
UNIVERSITY of ARIZONA
20-24TH APRIL
2017
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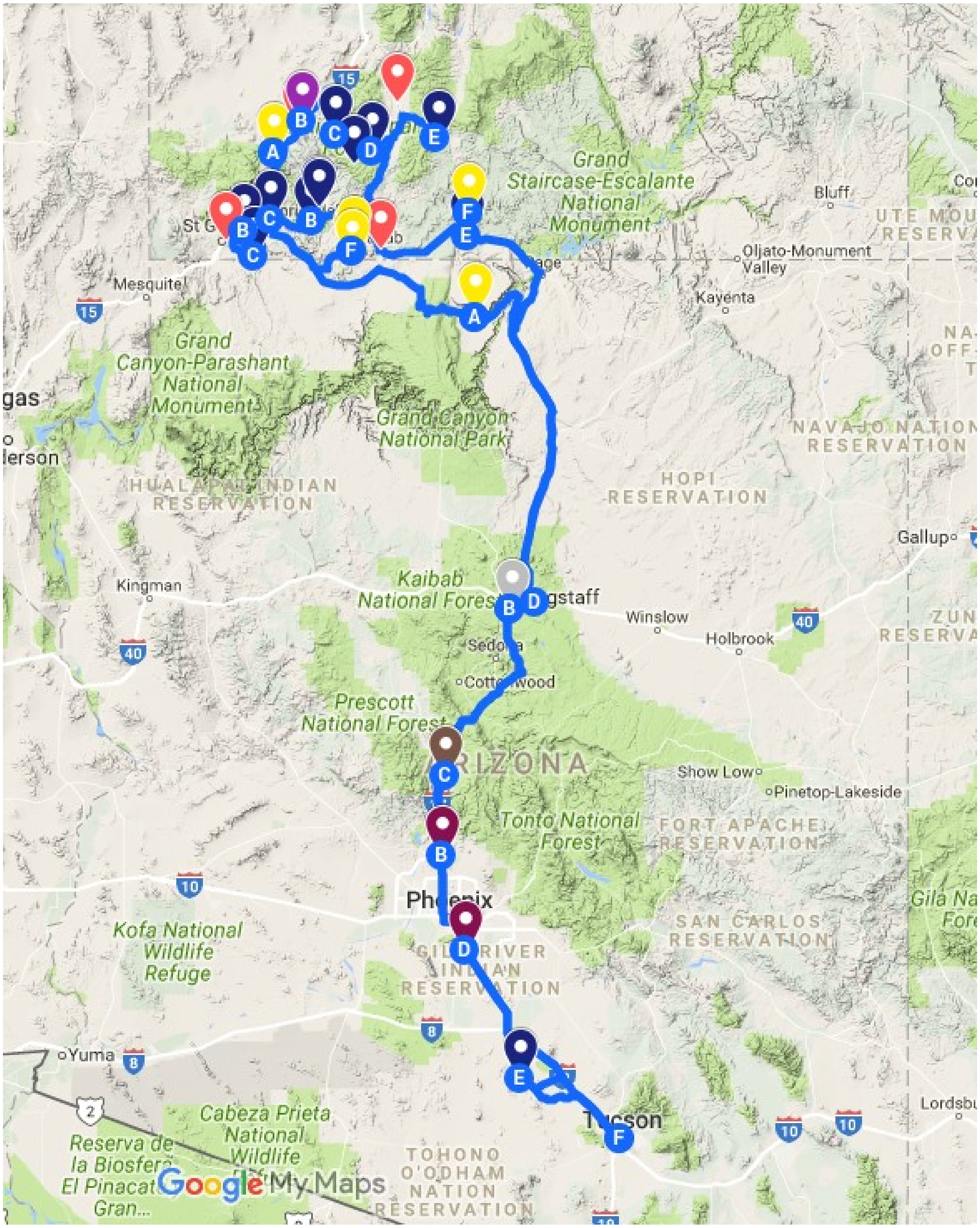
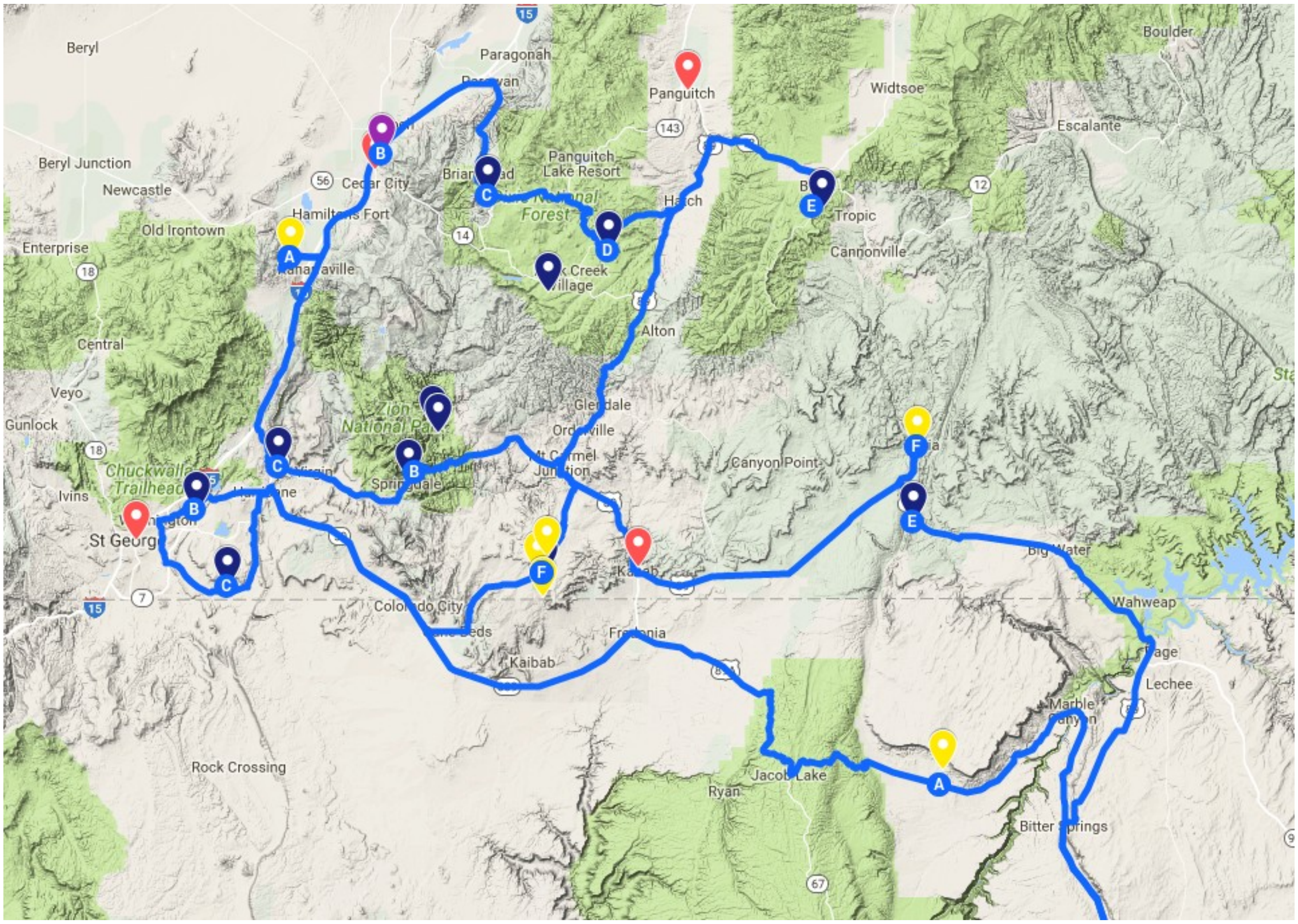
PTYS594A:
PLANETARY
GEOLOGY
FIELD STUDIES
LUNAR &
PLANETARY
LABORATORY
southwestern
UTAH & ZION
national park



Overview map

Red:	Hospital
Blue:	Topic site
Yellow:	Camp
Brown:	Lunch
Purple:	Shower
Maroon:	Phoenix Rendezvous
Grey:	Flagstaff Rendezvous



Day 2, 3, 4

Red:	Hospital
Blue:	Topic site
Yellow:	Camp
Purple:	Shower

Cover image: Eva Landis

PTYS 594A Participants; Spring 2017

Students:
Corey Atwood-Stone
Ali Bramson
Laci Brock
Saverio Cambioni
Anthony Garnello
Tad Komacek
Margaret Landis
Daniel Lo
Tom McClintock
Sarah Peacock
Kyle Pearson
Adam Sutherland
Jess Vriesema
Mattie Del Tigges
Hannah Tanquary
Donna Viola

Faculty:

Vic Baker	Expert on everything
Christopher Hamilton	Assisting
Joseph Spitale	Leader

20 April 2017

Hello everyone and welcome to another edition of the LPL Field Trip Guide!

This semester we're headed to Zion and Bryce National Parks.

Zion will have had that designation for 98 years this year, and before that it was Mukuntuweap National Monument (designated by William Howard Taft, who got stuck in the White House bathtub—allegedly—and was later the Chief Justice of the Supreme Court).

Bryce Canyon National Park is most widely known for its hoodoos and, to its namesake, as "helluva place to lose a cow." Apparently Thor's Hammer can be found around here, too.

Let's have a fun Crawl Up the Colorado Plateau 2017!

Margaret Landis

Editor
(And will attempt to Ken Burns the heck out of this trip)

PTYS 594A Itinerary; Spring 2017

Day 1 (4/20 Thursday):

08:00	Leave LPL; **Adam Sutherland** talks about basin and range via the CB
09:30	Establish rendezvous entering Phoenix
10:15	Rendezvous at Chevron station on Carefree Hwy (Exit 223A)
10:30	Resume on I-17 N
12:15	Pick up Tad at Flagstaff airport (one truck only)
12:30	Lunch at Walnut Canyon
13:30	Leave Walnut Canyon
16:30	East Kaibab monocline
	Sarah Peacock talks about Anticlines / Synclines / Monoclines
	Margaret Landis talks about Park system
18:00	Leave monocline
18:30	Camp near Paria; 4800'

Day 2 (4/21 Friday):

08:00	Leave camp
10:00	Zion visitor center
	Ali Bramson gives overview of Zion National Park geology
	JessVriesema talks about cross bedding
	Take bus up Zion Canyon
	Weeping rock: **Kyle Pearson** talks about sapping, springs, aquifers
	Hike Virgin Narrows trail (or echo Canyon if Virgin Narrows closed)
	Hannah Tanquary talks about faulting / jointing
	Saverio Cambioni talks about Fluvial processes, erosion
	Lunch somewhere in Canyon
	Springdale landslide: **Tom McClintock** talks about landslides
15:30	Leave Zion NP
16:30	Hurricane Fault
17:00	Leave Hurricane Fault
18:00	Camp near Cedar City; 6000 -- 7500'

Day 3 (4/22 Saturday):

08:00	Leave camp
08:30	Shower stop in Cedar City (Joe visits ranger station if necessary)
09:30	Leave shower stop
10:30	North View overlook
	Daniel Lo talks about Grand staircase, CO plateau stratigraphy
11:00	Leave overlook
11:30	Mammoth Cave (de-scope to Ice Cave if Mammoth closed)
	Corey Atwood-Stone talks about lava tubes
12:00	Lunch at Mammoth Cave
13:30	Leave Mammoth Cave
14:30	Bryce Canyon visitor center
	Tad Komacek gives an overview of Bryce Canyon geology
	Rainbow point
	Mattie Tigges talks about hoodoos
	Possible hike if time permits
17:00	Leave Bryce Canyon
18:30	Camp south of Coral State dunes; 5600'

Day 4 (4/23 Sunday):

08:00	**Laci Brock** talks about Flora / fauna
08:30	Leave camp
09:00	Coral State Sand Dunes
	More from **JessVriesema** on Dunes
10:30	Leave dunes

12:00	Virgin anticline
12:30	Leave anticline
13:30	Dinosaur tracks; Lunch
	Donna Viola talks about dinosaurs
15:30	Leave Dinosaur tracks
18:00	Camp at Jacobs Pool; 5200'
	Anthony Garnello talks about the Vermillion cliffs

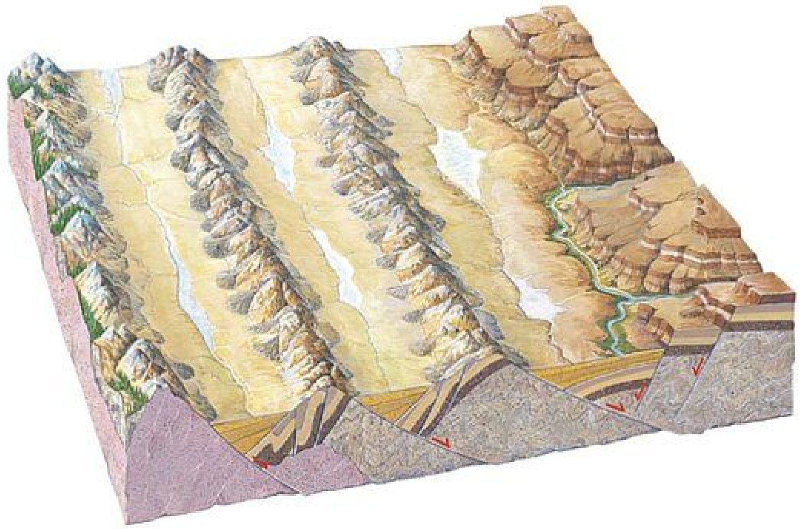
Day 5 (4/24 Monday):

08:00	Leave camp
	Drop off Christopher, Donna, and Tad at Flagstaff airport
12:00	Lunch at Badger Springs trailhead
13:00	Leave Badger Springs
13:30	Establish rendezvous entering Phoenix
14:15	Rendezvous at Chevron station on Wild Horse Pass Blvd; Exit 162
14:30	Resume on I-10 S
16:30	New Giant Fissure near Tator Hills
	Margaret Landis talks about land use, subsidence, etc.
17:00	Leave Giant fissure
18:30	Arrive LPL

Basin and Range

Rifting

- Starting forming 17 Mya.
- Formed due to continental rifting - continent stretches in one direction and is pulled apart.
- Rifting can split a continent in two, or stop short, in the case of B&R Province.
- The rifting happened East-West.
- Stretched to twice the original width.



Faulting

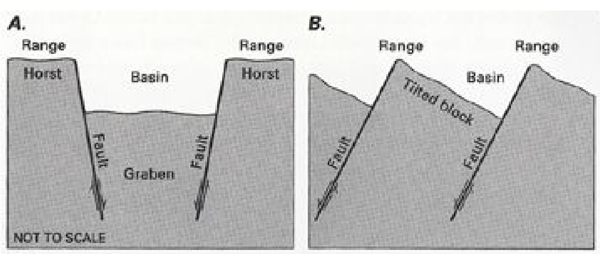


Figure 33. The alternating basins and ranges that characterize the topography of the area were formed during the past 17 million years by the gradual movement along faults. A, horst and graben blocks of the Earth's crust. B, tilting of blocks of the Earth's crust. The arrows indicate the relative direction of movement of rocks on either side of the faults.

