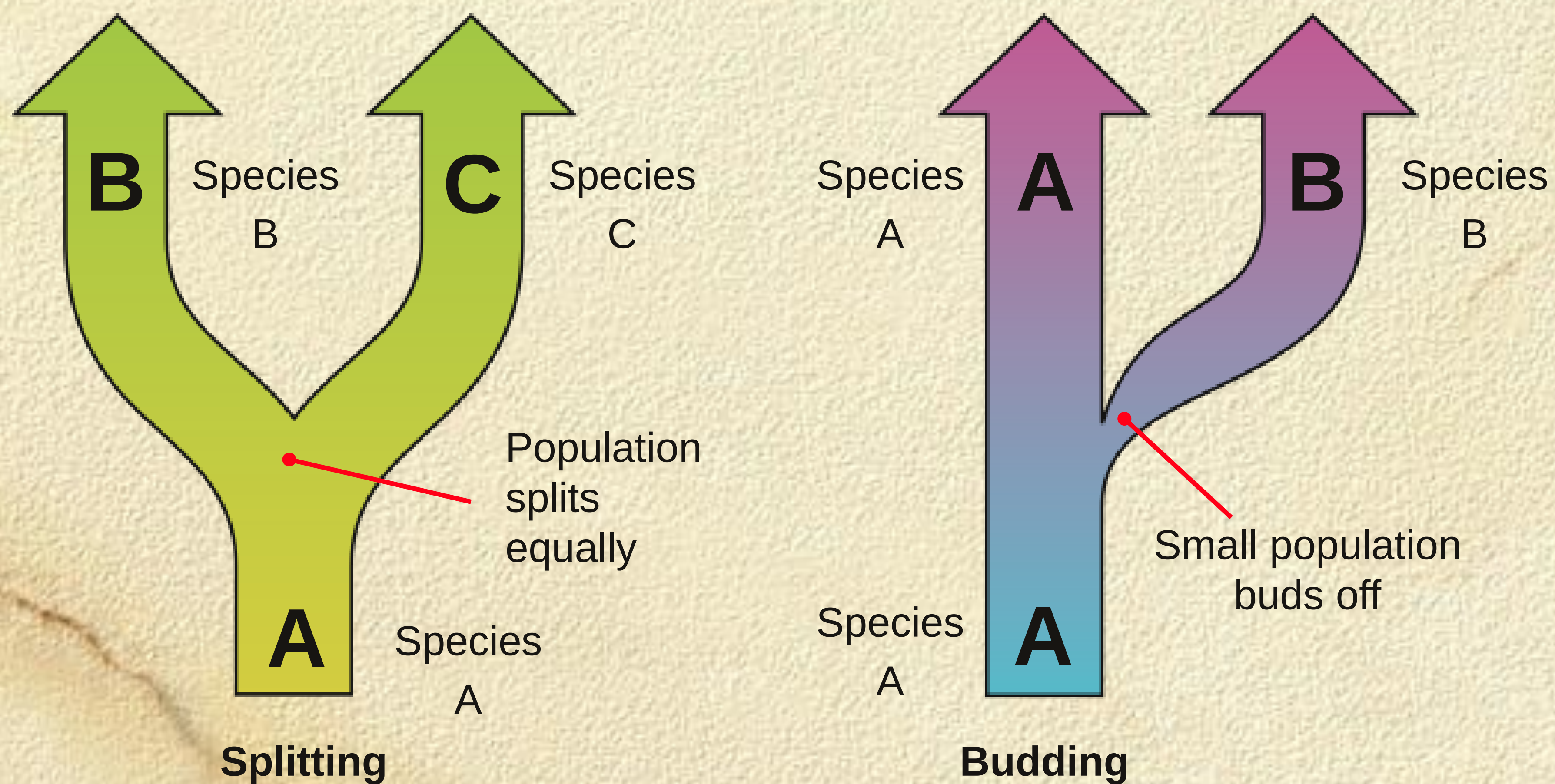
Speciation

- **Speciation** refers to the process by which new species are formed.
- Speciation occurs when **gene flow** has **ceased** between populations where it previously existed.
- Speciation is brought about by the development of **reproductive isolating mechanisms** which maintain the integrity of the new gene pool.

Different species of swallowtail butterflies in the genus ***Papilio***

Splitting & Budding

- Taking a very simple view, speciation can happen in one of two ways:
  - **Splitting**: A species could split fairly equally into two populations that evolve differently until they eventually become separate species.
  - **Budding**: A small part of the species population could “bud off” from the main part and evolve rapidly (in geological time-scale terms) to form a new species while leaving most of the original species population unchanged.

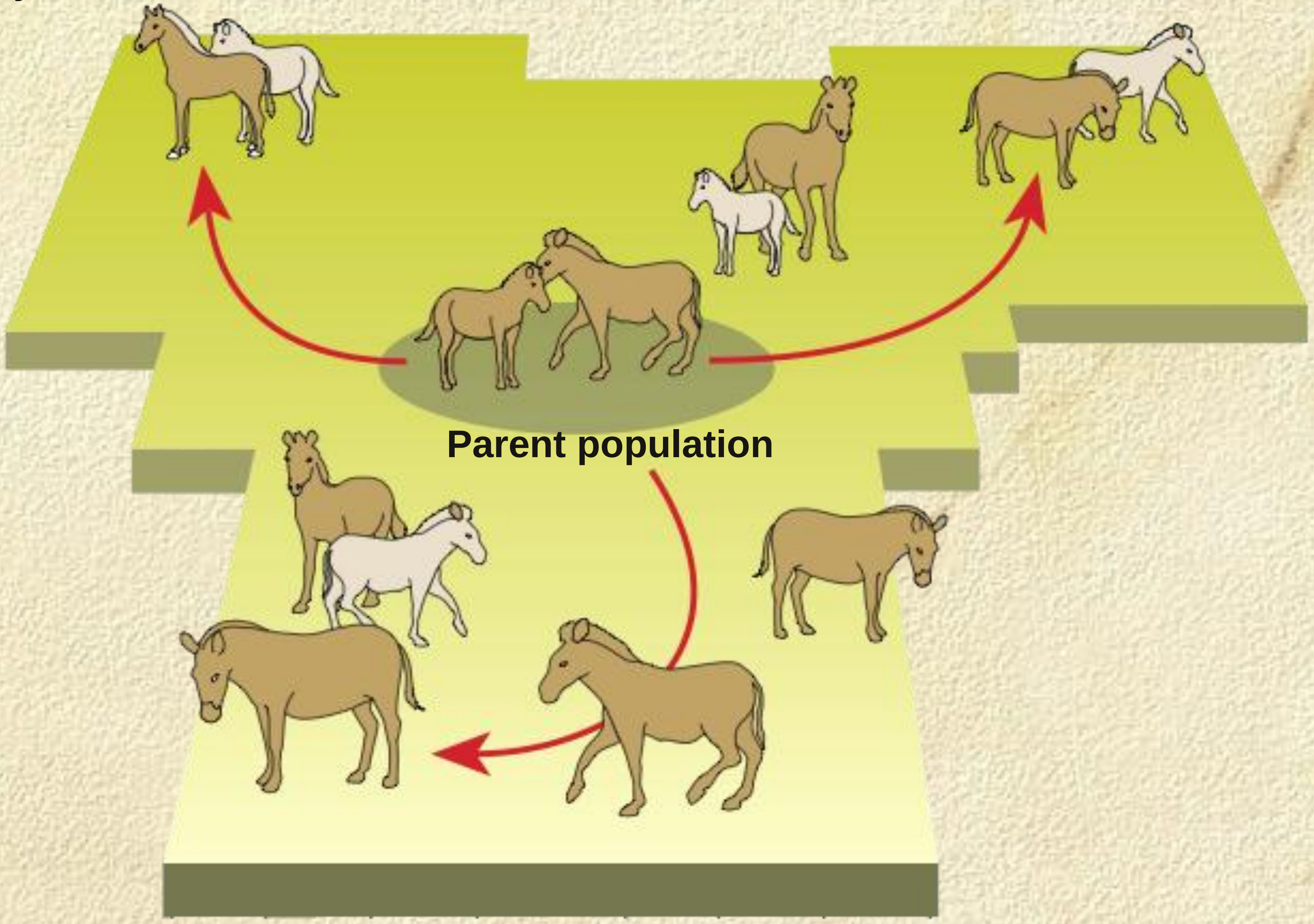


Types of Speciation

- Several models have been proposed to account for new species among sexually reproducing organisms:
  - **Allopatric speciation**: Populations become geographically separated, each being subjected to different natural selection pressures, and finally establishing reproductive isolating mechanisms.
  - **Sympatric speciation**: A population forms a new species within the same area as the parent species.
  - **Parapatric speciation:** The speciating populations are only partially separated geographically, so some individuals on each side are able to meet across a common boundary during the speciation process.

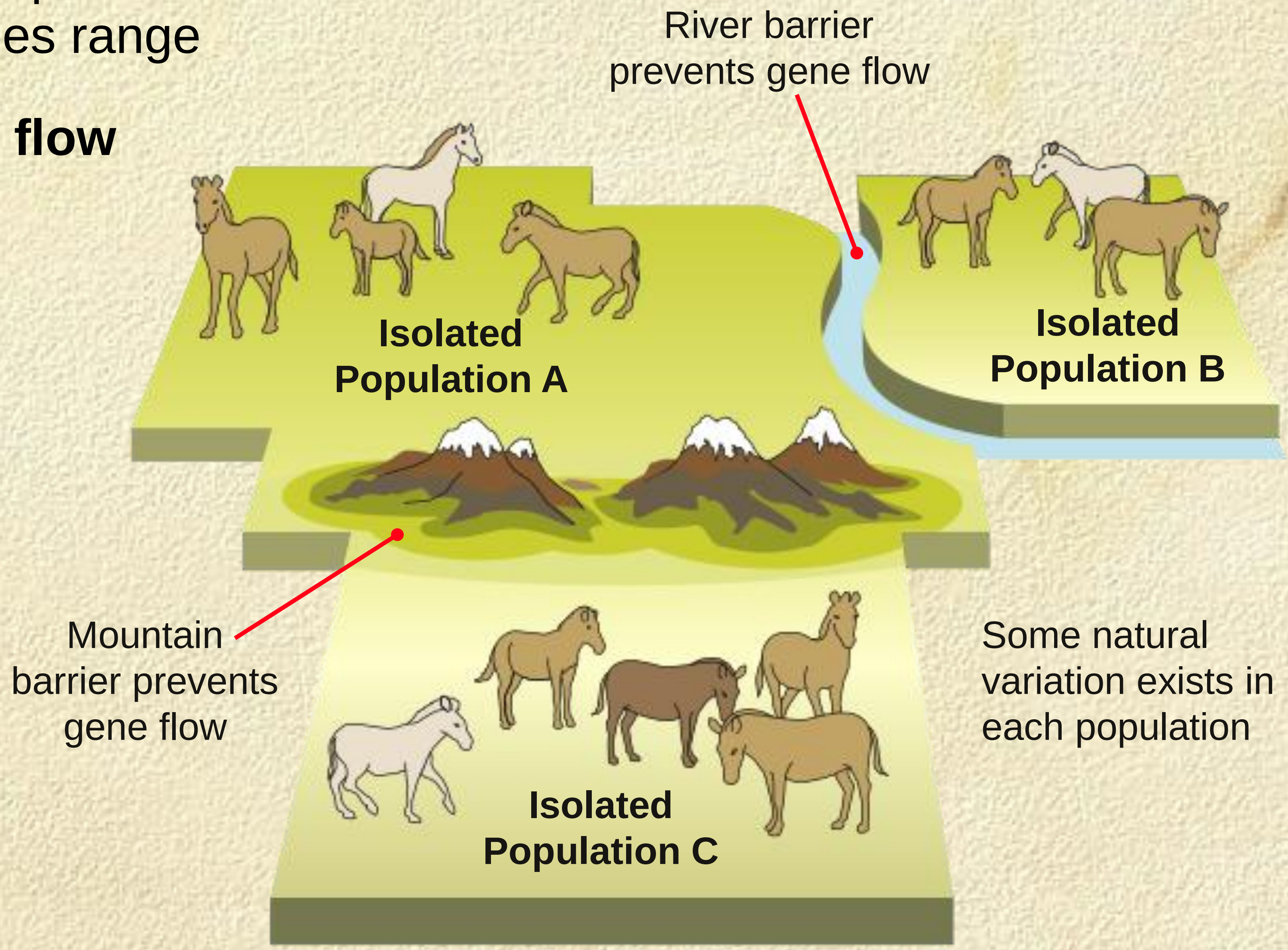
Allopatric Speciation 1

- STAGE 1: **Moving into new environments**
  - The parent population expands its range and occupies new parts of the environment.
  - Expansion of the range may be due to competition.
  - The population has a common gene pool with regular gene flow (any individual has potential access to all members of the opposite sex for the purpose of mating).



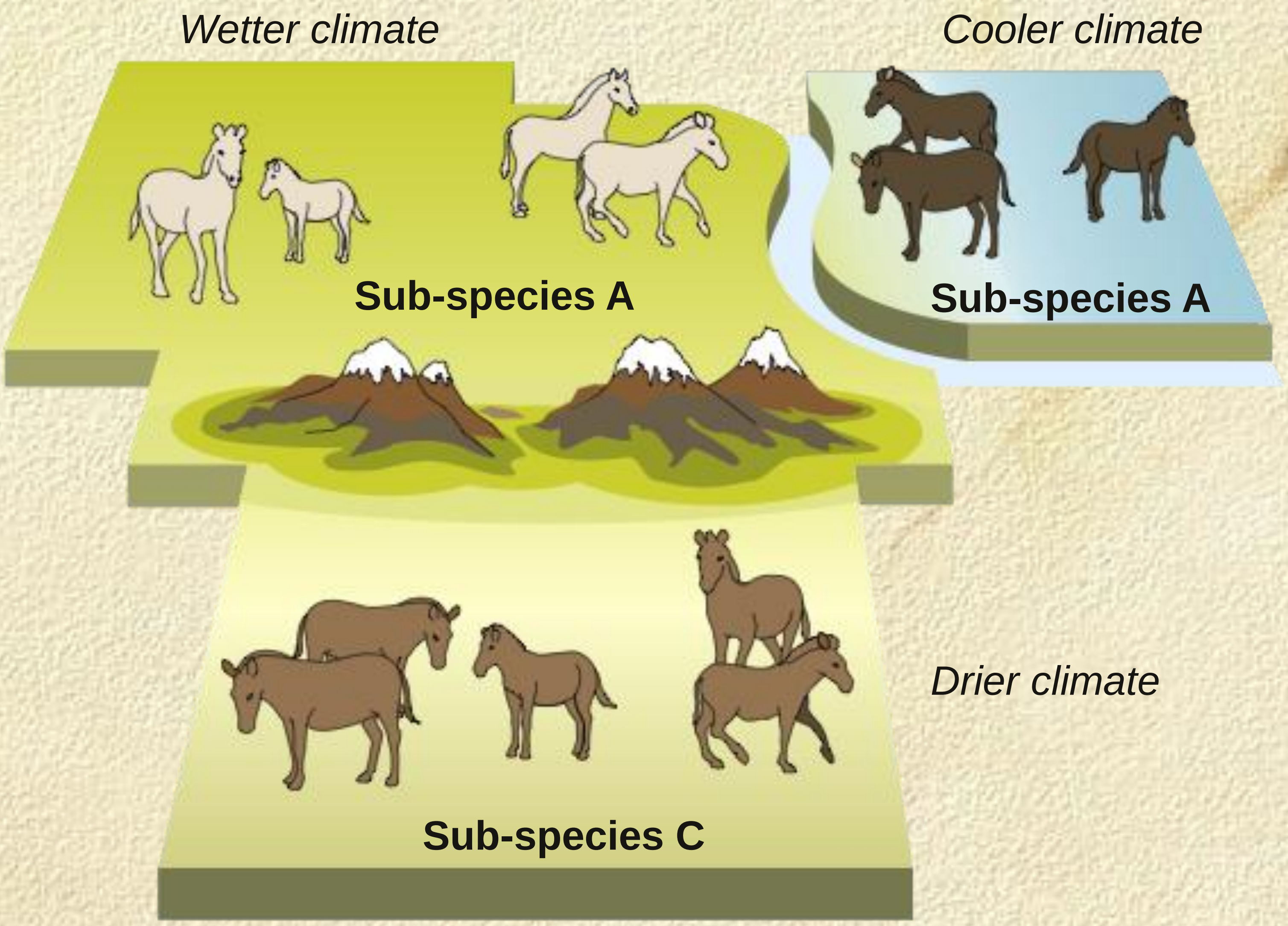
Allopatric Speciation 2

- STAGE 2: **Geographical isolation**
  - Gradual formation of **physical** barriers may isolate parts of the population at the extremes of the species range
  - As a consequence, **gene flow** between these isolated populations is prevented or becomes rare.
  - Agents causing **geographical isolation** include: continental drift, climatic change, and changes in sea level (due to ice ages).



