# Darwin in the Garden



Talking points based on walk: Exploring Evolution in the Leaning Pine Arboretum

**Theme:** Darwin traveled the world before he understood the origin of species, but all we have to do is visit Mediterranean gardens to illustrate how the Earth and its biosphere have been evolving for billions of years.

**Our walk and poster display are based on four big ideas:**

First, like remote volcanic islands, the geographical isolation of Mediterrranean climates on five continents provides multiple opportunities for plants to evolve specialized adaptations to survive extended dry seasons, years of drought, and occasionally devastating wildfires.

Second, the co-evolution of plants and animals influences their anatomy and physiology, particularly as plants reward and repel animals.

Third, plant cells fix inorganic carbon from the atmosphere, but cannot fix other key nutrients from atmospheric nitrogen and phosphate minerals. This is explained by their evolutionary history of symbiotic relationships with fungus and bacteria.

Fourth, the co-evolution of the Earth and its biosphere can explain the persistence of liquid oceans, the composition of the atmosphere, and the diversity, abundance, and distribution of the six kingdoms of life.

**First Panel – Relationships of plants in Mediterranean gardens**

1. Some plants are California natives, but others are from South America, Africa, Australia, and Europe.
2. How are these plants related to each other and to plants in adjacent climates?
3. These plants illustrate convergent evolution and adaptive radiation before and after the break up of Pangaea.
4. Plants acquired adaptations to survive daily and seasonal changes in Mediterranean climates.

**Second Panel – Relationships of plants and animals**

5. Plants are solar powered chemical factories making proteins, sugars, fats, toxins, pigments, and fragrances.
6. Roots, stems, vascular structures, leaves, seeds, flowers, and fruits improve plant physiology.
7. Plants reward and repel animals like insects, birds, reptiles, and mammals seeking food and shelter.
8. Plants and animals co-evolve by means of natural selection and in response to changing environments.

**Third Panel – Relationships with algae, fungi, and bacteria**

9. Algae, cyanobacteria and fungi invaded the land early by forming symbiotic relationships called lichen.
10. Land plants with vascular structures, spores, seeds, and flowers evolved from green algae.
11. Cyanobacteria and fungi provide nutrient nitrogen and phosphorus that help plants live on land.
12. Algae acquired chloroplasts and mitochondria through endosymbiotic relationships with bacteria.

**Fourth Panel – Relationships of the Earth and its biosphere**

13. The building blocks of the biosphere are ecosystems, organisms, cells, molecules, and metabolic processes.
14. The Earth and its biosphere co-evolved with the carbon cycle and water, nutrient, and mineral cycles.
15. The biosphere co-evolved with the changing oceans, atmosphere, land, and Sun (and even wildfires).
16. From daily and seasonal cycles to billions of years of global evolution, it's all about energy flows.

**Eight guiding questions help us observe and explain the natural environment:**

1. What do you see (observations and descriptions)?
2. What are natural systems made out of (composition and structure)?
3. How do natural systems work (material properties and interactions with energy)?
4. How do natural systems change over time (evolutionary processes)?
5. Where do natural systems come from (origin and/or formation from building blocks)?
6. What are the relationships between the parts of a system (interactions and/or common origins)?
7. What are the relationships between natural systems (interactions and/or common origins)?
8. How do natural systems become more complex over time (entropy decreases)?

# What did Darwin do?

Born two centuries ago on February 12 1809, Darwin was a 19th century geologist and naturalist who traveled around the world in the HMS Beagle and collected specimens from many remote and isolated habitats including the Galapagos Islands. When he realized that isolated populations of animals evolved by means of natural selection, he documented his findings in many volumes including the now famous “The Origin of Species by Means of Natural Selection”, first published 150 years ago in November of 1859.

Darwin circled the globe on the Beagle from 1831 to 1835 observing geology and collecting fossil mammals, modern mammals, birds, fish, and reptiles. When Darwin returned to England, he was recognized as a promising naturalist and geologist. He published findings in zoology and geology from 1839 to 1846. He became the secretary of the Geological Society in 1838.

As a naturalist, Darwin was interested in a wide variety of subjects related to our evolving planet, ranging from the origin of life to human evolution. His opportunities to investigate these subjects were limited by the available information and analytical tools of his time. DNA was unknown and cellular processes were poorly understood. Little was known about the forces creating and moving continents and the variations in the composition of the atmosphere. The multitude of symbiotic relationships in the biosphere and the extraordinary role of bacteria, fungi, and algae in the evolution of plants and animals were poorly understood.