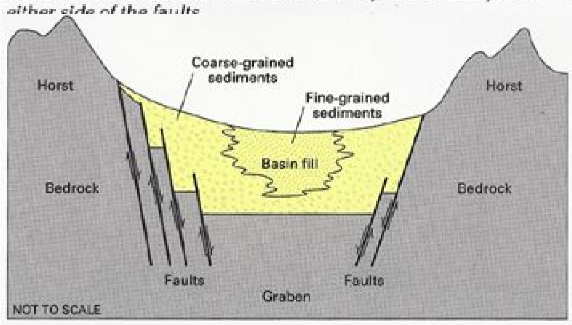
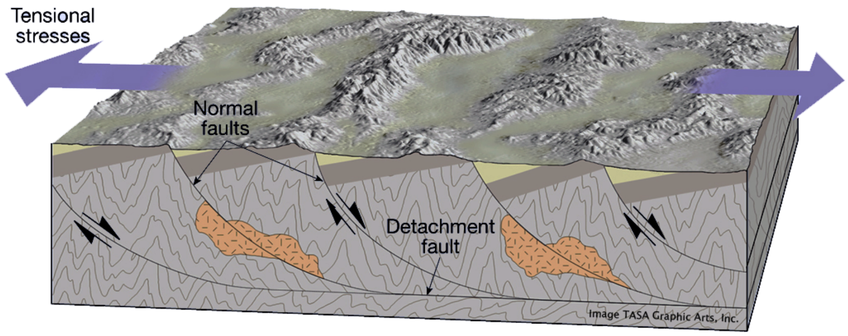


Figure 34. Basin fill is located between bedrock mountain blocks and contains fine-grained sediments near the center of the basin. Coarse-grained sediments were deposited near the basin margins, primarily as alluvial fans.

- The outer crust is less flexible than the mantle, so the stretching breaks the crust and faults appear.
- Possible models range from horst and graben, tilted block, and listric faults.
- Normal faults: up down motion with no overhanging edge. Listric: curved normal faults
- Tilt patterns rule out horst and graben.
- The faults run perpendicular to the direction of rifting. With the fault plane angle of 60 degrees.
- The blocks of rocks slide down, creating alternating ridges and valleys.
- The low area becomes filled with sediment from the eroding blocks.
- The basins are quickly filled with rock and sediment eroded from uplifted sections on a much quicker timescale than the rifting, filling up thousands of feet to level the basin.

Adam Sutherland



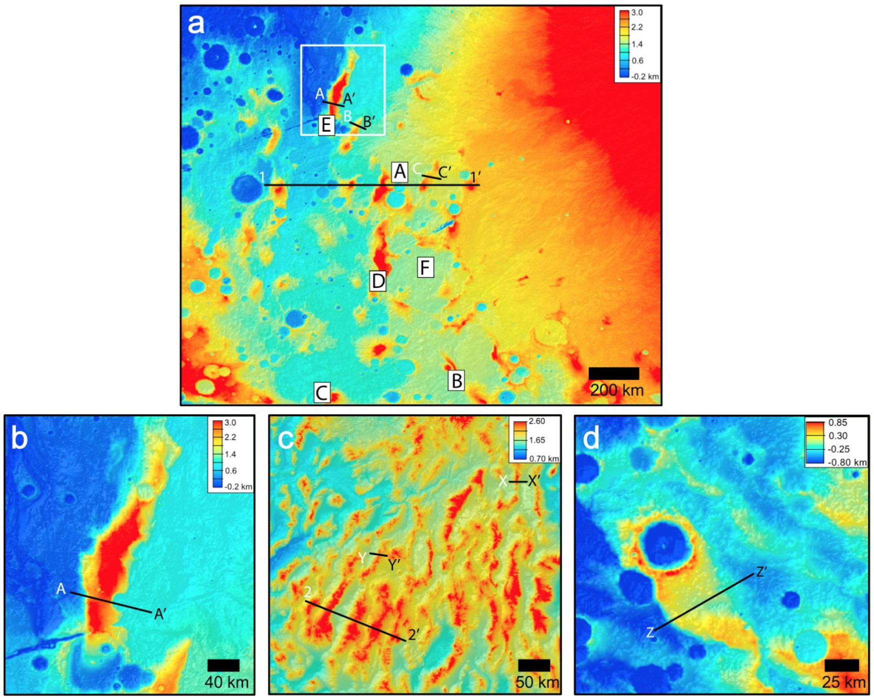
Current extent

- Surrounded by the Columbia Plateau, Wasatch Fault, Colorado Plateau, Rio Grande Rift, Sierra Madres, the Pacific Ocean, the Sierra Nevadas.
- B&R Province includes the Great Basin
- Endorheic basin - does not drain to the ocean, evaporation is the only way for water to leave → salty lakes.
- The Great Basin is a collection of a large number of smaller basins.
- Lake Bonneville, a pluvial lake due to increased rainfall with no outlet for to drain, existed from 32,000 to 14,500 years ago.

Ecology

- Rain shadows from the Sierras and Cascades. As well as individual rain shadows from each ridge.
- Salty lakes- the region has organisms that are adapted to live in incredibly dry regions or salty.
- Most precipitation is from the mountains and flows down to the basins.
- Current sediment basin are aquifers that provide water for Phoenix and Tucson.

Connection to Mars



a),b) STRB, c) Basin and Range Province, d) Amenthes Rupes thrust fault

- South Tharsis Ridge Belt on mars shares a similar structure to the B&RP.
- It consists of 29 ridges separated by 130 to 260 km, with average relief of 1.5 km above the surrounding plains.
- This region on mars was previously thought to have a compressional history but similarity to basin and range suggest rifting.
- Basin and Range-style wide rifting could be expected for early Martian conditions.
- But plate tectonics on Mars is controversial, but evidence of rifting would suggest that it was active at some point.
- But some B&R formation scenarios do not require plate tectonics.
- Ridge spacing is proportional to crust thickness, so we can learn about the crust of Mars from this ridge belt.

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Sarah Peacock
Anticlines / Synclines / Monoclines

See additional handout

The National Parks System & Federal Land Management Policy
Margaret Landis

Key Points

- The National Park System grew out of a movement in the late 19th/early 20th century movement towards preserving natural landmarks and historical resources
- Public lands are either bought, donated, or retained from the incorporation of western territories into the US, and can be made into national monuments by executive order or national parks (including historic sites/parks) by Congress
- Public lands, depending on their designation, are managed by various organizations within the Department of the Interior and can include collaborations with local agencies
- Utah especially has been a contentious area for managing natural resources, preserving landscapes, and balancing federal vs. state power

We have become great because of the lavish use of our resources. But the time has come to inquire seriously what will happen when our forests are gone, when the coal, the iron, the oil, and the gas are exhausted, when the soils have still further impoverished and washed into the streams, polluting the rivers, denuding the fields and obstructing navigation. --Theodore Roosevelt (1908)

National Park System (NPS) and Federal Land Management Brief History

- 3 March 1849: Department of the Interior is founded (Figure 1). Previously, land management/resource policy was placed under the purview of the Department of State. Department of the Interior is a federal executive department, meaning that the director is a presidential appointee and that its employees can be presidential appointees, civil servants, or contractors.
- 1891: General Revision Act/Land Revision Act is passed by Congress. This reformed land management policy so that areas of high timber or mineralogical wealth were acquired by the federal government on behalf of the American people. This was also passed to address timber fraud (in which private citizens abused the then current forestry system for personal monetary gain), and to address growing concerns about mining runoff in local drinking water.
- 1 March 1872: Congress establishes Yellowstone National Park out of parts of Montana and Wyoming Territories and places its management under the control of the Secretary of the Interior.
- 17 June 1902: National Reclamation Act creates a system by which profits from the sale of semi-arid public lands would be used to fund irrigation projects. This program is run by the Department of the Interior and drove the damming of almost every western American river.
- 1 February 1905: National Forest Service established as part of the Department of Agriculture to manage public timberlands.
- 8 June 1906: Congress passes the Antiquities Act in order to ensure "... the protection of objects of historic and scientific interest". This act allows for the creation of national monuments by executive order (i.e. does not need approval

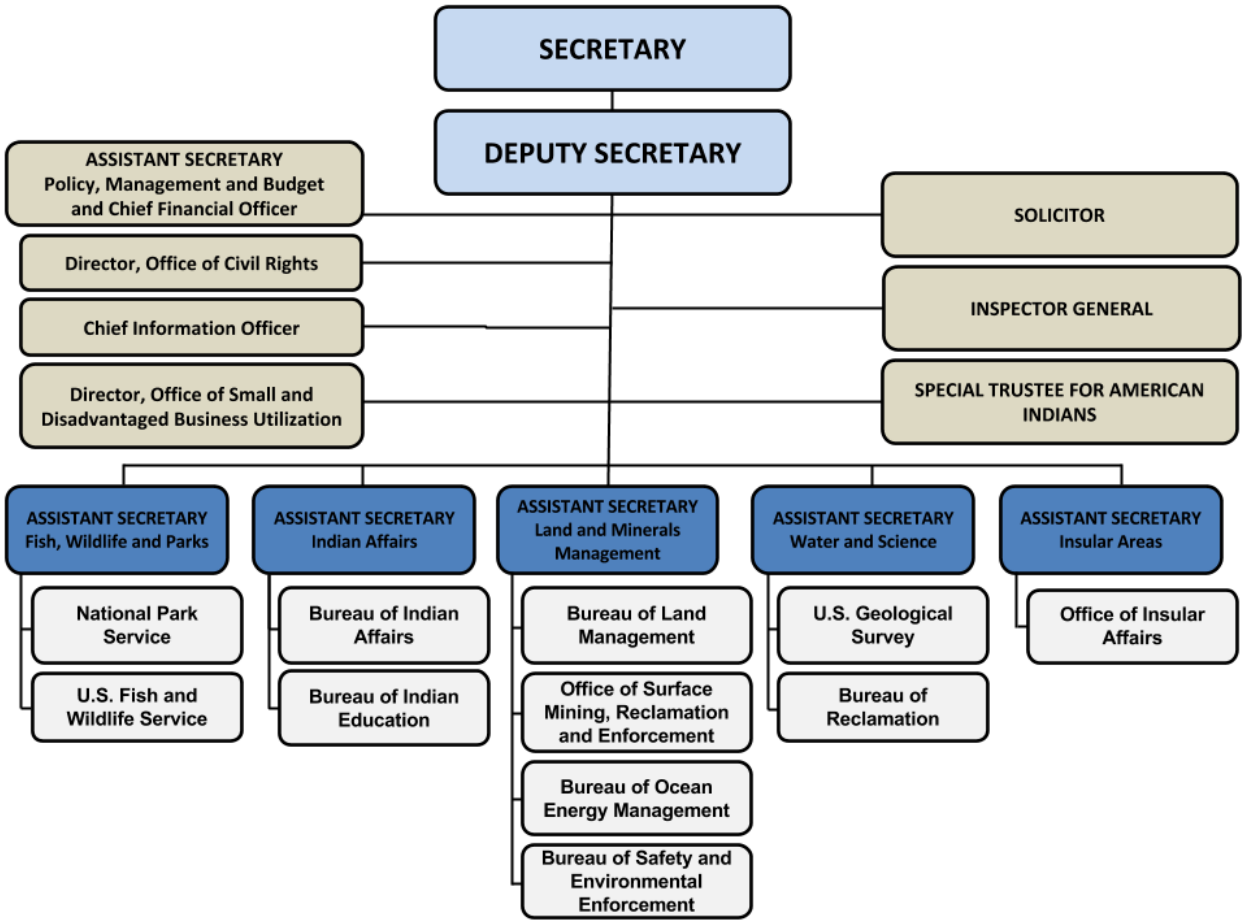

Figure 1. Organizational chart for the Department of the Interior. The National Park Service falls under the purview of the Assistant Secretary for Fish, Wildlife, and Parks, while the Bureau of Land Management falls under the Assistant Secretary for Land and Minerals Management. The United States Geological Survey is separate from both, and under the Water and Science section. Image credit: Department of the Interior, https://www.doi.gov/whoweare/orgchart

from Congress) in response to national heritage sites being looted, like Mesa Verde, which was common in the early 20th century. This act gives federal legal protection and funding to the curation of these sites.

- 25 August 1916: Woodrow Wilson signs the Organic Act, creating the National Park Service as a part of the Department of the Interior, in order to:
    - "…promote and regulate the use of the Federal areas known as national parks, monuments and reservations…by such means and measures as conform to the fundamental purpose of the said parks, monuments and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." (Figure 2)

Figure 2. Stephen Mather, first director of the National Parks Service, with an early field trip vehicle. Image credit: Yellowstone Photograph Collection

- Subsequent amendments in 1970s clarified the types of sites that could be preserved under the Organic Act, including battlefields and other historic sites. Sites that cross state lines are particularly helpful to administer as NPS sites.

National Park System/Federal lands designations
Note: the disturbing or pilfering of human artifacts or other natural resources is prohibited in all NPS areas!

- National Monument
    - Who creates/designates it: President, by executive order
    - What is it made of: preserves at least one “nationally significant” resource on existing federal lands, generally smaller in area than national parks
    - Who administers it: National Park Service
    - Activity restrictions: Leave it the way you found it! Restrictions on camping, fires, hunting, and dogs are expected.
    - Example: Walnut Canyon National Monument (Figure 3)

Figure 3. Walnut Canyon, including a historical human dwelling and distinctive cross bedding.

- National Park
    - Who creates/designates it: Congress
    - What it is made of: A generally larger area than national monuments, from preexisting federal lands including national monuments. Private lands can be donated or willed to the federal government for the establishment or expansion of national parks (e.g. the Rockefeller family buying up and then donating land for numerous parks, including the Marsh-Billings National Historical Park in Maine and Grand Teton National Park in Wyoming).
    - Who administers it: National Park Service
    - Activity restrictions: Leave it the way you found it! Restrictions on camping, fires, hunting, and dogs are expected.
    - Example: Yellowstone National Park (founded as a National Park, predates the National Park Service itself)
    - Example: Joshua Tree National Park (founded as a national monument in 1936, was changed to a national park in 1994 by Congress as part of the California Desert Protection Act, Figure 4)

Figure 4. Spheroidal weathering and Joshua trees at Joshua Tree National Park.

- National Recreation Areas
    - Who creates/designates it: Congress
    - What it is made of: Originally used to describe areas around dam reservoirs, this designation has been expanded to include federal lands designated by Congress and managed by the NPS as well as the US Forest Service (Department of Agriculture).
    - Who administers it: Many of these sites are also co-managed between the National Park Service and other groups (including local land management organizations).

- Activity restrictions: Bring your speedboat! (and take your garbage when you leave). Recreational hunting is possible in some areas, but restrictions vary by site.
- Example: Glen Canyon National Recreational Area (managed by the NPS, is on the border of Arizona and Utah and includes Lake Powell)

- National Historic Park/Sites:
    - Who creates/designates it: Congress
    - What it is made of: Locations with particular American historical interest. Parks tend to be more area-extensive than sites. Congress can also use designations like national military park, national battlefield park, national battlefield site, and national battlefield to designate historical sites that are related to American military history. National memorial sites are a separate designation but also commemorate a historical figure (which may or may not be related to a home that figure lived in, or where they were assassinated).
    - Who administers it: National Park Service
    - Activity restrictions: Many of these sites are historical structures or locations, so are not all commonly used for outdoor recreation. However, in outdoor areas, the same principle of leave it the way you found it is expected.
    - Example: Ft. Bowie National Historical Site, Arizona (near Chiricahua NM, where the Chiricahua Apaches and US Army fought extensively)
    - Example: Ft. Vancouver National Historical Park, Washington (Figure 5).