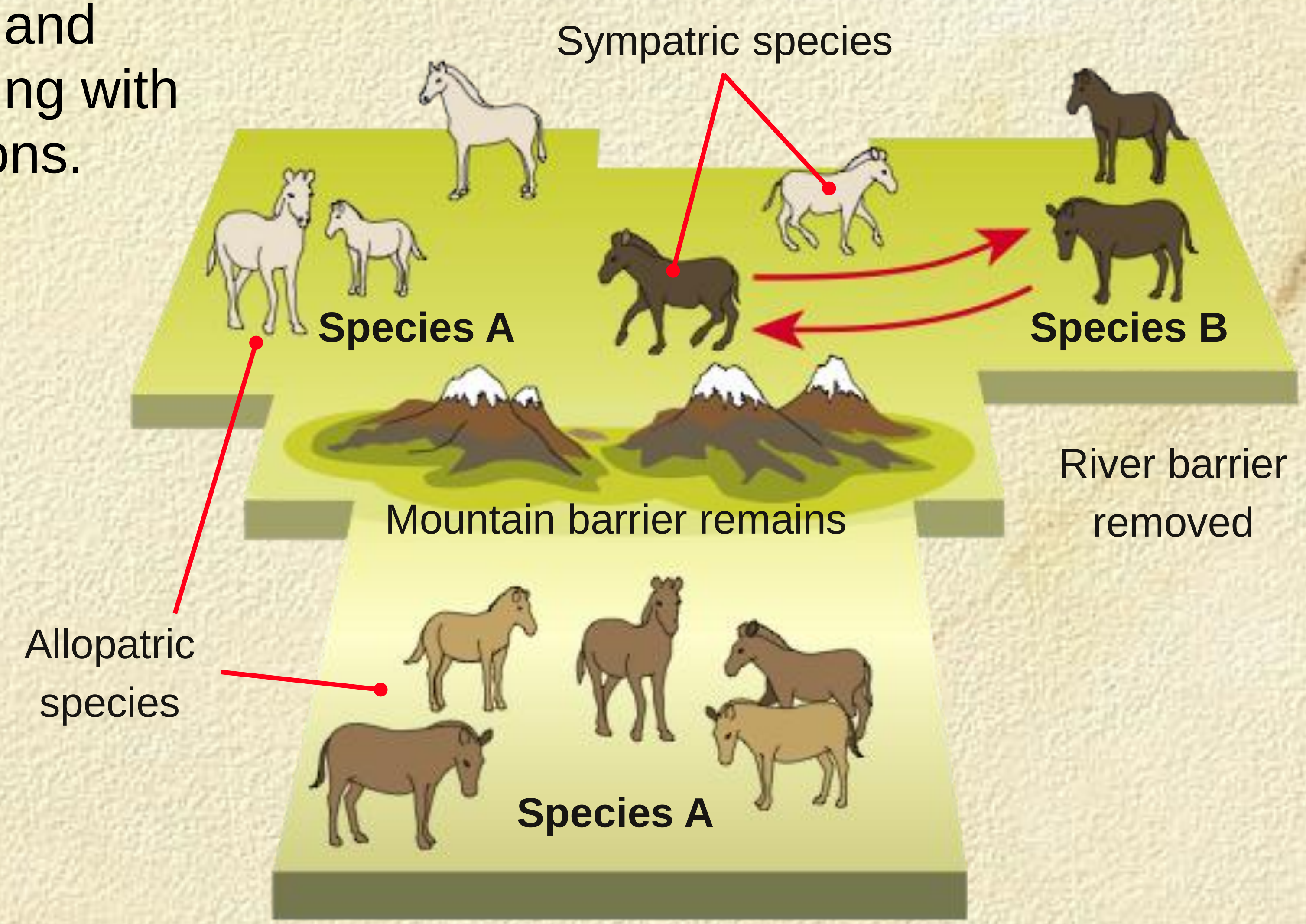
Allopatric Speciation 3

- STAGE 3: **Formation of a subspecies**
  - The isolated populations may be subjected to quite different selection pressures.
  - These selection pressures will favor those individuals with traits suited to each environment.
  - Allele frequencies for certain genes change and the populations take on the status of a subspecies (reproductive isolation is not yet established).



Allopatric Speciation 4

- STAGE 4: **Reproductive isolation**
  - Each separated subspecies undergoes changes in its genetic makeup and behavior. This will prevent mating with individuals from other populations.
  - Each subspecies' gene pool becomes reproductively isolated from the others and they attain species status.
  - Even if geographical barriers are removed to allow mixing of the populations, genetic isolation is complete.



Sympatric species: Closely related species with overlapping distribution
Allopatric species: Closely related species still geographically separated

Sympatric Speciation

- **Sympatric speciation**: A new species within the same area as the parent species.
  - There is no geographical separation between the speciating populations.
  - All individuals are, in theory, able to meet each other during the speciation process.
- Sympatric speciation is rarer than allopatric speciation among animals, but it is probably a major cause of speciation among plants.
- Sympatric speciation may ocur through:
  - A change in **host preference**, **food preference** or **habitat preference**.
  - The **partitioning** of an essential but limiting resource.
  - **Instant speciation** as a result of polyploidy (particularly among plants, as in the evolution of wheat).

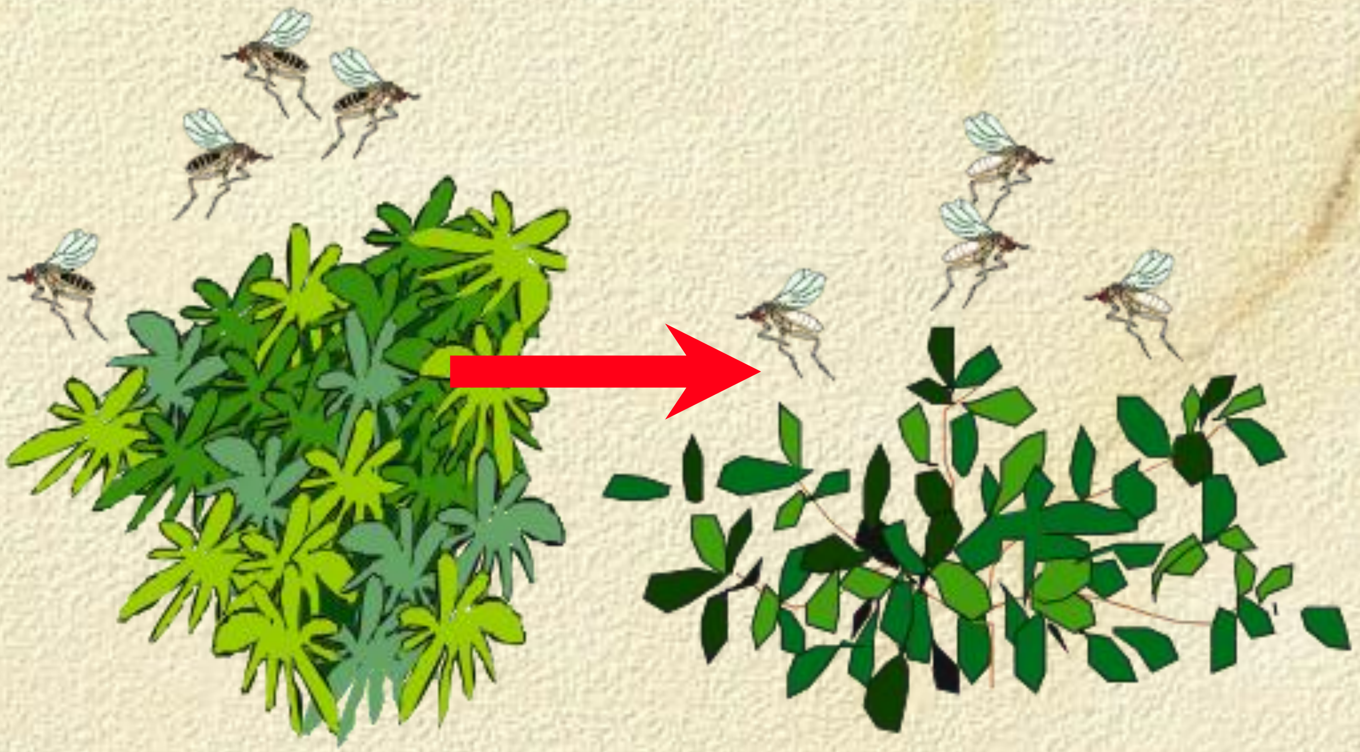
Wild Einkorn

Common Wheat

Sympatric Speciation 1

- **A change in habitat preference**:
  - It is not uncommon for some insect species to be conditioned to lay eggs on the plant species on which they themselves were reared.
    - If the normally preferred plant species is unavailable, then the insect may be forced to choose another species to lay eggs on.
    - A few eggs surviving on this new plant will give rise to a new population with a new plant species preference.

An insect forced to lays its eggs on an unfamiliar plant species may give rise to a new population of flies isolated from the original population

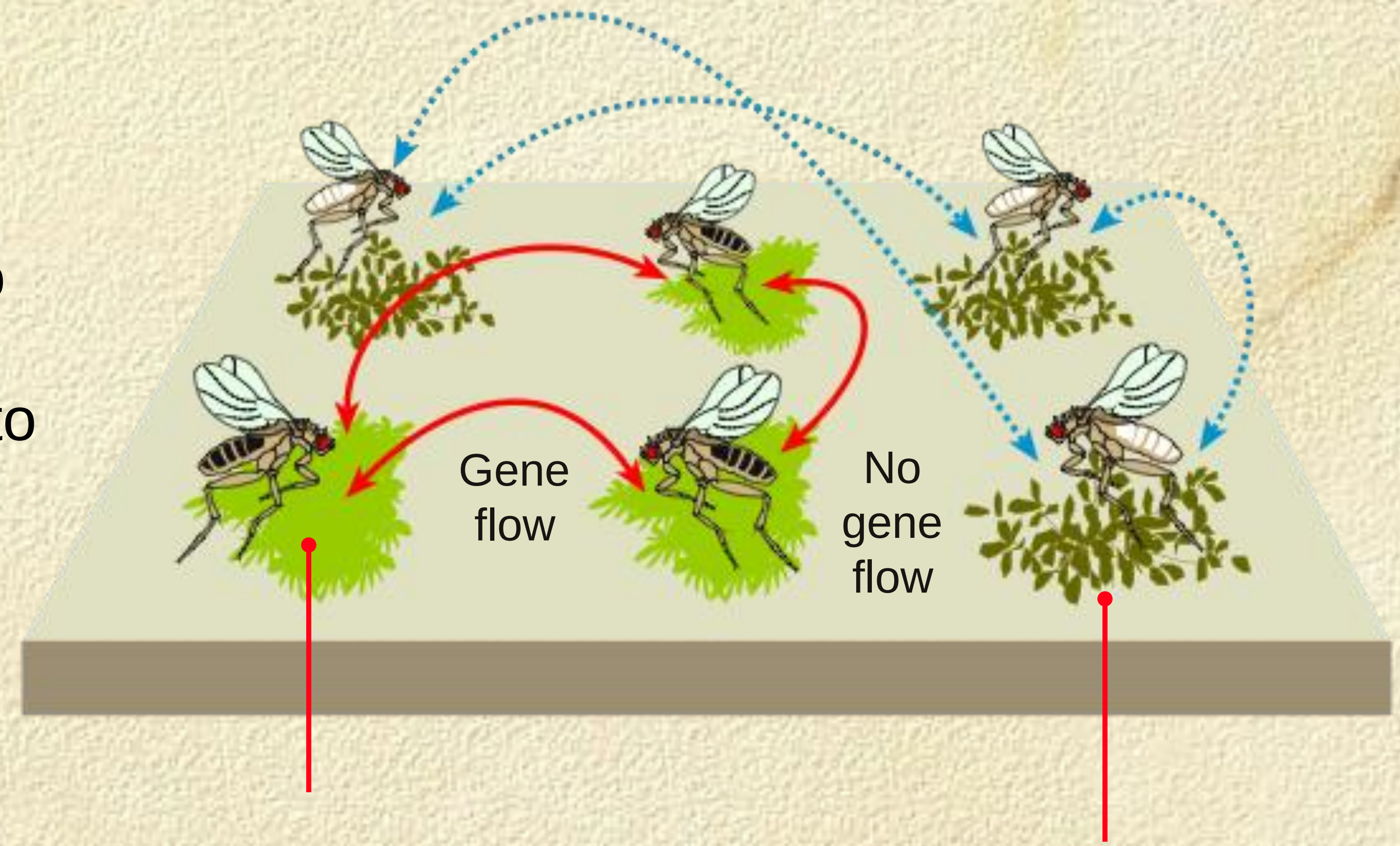


Original host plant species

New host plant species

Sympatric Speciation 2

- **Establishing reproductive isolation**:
  - If mating and rearing of offspring takes place entirely within the habitat, then the population will become reproductively isolated.
  - Further differentiation of the two populations is likely as each becomes increasingly adapted to their respective habitats.
  - Ultimately, the two groups will diverge to be recognized as separate species.



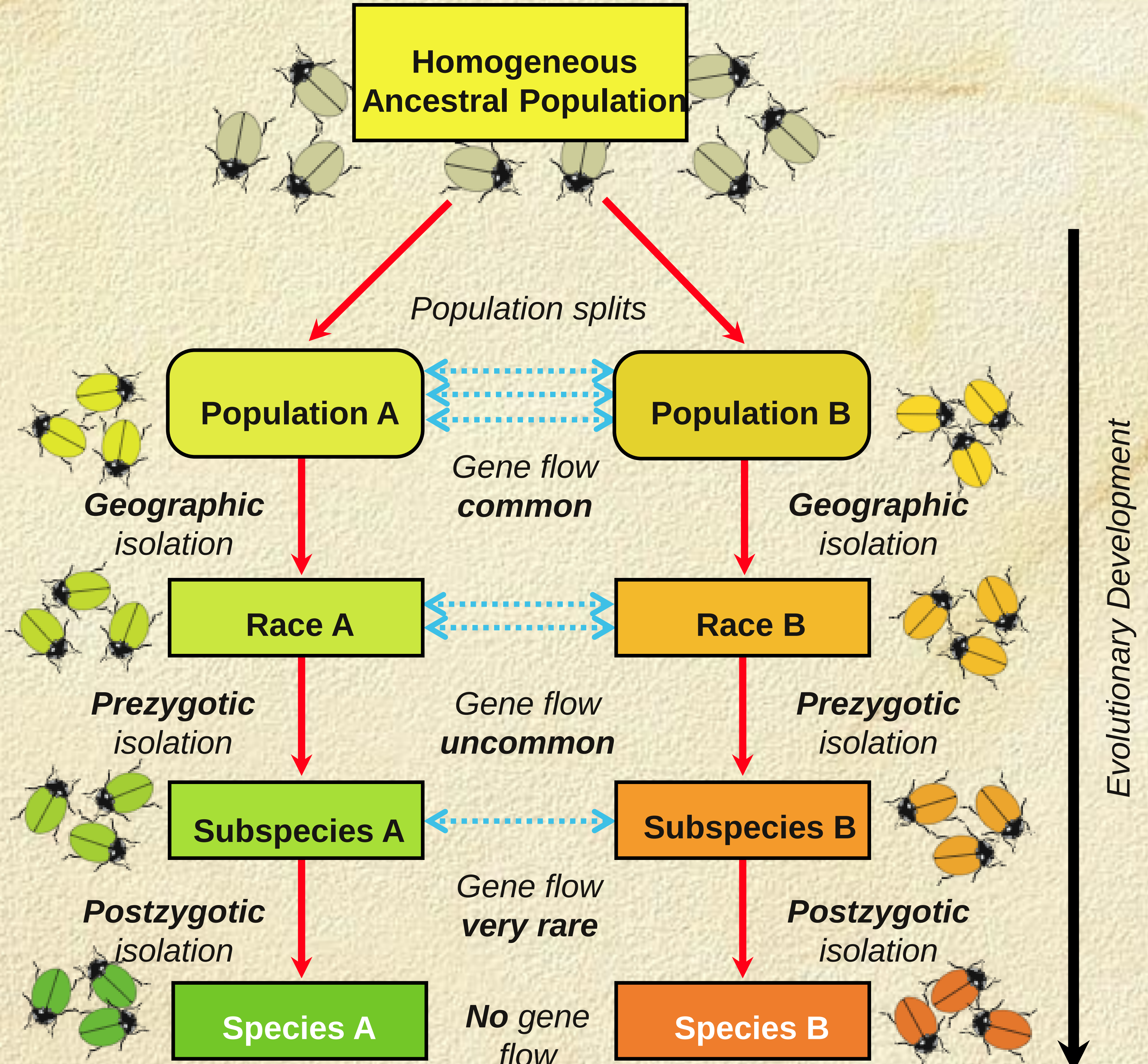
Sympatric Speciation 3

- Polyploidy involves the **multiplication** of **whole sets of chromosomes** (each set being the haploid number N).
- Polyploids occur frequently in **plants** and in some animal groups such as rotifers and earthworms.
- When such individuals **spontaneously** arise, they are **instantly reproductively isolated** from their parent population.
- As many as **80%** of **flowering plant species** may have originated as polyploids.

Different species of *Chrysanthemum* (right) have arisen as a result of polyploidy. They have chromosome numbers (2n) that are multiples of **18**: 2n = 18, 36, 54, 72, and 90.

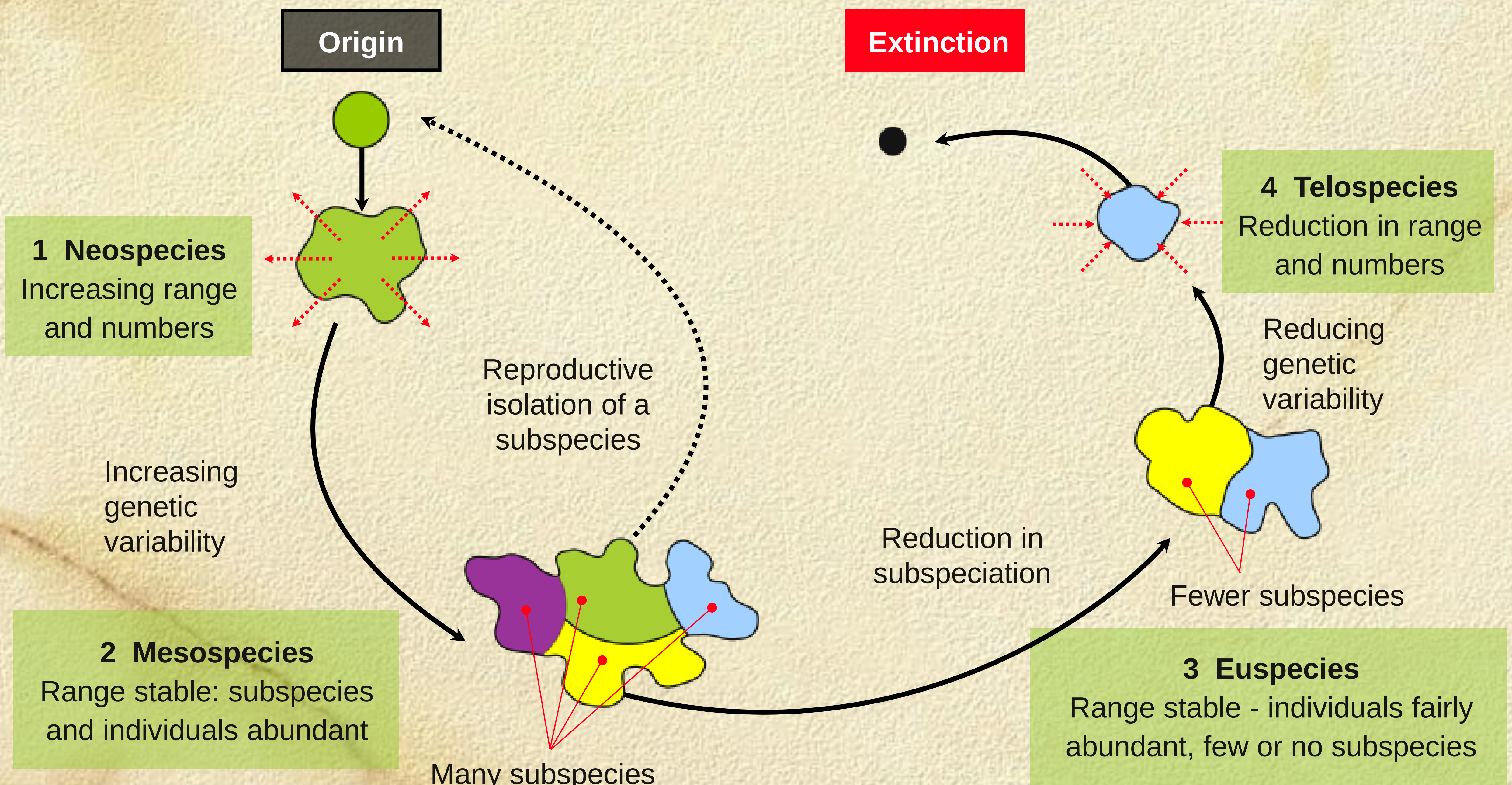
Stages in Species Formation

- Different types of isolating mechanisms operate and different amounts of **gene flow** take place as two populations diverge to form **new species**.