Despite these limitations, Charles Darwin explained the formation of volcanic islands, coral reefs, continents, and other ground movements. He emphasized the power of time and repeated and cumulative actions on a small scale. He observed the influence of climate on life, noted the geographic distribution of animals, and recognized the isolating function of land or sea barriers. He was a fan of Lyell’s new uniformitarian geology as distinguished from the catastrophism that preceded it. We now know that the history of the Earth and its biosphere have been shaped by both gradual change and by natural catastrophe and that the tempo of evolutionary change may vary under local or global stress.

On the grounds that the Earth’s internal processes were unknown, Darwin was able to dismiss Lord Kelvin’s thermodynamic argument that the Earth was not old enough for evolution to have occurred because it had not yet lost its original heat of formation. At the time, plate tectonics was unknown and, radioactive decay, the heat source which drives plate tectonics and keeps the Earth’s interior warm, was unknown.

# What would Darwin do?

If he were alive today, perhaps Darwin would be a highly specialized scientist or perhaps he would be a generalist and naturalist pursuing the larger questions of today much as he did in his day. The Earth and its biosphere have undergone nearly five billion years of global evolutionary processes that followed the first nine billion years of cosmic evolution. Darwin’s focus would be on gradually accumulated changes in the geobiosphere, the outer portion of the Earth, as well as cataclysmic forces, some of which originated deep within the Earth or from the solar system beyond.

# What are we doing?

Darwin suffered through harsh conditions on board the Beagle for five years, but he would have been delighted to observe living specimens from Mediterranean climates around the world assembled in one place. In his youth, he had an insatiable appetite for observing plants, insects, and birds. Imagine if Darwin could wander through Cal Poly’s Leaning Pine Arboretum. In the spirit of Darwin, we have produced a photo gallery of our arboretum along with short stories describing some of the relationships among the objects found in the arboretum, some easily seen, some rarely seen, and some unseen without the help of the microscope so beloved by Darwin. We have also created a walk in our garden emphasizing evolutionary processes and a downloadable self guided tour guide on our website www.calpoly.edu/~rfield.

This is only the start. As the 2009 year of Darwin unfolds, there will be a number of events and exhibitions including numerous opportunities for student, faculty, and staff participation.

# What can you do?

The Sandwalk, “Darwin's Thinking Path” is shown in this photo. You can be an amateur or professional geologist, naturalist, and explorer. You can discover for yourself the relationships between the six kingdoms of life and the relationships among the Earth’s land, waters, atmosphere, and biosphere. You can start by examining our photo gallery, then take a walk, visit our website, visit other websites, and read about these subjects in the library at Cal Poly. You can ask questions about the structure, processes, and evolution of natural systems.

The origin, evolution, diversity, abundance, and distribution of life depend on interactions of energy and matter in the oceans, atmosphere, solid Earth, and Sun. Our planet and its biosphere are emergent properties of increasing environmental complexity. Global evolution studies explore the five billion years of physical, chemical, and biological evolution that have shaped the solid Earth, hydrosphere, atmosphere, and biosphere (including its molecules, cells, organisms, and ecosystems).

## A note about natural science:

The National Academy of Sciences says that it is the role of science to provide plausible natural explanations of natural phenomena. The ultimate question for Earth System History is: How did a giant cloud of cold dilute gas and dust evolve into astronauts in a spacecraft orbiting a planet orbiting a star? The short answer is that complexity grows when energy flows because simple building blocks combine to form complex systems.

The fact is that the solid Earth, hydrosphere, atmosphere, and biosphere appear to have undergone nearly five billion years of physical, chemical, and biological evolution because of the flows of energy and matter through these systems, a process of global evolution. To quote Charles Darwin, from the Origin of Species, “There is grandeur in this view of life, with its several powers, and that from so simple a beginning endless forms most beautiful and most wonderful have been and are being evolved.”

For thousands of centuries, our ancestors puzzled over the forces of nature which were a constant threat to their survival. They imagined that animal spirits or supermen created and controlled the world around us including the Sun, moon, and fixed stars in the heavens. To this day, the most popular beliefs held by humanity about the origin of the universe and the Earth involve unseen hands and minds exerting unexplained forces on microscopic and astronomical scales, apparently in violation of the known laws of physics. Scientifically minded people debate the extent to which the changes that have occurred over time are the result of cataclysmic geophysical and astrophysical events or the result of the gradual accumulation of small changes over time.