Figure 5. Rebuilt Ft. Vancouver trading post buildings.

National Forest

- Who creates/designates it: Department of the Interior, from land held for public use by the US federal government
- What it is made of: Land either bought or held since time of incorporation of surrounding territory into the United States
- Who administers it: US Forest Service

    - Activity restrictions: Fires only in designated areas, mining and logging are possible via permit only. Hunting okay if safety rules and regulations are followed.
    - Example: Coconino National Forest
- Bureau of Land Management land
    - Who creates/designates it: Department of the Interior, from purchases or claims of homesteading land
    - What it is made of: Land homesteaders (c. 19^{th} century) didn't want, grazing lands that are still held by the federal government
    - Who administers it: Bureau of Land Management (BLM)
    - Activity restrictions: Mining, logging, coal extraction, etc. are allowed by permit or lease. Hunting is allowed, but off road driving is not.
    - Example: Many of the locations where we camp, areas adjacent to national parks, designated wilderness areas.

Figure 6. View of Canyonlands National Park. Oil and gas drilling near the border of this park, as well as in the Moab area, has been a hotly contended issue in Utah politics.

Federal Land Management in Utah

- Zion/Canyonlands/Moab natural gas drilling (Figure 6)
    - BLM held lands adjacent to national parks in Utah are natural gas rich, and the current lease system allows for gas companies to bid for and develop extraction infrastructure on the land. The Department of the Interior is responsible for managing the extraction, including setting rules for methane production and other environmental standards.
    - The domestic production market for oil and gas in the US is $20.9B (FY15) and generates $2.3B (FY15) in royalties, which are then used for public or tribal works projects.
    - This begs the general resource management questions: Does oil/gas development policy make the best use of publicly held lands? What about the greenhouse gasses or other environmental impact generated by the extraction, or by the use of these resources? What are the impacts on nearby protected areas (e.g. National Parks)? What are the impacts on NPS tourism?
    - In 2016, Terry Tempest Williams and Brooke Williams (life-long residents of Utah, writers, and environmental activists, Figure 7)

participated in an open quarterly BLM lease auction, formed an exploration company (Tempest Exploration, LLC), and stated in their development plan they would keep the natural gas in the ground until environmental risk assessment found the risk of increasing global climate change was less that the benefit of adding the natural gas into the US energy economy.

- 20 million acres of public land are leased but not being developed by the lease-holding energy company for a variety of reasons
- Some of these leases have lapsed and the BLM is not currently being paid rent for these areas
- Tempest Exploration, LLC was denied these leases because a more intense that typical review process found they had no intent to extract the natural gas

Figure 7. Terry Tempest Williams and Brooke Williams. Photo credit: Trent Nelson, Western Environmental Law Center

- Bears Ears National Monument
    - Area in south-central Utah along the Arizona border had been included in previous national monument proposals, including Escalante National Monument in the 1930s, but had not been protected
    - The proposed area for Bears Ears National Monument is host to many Navajo, Hopi, Ute, and Zuni cultural sites, including Newspaper Rock (which we visited on a previous Canyonlands field trip, Figure 8).

Figure 8. Newspaper Rock is one of the petroglyph sites now protected by Bears Ears National Monument.

- Was made national monument (with significant cuts to the initial proposal) by executive order by Barack Obama on 28 December 2016. This monument's management would be a cooperation between the BLM (which administered much of the land that was used to form the national monument) and a coalition of Native American groups.

- Strongly divided opinions in Utah:
  - "We have always looked to Bears Ears as a place of refuge, as a place where we can gather herbs and plants and as a place of sacredness. It is a place of safety and fortitude. It is a place where our ancestors hid and survived from U.S. cavalry during the Long War."—Russell Begaye, Navajo Nation president
  - "A Bears Ears national monument is not supported locally. It would exacerbate an already tense situation, and fan the flames of conflict on Utah's public lands." --Governor Gary R. Herbert of Utah

Water Management in Arizona

- About 53% of Arizona's water comes from groundwater sources.
- 70% of the total water use in Arizona is due to agriculture.
- Removing water from the subsurface can cause surface subsidence and result in earth fissures (Figure 9).

Figure 9. Map of Arizona areas of active land subsidence based on InSAR data. Credit: Arizona Department of Water Resources.

Planetary Connection (tenuous)

- Resource management is going to be an issue wherever people and resource expensive activities occur
- Protecting areas for scientific/research/preservation value will always be in tension with resource extraction

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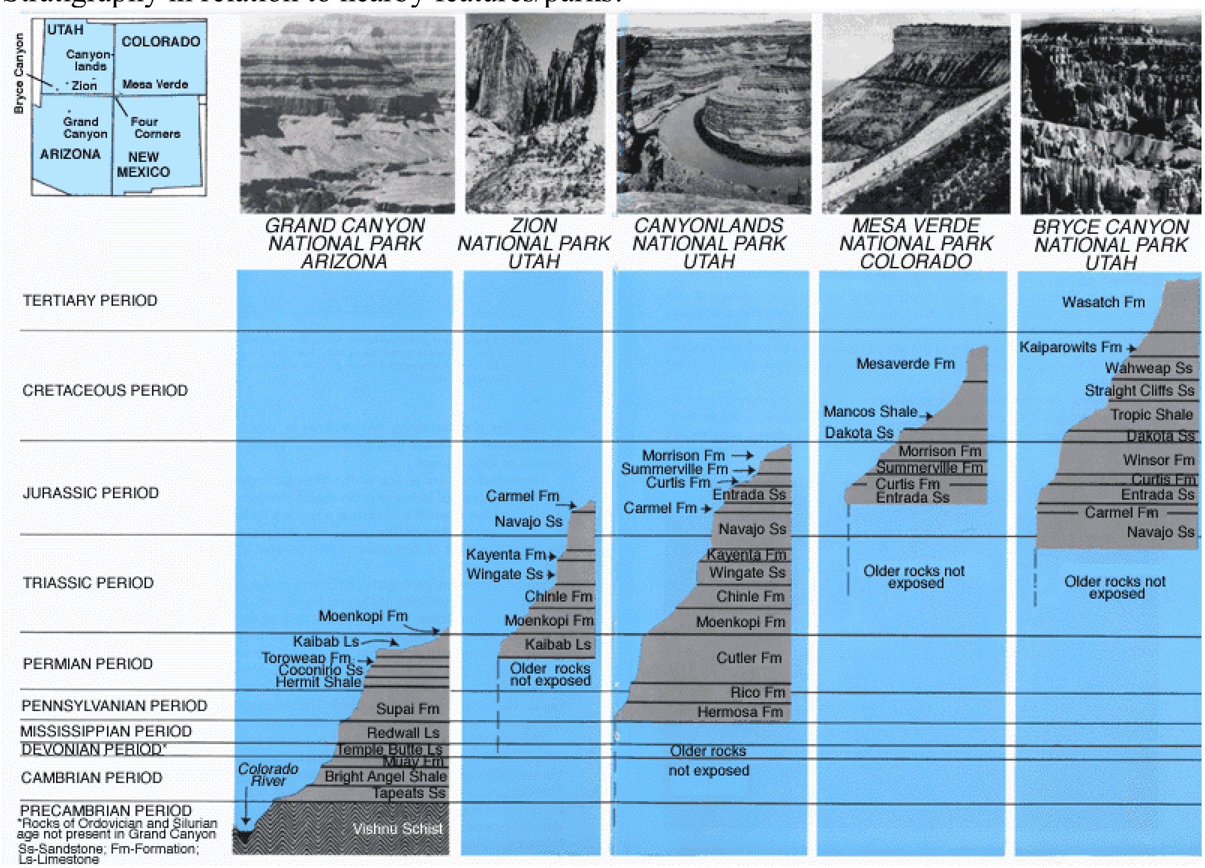
Overview of Zion National Park
Ali Bramson

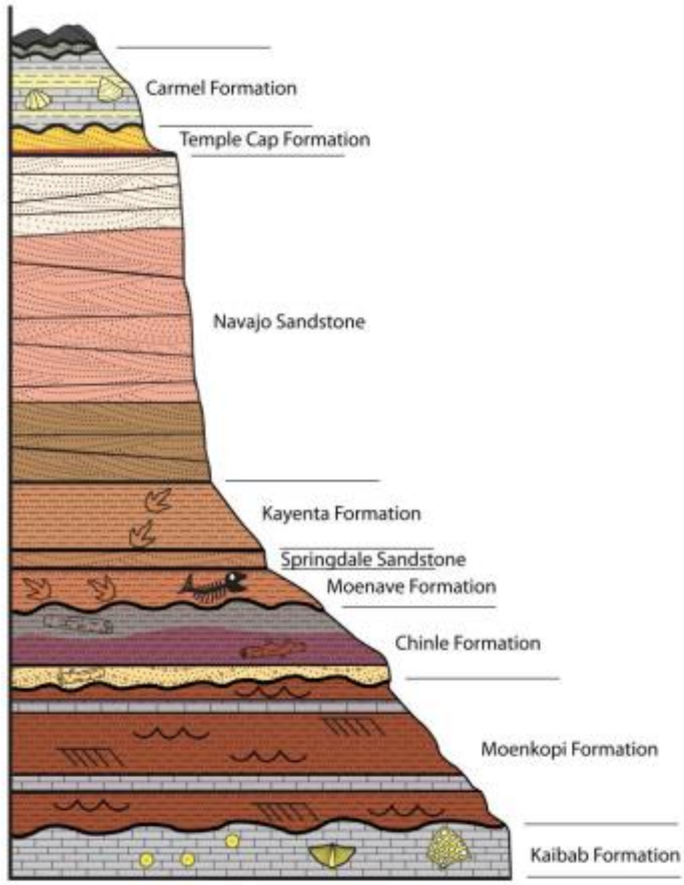
Location of Zion National Park.
Zion is located on the Colorado Plateau (see Daniel's talk), North of Grand Canyon in southern Utah. To the West it is bounded by Hurricane Fault and the Basin and Range Province; to the East it is bounded by Sevier Fault [Stewart 2005].

Stratigraphy in relation to nearby features/parks:



https://pubs.usgs.gov/gip/geotime/strat.gif

Stratigraphy in Zion (more about this also in Daniel's talk):
Basically the bottom-most rocks in Zion, though not well-exposed, are the Permian aged Kaibab Limestone. This is the same layer that caps the top of the Grand Canyon (see above). In total, the stratigraphy in Zion Stratigraphy spans only about 100 Myr of time. But, a lot happened in that time!



https://www.nps.gov/zion/learn/nature/images/ZionStratColumn_small_1.jpg
Image by Geoscientist-In-the Park David Tarailo, sponsored by the Geological Society of America, GeoCorps Program, 2012.

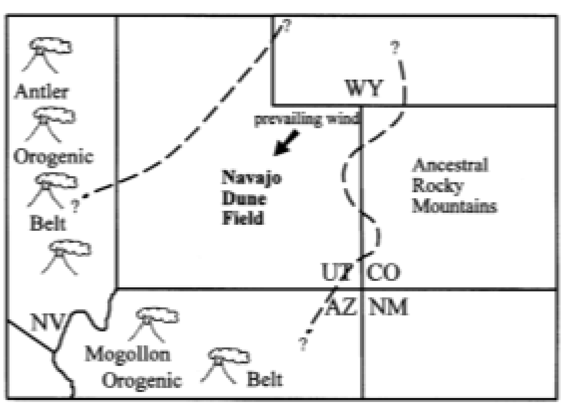
Geologic History of Zion National Park [National Park Service; Wier 2011]:

1. The Kaibab Formation forms ~270 Myr in a Permian shallow sea on the West coast of Pangaea. This deposits marine limestones and siltstones. This formation contains many fossils. This unit is only exposed in a small corner of the Kolob Canyons but can also be seen in outcrops of Hurricane Fault. This unit also is most famous for being the resistant cap rock at the top of the Grand Canyon, making the oldest layers in Zion are the youngest units of the Grand Canyon.
2. The Permian sea retreats.
3. In the early-to-mid Triassic, ~250 Myr ago, the tidal deposits of the Moenkopi formation form in slow river systems and broad coastal flooding of the plains. This layer is mudstones, sandstones and siltstones containing ripple marks, with occasional limestones and gypsum deposits indicating periods of higher shorelines and evaporation of seawater. This layer can be seen in near the entrance to the Kolob Canyon Scenic Drive, as well as near Rockville to the southwest and west of the Chinle Trail. Off of State Route 9 south of Zion there are 1000 foot thick exposures of the unit from this time.
4. In the late Triassic to early Jurassic, ~225-185 Myr ago, a large river system spanned across the area depositing layers in river channels and flooding events. This time period is recorded in the Chinle Formation (mudstones, siltstones, sandstones, and conglomerates). This unit can be seen in the southwest part of the park off of Chinle Trail and by the Kolob Canyons. The top part of this layer is brightly colored due to weathering of volcanic ash that was brought in to this area by the rivers and streams

from the volcanoes to the southwest of the Colorado Plateau region. The younger Jurassic unit, the Moenave Formation (also mudstones, siltstones and sandstones) also forms in these streams, floodplains and lakes. This layer is easily seen across the park as a lower layer of reddish hillside rocks. Dinosaurs often roamed these ancient lakes and streams, and their muddy footprints are preserved in some regions (esp. St. George, UT) within this unit. The Kayenta Formation then forms layers in river floodplains and lakes (mudstones) and stream channels (thin sandstone layers). Dinosaur footprints are also found in this unit. This unit is the sloped, reddish-brown one right below the nearly vertical cliffs and can be seen easily in Zion Canyon and Kolob Canyons. The most prominent sub-unit within this formation is the Springdale Sandstone, which formed from the main river channel. Smaller parts of this river are what deposited the other parts of the Moenave and Kayenta units. This sub-unit is more resistant, so the Moenave layers below it erode away and undercut this unit and often lead to large boulder falls from above that have damaged roads and buildings in the park.

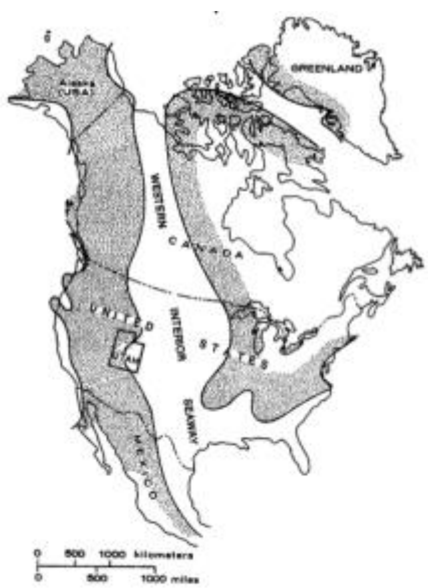
NPS photo/Adrienne Fitzgerald
https://www.nps.gov/zion/learn/nature/images/SprgdlSS-Kayenta_view-labels_xs.jpg

5. The Jurassic climate ~180 Myr ago turns the entire region (Colorado Plateau and beyond) into an arid, hot, Sahara-like desert, depositing thick cross-bedded sandstones from sand dunes blowing in the wind. This led to the largest known sand desert (erg) in the history of Earth. These sand dunes likely reached 100s of feet in height. Sandstones preserve the bottom-most part of these dunes, and continued to pile up layers and layers of various dunes (turning to rock from the pressure from above the cementing minerals in the groundwater that percolated through) until it reached a geologic unit of rock >2000 feet thick (the Navajo Sandstone). The orientation of the cross-bedding has indicated that the dominant wind pattern across Zion at this time was from the north-northeast. The sand grains that make up the bedding are fine, well-sorted, and well-rounded and also contain zircon. This suggests the material came from very far away, perhaps transported by rivers and wind from as far away as the ancient Appalachian Mountains (which would have been as tall as the Himalayas are today). The various colors in this unit result in differing amounts of iron oxide in the rock (white = lack of iron; red = lots of iron).