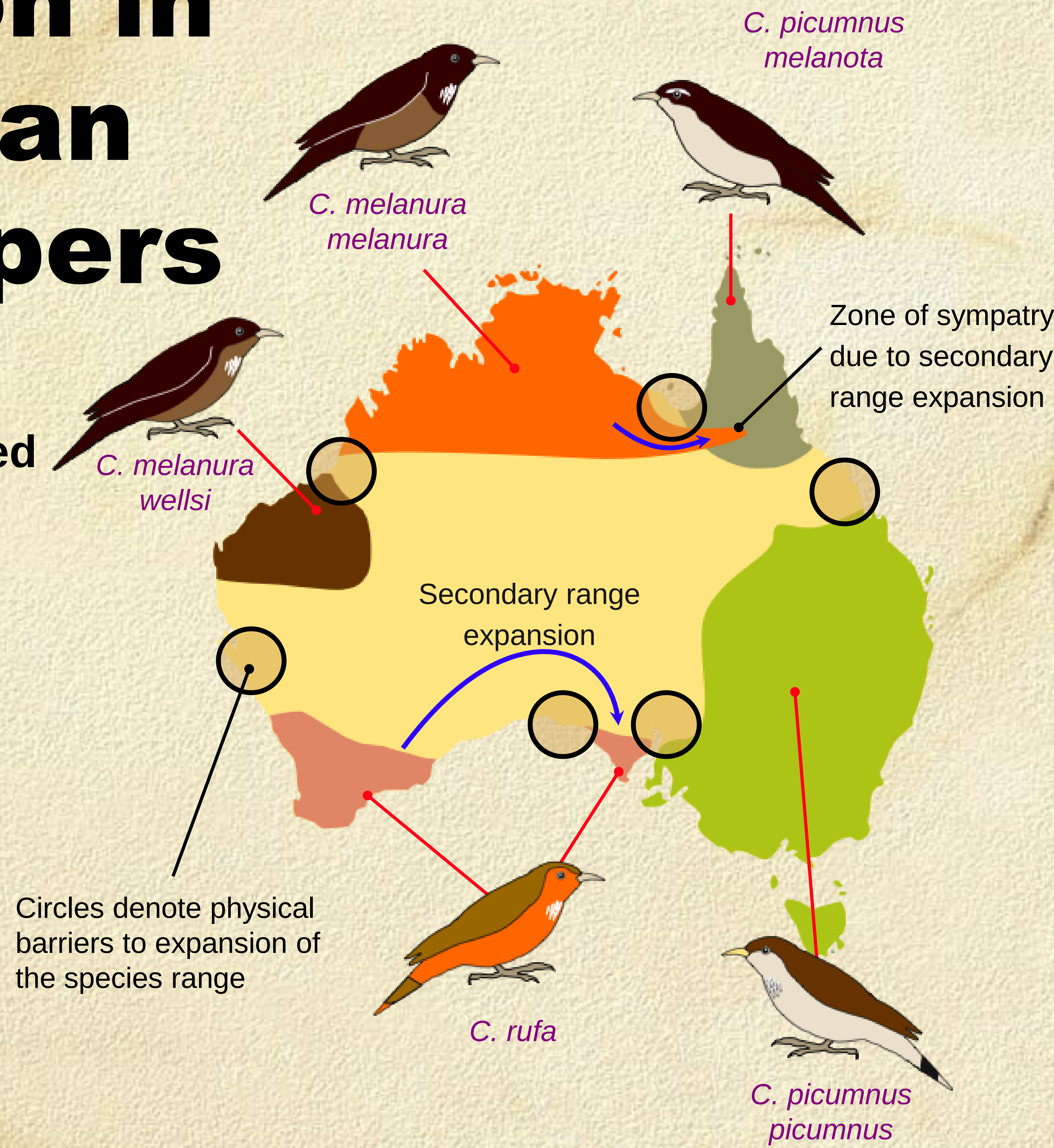
Life Cycle of Species

- Species undergo a **life cycle** of stages including **formation**, **maturation**, and **final extinction**.
  - This cycle may take from between 1-20 million years, depending on the species.



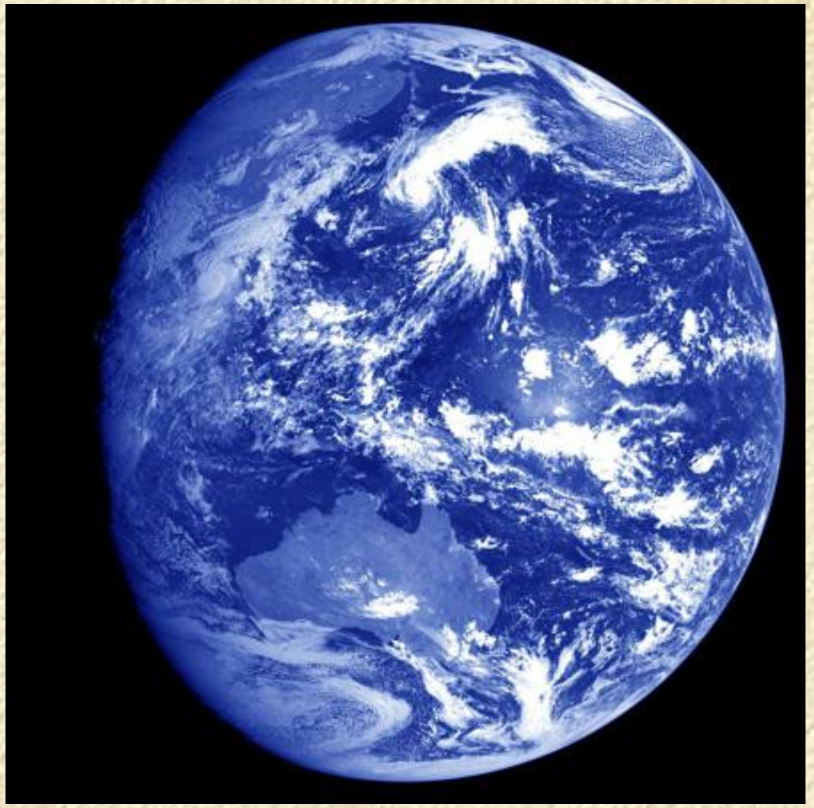
Speciation in Australian Treecreepers

- Treecreeper species populations are **isolated** by large regions of inhospitable habitat (desert and dry areas).
- These **geographical barriers** (circles) are thought to have contributed to their speciation.



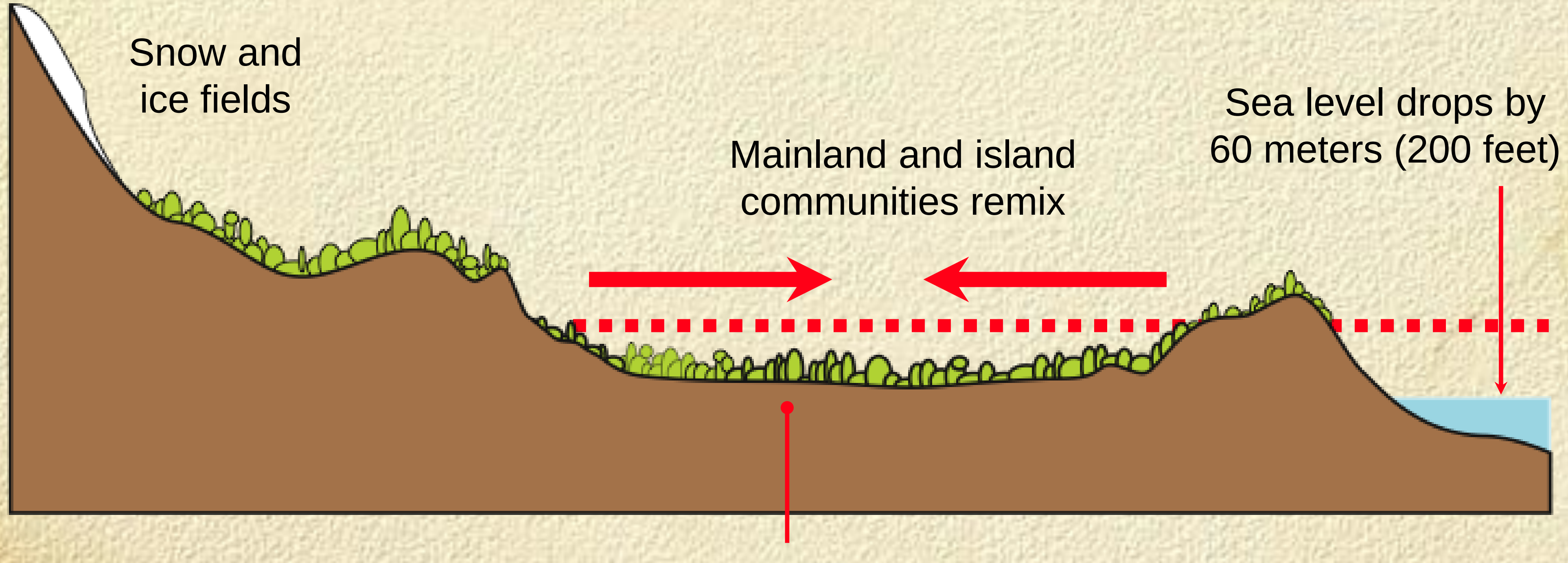
Factors Affecting Distribution

- **Changes in sea level**
  - Oscillations between periods of climatic cooling (**ice ages**) and periods of warming (**interglacials**) cause sea levels to rise and fall.
  - Falls in sea level during ice ages may create important land bridges.
  - Rises in sea level during interglacial periods create geographical barriers and may prevent gene flow between populations.
- **Continental drift**
  - The crust of the Earth is in constant motion, moving whole continents and sea floors.
  - The movement of continents, at times joining and at other times separating, has had a powerful effect on the distribution of organisms.



Ice Ages

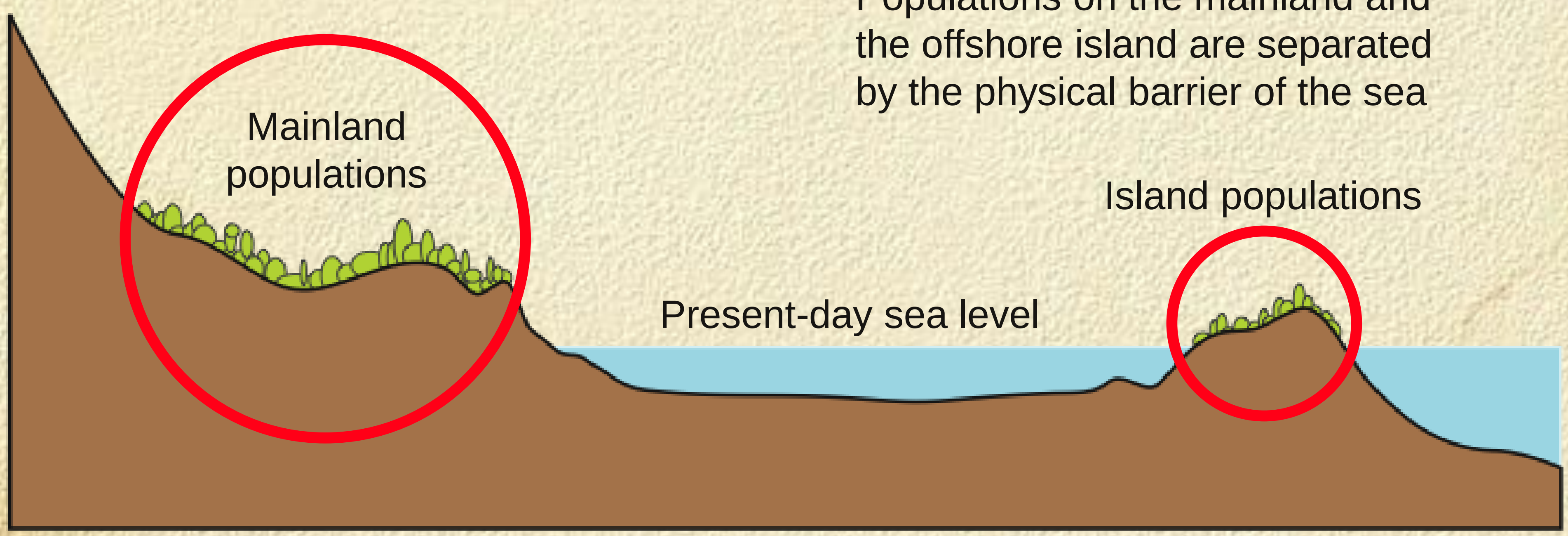
- During ice ages, vast amounts of sea water are lost as snowfall on the land and polar caps. This has the effect of causing a large **drop in sea level** (up to **60 m**).
- Areas previously isolated by water may develop land bridges, allowing species to move from one region to another.



After the sea bed has been exposed for thousands of years, recolonization by terrestrial plants and animals may occur, allowing dispersal of island species to to the mainland and vice versa.

Warm Periods (Interglacials)

- In **interglacial periods**, species may again be isolated by a rise in sea level.
- Separated on either side of a now submerged land bridges, they may evolve in response to very different selection pressures.



These isolated populations may be subjected to different **natural selection** pressures and may ultimately give rise to separate species.

Continental Drift 1

- The movement of continents moved whole assemblages of plants and animals across the surface of the Earth.
- As well as creating geographical barriers in the form of oceans, it brought new combinations of species together.

Late Palaeozoic

250 million years ago

The continents formed a single landmass; dinosaurs and mammal ancestors roamed the earth.

Paleocene – Mid Eocene

65-46 million years ago

Most continents were separated, North America and Europe joined; Mammals underwent adaptive radiation into many forms.

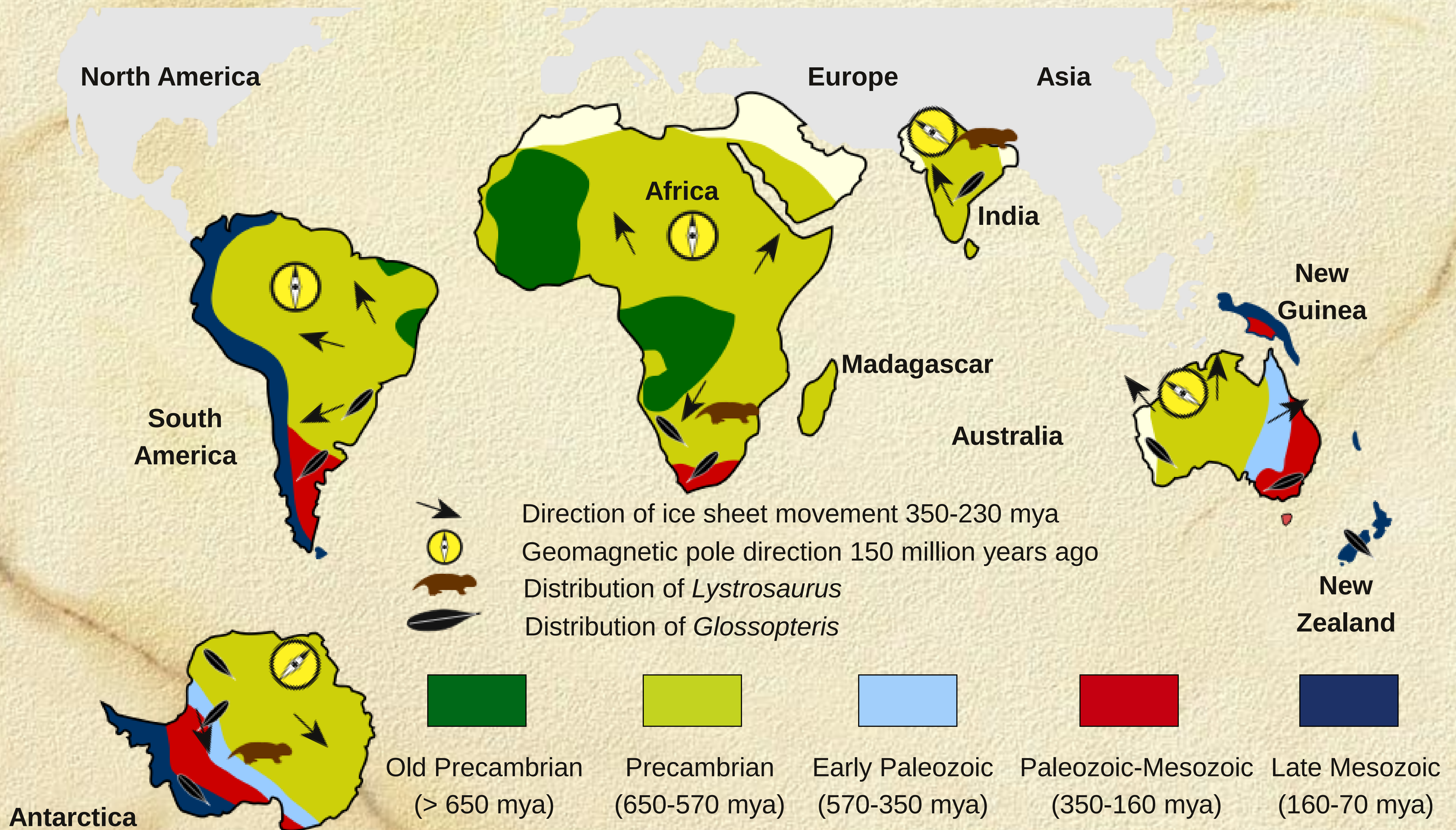
Late Eocene

46-38 million years ago

Europe split away from North America and joined Asia. India was still an island, with South America joined to Antarctica.