According to Wikipedia:

Many modern philosophers of science use the terms methodological naturalism or scientific naturalism to refer to the methodological assumption that explanations of observable effects are practical and useful only when they hypothesize natural causes (i.e., specific mechanisms, not indeterminate miracles). In other words, methodological naturalism is the view that the scientific method (hypothesize, predict, test, and repeat) is the only effective way to investigate reality.

Methodological naturalism can be contrasted with metaphysical naturalism or ontological naturalism, which refers to the metaphysical belief that the natural world (i.e. the universe) is all that exists and, therefore, nothing supernatural exists. In metaphysical naturalism's paradigm observable events in nature are explainable only by natural causes.

This distinction between the two types of naturalism is made by philosophers supporting science and evolution in the creation–evolution controversy to counter the tendency of some proponents of Creationism or intelligent design to refer to 'methodological naturalism' as 'scientific materialism' or as 'methodological materialism' and conflate it with 'metaphysical naturalism'. These proponents of creationism use this assertion to support their claim that modern science is atheistic, and contrast it with their preferred approach of a revived natural philosophy which welcomes supernatural explanations for natural phenomena and supports theistic science.

## First Panel – Relationships of plants in Mediterranean gardens

Some plants are California natives, but others are from South America, Africa, Australia, and Europe.

Continents with western coastlines between 30 and 40 degrees north or south latitudes have mediterranean climates as a result of the availability of sunlight, moderating marine influences, and seasonal variations in precipitation.

Similar climatic characteristics and environmental pressures play a role in plant evolution; similar anatomical structures can be found in various regions with widely differing genetic backgrounds.

Summers in Mediterranean climates are dry because of the seasonal presence of subtropical high pressure cells, often lasting five months. Rain is usually abundant in the winter as the polar jet stream brings periodic storms to lower latitudes.

Mediterranean climates are characterized by woodlands and shrublands (called chaparral in California). Physical and biological factors alternately influence aquatic communities as conditions vary seasonally from drought to fire to flooding. Evolution has favored organisms that can readily recover from these extremes.

## How are these plants related to each other and to plants in adjacent climates?

Despite the fact that plants from different mediterranean regions can often thrive in any of the regions, they are not closely related to each other. Because of the geographical isolation of the various regions with mediterranean climates from each other, plants indigenous to these regions are more closely related to plants in adjacent climate regions than to each other. The genetic closeness of two species is not based on appearance or function but whether the last common ancestor (LCA) is also a member of the same group.

If all group members have a common ancestor in the group, they are monophyletic. Mammals are monophyletic because the LCA of all mammals was a mammal. Other groups that are monophyletic include: birds, insects, the entire kingdom of animals is monophyletic, the entire kingdom of plants, and green algae.

Trees evolved many times from herbaceous plants, so their LCA is not a tree. Therefore trees are not monophyletic, they are polyphyletic. Warm blooded animals are polyphyletic because mammals and birds are warm blooded, but their LCA was neither a mammal, nor a bird, nor warm blooded. Marine mammals are polyphyletic as are mediterranean plants and succulents. Green, brown, red, and golden algae evolved independently from non-algal ancestors so algae are a polyphyletic group.

## These plants illustrate convergent evolution and adaptive radiation before and after the break up of Pangaea.

“Totally unrelated families of plants have evolved similar body shapes to cope with similar environments on different continents. There are only a limited number of ways to adapt to the environment, as dictated by physical laws and feasibility.

“The succulent Euphorbias of Africa and the Cacti of the Americas are examples of plants that evolved to their environment by their shape (morphology). These two unrelated plants (cacti and Euphorbias) in different parts of the world, but under similar conditions of water availability and temperature have evolved similar forms.

To the "general public" the succulents of Africa can be confused with the cacti of the Americas, even though the plants are unrelated. This similarity of shape according to similarity of environment for unrelated plants is called Convergent Evolution.

“The similar forms/shapes/features are: round body shape or, upright candle shape, reduced or no leaves on plant, spines/thorns on the plant body, and water storage within the plant.” These adaptations suit plants in water limited environments as described on the next panel. photos and text from www.cssnz.org

## Plants acquired adaptations to survive daily and seasonal changes in mediterranean climates.

Deciduous trees lose their leaves to minimize the stress of winter. Evergreens have modified leaves to minimize metabolic function during hard times. Water storage is essential to enable plants to survive between infrequent rainfalls in the summer.