Navajo Sandstone deposition location, Figure adopted from Peterson 1994, Figure 5 from Davis and Eves (2002).

6. A shallow inland sea starts to encroach across the region during the middle Jurassic (~175 Myr ago), leading to a complicated coastal situation that left behind a variety of layers that make up the Temple Cap Formation: mudstones in tidal flats, sandstones in aeolian dunes on the sea shore and sandy beaches, and limestones when it was underwater. The East Rim Trail features an outcrop of ancient sand dunes from this formation, and can also be seen by looking at the high parts of the West Rim Trail. The Temple Cap is hard to get to and can only be seen from afar (though seen easily); so far little fossils have been found in this layer but it could be related to the fact it is hard to see this layer up-close.
7. The Carmel Formation forms in the Jurassic's shallow interior seaway, about 165 Myr ago, and contains many marine fossils in its marine mudstones, limestones and gypsum layers (during evaporative coastal lake episodes). This shallow sea was called the Sundance Sea and the climate was warm and humid. Lots of ocean life lived in this region at the time. The area was surrounded by an arid coastline and there were deserts to the south and east. This unit can't be seen in most of the park except near the park's east entrance. One can also come across it at high points of the East and West Rim Trails.



8. In the early Cretaceous, ~120 Myr ago, rivers flowed across the region northeast towards an inland sea, depositing the conglomerates and sandstones of the Cedar Mountain Formation. These rivers flowed in this direction due to new mountains appearing from the Sevier Orogeny (an orogeny is a mountain-building tectonic event). This layer is exposed mostly in the east of the park.

Location of Cretaceous Western Interior Seaway, from Peterson and Turner-Peterson, 1989, Figure 9 in Davis and Eves (2002).

9. Time goes on and additional layers form across the region, adding thousands of feet of additional stratigraphy.
10. 90 million years ago or so, Zion was still at or near sea level (and had been for the previous 430 Myr or so). An oceanic seaway stretched from the area eastwards for 1000 miles all the way across the location of the present-day Rocky Mountains to what is currently St. Louis.
11. This orogeny is a very slow process, vertically pushing the crust up such that over time, the elevation of Zion has risen from near sea level to 10,000 feet (~2.5 miles) above sea level. A lot of this uplift occurred ~70-45 million years ago, and also caused the formation of the Rocky Mountains. Fun fact: this uplift is still occurring today and caused a magnitude 5.8 earthquake in 1992 outside the park's south entrance (in Springdale).

12. ~20 Myr ago, the Basin and Range extension starts producing the Colorado and Markagunt Plateaus (which are bounded by the Hurricane and Sevier Faults).
13. Due to the uplift and tectonic events that have been occurring across the region, the streams (related specifically to North Fork of the Virgin River) across the Colorado Plateau are able to pick up speed as they go downhill and are thus able to do more erosion, cutting into any of these more recent rock layers. For the most part any layers above the Cedar Mountain Formation are not seen anymore in Zion due to so much erosion across the region.
14. These streams also have the power to carve the deep canyons seen in Zion, and continue to do so today. Most of the canyon carving has occurred in the last ~6 Myr. Before that, the Colorado Plateau rivers actually drained towards the middle of the plateau. They finally cut through to the sea and the large elevation drop enhanced their erosive power. Fun fact: A slot canyon is being carved through the Navajo Sandstone down into the Kayenta Formation still today.
15. Lava flows in the last 100,000 – 1.4 million years erupted, and capped the mesas and buttes on the southwestern edge of the park. This the only exception to the missing stratigraphy of the last ~120 Myr in Zion. These dark lava flows would have come into the area after Zion already looked basically like what we see it to be today.

The Canyons:
There are 2 types [Stewart 2005]:

- V-shaped: formed into the Kayenta rocks, which are less competent. Erosion happens in smaller blocks which either fall individually as rock falls or fall together as landslide events. This results in shallower slopes that are at the angle of repose.
- Steep-cliffed: formed into the Navajo sandstones, which are more resistant to erosion - they are hard uniform rock with minimal fractures - gets eroded into deep, narrow canyons (weak materials can't support these cliffs). Erosion generally happens along any joints (weaknesses in the form of vertical fractures). Erosion into stronger materials forms steep "Slot Canyons" (i.e. The Narrows). Sometimes you may get widening at the base due to undercutting of those layers below. You are left with vertical cliff faces when the overhanging block breaks along any vertical joints. You form arches when only some of that overhanging block falls (i.e. Great Arch and Kolab Arch).

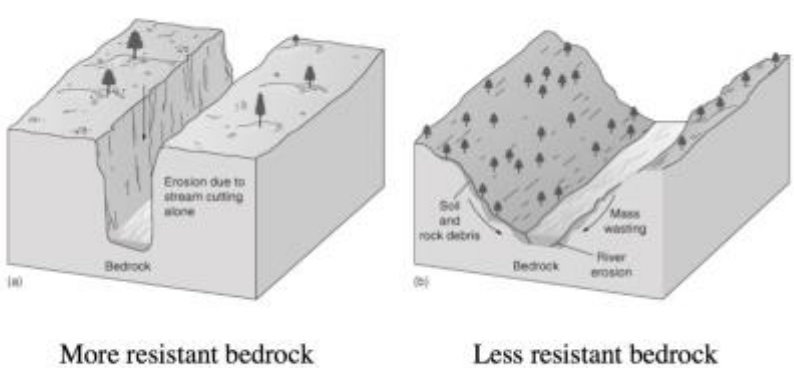
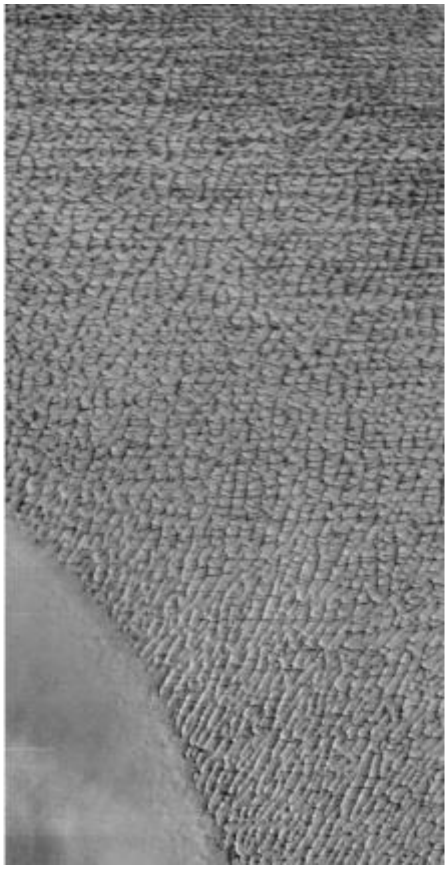


Image from Stewart (2005)

In Zion, freeze thaw cycles are the main driver of joint formation and mass wasting. This process occurs when you have water that gets into a joint and freezes (either at night or in seasonally in the winter). The ice expands and pushes the joint to open more and more each event until the block separates.

Planetary Analogs:



During the time of the desert described in bullet 5, a huge sea of sand, called an erg, extended from current-day Nevada and Arizona to Colorado and Wyoming, stretching hundreds of miles across. A planetary analog to a large polar erg can be found at the Martian north pole and is called Olympia Undae. This expansive sand sea features many complex sand dunes that are often frost-covered. This erg covers ~470,000 km^2 in area over a length of 1,100 km [Lancaster & Greeley, 1990]. It is on the same order of size as the largest active erg currently on Earth (the Rub' Al Khali in the Arabian Peninsula).

VIS image V11882001 at 82 degrees N, image taken during Northern spring. Resolution is ~20 m/pixel.

Many of the types of rocks that make up the stratigraphy at Zion have also been seen on Mars and studied with the rovers. Curiosity's CheMin instrument has measured properties of mudstones at multiple sites, which were likely deposited by water entering the lakes that are thought to have once occupied Gale Crater. Curiosity has also observed cross-bedded sandstones in Mount Sharp.

Left: Crossbedding at Mount Sharp, image taken by the MastCam instrument on Curiosity, NASA press release: https://www.nasa.gov/image-feature/jpl/msl/pia19818/vista-from-curiosity-shows-crossbedded-martian-sandstone
Right: Crossbedding in the Navajo Sandstone, image from the National Park Service: https://3dparks.wr.usgs.gov/zion/photos/3d153.jpg

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Coral Pink Sand Dunes State Park

LPL Field Trip Spring 2017
Jess Vriesema

Fun Facts

- These dunes have often been used in several Hollywood movies.
- The perceived colors of the sand change with time of day. They appear most "pink" at dawn and dusk. (Doelling et al. 1989)
- The park is a popular destination for ATV enthusiasts. ATVs are allowed only in certain areas of the park, as there are sensitive ecosystems elsewhere in the park.
- It is 13 km long and averages 1.1 km in width (Wilkins and Ford, 2006).
- The park's official website estimates the age of the dunes to be 10,000–15,000 years old.
- The dune ecosystem supports a diverse population of insects, including the Coral Pink Tiger Beetle, which is found only here.
- Melting snow sometimes creates small ponds in the dunes that support amphibians such as salamanders and toads.

The Sand

Gregory (1950) suggested that the sand comes from the washes in the Vermillion Cliffs west of Sand Canyon, which was eroded and reworked over time. The dunes get their "coral pink" color from the reddish Navajo sandstone they came from. Doelling et al. (1989) describes this unit as follows:

> *"The Navajo Sandstone is generally a light-colored, fine- to medium-grained friable sandstone, massive, and weakly cemented with carbonate and iron oxide. It displays an elaborate array of high-angle crossbeds and forms steep smooth cliffs or domes, monuments, and other bizarre erosional forms separated by broad, bare-rock surfaces and sand-covered areas. Locally thin lenses of limestone, dolomite, or dark-red sandy mudstone are also present.*
>
> *"The light hue of the Navajo Sandstone has been described with almost every color; white, tan, buff, salmon, pink, vermilion, brown, red, yellow, cream, orange, and gray. Hematite produces the reddish colors, limonite the yellows, and ferrous iron minerals the browns and occasional greens. The color is due to the amount and oxidation state of the iron oxides present in the cement or in the overgrowths of the sand grains.*
>
> *…*
>
> *"The Navajo is friable and weakly cemented, usually by calcite or dolomite intermingled with varying amounts of iron oxide. The better the degree of cementation, the greater the resistance to erosion."*

Ford et al. (2012) suggested that the color comes not just from cementing, but also from a coating of iron oxides on the individual sand grains.

The Navajo sandstone unit has three main units. The lower and upper units appear to have better calcareous cementation and are present as majestic cliffs, while the middle unit is friable (crumbles easily) and forms low domes, conical hills, gentle slopes, and loose sand. For this reason, it is thought that the sand from the Coral Pink Sand Dunes originates from this middle unit, but was loosed via erosion. (e.g. Doelling et al., 1989)

Formation

Winds in this region blow primarily from the south and southwest. As shown in Figure 1, winds south of the dunes are funneled in a narrow gap between the Moccasin mountains to the southwest and the Moquith Mountains to the east of the dunes, called the Vermillion Gap. This gap is in part due to the presence of the Sevier fault line (see Figure 2), which runs along the length of the state park.

As the wind gets funneled in the Vermillion Gap, the wind speed increases due to the Venturi effect and the stronger winds entrain more loose sand. Travelling northward, the gap widens and the winds decrease. The sand grains fall out of the wind and are deposited in this region, forming sand dunes. This mechanism, driven by a southerly wind, gives the southern

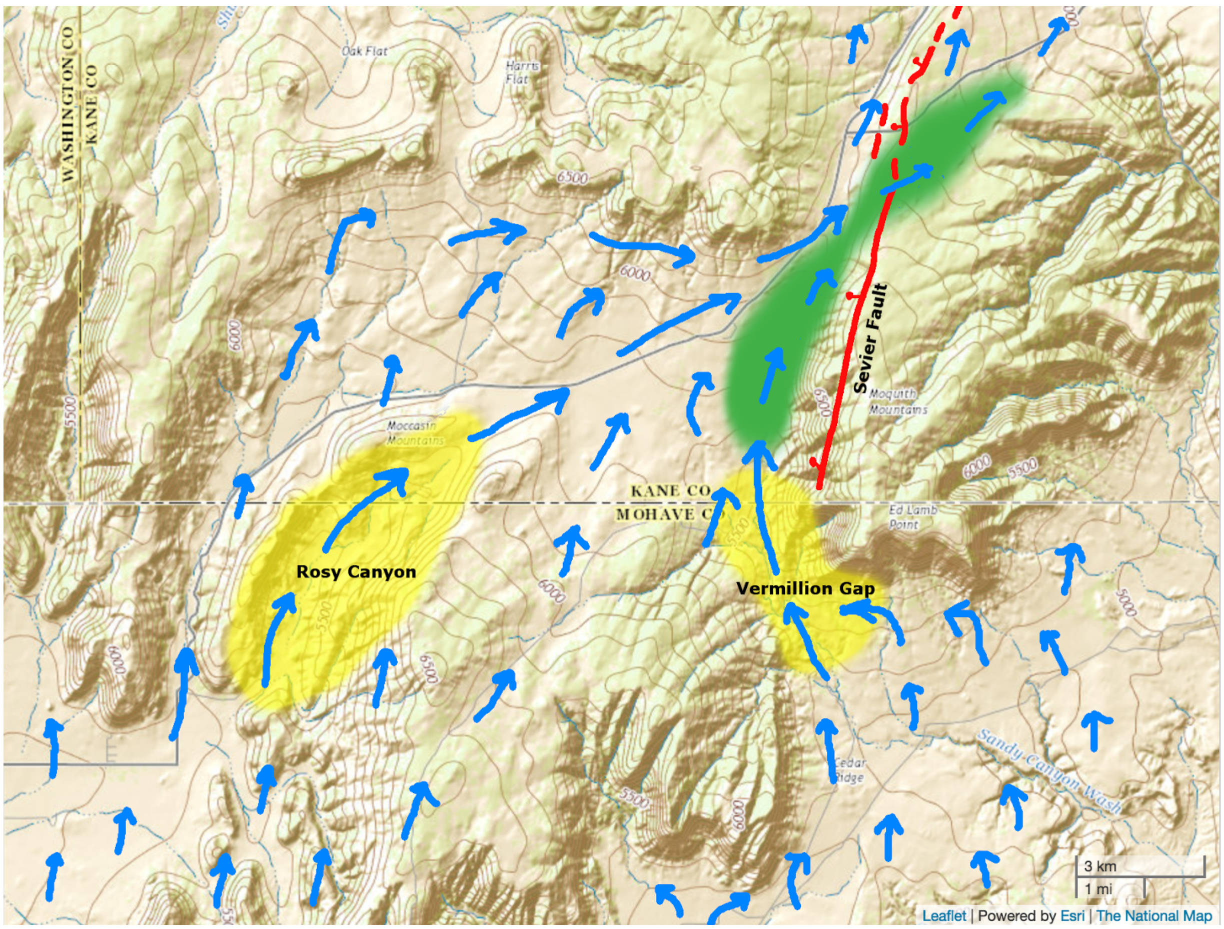

Figure 1: A sketch of the Coral Pink Sand Dunes region with conceptualized wind flow (blue arrows) and the rough location of the dunes (green). The approximate Sevier fault line is also indicated in red, although its location beyond what is drawn is unknown. Background image from *The National Map*.

dune field a north-south orientation.