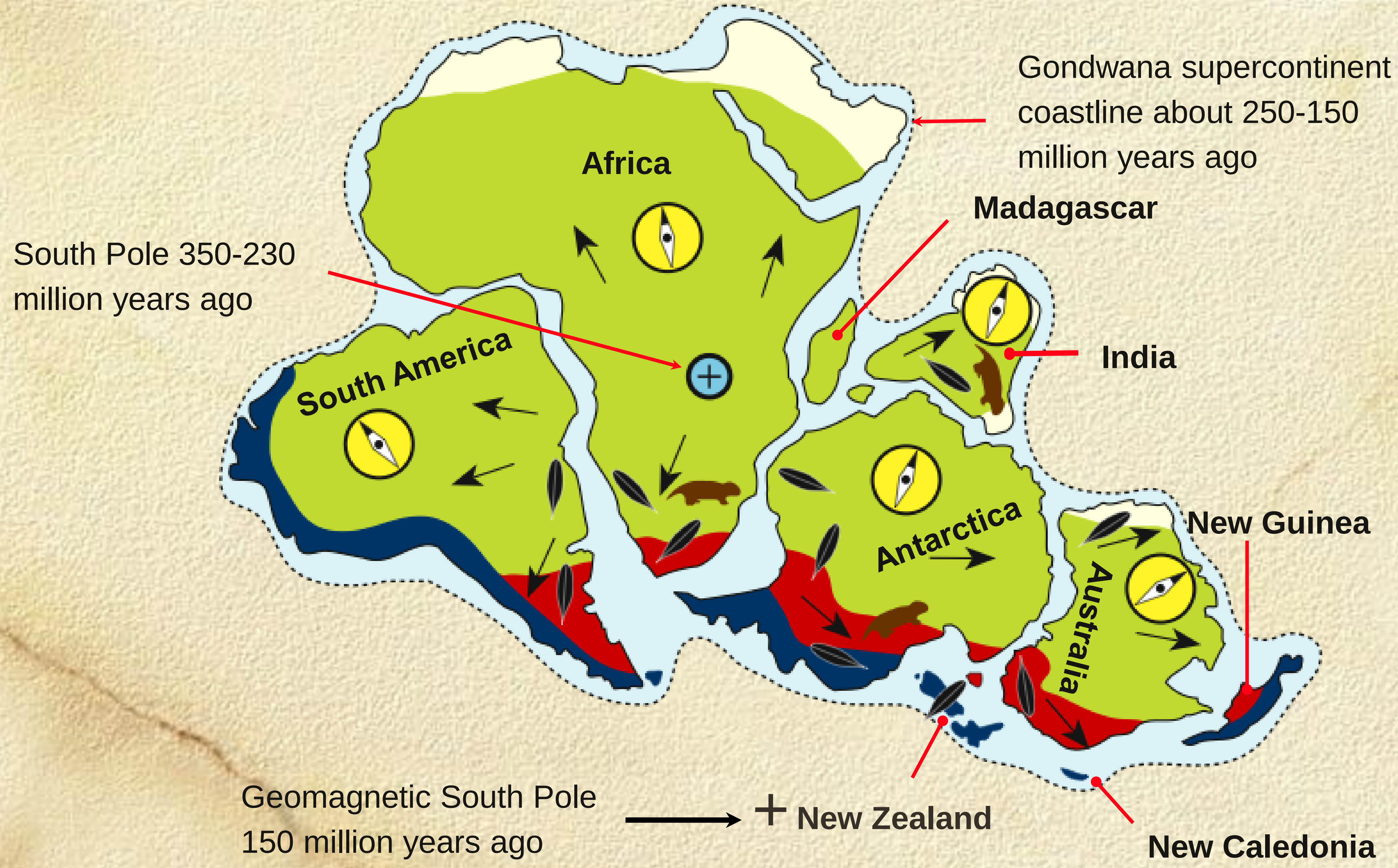
Continental Drift 2

- A map of the present day world showing the evidence for how present-day lands once made up the supercontinent of **Gondwana**.



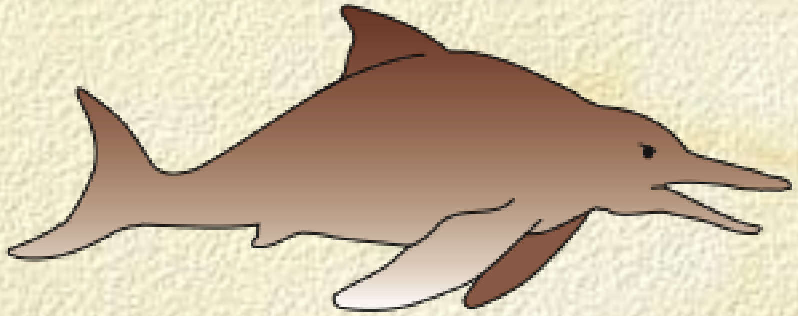
Continental Drift 3

- The continents and islands that once comprised **Gondwana** may be fitted together to form a single landmass.

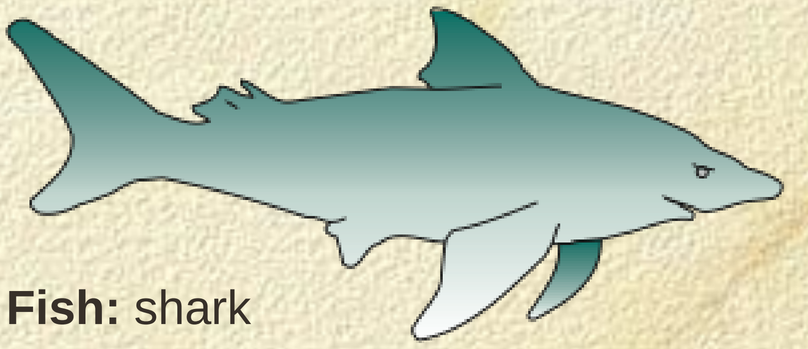


Convergent Evolution

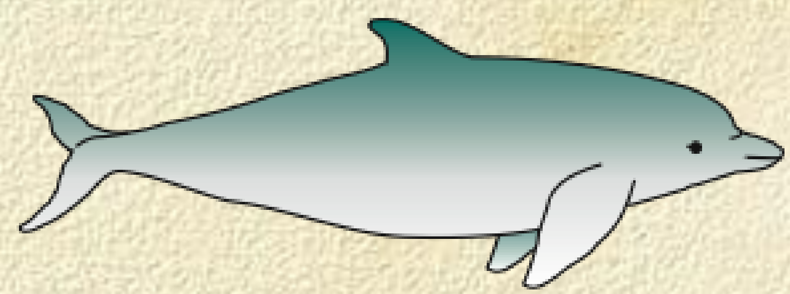
- Not all similarity is inherited from a **common ancestor**:
  - Species from different evolutionary branches may resemble each other if they have similar ecological roles.
  - This is called **convergent evolution**.
- Similarity due to convergence is not a basis for including species in the same taxonomic group.
  - Example: The **swimming carnivore niche**.
  - This niche was exploited by a number of unrelated vertebrate groups at different times in the history of life.
  - The selection pressures of this niche produced fins or flippers and a streamlined body shape for rapid movement through the water.



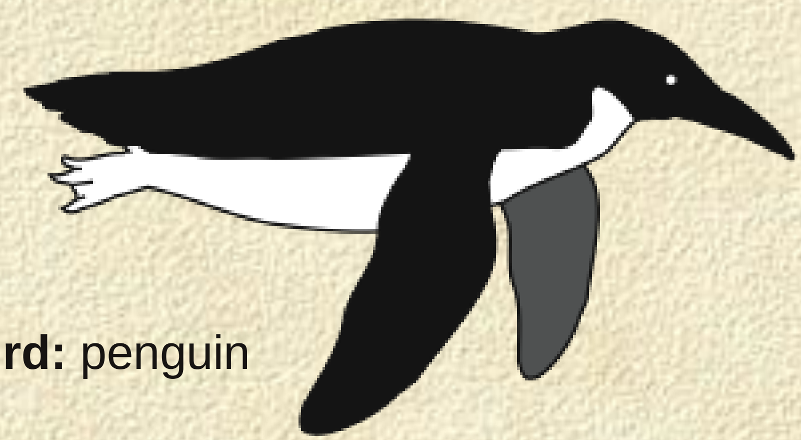
Reptile: icthyosaur (extinct)



Fish: shark



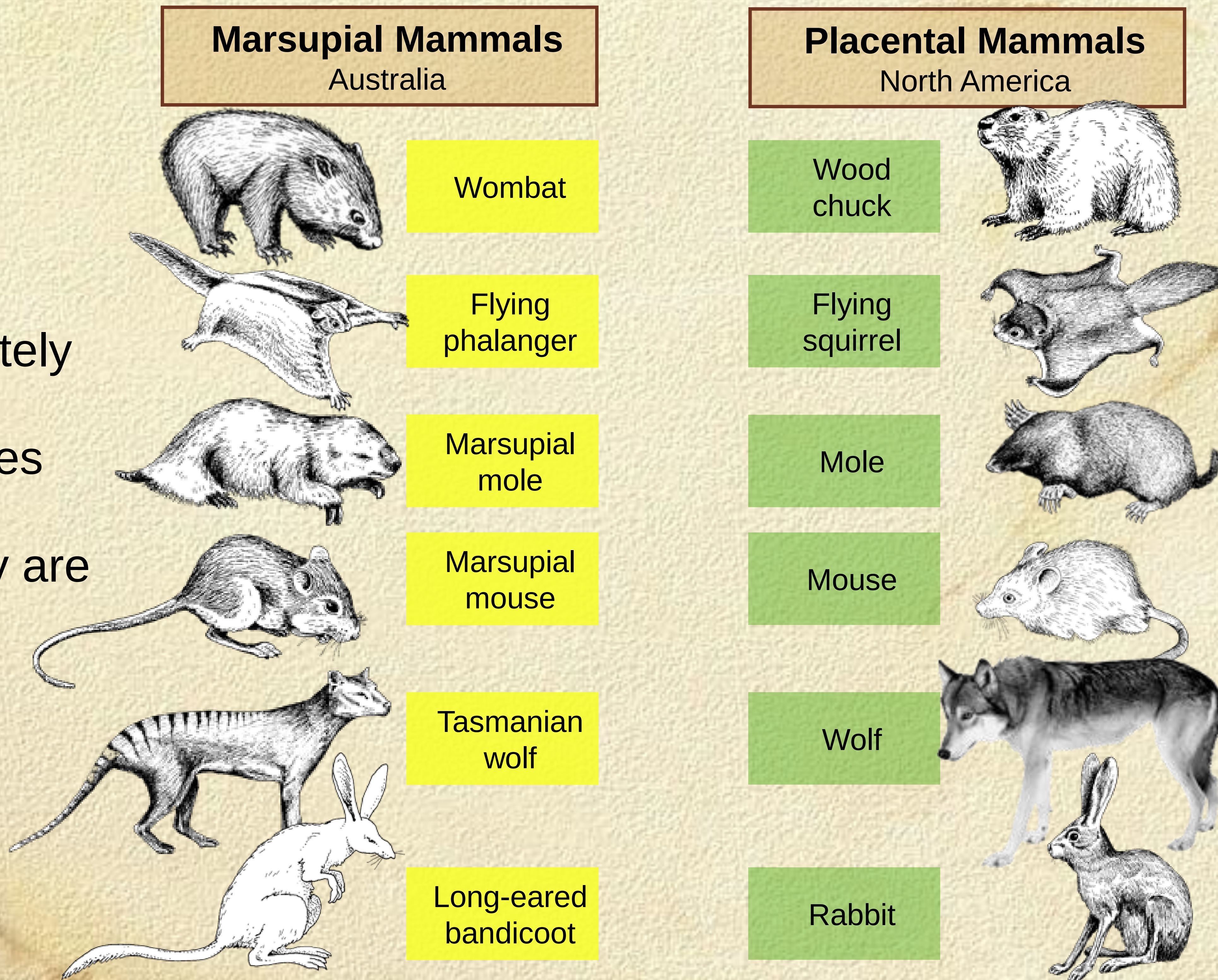
Mammal: dolphin



Bird: penguin

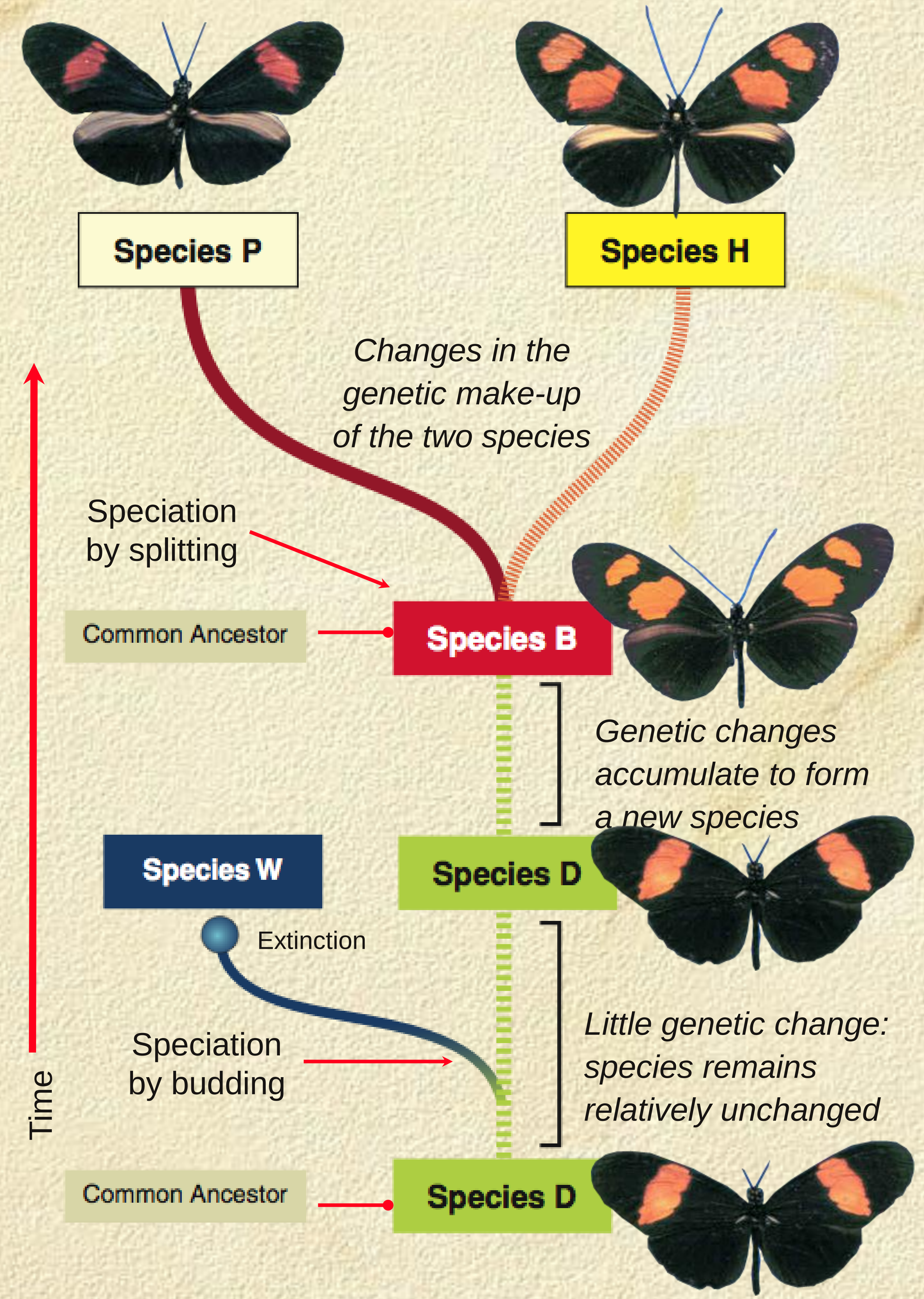
Convergent Evolution in Mammals

- **Marsupial** and **placental** mammals have evolved separately to occupy equivalent niches on different continents; they are **ecological equivalents**.



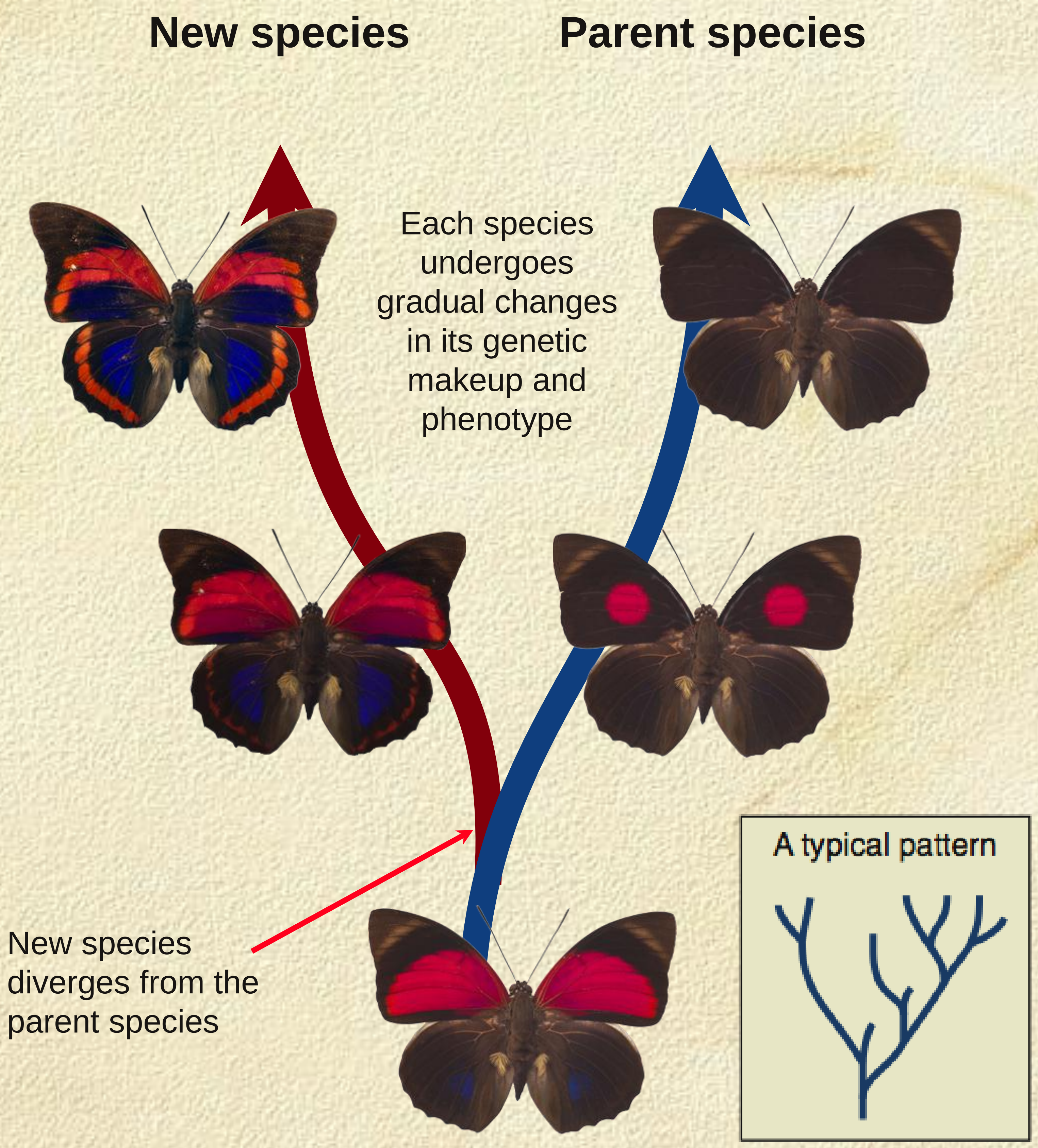
Divergent Evolution

- The diversification of an ancestral group into two or more species in different habitats is called **divergent evolution**.
- When divergent evolution involves the formation of a large number of species to occupy different niches this is called an **adaptive radiation**.
  - A hypothetical family tree showing divergence from common ancestors on two occasions is shown here:



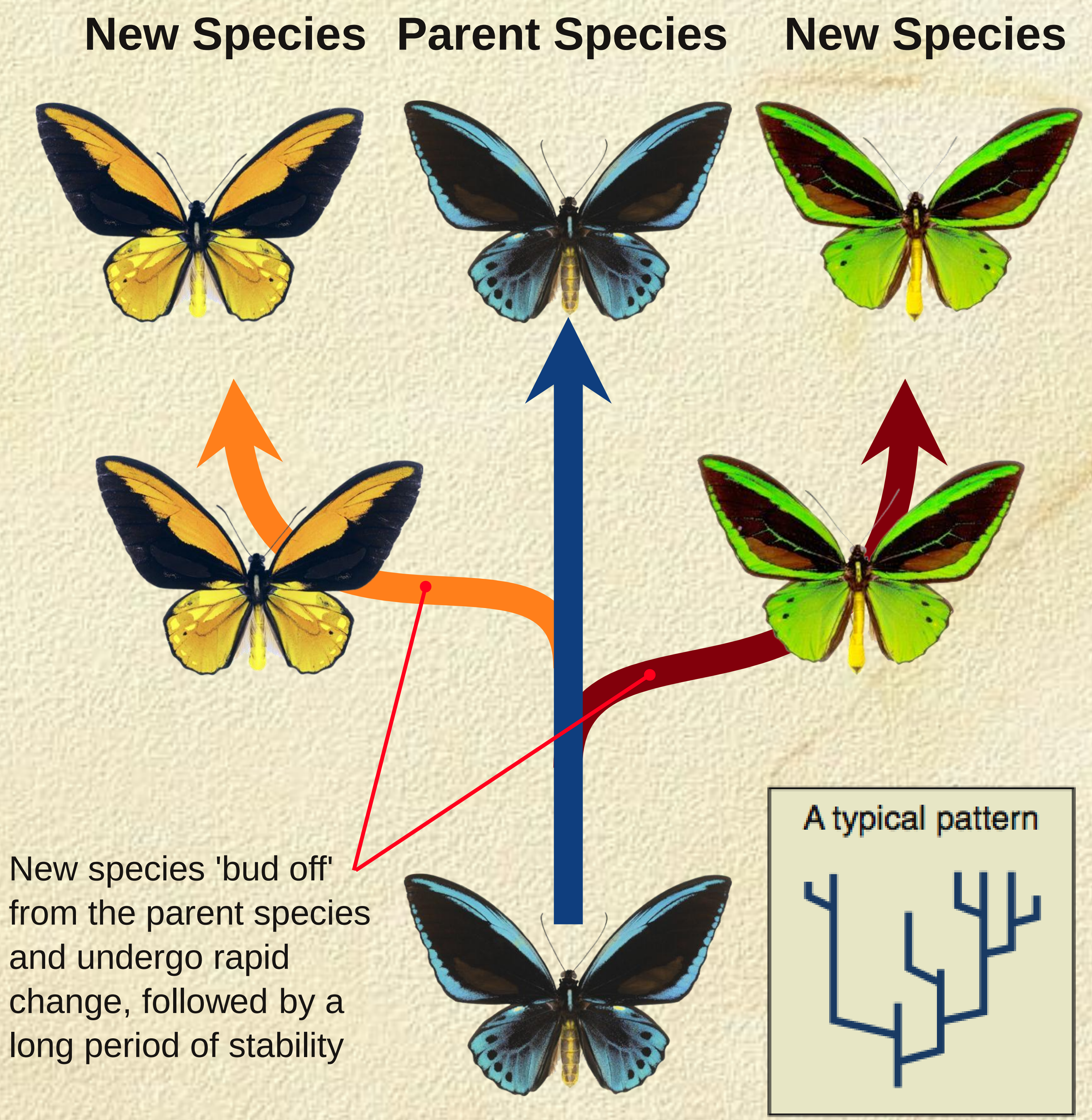
Gradualism

- **Gradualism** assumes that populations slowly diverge from one another by accumulating adaptive characteristics in response to different selective pressures.
- If species evolve by gradualism there should be transitional forms seen in the fossil record (as with the evolution of the horse).



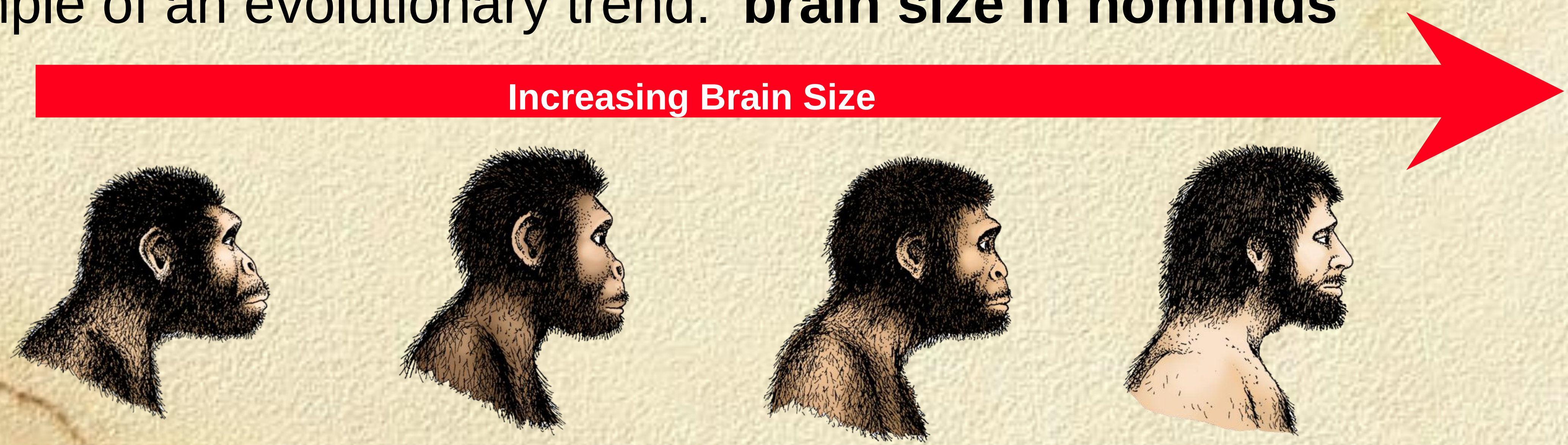
Punctuated Equilibrium

- There is abundant evidence in the fossil record that, instead of gradual change, species stay much the same for long periods (**stasis**) and then have short bursts of evolution that produce new species quite rapidly.
- According to this **punctuated equilibrium theory,** most of a species existence is spent in stasis and little time is spent in active evolutionary change.



Macroevolution

- Macroevolution refers to evolutionary changes above the level of the species: **changes in genera or orders**.
- Macroevolution is concerned with changes in the kinds of species over evolutionary time and includes:
  - The **origin of unusual features** (evolutionary novelties).
  - The origin of **evolutionary trends** (e.g. increased brain size in primates).
  - **Adaptive radiation** (a form of divergent evolution).
  - **Extinction**.
- Example of an evolutionary trend: **brain size in hominids**



A. afarensis	*H. habilis*	*H. erectus*	*H. sapiens*
440 ml	**575 ml**	**1100 ml**	**1450 ml**

The Evolution of Novel Features

- A change in a basic design element in an organism can produce a unique feature.
  - Examples include the evolutionary development of:
    - **Flowers** in angiosperms.
    - **Feathers** in birds.
    - **Wings** in insects.

The Evolution of Novel Features

- These new structures or **pre-adaptations** are usually variations of some existing structure already in use for some other function:
  - The feathers of birds have evolved from the scales of reptiles.
  - The bones of the middle ear in mammals have been modified from equivalent bones of the reptilian jaw.
- Novel adaptations are thought to arise through changes to regulatory genes.
- This can result in changes to body structure, or to the rate or timing of development.

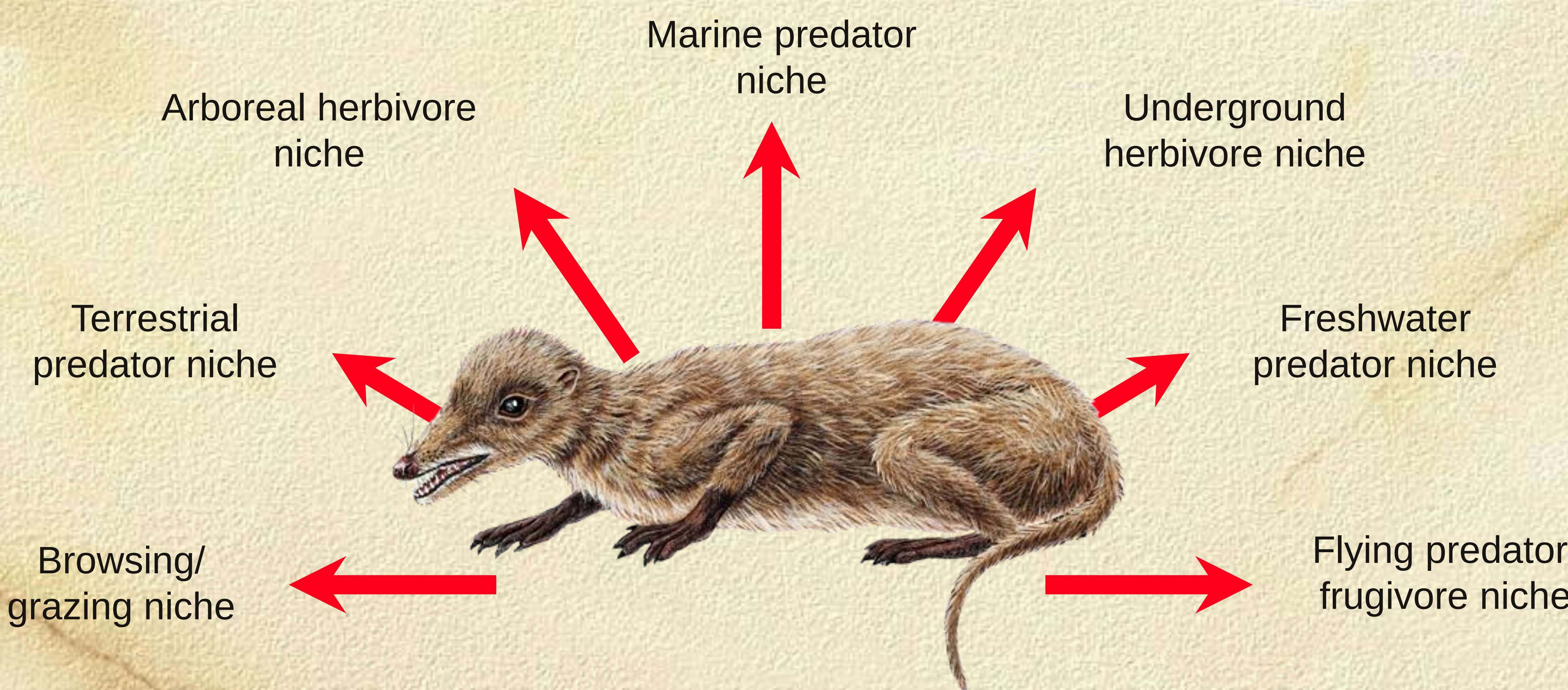
Adaptive Radiation

- When an organism develops a new adaptive feature, a new niche may become available to it.
- Once new niches are made available, new species develop to exploit different habitats and there is a radiation from the point of species origin.
- Adaptive radiation is more common in periods of major environmental change, e.g. cooling climates.
  - These changes may be the driving force for adaptive radiation or they may have an indirect effect by increasing extinction rates.

The early ancestors of whales left the land to exploit a new niche as marine predators

Adaptive Radiation

- **EXAMPLE**: The radiation of the **mammals** occurred after the extinction of the dinosaurs, which has made niches available for exploitation.

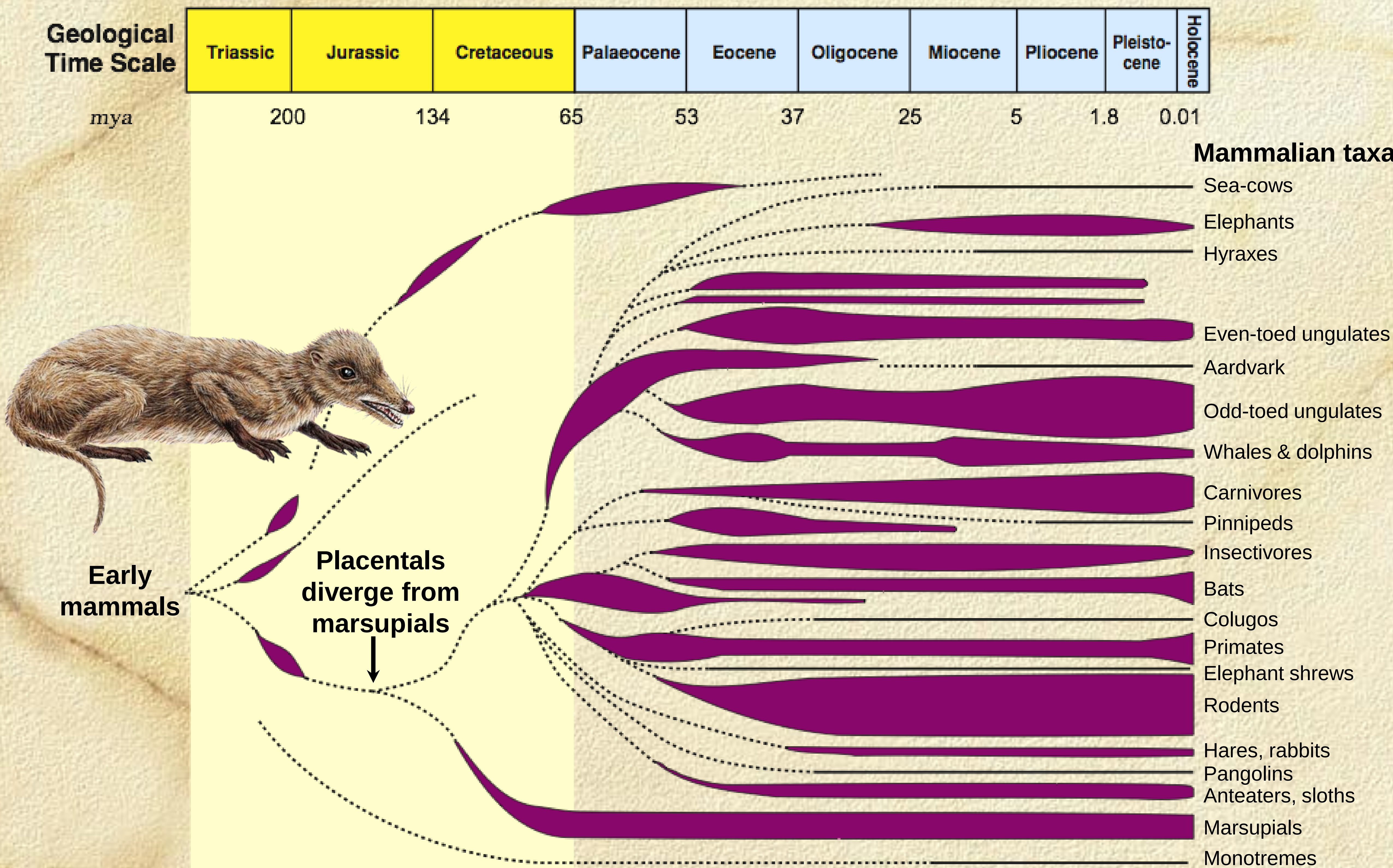


Megazostrodon

an early mammal ancestor

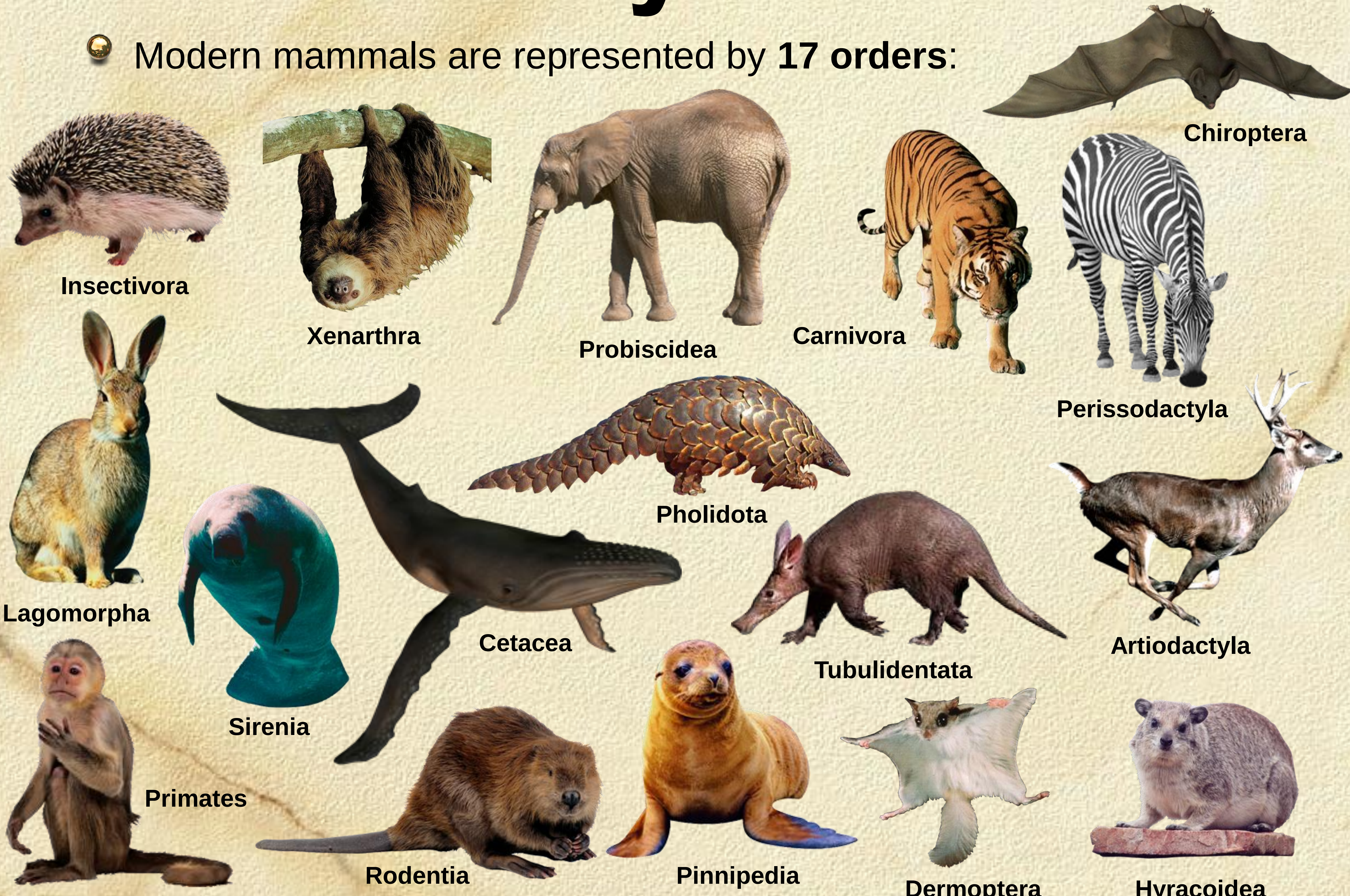
Mammal Adaptive Radiation

- The mammals have diversified widely to fill many different niches:

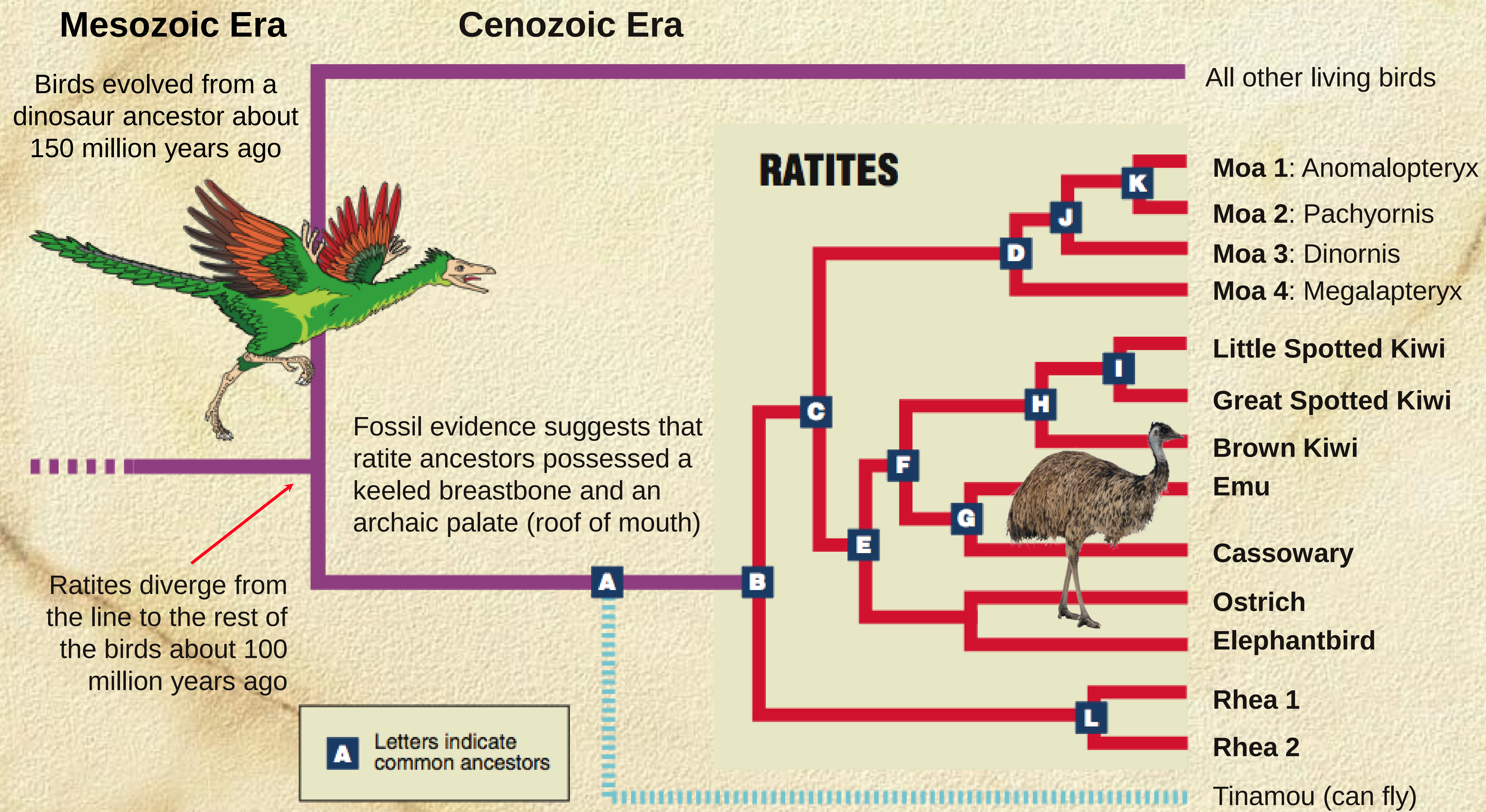


The Diversity of Mammals

- Modern mammals are represented by **17 orders**:



Divergence and Radiation of the Ratites



Coevolution

- **Coevolution** is used to describe cases where two (or more) species reciprocally affect each other's evolution.
  - Each party in a co-evolutionary relationship exerts selective pressures on the other and, over time, the species become mutually dependent on each other.
- Coevolution is a likely consequence when different species have close ecological interactions with one another. These relationships include:
  - **Predator-prey** relationships
  - **Parasite-host** relationships
  - **Mutualistic relationships** such as those that have arisen between plants and their pollinators (photos, right).

Bees are excellent pollinators and collect nectar from many flower types.

Beetles are an ancient group with many modern species. Their high diversity has been attributed to coevolution with flowering plants.

Acacia-Ant Coevolution

- Flower structure has evolved in many different ways in response to the many types of animal pollinators.
- Flowers and their pollinators have coordinated traits known as **pollination syndromes**.
  - This makes it relatively easy to deduce pollinator type from the appearance of flowers (and vice versa).
- Plants and animals involved in such pollination associations often become highly specialized in ways that improve pollination efficiency: innovation by one party leads to some response from the other.

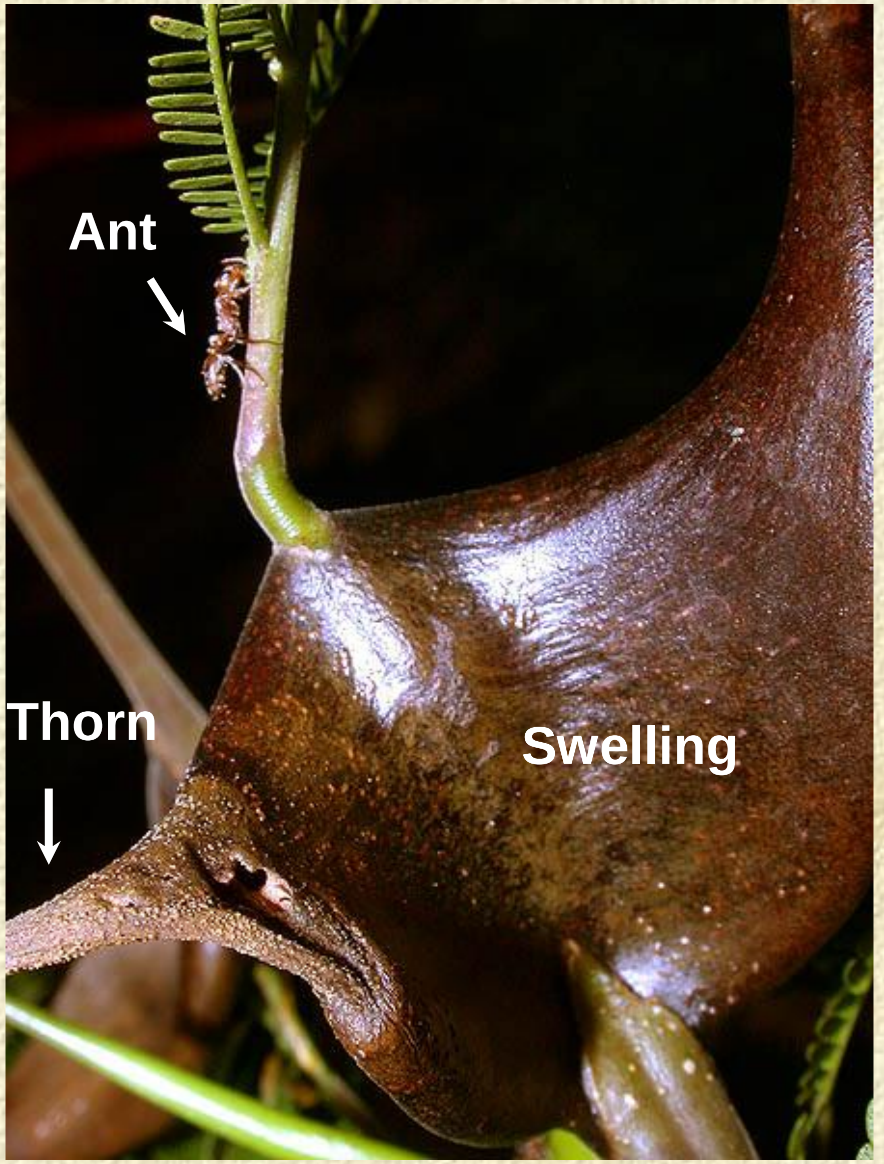


Photo courtesy of Alex Wild

The long, hollow thorns of the **swollen-thorn *Acacia*** provide living space for the aggressive stinging ***Pseudomyrmex*** ants which patrol the plant and protect it from herbivores. The *Acacia* provides the ants with protein-rich food.

Flowers and their Pollinators

- Flower structure has evolved in many different ways in response to the many types of animal pollinators.
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- Plants and animals involved in such pollination associations often become highly specialized in ways that improve pollination efficiency: innovation by one party leads to some response from the other.

The sweet fragrance of many flowers is attracts their nectar seeking pollinators, but flowers pollinated by many flies can give off dung or rotten meat smells.

Pollination Syndromes: Birds

- **Bird pollinators** typically:
  - Usually require a perching site, although some, like hummingbirds, can hover.
  - Have good color vision, including red and poor smell.
  - Feed during the day
  - Have high energy requirements
- **Bird-pollinated flowers** are typically:
  - Large and damage resistant
  - Red or other bright colors
  - Not very fragrant
  - Open during the day
  - Produce copious nectar

Hummingbirds can hover and are able to feed from hanging flowers. Their long tongues can take nectar from flowers with deep tubes. As they feed, their heads are dusted with pollen.

Pollination Syndromes: Bats

- **Bat pollinators** typically:
  - Are active during the night but cannot fly in foliage
  - Color blind but with an excellent sense of smell
  - Have high energy requirements
  - Have high blossom intelligence
- **Bat-pollinated flowers** typically:
  - Open at night
  - Are light or drab colored
  - Produce strong, often bat-like odors
  - Are an open shape to allow easy access
  - Produce plentiful nectar and pollen

The short-tailed bat (above) crawls on the forest floor, feeding on and pollinating the rare parasitic plant, ***Dactylanthus*** (below). The drab flowers do not attract other pollinators.

Pollination Syndromes: Beetles

- **Beetles**:
  - Are an ancient group with many modern representatives
  - Have a good sense of smell
  - Have hard smooth bodies
  - Consume ovules as well as nectar and pollen
- **Beetle-pollinated flowers** are typically:
  - Members of ancient plant groups
  - Produce strong, fruity odors
  - Are large, often flat, with easy access

Ovule herbivory by beetles may have driven the evolution of protective carpels in angiosperms.

Pollination Syndromes: Bees

- **Bees** typically:
  - Are strong, with medium length tongues
  - Color vision into UV, but not red
  - Have a good sense of smell
  - Require both nectar and pollen for feeding brood
  - Have high blossom intelligence and can communicate with their social group
- **Bee-pollinated** flowers are:
  - Fragrant, often with a complex structure
  - Typically blue, purple, lavender, yellow or white (not red)
  - Offer nectar and pollen as rewards

Bees favor bright, fragrant flowers with **nectar guides** (patterns or lines used to guide the insect to the reproductive parts of the flower). Some nectar guides are only visible in the UV.

Predators and Coevolution

- **Predators** have evolved to exploit prey; hunting ability is paramount so they have adaptations to improve hunting efficiency, including:
  - Speed, strength, and stamina
  - Good vision and hearing
  - Offensive weapons (teeth, claws)
  - Hunting strategies such as group cooperative behavior
- **Prey** have evolved numerous strategies to protect themselves from predators, including:
  - Large size and strength
  - Protective coverings
  - Defensive weapons (e.g. horns)
  - Toxicity

Lions may hunt cooperatively to increase their chances of securing a kill from swift, herding species such as zebra.

Coevolution and Mimicry

- Palatable insect species may evolve to resemble toxic or unpalatable species. This is called **Batesian mimicry**.
- Plants may evolve mimicry to protect themselves from herbivores:
  - Female *Helicornius* butterflies will not lay their eggs on plants already occupied by eggs, because their larvae are cannibalistic.
  - Passionfruit plants have exploited this by creating fake yellow eggs on leaves and buds.

The dangerous common wasp

…and its harmless Batesian mimic, the wasp beetle

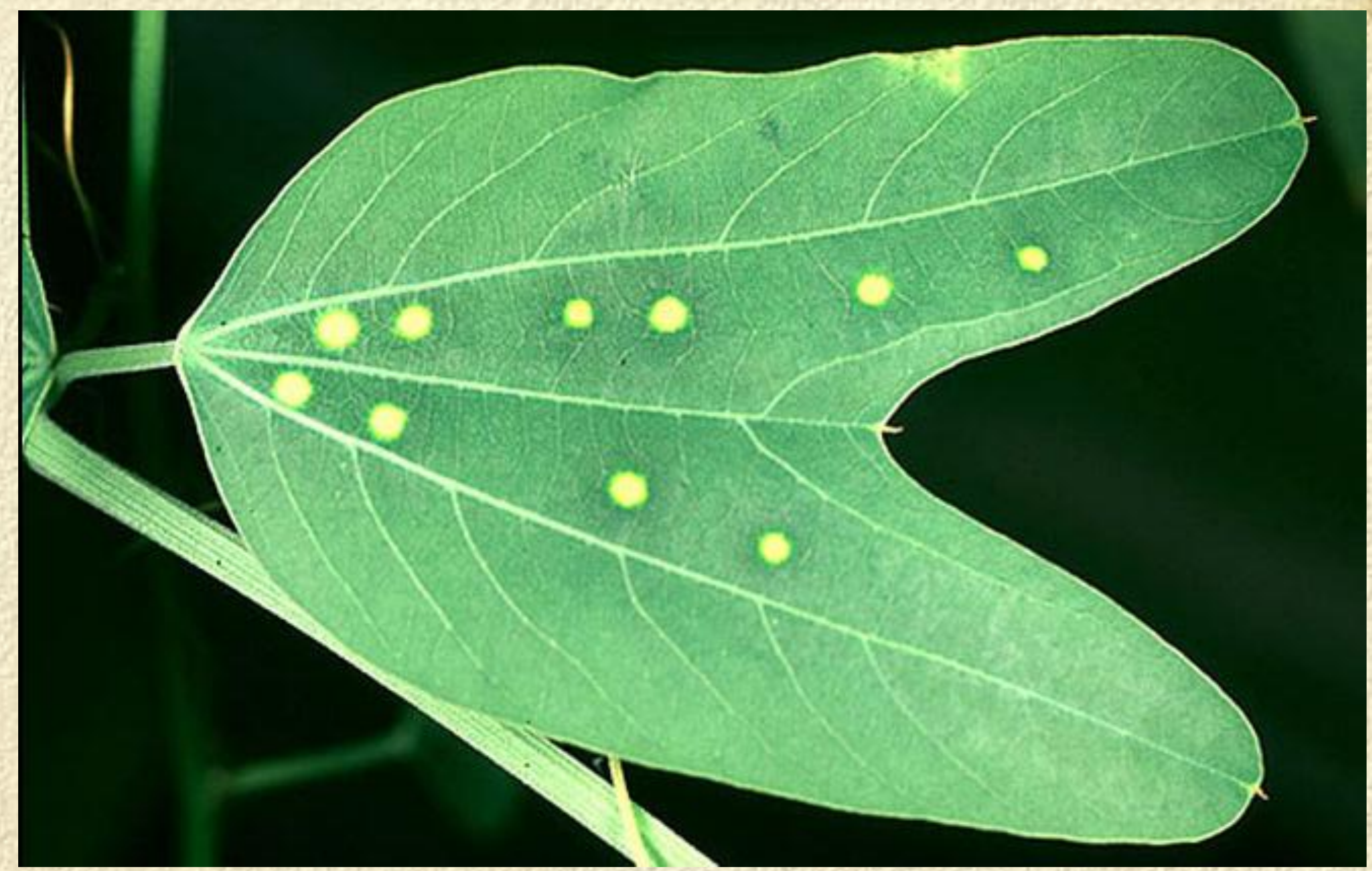


Photo courtesy of Missouri Botanical Gardens

Passionfruit plant (*Passiflora*) with egg mimics

Parasites and Coevolution

- Trypanosomes provide an example of host-parasite coevolution.
  - They must evade their host defenses, but…
  - Virulence is constrained because they must keep their host alive.
- Molecular studies show that ***Trypanosoma brucei*** coevolved in Africa with the first hominids around 5mya.
- However, ***T. cruzi*** contact with human hosts occurred in South America only after settlements were made by nomadic cultures.