Succulent plants have a swollen or fleshy appearance because they adapted to arid climate or soil conditions by retaining water in their leaves, stems and/or roots. Succulent plants evolved repeatedly because they thrive where rainfall varies seasonally.

Round bodies enclose more volume of plant per surface area. This reduces exposure to the sun and to drying winds and maximizes water storage. Upright candle shapes also reduce exposure to harsh sunlight, especially when the sun is high in the sky. Having photosynthetic stems may reduce or eliminate the need for leaves that can dry out.

Spines can fend off animals that are attracted to the water stored in succulents. Spines can collect and channel dew toward roots. Spines can also store excess minerals and salts that are extracted by plants living in dry soils.

# Second Panel – Relationships of plants and animals

Plants are solar powered chemical factories making proteins, sugars, fats, toxins, pigments, and fragrances.

Animals and fungi rearrange the building blocks of life that they consume into more complex molecules. Cells need proteins, polysaccharides, and membranes that are built from amino acids, sugars, and fats. Primary producers like plants not only arrange building blocks, but also create them from simpler molecules like carbon dioxide, water, basic nutrients (nitrates and phosphates), and minerals (iron, silica, calcium, and magnesium). Sugars and fats contain carbon, hydrogen, and oxygen. All amino acids also contain nitrogen. All nucleic acids also contain nitrogen and phosphates. Magnesium is a critical element in chlorophyll.

Animals use proteins as a source of energy and as building blocks for muscles, but proteins have served critical cellular functions for billions of years. Proteins serve as enzymes or catalysts to promote metabolic processes in all organisms. Enzymes help plants synthesize glucose from carbon dioxide in “the most commonly used chemical reaction by which inorganic carbon enters the biosphere”, as Wikipedia says. Proteins are polymers of amino acids arranged in sequences translated from RNA which is transcribed from DNA.

Plants manufacture pigments for practical not artistic purposes. Chlorophyll absorbs sunlight. Its electronic properties allow it to transfer the absorbed energy to molecules that split water during photosynthesis. White, yellow, red, blue, and violet flowers evolved that attract pollinating insects and birds. Colorful fruits attract animals that disperse the seeds they contain. Evolution led to fragrances that attract animals and toxins that repel grazing, particularly on fragile leaves.

Roots, stems, vascular structures, leaves, seeds, flowers, and fruits improve plant physiology.

Plants are multicellular organisms with highly evolved structures that help them compete in the challenging and diverse environments found on land. In vascular plants, phloem transports glucose from photosynthesizing leaves. Xylem transports water and minerals absorbed by roots in the soil.

Roots also anchor stems of plants. Stems raise leaves and other plant structures above predators and above the shadows of rivals.

Early plants produced spores before seed producing plants evolved. Flowering plants produce pollen that fertilizes eggs in ovaries in the flowers. The resulting seeds are often encapsulated in fruits that attract animals. Natural selection favored dispersal of seeds that pass through animal digestive tracts undigested.

Fundamental cell metabolism rarely changes. The anatomy and physiology of plants evolve under selection pressures from other plants, animals and abiotic factors. Virtually every structure of a plant has been modified in ways that accommodate the physical and biological environment.

Plants reward and repel animals like insects, birds, reptiles, and mammals seeking food and shelter.

Plants provide a variety of habitats for land animals. They provide shelter from extremes of temperature and moisture. Predators can find prey in these settings, but prey can find safety as well.

Succulent plants store food and water in leaves to enhance survival in challenging environments. Succulents may have spines or needles to defend these resources from large animals.

Some plants evolved specific features that feed or shelter specific beneficial animals and that defend against excessively aggressive grazers. Flowering plants co-evolved with insects that help spread pollen. Some birds perform similar functions. Some plants are selective in rewarding or repelling animals.

Chili peppers repel mammals whose digestive tracts damage or destroy the seeds but not birds that help spread the seeds. Some seeds foster dispersal with coatings that inhibit germination unless they have passed through the guts of certain animals.

Plants and animals co-evolve by means of natural selection and in response to changing environments.

Spore producing plants do not require animals to spread their spores. Some seed producing plants like conifers use fire to activate their seed cones. Flowering plants co-evolved with the animals that feed on their nectar and disseminate their pollen to other flowers.

Some flowers attract any pollinator while others have evolved special features to attract only one particular animal. Specialization insures that the pollinator delivers pollen to plants of the same species. Insect and bird color vision may have co-evolved with colors in flowers.