The northern half of sand dune region is bent somewhat to the east. This may be due to southwest winds coming from Rosy Canyon (Ford et al., 2012). These winds, along with those from the Vermillion Gap, may be further decelerated by a Sevier fault scarp near where the fault and the dune field meet, causing more sand to be deposited there (see Figure 2). This sand may then be picked up by strong winds accelerated via the Venturi effect due to the gap between Esplin Point and this scarp. This likely contributes to the upper dune field, which is further away from the Vermillion Gap.

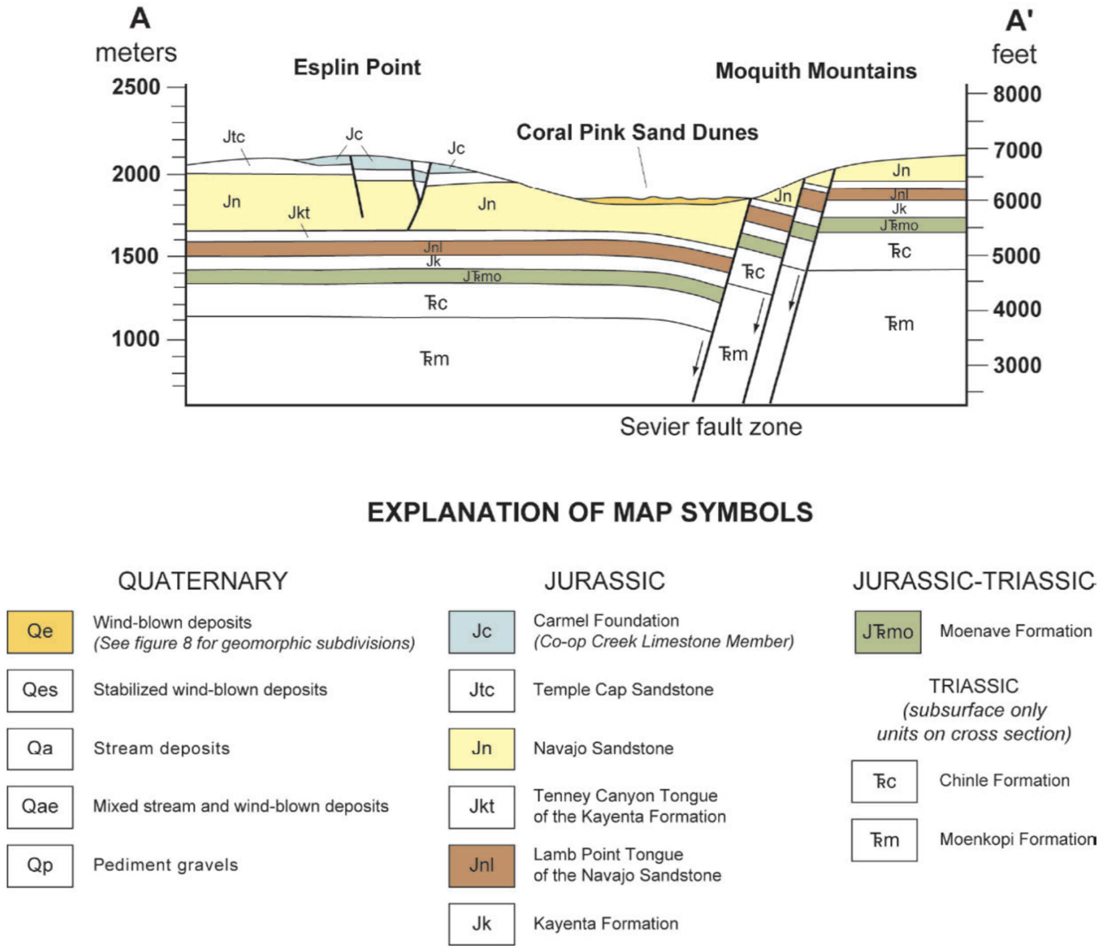

Figure 2: This map shows the gap between the Sevier fault scarp and Esplin Point as well as the stratigraphy in this region.

Evolution

Dunes grow when more sand is deposited on them from surrounding areas than is removed from them. Dunes migrate as winds blow over them in a similar direction for prolonged periods of time.

In the case of the Coral Pink Sand Dunes, the southerly winds on the lower dune field generally move the sand in a northeast direction. With some imagination, this may be observed in Figure 3. The migration mechanism is explained in Figure 4.

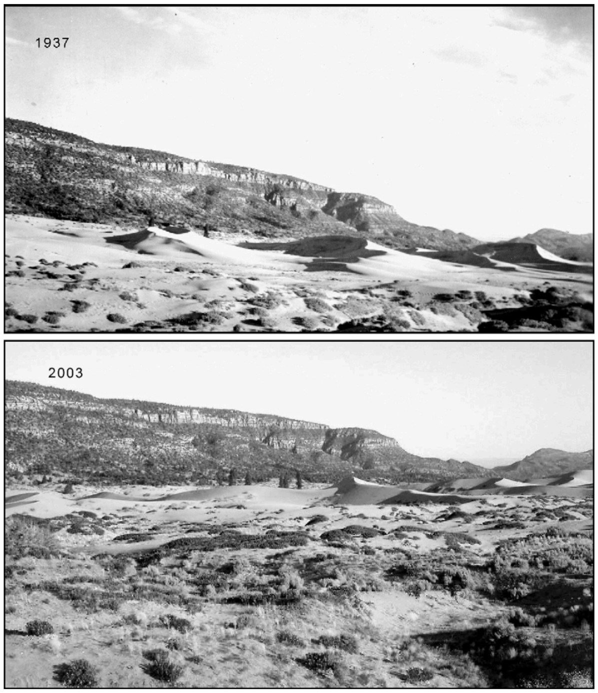

Figure 3: The 1937 photo was taken by H.E. Gregory in 1937 (Gregory, 1950), and the 2003 photo was taken by D. E. Wilkins or R. L. Ford in July 2003 (Wilkins and Ford, 2006).

Wilkins and Ford (2006) used a nearest-neighbor analysis to compare dunes in 1960 to those in 1997. They noticed that there has been a decrease in dune activity coincident with the increase in precipitation since 1961, though they cautioned that this conclusion was not uniform across the dune field. They also found that sediment from the southwest (upwind direction) has been transferred to a more interior concentration since 1961 as vegetation has crept up on the edges of the dune field and has hindered dune evolution. Furthermore, the mean dune length has increased, likely because dunes have merged. Finally, they suggest that the dune field is currently sediment-starved relative to other points in its history, so "the system is apparently adjusting to an earlier sediment influx that is presently working its way through the system".

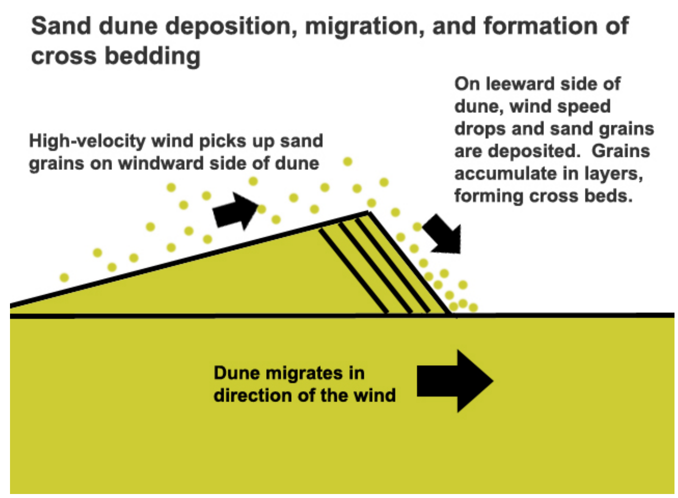

Figure 4: Diagram showing how sand dunes migrate.

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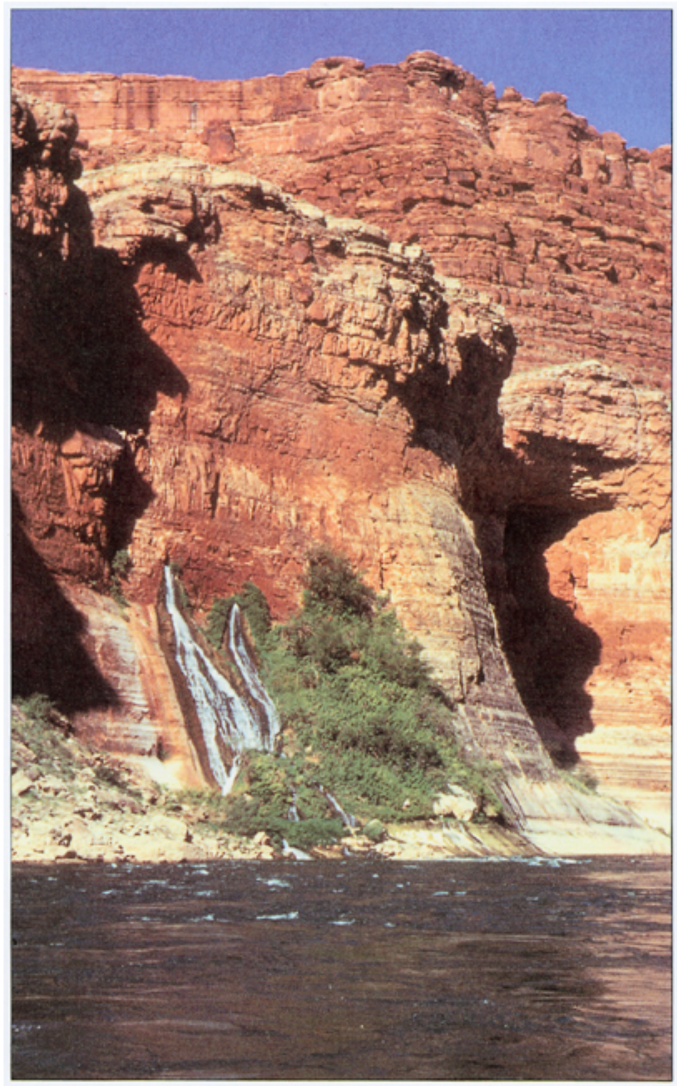
Springs and Aquifers
Kyle Pearson
Zion National Park 2017

Spring – a natural situation where water flows from an aquifer to the surface of Earth. Movement of water can be facilitated when on the side of a hill or valley creating a stream. A spring can form when an aquifer overflows with water such that it reaches the surface of the Earth. Springs are not only limited to Earth's surface; hot springs are present at depths of over 2 km in the ocean and they discharged water rich with minerals and sulfur.

Aquifer – an underground layer of rock that is permeable enough to contain water and can be used to supply wells or springs. Could contain gravel, sand or silt or carve out limestone caves like in karst terrain.

Spring Formation – a spring may result from karst topography, which we saw in Florida. In Zion, springs originate from limestone channels where weak carbonic acid (rainwater percolating through organic material in soil) enters fractures in bedrock and dissolves it. In this case, groundwater travels through a network of cracks and fissures to openings in the surface ultimately resulting in a spring. When the water reaches an area where it can no longer dissolve rock vertically it will start the process horizontally and excavate a cave. When the cavern becomes large enough it can trap groundwater and hollow out more rock and create a network of channels to move water beneath the surface.



R.D. MacNish, U.S. Geological Survey

Figure 133. Ground water discharges from springs in the Redwall Limestone and cascades into the Colorado River at Vasey's Paradise in the Grand Canyon.

Water from a spring may not always be clear because it can come in contact with naturally occurring minerals on the way to the surface. For instance, if the water has to travel a further distance to the surface it will potentially be in contact with more minerals along the way. It also depends on where the water that recharges the aquifer is coming from. Water may not be safe for consumption from a spring because it is crudely filtered by rock. Lack of sunlight will cause most algae and plants to die however bacteria can still be present. Hot springs usually occur in regions of recent volcanic activity and are fed by water heated by contact with hot rocks far below the surface.

Coconino-De Chelly Aquifer

A large aquifer under the Colorado Plateau that hosts water yielding rocks of early Permian age. The aquifer is comprised of Coconino, De Chelly and Glorieta Sandstones, San Andres Limestones and the Yeso and Cutler formations. The Coconino and De Chelly Sandstones generally consist of well-sorted quartz sandstone with thin interbeds of siltstone, mudstone, and carbonates. The Glorieta Sandstone consists of well-sorted, well-cemented, fine to medium quartz sandstone. The San Andres Limestone consists of dolostone, limestone, and fine-