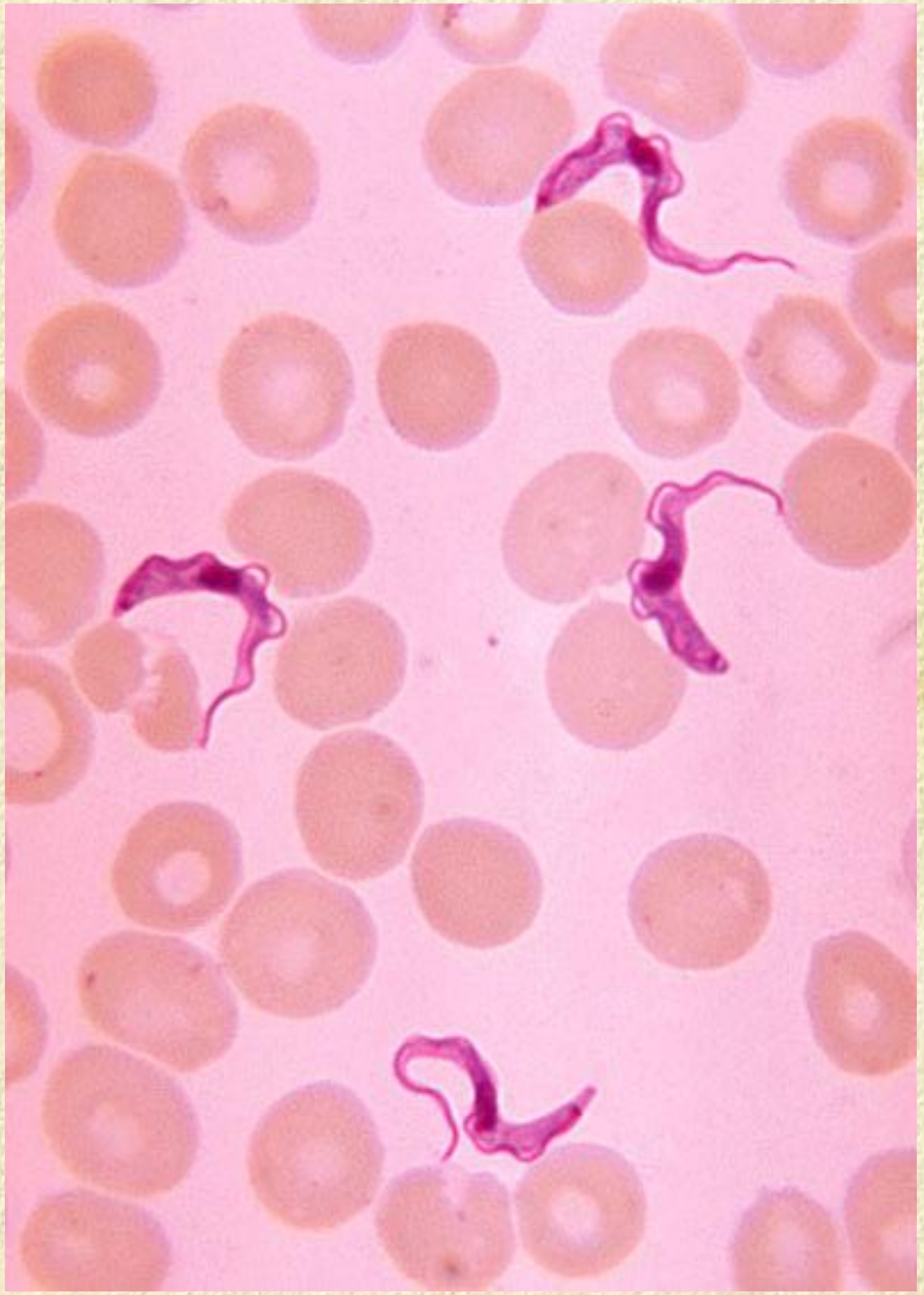


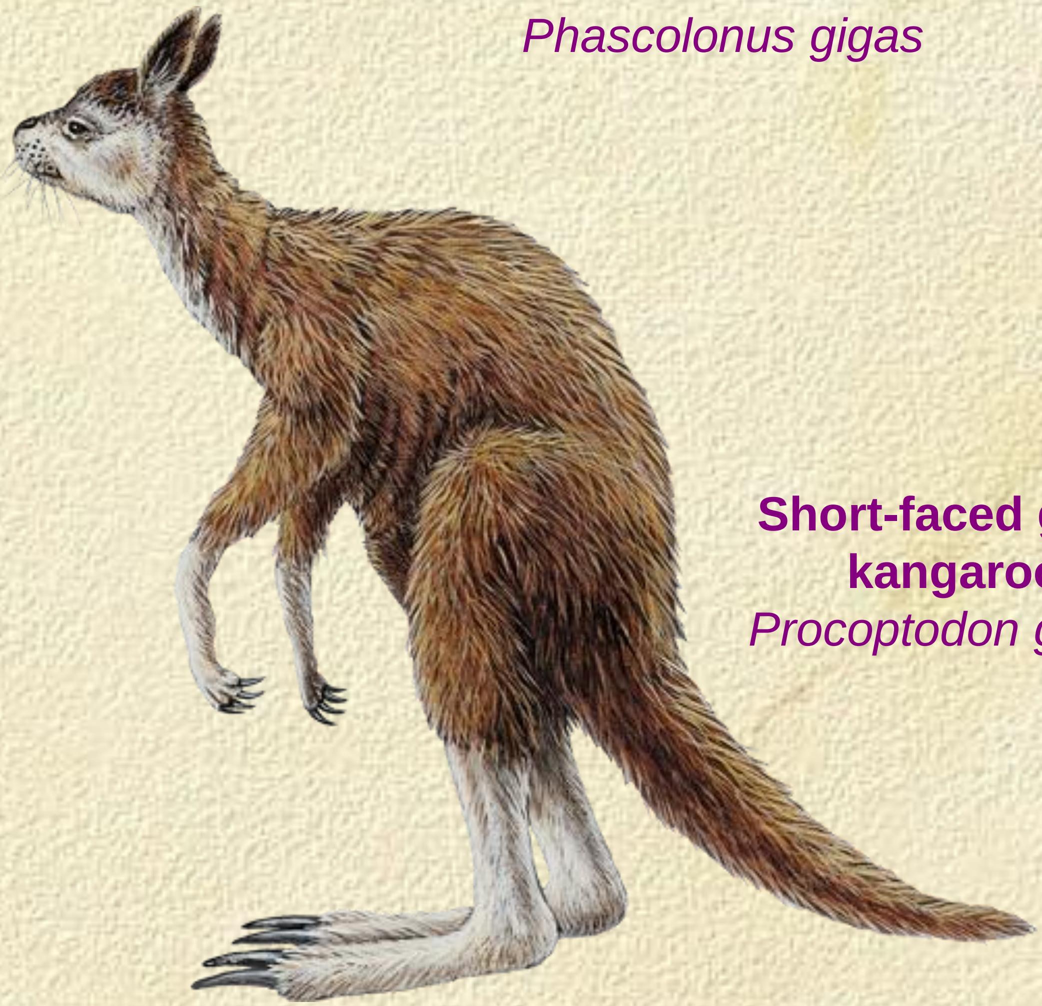
Photo courtesy of CDC

Trypanosome parasites in human blood

Extinction

- Most species that have ever lived are now extinct.
- Entire lineages that were once dominant have now disappeared or have dwindled in numbers as other radiations have flourished.
- Often, the extinction of one group has allowed another to undergo extensive radiation into free niches: large scale species changes are probably opportunistic events.
- **Radiations** may follow **extinctions** but are rarely the cause of them.

Giant wombat
Phascolonus gigas



Short-faced giant kangaroo
Procoptodon goliah

The extinction of megafauna, such as Australia's giant kangaroo and giant wombat, was a global phenomenon. Africa is now the only continent still with a significant mammalian megafauna.

Background Extinction

- **Background rates of extinction**
  - A background rate of extinction describes the steady rate of species extinction that is a natural feature of evolving taxonomic groups.
  - The causes of such extinctions vary. Larger and more complex organisms generally have higher rates of background extinction than simpler organisms.
  - Studies of the fossil record show that each taxonomic group has species with a characteristic “duration of existence” before becoming extinct.
  - This provides the average background extinction rate for the taxonomic group.

Examples of the estimated average species duration

Taxonomic group	Species duration (millions of years)
Mosses and liverworts	20 +
Higher plants	8-20 +
Bivalves	11-14
Snails	10-13
Ammonites	1-15
Trilobites	1 +
Beetles	2 +
Freshwater fishes	3
Snakes	2 +
Mammals	1-2 +

(After Stanley, 1985)

Mass Extinctions

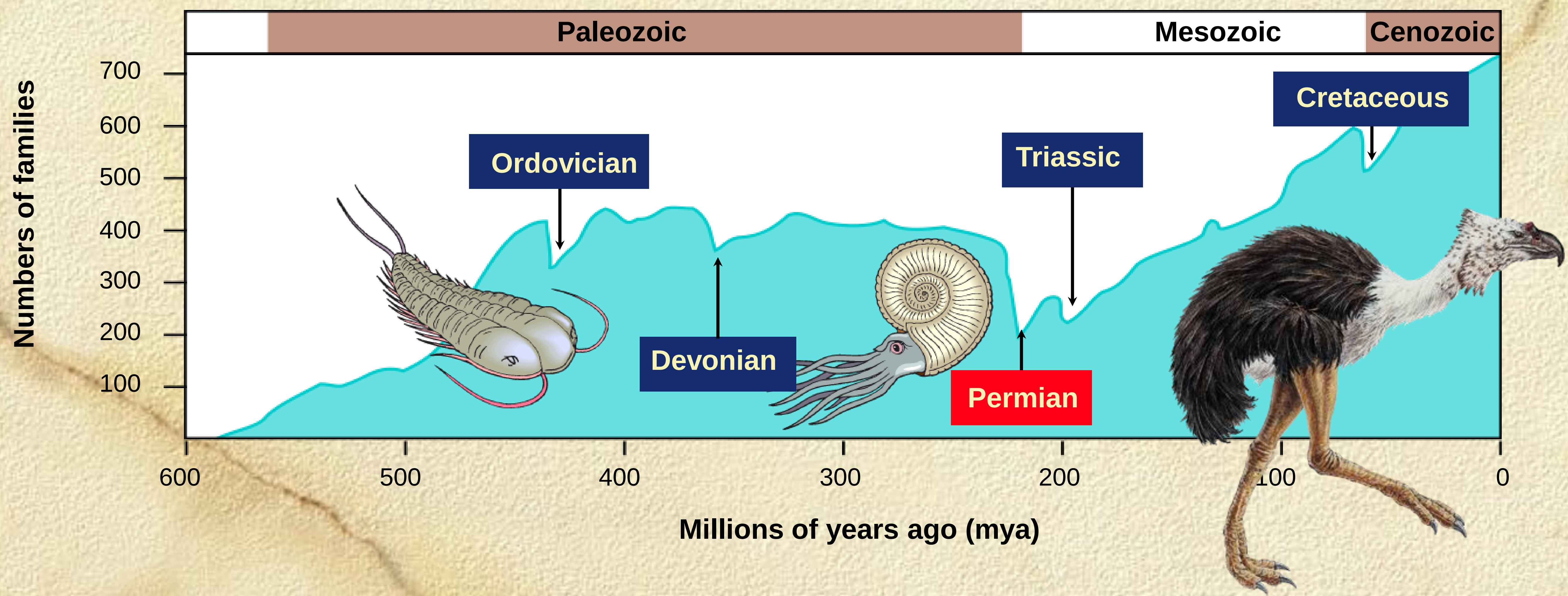
- Superimposed on average rates of background extinction, there are five **mass extinction** events in the Earth's history.
- A mass extinction is an abrupt increase in extinction rates affecting huge numbers of species at the same time.
  - During these episodes the diversity of major groups declines.
- Two of the five mass extinction events, the Permian and the Cretaceous have been intensively studied.

Dinosaurs became extinct during the Cretaceous extinction 65 mya

Trilobite diversity was severely depleted during the Cambrian-Ordovician extinction event. They eventually became extinct some 300 million years later, in the Permian.

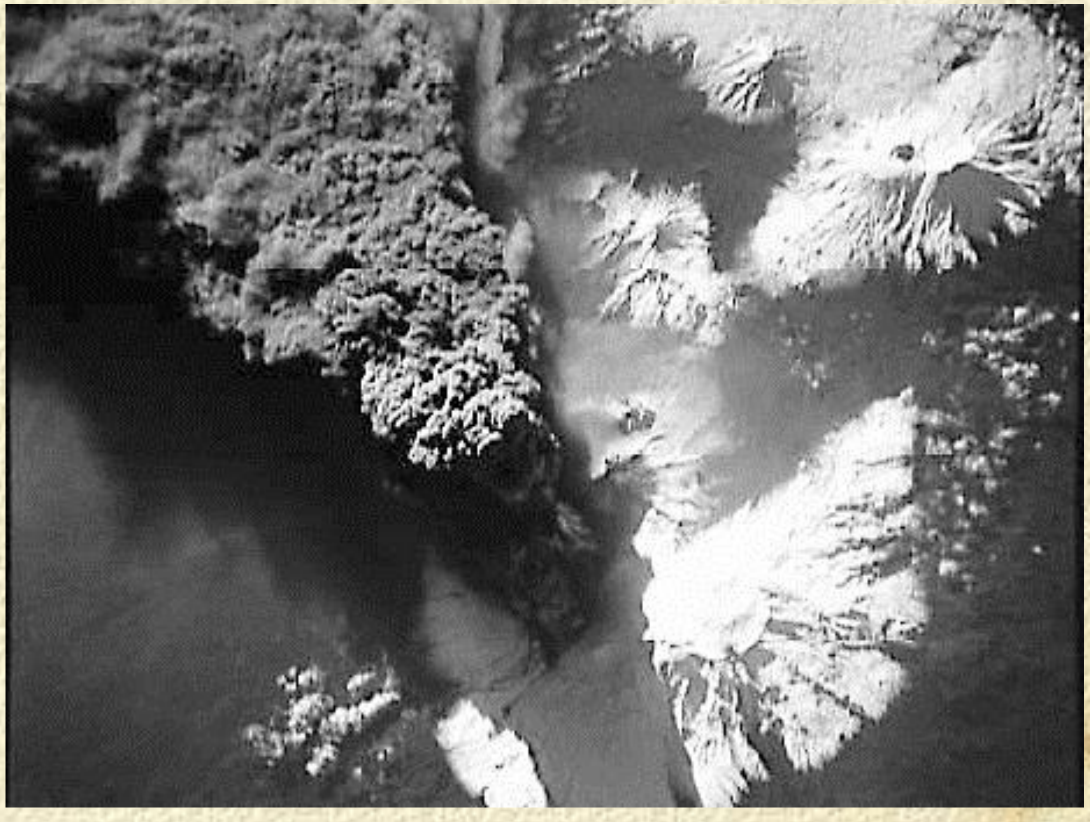
Mass Extinctions

- **The Permian extinction** (225 mya) marks the Palaeozoic-Mesozoic boundary
  - Over 90% of marine species perished and probably many terrestrial ones also
- **The Cretaceous extinction** (65 mya) marks the Mesozoic-Cenozoic boundary
  - Exterminated more than half the marine species and many families of terrestrial plants and animals, including dinosaurs (but not their descendants, the birds) .



Causes of Mass Extinctions

- Mass extinctions are the result of more widespread and possibly catastrophic events than those that affect individual species.
- Theories for mass extinctions include:
  - Changes in climate due to continental drift (slow). Sea level changes caused by successive ice ages and interglacials are implicated in most cases.
  - Dust from volcanic activity on a huge scale causing a cooling of the planet (faster).
  - Asteroid/comet impact causing a dust cloud and cooling effect (immediate).



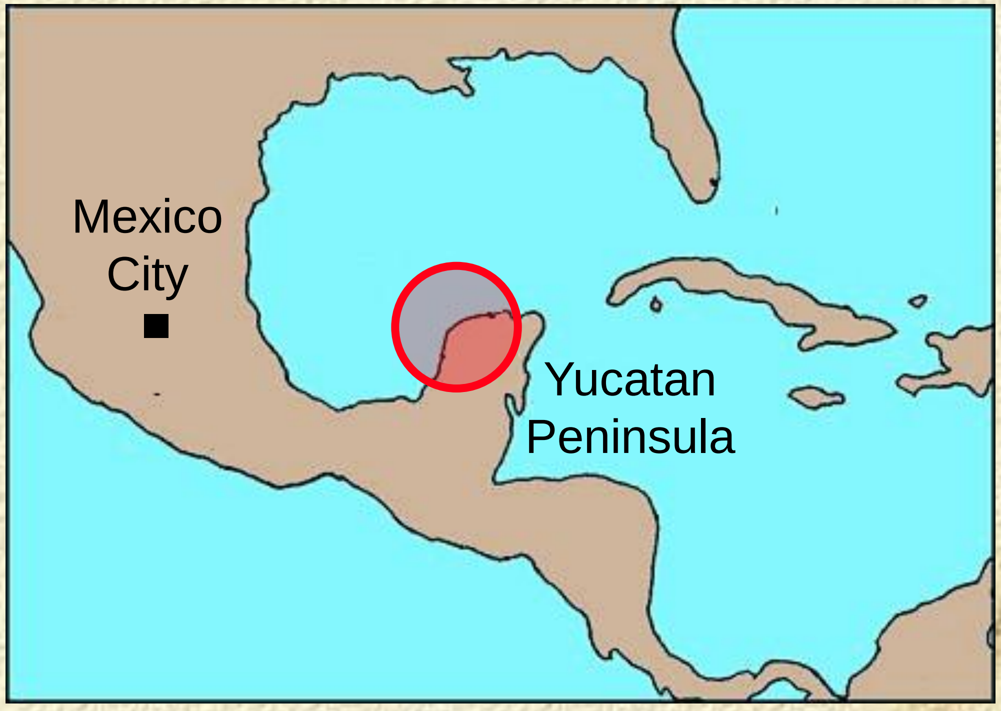
Erupting volcano from satellite

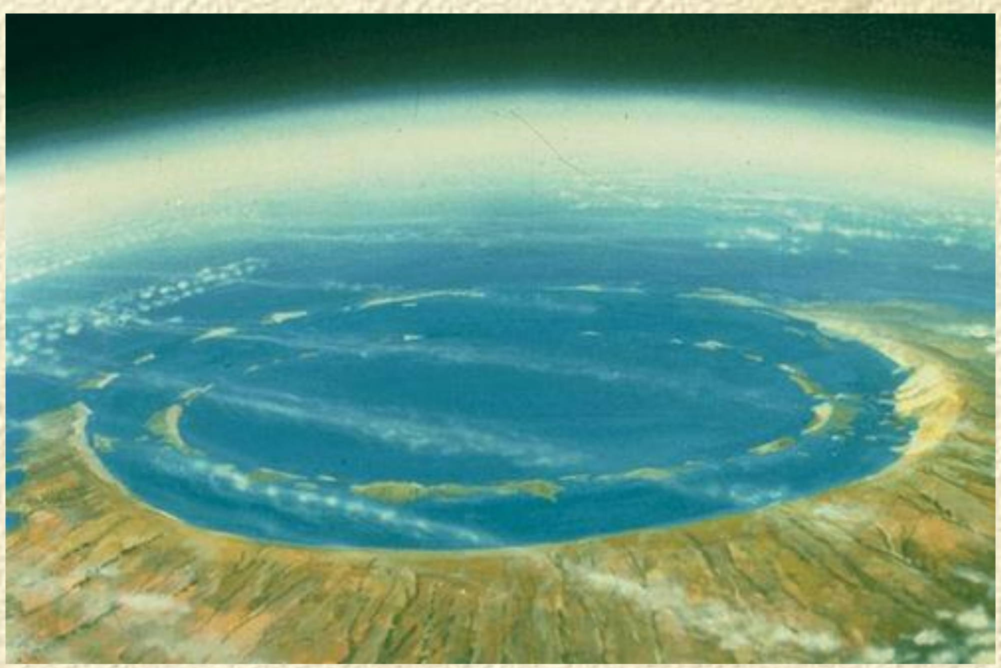
NASA

Asteroid impact (artist's impression)

Causes of Mass Extinctions

- The **Permian** extinctions occurred at about the time the continents merged to form the super-continent of Pangaea. This would have caused a major disturbance or destruction of many habitats and altered the climate.
  - There is good evidence for an asteroid or comet strike at this time, which may have created a cloud of dust, blocking light and inducing a "nuclear winter".
  - A probable site for the impact crater lies just off the coast of the Yucatan Peninsula in Mexico.
  - In 2006, an even bigger asteroid impact crater was found under the Wilkes Land ice sheet of Antarctica. It may also have been responsible for a mass extinction.