The leaves of milkweed evolved toxins that discourage grazing by insects. The monarch butterfly caterpillar feeds on milkweed. It evolved the ability to store the toxin in its tissues. The caterpillar and the butterfly phase have warning colors to repel predators. The butterfly can over-winter in massive clusters without suffering from extreme predation. Its migration and dormancy help it adapt to seasonal changes.

# Third Panel – Relationships with algae, fungi, and bacteria

Algae, cyanobacteria and fungi invaded the land early by forming symbiotic relationships called lichen.

Long before plants had evolved and adapted to life on land, lichen were covering rocks. The symbiosis of a fungus with one or more photosynthesizers is not a particularly rare nor difficult evolutionary step.

Lichen evolved many times with a number of fungi and either a green algae or a cyanobacteria or in some cases a ménage a trois involving species from all three kingdoms. Lichen occur in three forms: crustose, foliose, and fruticose, which as the names suggest, form a flat crust on rocks, form tiny leaf-like shapes, and form strands that hang from trees or other surfaces like fruit.

Algae thrive in aquatic environments and dry out and die on land. Fungus resists dehydration better than algae, but likes moisture and needs a food source because it cannot do photosynthesis. Lichen is more adaptable to land than fungus or algae alone because the fungus shelters the algae from dehydration and the algae produces food that it shares with the fungus. If the algae do not produce, the fungus may survive by consuming the algae.

As lichen invaded the land, fungus and algae could efficiently decompose rock minerals and enrich soil with nitrogen and phosphorus compounds. This enrichment provided nutrients for future plants. The lichen also attracted grazing animals whose waste products also enriched the soil, increasing plant resources for land animals.

Land plants with vascular structures, spores, seeds, and flowers evolved from green algae.

“Producers” are organisms that produce their own food, usually by fixing inorganic carbon via photosynthesis. Several steps are necessary for producers to thrive on land. Evolutionary processes allowed plants to become more independent of water in stages. Mosses evolved from green algae and thrive in damp environments.

Horsetails and rushes were early invaders of land rooted in wetlands. Early vascular plants could grow taller and compete for sunlight better than rivals because their vessels transport water and minerals from roots to stems. Leaf evolution produced better solar collectors than thin stems alone.

While plants developed greater complexity anatomically and physiologically, they also contributed to a more complex ecosystem that created niches that enable primitive plants to continue to thrive in suitable environments in modern times.

Cyanobacteria and fungi provide nutrient nitrogen and phosphorus that help plants live on land.

Green algae evolved from “consumers” that did not make their own food. They did not have the ability to manufacture nutrient nitrogen from atmospheric nitrogen, nor to produce nutrient phosphates from inorganic matter. Green algae got their nutrients from their rich aquatic environment. When they invaded land within lichen, their fungal symbiotic partners provided needed nutrients.

As plants evolved from green algae they were also unable to produce these nutrients but could acquire them from the soil because of the algae, fungus, and lichen that preceded them on land. To this day, plants have special hidden relationships with fungus and bacteria in the soil. Some plants are legumes with root structures known as rhizomes that evolved to foster close symbiotic relationships with other kingdoms necessary for plants to thrive in nutrient poor environments.

Knowledge of the evolutionary history of the biosphere helps us understand why certain organisms perform some functions but not others.

Algae acquired chloroplasts and mitochondria through endosymbiotic relationships with bacteria.

Like lichen, algae evolved many times. The last common ancestors of green algae, brown algae, red algae, golden algae were not algae but consumers that could not produce food.

How did each of these lines of algae become producers? Their consumer ancestors formed symbiotic relationships with producers, namely cyanobacteria. Living in close proximity, consumers engulfed the cyanobacteria with their large flexible cell bodies and membranes.

A captive cyanobacteria that resisted the normally fatal attack and continued to harvest sunlight and produce food for itself as well as for its grazer was sheltered from other grazers.

A bird may lose its ability to fly over many generations if there are no predators and food is accessible. Similarly captive cyanobacteria developed a simpler lifestyle that became synchronized with its captor. The history of evolving from captured cyanobacteria explains why chloroplasts have a double cell membrane and have retained a small number of their own genes outside of the algae cell nucleus.

By the way, an ancestral consumer microbe acquired mitochondria by capturing a respiring bacteria. Respiration is a powerful process for extracting energy from food.

# Fourth Panel – Relationships of the Earth and its biosphere

The building blocks of the biosphere are ecosystems, organisms, cells, molecules, and metabolic processes.