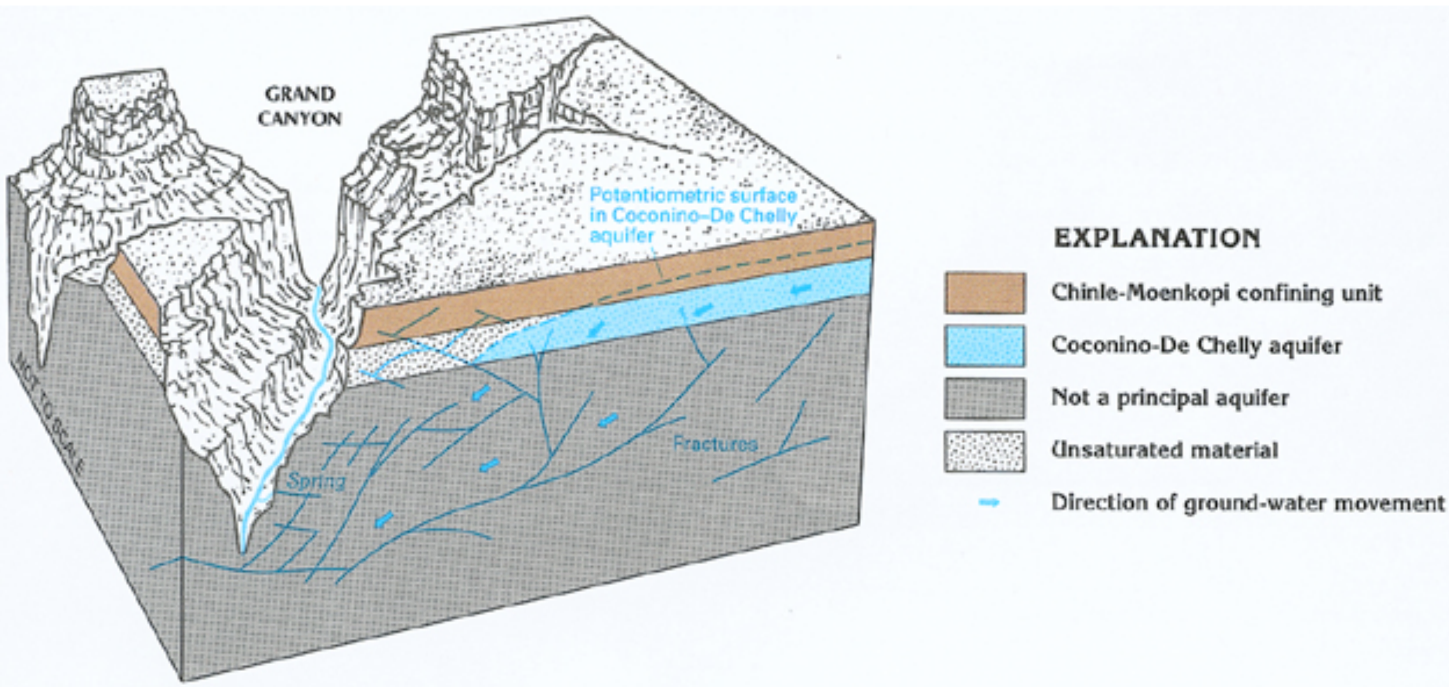
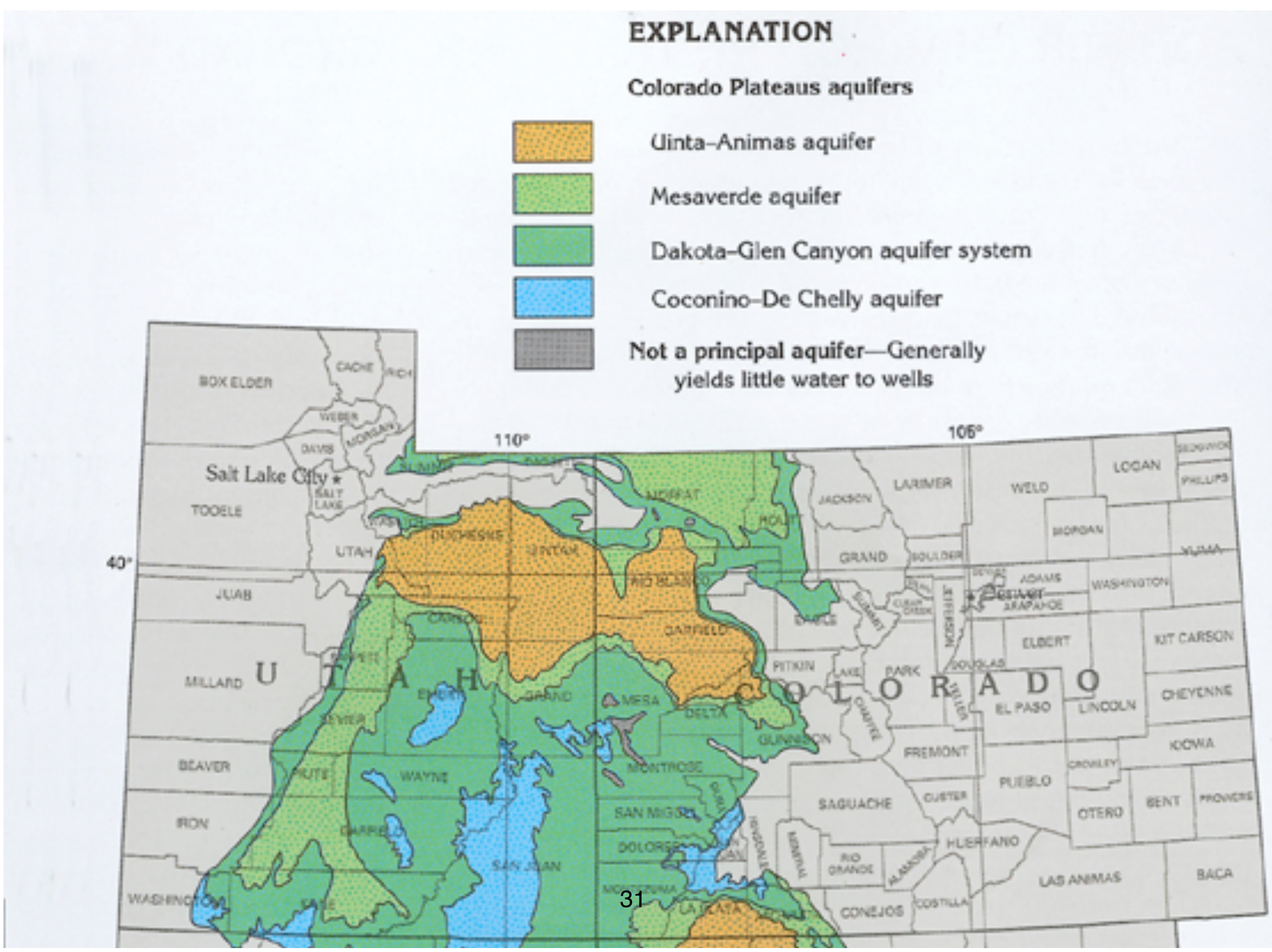


Figure 131. *Fractures in the vicinity of the Grand Canyon act as conduits that allow ground water to drain from the Coconino–De Chelly aquifer. The water emerges from underlying rocks at springs in the Grand Canyon and canyons of tributaries of the Colorado River.*

grained clastic rocks. The carbonate rocks in the San Andres Limestone are characterized by solution openings, which substantially increase the hydraulic conductivity of the formation. The Yeso Formation consists of interbedded sandstone, siltstone, limestone, anhydrite, and gypsum and forms a low-permeability zone in the aquifer. The Cutler Formation consists of shale, siltstone, sandstone, arkose, and arkosic conglomerate.

Discharge of this aquifer is mainly in the Colorado Rivers and Green rivers. In the Grand Canyon a series of spring emerge from the redwall limestone that originate from the Coconino-De Chelly aquifer. The aquifer is recharged from the Paradox Basin, San Rafael well, Circle Cliffs Uplift, Defiance Uplift, Zuni uplift and Mogollon Slope.

Weeping Rock - The water dripping down the rock started as rain and snow in Echo Canyon, located at the top of the cliff. Even though the Navajo sandstone looks solid there are tiny spaces between the grains where some of the rain water and snow melt percolate down and become ground water. After the water percolates down it reaches mudstone at the Kayenta formation and causes the water to spill out horizontally where it meets the canyon's wall and drips off the top of the alcove.



Hannah Tanquary
Faulting/Jointing
LPL Field Trip, Spring 2017

Joints and faults are both types of fractures which occur in the crust of the Earth and other rocky planets. Joints are fractures caused by tensional forces, and do not usually exhibit evidence of relative movement between one side of the joint and the other. Faults are fractures along which visible relative movement has taken place. It is in the vicinity of faults, not fractures, that earthquakes are likely to occur[1]. Faults and joints are not alike geologically, but are often grouped together since their surface expression can appear similar.

Fault

Normal fault in Mosaic Canyon, Death Valley. http://geotripperimages.com/Tectonic_Processes/Faults.htm

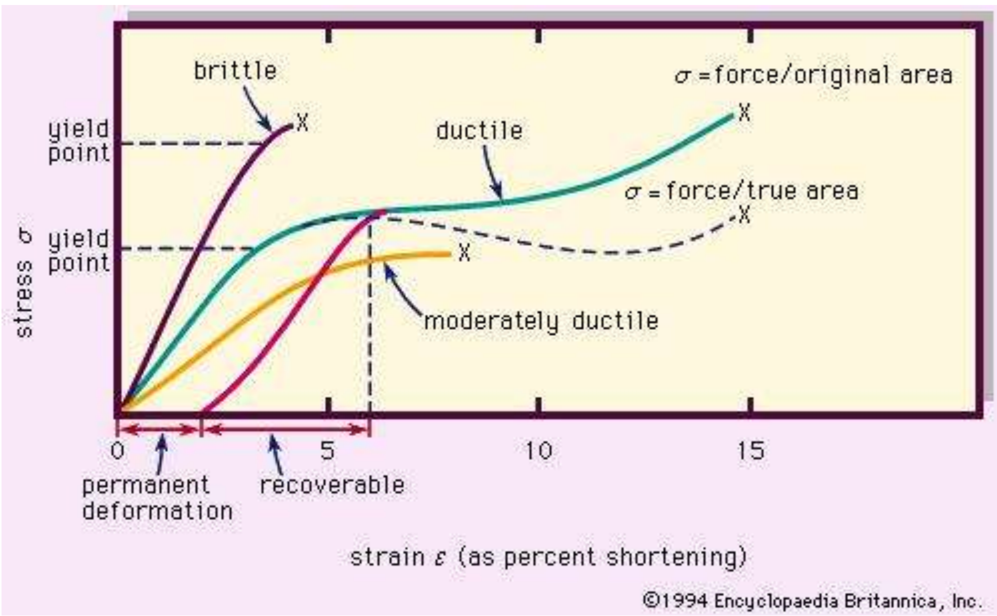
Jointing

Joints enlarged by dissolution in Jurassic anhydrite near Fort Dodge, Iowa.
http://www.gly.uga.edu/railsback/FieldImages.html

Faulting

A fault is a planar discontinuity in a rock body caused by movement of the rock mass. On Earth, the largest faults form the boundaries between the tectonic plates. These plates are the major sections of the Earth's crust which form its lithosphere and move relative to one another on geologic timescales.

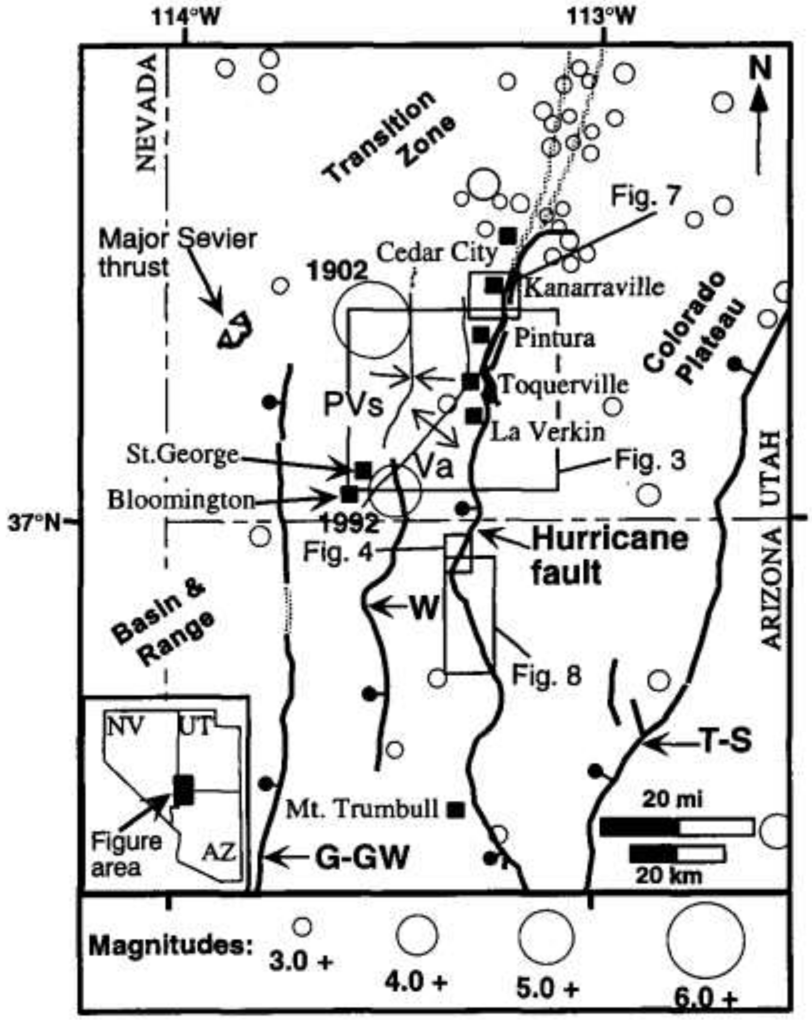
Motion of Earth's crust can cause stress to accumulate within the rock mass. When the stress exceeds the strain threshold of the rock, the energy is dissipated, resulting in (sometimes violent) fracturing of the rock body. Depending on the rheology of the rock, deformation can occur slowly via shearing, or quickly via fracture. The ductile lower crust and mantle tends to deform gradually via, whereas the brittle upper crust reacts by instantaneous release, causing fault motion. However, a fault in ductile rocks can also release instantaneously if the strain rate is too great. This release of energy can result in earthquakes, which are most common near fault zones[2,3].



Typical stress-strain curves for rocks of differing physical characteristics. Each X *represents the point of fracture for the corresponding material. https://www.britannica.com/science/rock-geology/images-videos*

Faults range in size from micrometers to thousands of kilometers in length, and can be tens of kilometers in depth. Not all faults intersect the Earth's surface, but when this occurs, the surface expression is call the fault line, and is the feature typically plotted on maps. Faults are rarely a single fracture, so the term fault zone is used to describe the deformation associated with a fault plane[2,3].

The **Hurricane Fault** runs along the boundary between the Colorado Plateau block and the Basin and Range geologic province. It is 250 kilometers long, and runs from Cedar City, Utah, southward into northwestern Arizona[4].



Location map showing hurricane fault, surrounding features, and earthquake epicenters.
"Neotectonics, fault segmentation, and seismic hazards along the Hurricane fault in Utah and Arizona", Stewart et al, Brigham Young University Geology Studies, Volume 42, Part 11, 1997, pp.235-278.

Jointing

A joint is a natural break in the continuity of a layer of rock or a rock body. Unlike a fault, a joint shows no visible movement parallel to the plane of fracture.[5] Joints are ubiquitous in almost every exposure of rock. The most substantial jointing occurs in the most highly competent rocks such as sandstone, limestone, quartzite, and granite. Joints can present as open features, or can be infilled with other materials. When filled with precipitated minerals, the joint is call a vein. When filled with magma, they are called dikes[6].

Joints are formed as a result of tensile stresses on a rock body or rock layer. These tensile stresses can be induced by some external source, e.g.

- stretching of layers

- external compression or fluid injection causing increased pore fluid pressure

or by internal stresses, e.g.

- shrinkage caused by cooling.

When the rock's tensile strength is exceeded, the rock fractures in a plane parallel to the direction of maximum principle stress and perpendicular to the direction of stretch[5,6].

Joints in the sedimentary rocks of the foreground and a more varied set of joints in the granitic rocks in the background. Image from the Kazakh Uplands in Balkhash District, Kazakhstan. Public Domain.

Faulting on Mars

While the primary cause of faulting on Earth is its mobile, constantly deforming lithosphere, Mars has no such analog. Faulting on Mars has occurred in response to loading stresses and global contraction. The primary driver of these loading stresses is the Tharsis volcanic province which covers about 15% of the surface of Mars. This 8 km high bulge has been the dominant source of lithospheric flexural stress which has led to the majority of Mars' faulting[7].

1. http://imnh.isu.edu/digitalatlas/
2. USGS & Earthquake Glossary – fault traces
3. USGS & Fault Lines
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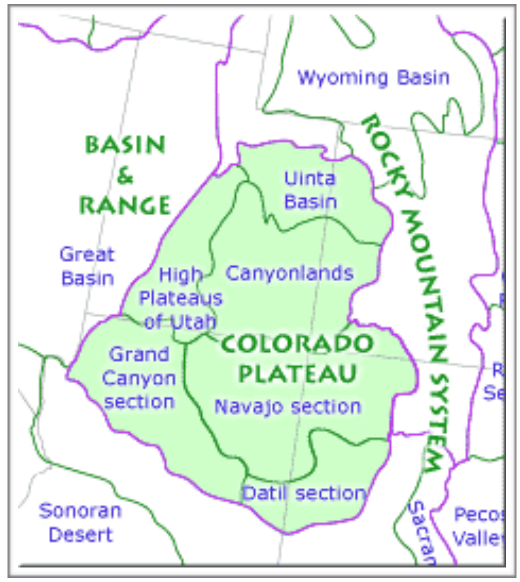
Fluvial and erosive processes



- Zion National Park is a monument to erosion and the impact that water has in a dry, sparsely vegetated landscape. **Zion park is located along the edge of the Colorado plateau**, and it was a relatively flat basin near sea level around 240 million years ago.