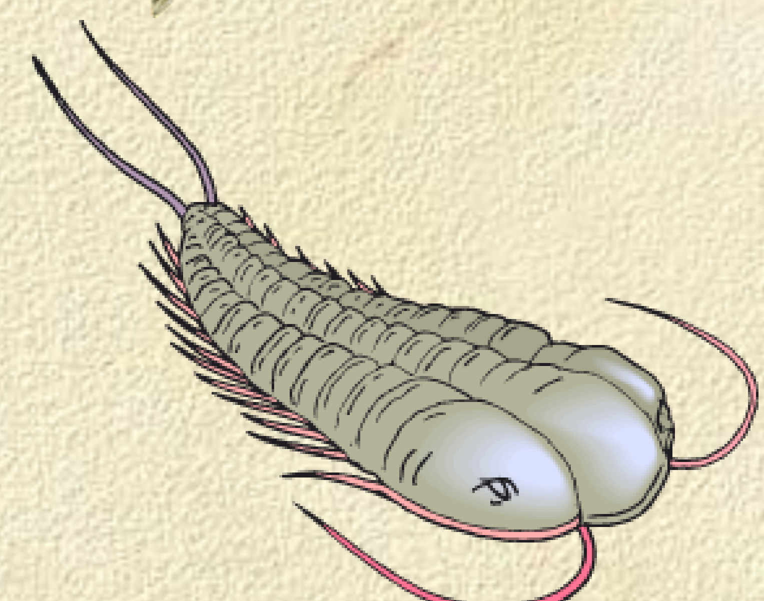




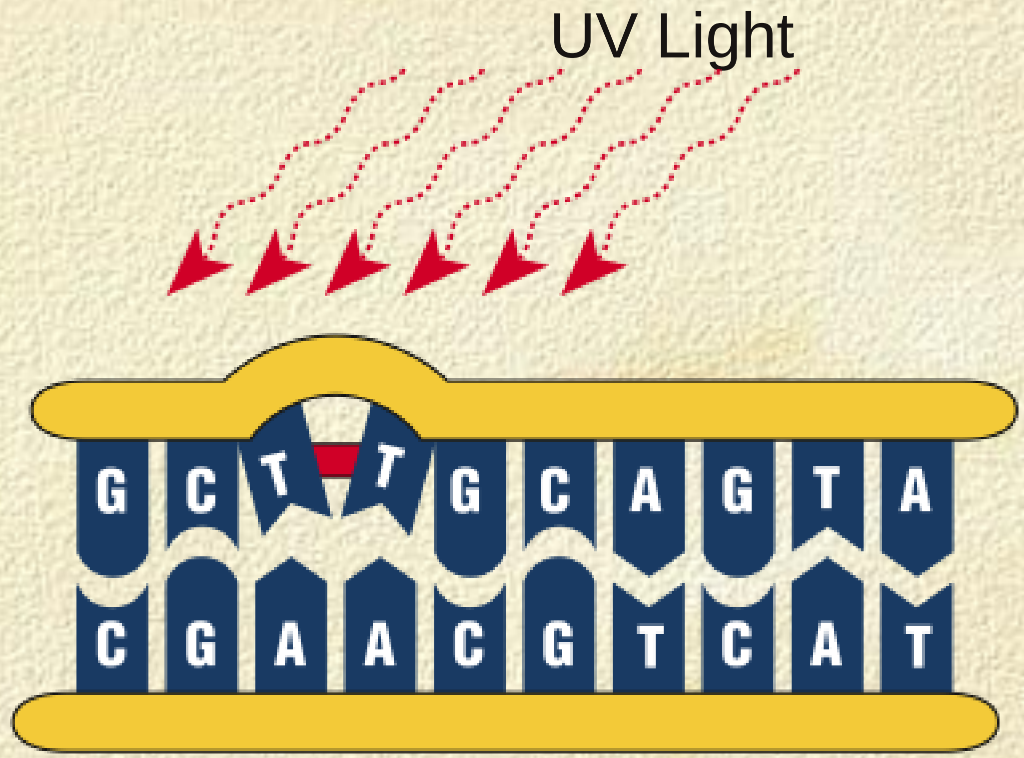
The Chicxulub crater left by an asteroid impact off the Yucatan Peninsula, Mexico

Micro- vs Macroevolution

- The mechanisms of gene pool change and natural selection represent the modern synthesis of evolution.
  - The **gradualist** view is that, over long periods of time (millions of years), **microevolutionary** processes are sufficient to account for the origin of new genera, families, orders and phyla.
  - The **punctuated equilibrium** view is that most morphological change occurs during abrupt speciation events and, once in existence, species then change very little.
- **Evo-Devo** is seen as a cornerstone of a more modern synthesis. Large changes in form are possible through changes in development.
- The debate is not about the **fact of evolution**; only about the relative importance of different evolutionary mechanisms.

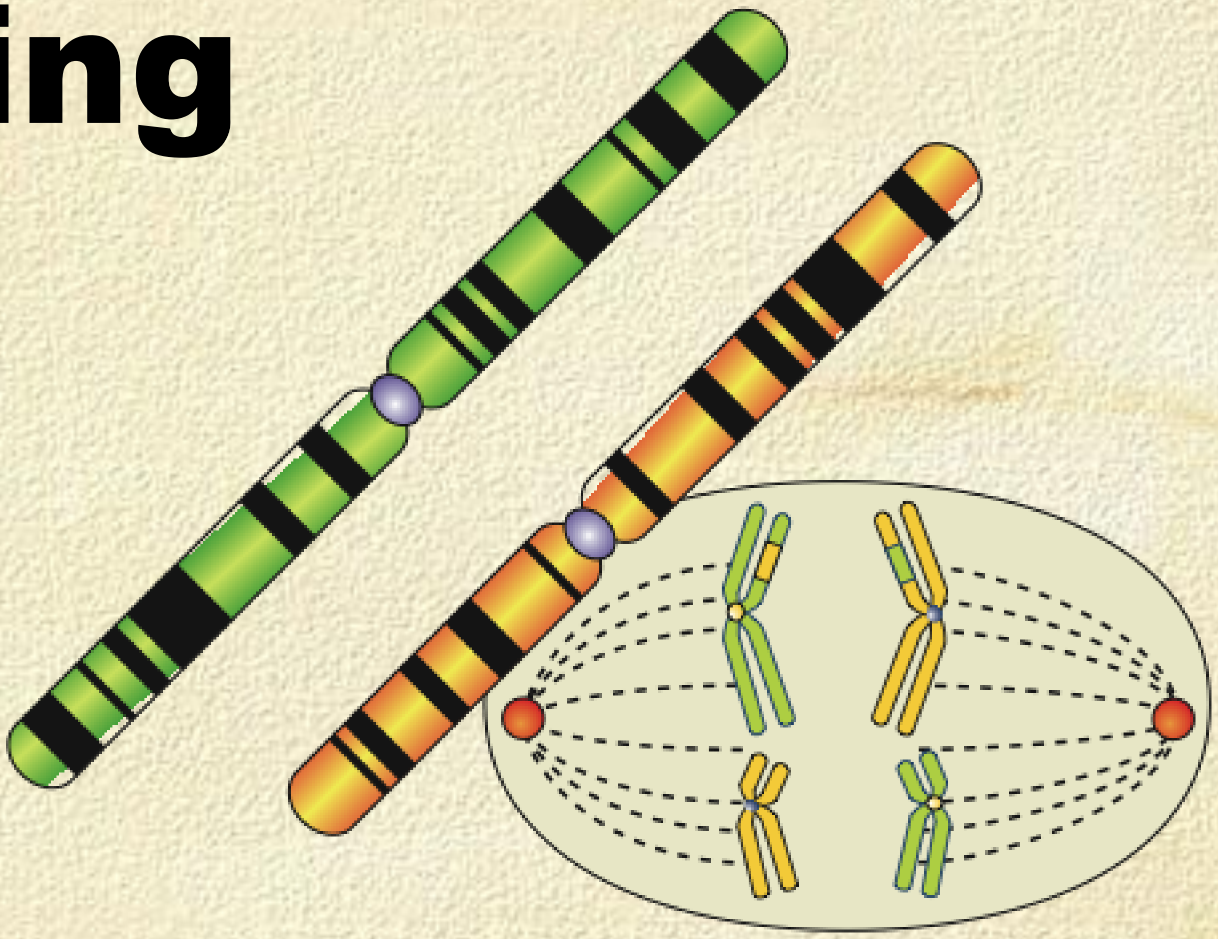


Forces Operating in Evolution

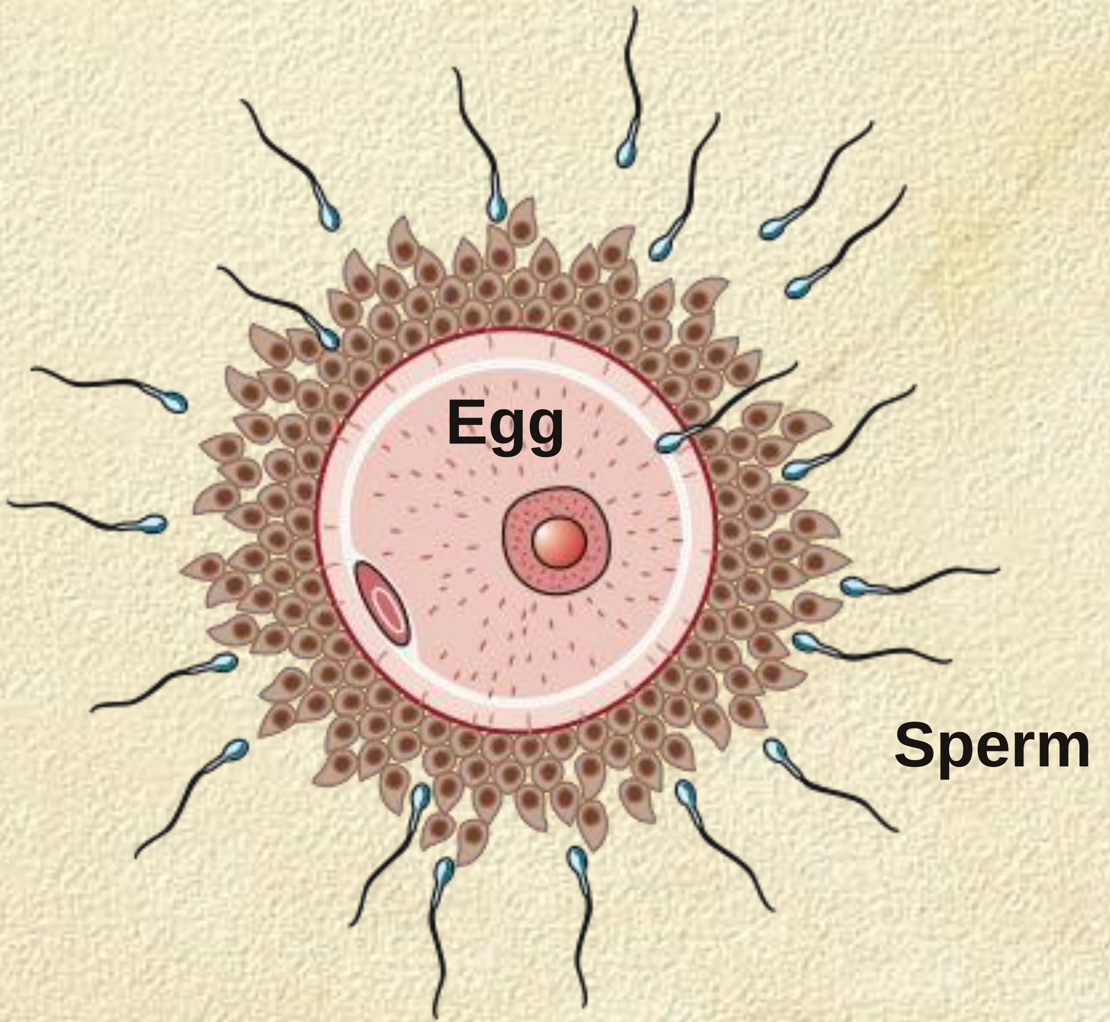


- Various “forces” or phenomenon have a part to play in the evolutionary process:
- At the molecular level:
  - **Point mutations**
  - **Control** of **gene expression**
  - Rate of **protein synthesis**

Forces Operating in Evolution



- At the chromosomal level:
  - **Crossing over**
  - **Block mutations**
  - **Polyploidy**
  - **Aneuploidy**
  - **Independent assortment**
  - **Recombination**

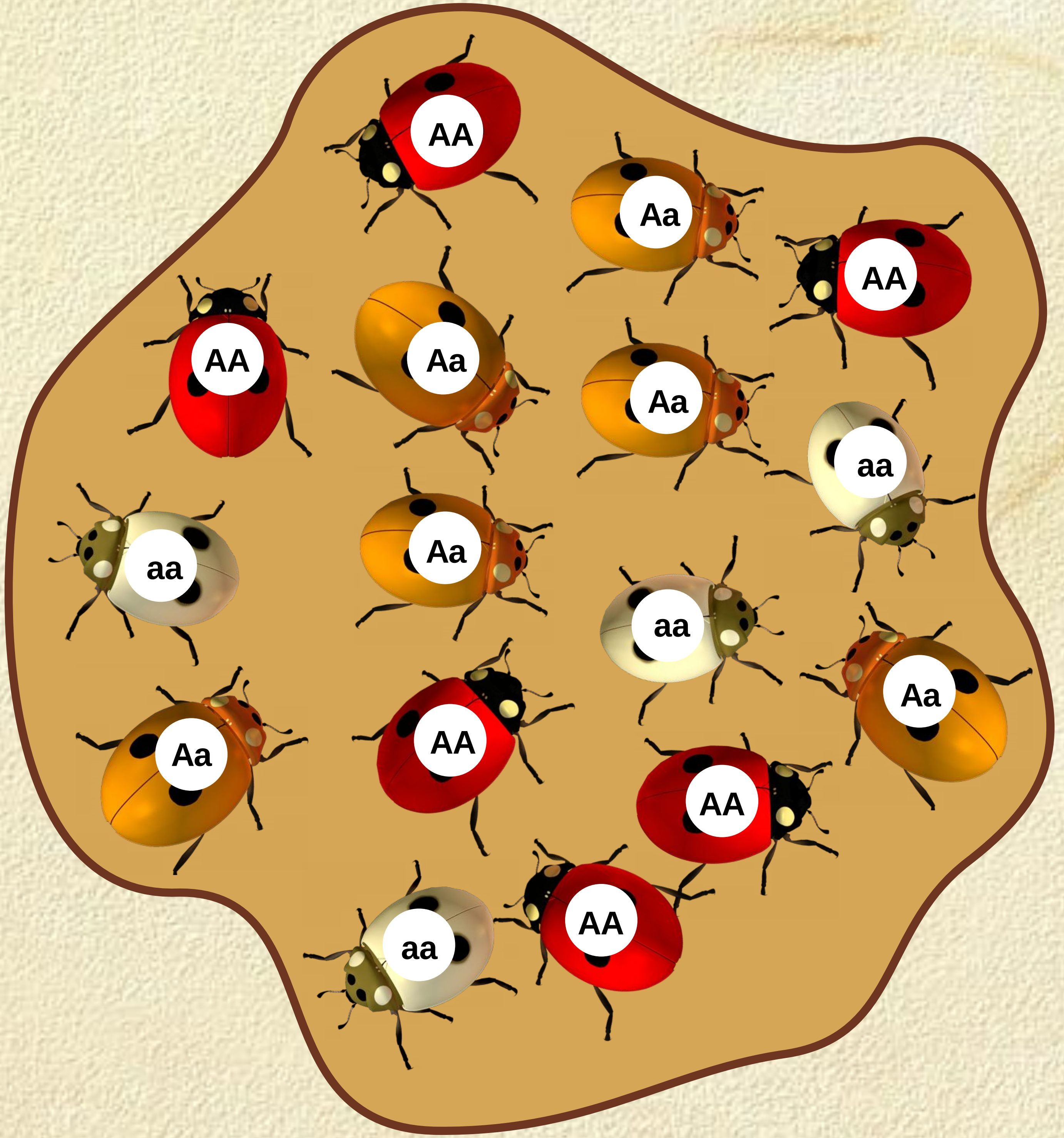


Forces Operating in Evolution

- At the organism level:
  - **Environmental modification** of phenotype
  - **Reproductive success**
  - **Selection pressures**
  - **'Fitness'** of the phenotype

Forces Operating in Evolution

- At the population level:
  - **Genetic drift** and **population size**
  - **Natural selection** altering gene frequencies
  - **Mate selection**
  - **Intraspecific competition**
  - **Founder effect**
  - **Immigration/emigration** (gene flow)
  - **Population bottlenecks**



Forces Operating in Evolution

- At the species level:
  - **Geographical barriers**
  - **Reproductive isolation** (prezygotic and postzygotic)
  - **Selection pressures**
  - **Interspecific competition**