Energy and materials flow into and out of open systems like the Earth and its biosphere. For plants the energy source is the Sun and the materials flowing in include carbon dioxide, water, nutrients (nitrogen and phosphorus), salts, and minerals (iron, magnesium, and calcium).

The metabolic processes in cyanobacteria, algae, and land plant cells convert simple molecules into more complex building blocks like amino acids, sugars, fats, and nucleic acids.

Cellular processes also build proteins from amino acids, complex carbohydrates like cellulose and lignin from sugars, membranes from fats, and RNA, DNA, and ATP from nucleic acids.

Animals and fungi use the complex molecules that plants produce as energy sources and as building blocks for new molecules. Many organisms use sunlight for information about the environment.

The Earth and its biosphere co-evolved with the carbon cycle and water, nutrient, and mineral cycles.

By transforming materials in the physical environment, organisms from all six kingdoms affect the flow of energy and materials and alter the composition and structure of the land, oceans, atmosphere, and biosphere.

Cyanobacteria have been fixing carbon dioxide and releasing oxygen for billions of years. Over time the atmosphere has lost most of its carbon dioxide and acquired all of its oxygen. In the past billion years, algae and land plants have contributed to these changes. All living things contribute to the cycling of energy and materials in the geobiosphere.

The rise in atmospheric oxygen and dissolved oxygen in the oceans provided increased opportunities for the evolution and dispersal of organisms that use aerobic respiration to extract high levels of energy from sugar, fat, and protein. Oxygen abundance also fostered the rise of complex multicellular organisms including animals and land plants.

The biosphere co-evolved with the changing oceans, atmosphere, land, and Sun (and even wildfires)

Early in Earth history, volcanoes released water, carbon dioxide, and sulfuric gases to the atmosphere. Oceans formed and the water cycle carried salts and minerals from growing land formations to the sea.

Growth and movements of continents affect ocean currents and climate and influence the evolution and distribution of life on Earth. Over billions of years, the Sun has grown hotter, balancing the effects of decreasing carbon dioxide levels and maintaining liquid oceans through most of the Earth’s history. Radioisotopes heat the Earth, moving continents and powering earthquakes, volcanoes, hot springs and their microbes, and nuclear reactors.

Astrophysical and geophysical factors transformed the Earth’s surface into a giant snowball about 800 million years ago. Changes in the atmosphere and biosphere may have contributed to the explosion of hard-bodied animals nearly 600 million years ago. More recently, asteroids and global volcanic activity have produced drastic changes in plant and animal communities.

From daily and seasonal cycles to billions of years of global evolution, it's all about energy flows.

Plants have adapted to the daily variation in sunlight, temperature, and moisture associated with the daily rotation of the Earth on its axis. Plants control the flow of nutrients, fluids, and gases and metabolic processes including photosynthesis.
Animal behavior also has adapted to daily cycles of temperature and moisture. Animals may be active or inactive in response to diurnal variations in light levels. Warm blooded animals can be active when others are dormant.
Lunar cycles and tidal cycles also provide challenges and opportunities for animals. Leatherback turtles lay eggs above the high tide associated with the new Moon.
Plant and animal reproductive cycles are often synchronized to seasonal changes in sunlight, moisture, and temperature. Animal migrations and hibernation are synchronized to seasonal conditions. Some plants and animals die after producing the next generation rather than try to survive seasonal changes.

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Alfred Wallace wiki
Aposematic_coloration
Archaea
Catastrophism
Charles Darwin wiki
Charles Lyell wiki
Chromista wiki
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Convergent evolution wiki
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Euphorbiaceae wiki
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GalapagosGeology
grabov rat maps med climate
Halophytes wiki
History of Earth
Kingdom (biology) wiki
Lithops wiki
Lord Kelvin
Mediterranean climate wiki
Natural selection wiki
Cactus and Succulent Society of New Zealand
Pangaea wiki
Pangaea palaeo
Polyphyletic wiki
Protista
Protozoa wiki
Selection pressure wiki
Succulents wiki
Taxonomy of the Euphorbiaceae wiki
Timeline of evolution
trail of time
Uniformitarianism (science)
Walk thru time book and exhibit

Acknowledgements
I have received help from many people over the years, but this project has been specifically helped by Dr. John Perrine, my biology student TJ Eames, Catherine Trujillo of Cal Poly's library collections, state park natural history docent Joan Field, and Dr. John Peterson.