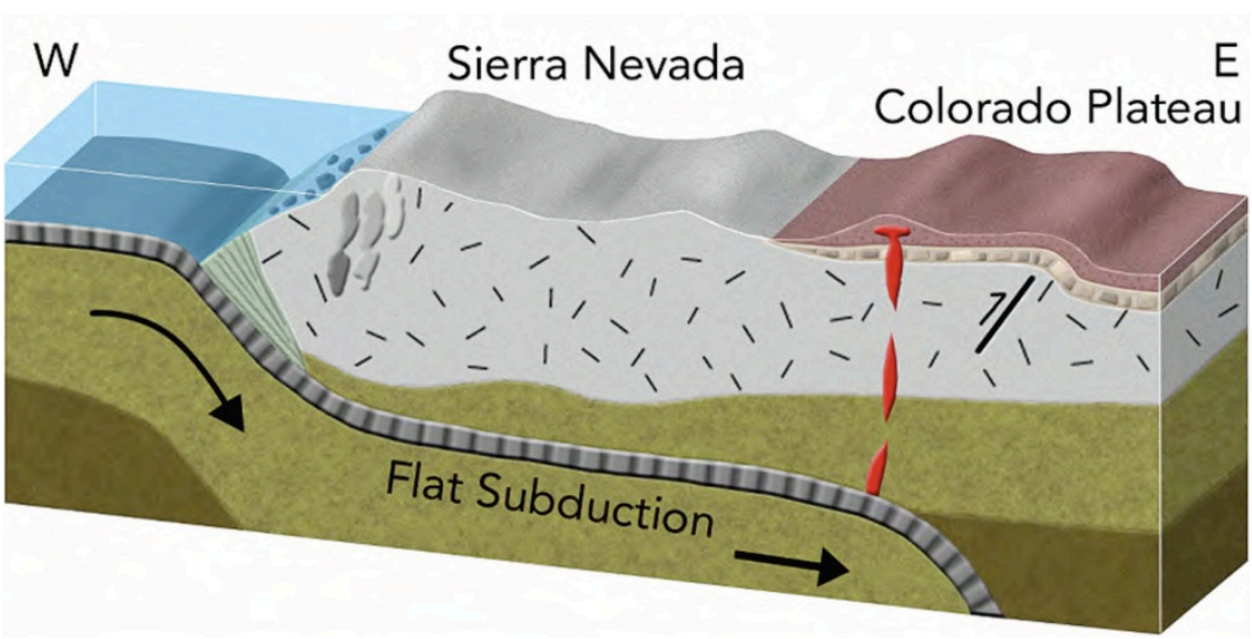
- From 240 millions years ago, **nearby mountains eroded** sand, gravel and mud, and streams carried these materials into the basin, where they were deposited in layers.

- The **weight of these layers caused the basin to sink**, and the top surface remained near sea level.

- Slowly, faces deep within the Earth pushed the surface up in a process called **uplift;** Zion elevation rose from near sea level to as high as 10000 feet above sea level.

- **Uplift aided erosion and weathering** giving runoff streams more speed thus allowing them to carry more sediment and eroding more rock. This created the narrow canyons that are presented today in Zion.

- These processes gave birth to the **Virgin River**, which created the Zion Canyon.



The Virgin river

Normally a small, placid stream, the **Virgin River does not seem capable of eroding** such an immense canyon as Zion, but…

- … **its steep gradient of about 13 meters** per kilometer allows it carrying away 1 more than 1 million tons of rock waste each year;

- … nearly all the s**ediment transport occur during floods** because the capacity of the river to move sediment increases exponentially as the streamflow increases.

The Virgin River has cut down about 396 m in about 1 million years, with a canyon cutting rate of about 40 cm every 1000 years (one of the most rapid rate of downcutting in North America).

- **Its massive erosive action started in the quaternary**, when the Virgin River could link with the Colorado River, which had started to flow through Grand Canyon.

- The **Virgin River began expanding its watershed into the Colorado Plateau**, at the expense of the Sevier River drainage, which has less erosive energy because of its gentle gradient.

The two dominant erosional processes

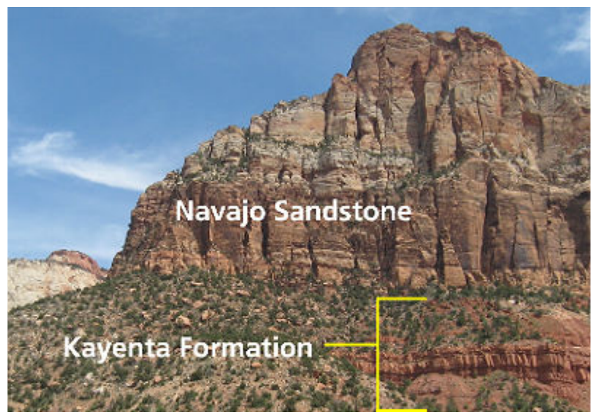
Downcutting and canyon widening are the two dominant erosional processes forming the canyons at Zion.

Downcutting

- Mainly due to the effect of the Virgin River, which acts as a ribbon of moving sandpaper through The Narrows.
- It is represented at The Narrows at the head of Zion Canyon where the North Fork of the Virgin River flows through a spectacular gorge cut into the Navajo Sandstone.

Canyon widening

- Mass wasting is also in effect in the canyons as their rivers cut through the softer limestone and cause large chunks of the upper layers to fall down.
- It makes use of the different erosional properties between the Kayenta Formation (which are softer and can be more easily eroded) and Navajo Sandstone.



Lakes in Zion?

- In the quaternary, **an eruptive cycle** produced basalt flows in the canyons.
- Since **basalt is more resistant to erosion than sedimentary rocks**, erosion has removed the surrounding sedimentary rock, forming a "reversed topography" in which the valleys that were once flooded with basalts are now ridges and plateaus.
- Impounded behind landslides and lava flows, **small lakes and ephemeral ponds filled the canyons of Zion.**
- About 100,000 years ago, **the Crater Hill basalt flow blocked the Virgin River** near the present-day ghost toe of Grafton. Behind this barrier, Lake Grafton grew to become the largest of at least 14 lakes that have periodically formed in the park

Comparison to Mars

- Fluvial processes and erosion may have characterized the Martian surface in the past, when **the planet was significantly warmer and wetter than it is at the present**.

- In fact, there is probably a much better sedimentary record of the first billion years of martian history than there is of the first billion years of the Earth's history.

The most striking fluvial erosion features on Mars are the **outflow channels**.

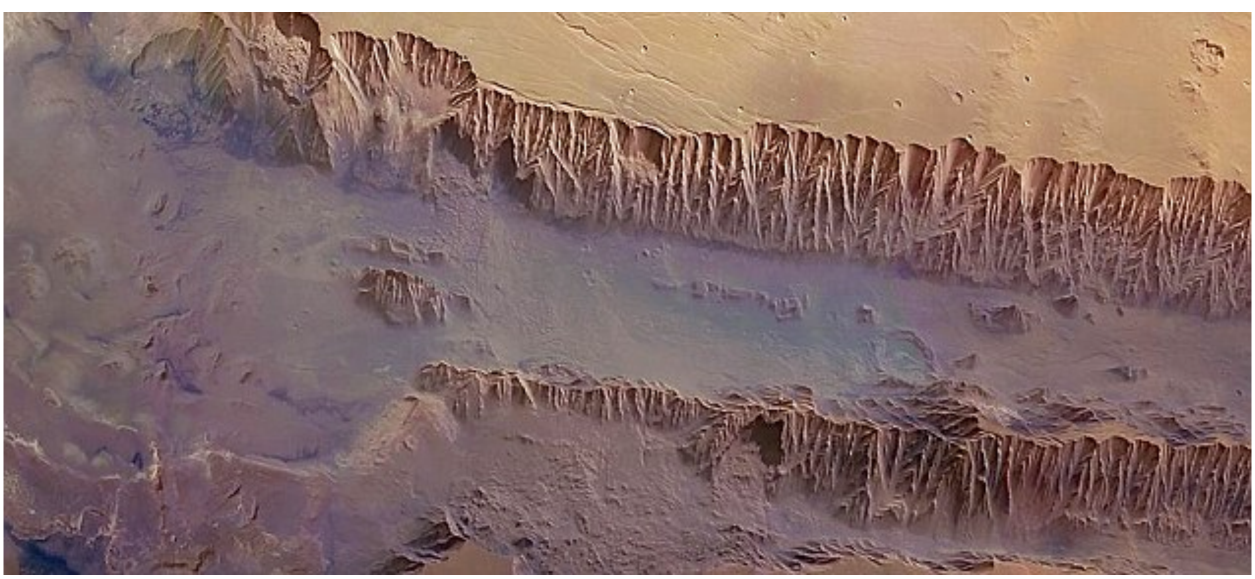
- These are most common in the **equatorial regions of Mars**, and are concentrated along the northern lowland/southern highland boundary. They generally arise from the highlands and debouch onto the lowland plains.

- The source regions usually show **very complex topography that earns them the name chaotic terrain**. The appearance of the chaotic terrain strongly suggests removal of subsurface material and widespread collapse of topography.

- The channels arise fully-born from these chaotic regions and may extend for many hundreds of kilometers.

Although clearly the result of fluid flow, outflow channels bear only superficial similarity to terrestrial rivers. They are much more similar to the types of features formed by catastrophic floods on Earth.

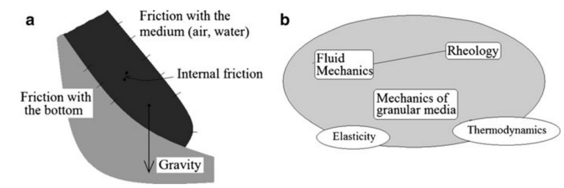
A second type of channel apparently caused by flow of liquid water is the **valley system**.



Landslides

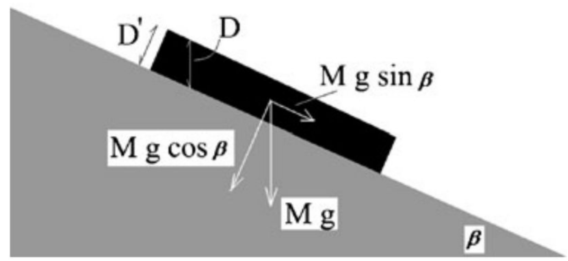
Tommy “Landslides” McClintock

Landslides - strictly defined as a flow of material under the force of gravity in which the moving material should be at least 1.1 times the density of water (1).



Physics of Landslides

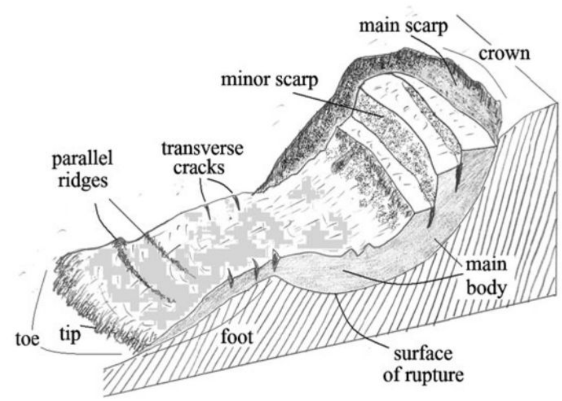
Can analyze landslides with increasing complexity - friction, cohesion, fluid mechanics, Non-newtonian fluids (i.e. rheology), granular flows.



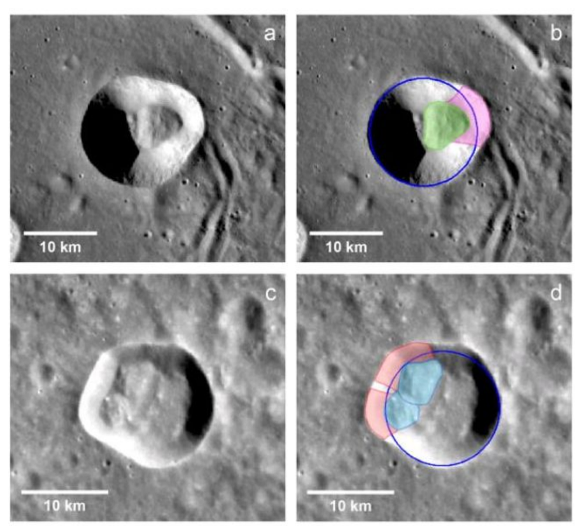
In the most simple treatment of a landslide, a mass will slide down a slope if the following condition is met:

$$\tan\beta > \mu = \frac{s}{p}$$

Beta - the slope angle
mu - coefficient of friction
s - shear strength
p - penetration hardness



Incorporating **cohesion** gives a more accurate description of the shear strength (as opposed to a simple surface estimate). **Fluid mechanics** yields information about flow rates and describes the type of flow (laminar, turbulent, etc.) by treating the landslide as a viscous material. Incorporating rheology brings us into the study of **Non-newtonian** fluids. Clay slurries, particle suspensions, muds can all have complex relationships between applied stress and the flow. The presence of **granular materials** complicates all of this even further. This is the inclusion of the deformation of individual grains (pebbles, rocks, boulders) embedded within the flow during a landslide.



Landslides in Zion National Park and Bryce Canyon

Last in-depth analysis of landslides in Zion was done in 1945 by Russel Grater (2), but they occur frequently and are communicated by an RSS feed (3). In Grater's paper, he claimed that a huge lake existed in the park due to a landslide, which quickly drained away as the slide eroded away. This theory stands in opposition to the idea that features of Zion were caused by glaciation.

I was not able to find a historical record of landslides in Bryce.

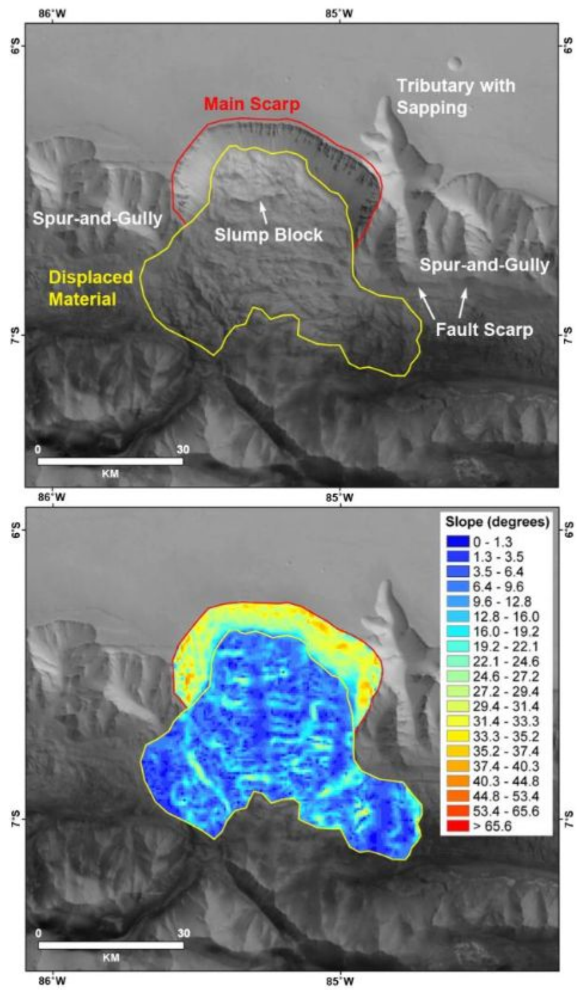
<u>Landslides on other worlds</u>

Landslides represent a significant geological process on other worlds. They can often be found inside impact craters, and yield information about failure mechanisms, tectonic activity, rheology, and seismology.

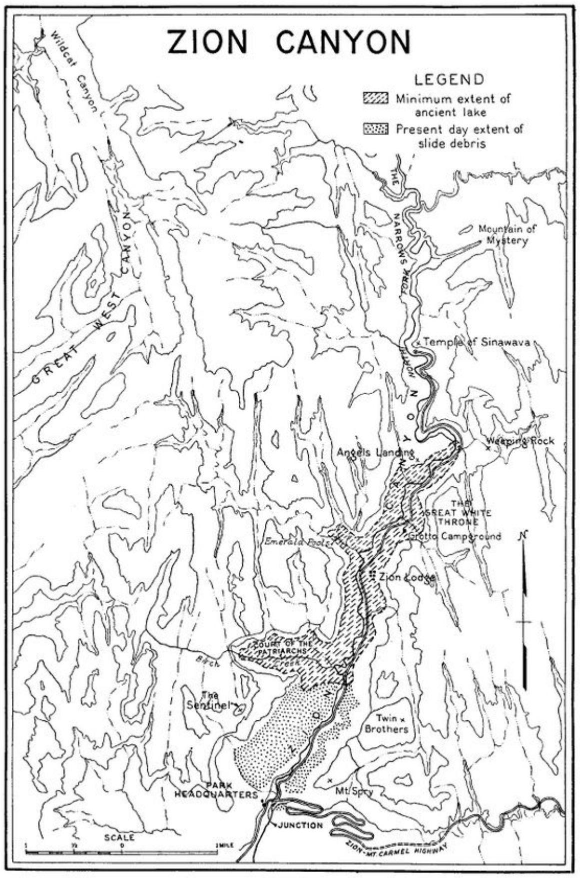
For recent examples of analyses of landslides occurring in our solar system, we can look at Brunetti et al. (2015) and Hooper et al. (2013). The first group looked at landslides detected in craters on both the Moon and on Mercury. The authors proposed that both of these were caused around the same time as the craters themselves, in a process called "incomplete terracing" of the walls of the crater.

The second group found a landslide in a crater found in a High-Resolution Stereo Camera image, and attributed its cause to seismic activity.

Craters with landslides on the moon (a) and mercury ©, with the associated mass maps on the right.



A crater on Mars with a mass mapped landslide.



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PTYS 594 (2017 Spring): Colorado Plateau Stratigraphy and the Grand Staircase

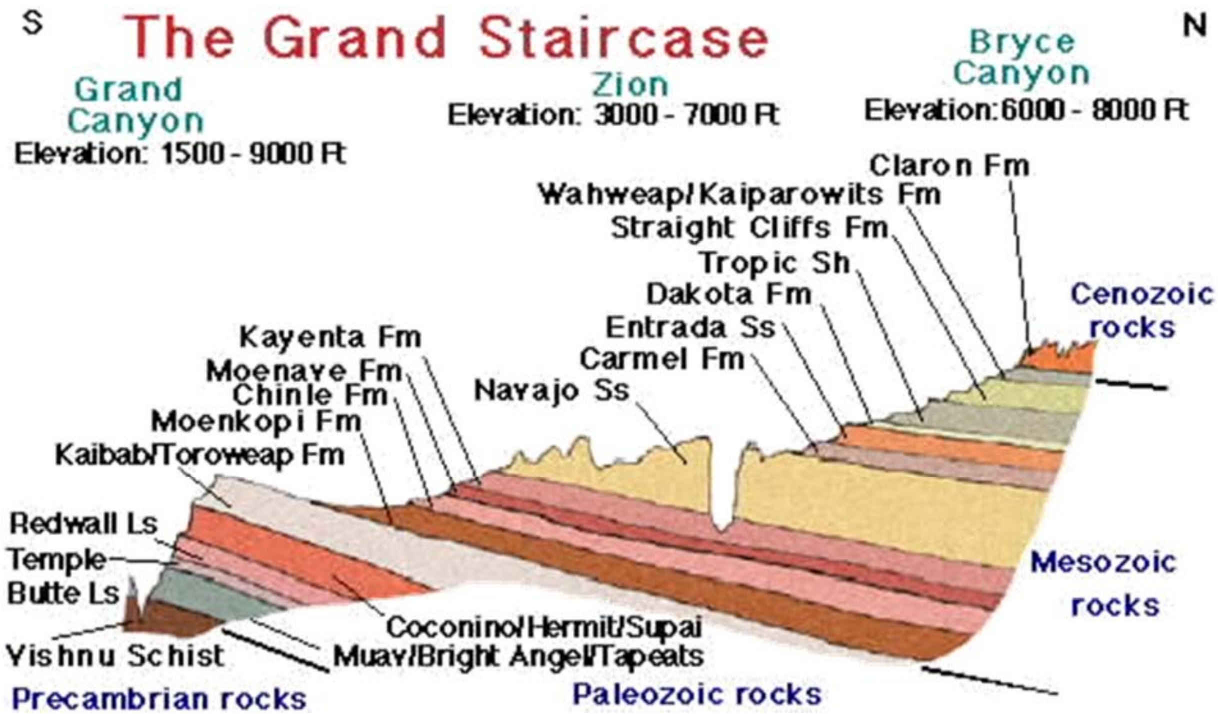

Image from http://jan.ucc.nau.edu/rcb7/Grand_Staircase.html

Coined by Charles Keyes in 1924, the Grand Staircase refers to a series of topographic benches and cliffs, stepping progressively up in elevation south to north from the Grand Canyon National Park, through Zion National Park, into the Bryce Canyon National Park and the Grand Staircase-Escalante National Monument. The sequence begins with the Tapeats sandstone, deposited 550 Mya in the Early/Middle Cambrian onto the 1.7 billion-year-old Vishnu basement rocks to form the Great Uncomformity. The Early/Middle Permian (240 Mya) Kaibab limestone, the youngest exposed formation in the Grand Canyon, is the oldest exposed formation in Zion National Park. In turn, the youngest exposed formation in Zion National Park, the Upper Cretaceous Dakota sandstone (100 Mya) is the oldest oldest exposed formation in Bryce Canyon. The sequence ends with the Eocene Claron formation, deposited 40 Mya.

These layers have undergone 1.5 to 3 km of uplift starting about 66 million years ago with the Laramide orogeny. The opening of the Gulf of California at ~5 Mya lowered the base level of the Colorado River, resulting in significant erosion of the sedimentary layers to form the canyons we see today.

Prepared by Daniel Lo

Unit	Exposure	Age (mya)	Thickness (m)	
Tonto Group				The Tonto group comprises three formations that mark the eastward migration of an ancient shoreline with decreasing grain sizes with age.
Tapeats	Cliff	525	30-100	The Tapeats Sandstone a shore deposit comprising medium- to coarse-grained sand and conglomerate. Ripple marks are common in this dark brown thin-bedded layer.
Bright Angel	Slope	515	80-140	The Bright Angel Shale is made of mudstone-derived shale that is interbedded with small sections of sandstone and shaly limestone. The color of this formation is mostly various shades of green with some brownish-tan to gray parts.
Muav	Cliff	505	40-250	The Muav Limestone is made of gray, thin-bedded limestone.
Temple Butte	Cliff	385	30-140	Deep channels carved into the Muav Limestone were filled with the freshwater Temple Butte Limestone. The limestone appears as purple in Marble Canyon, and as gray to cream-colored dolomite elsewhere.
Redwall	Cliff	340	120-240	The Redwall Limestone, composed of thick-bedded, dark brown to bluish gray limestone and dolomite, records the retreat of the sea in the Early/Middle Mississippian. The characteristic color of the Redwall comes from rainwater leaching of the iron-rich redbeds of the Supai and Hermit Shale above.
Supai Group		270-320		An unconformity of 15 to 20 million years separates the Supai Group from the Redwall Formation. Supai Group comprises marine and non-marine deposits of mud, silt, sand and calcareous sediments originating from the Ancestral Rocky Mountains in Colorado and New Mexico. Supai Group formations in the western part of the Grand Canyon contain limestone, indicative of a warm, shallow sea, while the eastern part consists of red siltstones and shale, probably deposited in a muddy river delta.
Watahomigi	Slope		30-90	The Watahomigi is a gray limestone with some red chert bands, sandstone, and purple siltstone.
Manakacha	Cliff		90	The Manakacha is made of pale red sandstone and red shale.
Wescogame	Slope		30-60	The Wescogame is also made of pale red sandstone and siltstone.
Esplanade	Slope		60-200	The Esplanade is another pale red sandstone and siltstone.
Hermit	Slope	280	30-270	The alternating thin-bedded iron oxide, mud and silt of the Hermit Shale were deposited via freshwater streams onto a broad coastal plain in a semiarid environment. The formation appears as deep red.

Unit	Exposure	Age (mya)	Thickness (m)	
Coconino	Cliff	275	20-180	Another unconformity separates the Hermit Shale from the Coconino Sandstone. The white to cream-colored Coconino Sandstone records a drastic change in the local environment as a sand sea developed in the area. Crossbedding patterns of the fine-grained, well-sorted and rounded quartz grains points to an eolian environment.
Toroweap	Cliff/Slope	273	60	Yet another unconformity separates the Coconino Sandstone from the Toroweap Formation. The Toroweap Formation is composed of red and yellow sandstone and shaly gray limestone interbedded with gypsum, deposited in a warm, shallow sea. Its three members records the transgression and then regression of the shoreline. Seligman is a yellowish to reddish sandstone and siltstone. Brady Canyon is a gray limestone. Wood Ranch is a pale red and gray siltstone and dolomitic sandstone.
Kaibab	Cliff	270	90-100	An unconformity separates the Toroweap from the Kaibab Limestone. The Deposited by an advancing warm, shallow sea, the Kaibab limestone is cream to gray in color. An unconformity marks the top of this formation.
Moenkopi		230	550	The Moenkopi Formation comprises gypsum, mudstones, limestones, sandstones, shales, and siltstones deposited in a shallow marine environment. The Red Canyon Conglomerate, the basal member of the Moenkopi, fills broad east-flowing paleochannels carved into the Kaibab Limestone. The depositional environment was a nearshore one where the seashore alternated between transgression and egression. Four major transgressive/regressive cycles have been documented. At Zion, the limestones and fossils of the Timpoweap, Virgin Limestone, and Shnabkaib members of the Moenkopi Formation document transgressive episodes. Regressive, red bed layers separate the transgressive strata. Ripple marks, mud cracks, and thinly laminated bedding suggest that these intervening red shale and siltstone units were deposited in tidal flat and coastal plain environments.
Chinle	Slope	220	170	Separated from the Moenkopi by an unconformity, the Chinle was formed from shale, gypsum, limestone, sandstone, and quartz deposited in a shallow river environment. Petrified wood and fossils of animals adapted to swampy environments are common. The abundant volcanic ash associated with Chinle deposition has altered to bentonite, which develops a popcorn-like surface texture following a rainfall. The Chinle is also known for its relatively plentiful uranium ore. The Chinle has a variety of colors – purple, pink, blue, white, yellow, gray, and red. The lowermost member of the Chinle, the Shinarump, was laid down in braided streams that flowed through valleys eroded into the underlying Moenkopi Formation. It consists of a white, gray, and brown conglomerate made of coarse sandstone, and thin lenses of sandy mudstone, along with

Unit	Exposure	Age (mya)	Thickness (m)	
				plentiful petrified wood. The Petrified Forest member of the Chinle is a bright, multicolored succession of volcanic-ash-rich mudstone and sandstone exposed in Petrified Forest National Park and the Painted Desert. The Chinle Formation interfingers with the upper part of the Wingate Sandstone to the east.
Moenave	Cliff/Slope	205	200	Early Jurassic uplift created an unconformity above the Chinle Formation that represents about 10 million years of missing sedimentation between it and the Moenave. The Moenave was deposited in a variety of river, lake, and flood-plain environments, recording periodic incursions of shallow seas from the north. The oldest beds of this formation belong to the Dinosaur Canyon member, a reddish rock layer laid down in slow-moving streams, ponds and large lakes. The upper member is the pale reddish-brown Springdale Sandstone, deposited in swifter, larger, and more voluminous streams than the older Dinosaur Canyon member. The next member in the Moenave Formation is the thin-bedded Whitmore Point, which is made of mudstone and shale.
Kayenta	Slope	200	100	The red Kayenta Formation's sand and silt were laid down in slower-moving, intermittent streambeds in a semiarid to tropical environment. Interbedded sandstone, basal conglomerates, siltstones, mudstones, and thin cross-beds are typical channel and floodplain deposits found in the Kayenta. Paleocurrent studies show that the Kayenta rivers flowed in a general westward to southwestward direction.
Navajo	Cliff	175	670	During the Jurassic the Colorado Plateau's climate increasingly became arid, and western North America became a huge desert. The Navajo Sandstone preserves the dunes from this ancient sand sea, with extensive cross-bedding. At Zion, measurements of single cross-bed sets suggest a minimum dune relief of 20 m. Typically the lower part of this remarkably homogeneous formation is reddish from iron oxide that percolated from the overlying iron-rich Temple Cap Formation while the upper part of the formation is a pale tan to nearly white color.
Temple Cap	Cliff	170	60	Broad tidal flats and streams carrying iron oxide-rich mud formed on the margins of the shallow sea to the west, creating the Sinawava member of the Temple Cap Formation. Flat-bedded sandstones, siltstones, and limestones filled depressions left in the underlying eroded strata. Desert conditions returned briefly, creating the White Throne member, but encroaching seas again beveled the coastline, forming a regional unconformity. Thin beds of clay and silt mark the end of this formation.
Carmel	Cliff	150	90	Transgression of a warm, shallow inland Sundance Sea deposited the limestone of the Carmel Formation. The four members of the Carmel Formation captured the details of a

Unit	Exposure	Age (mya)	Thickness (m)	
				complicated series of changing environments. The Co-op Creek member represents open marine and restricted marine environments. Sandstone and gypsum in the Crystal Creek and Paria River members signal a return to desert conditions in a coastal setting.
Entrada	Cliff	140	150	As the Sundance Sea withdrew northward near the end of the Middle Jurassic, another eolian system quickly advanced over the region and initiated deposition of the sandstone that makes up the Entrada Formation.
Dakota	Cliff	100	100	In the Middle/Late Cretaceous, subduction of the Farallon plate under the North American Plate resulted in the opening of the Western Interior Seaway. Subducting at a shallow angle, the younger and more buoyant lithosphere of the Farallon Plate exerted traction on the base of the lithosphere, pulling it down and producing a depression at the surface. This depression and the high eustatic sea levels allowed waters from the Arctic Ocean and the Gulf of Mexico to meet and flood the central lowlands, forming a sea that transgressed and regressed over the course of the Cretaceous. The Dakota Sandstone record this event. The pebble to cobble conglomerate and tan fossil-rich sandstone include alluvial fan and alluvial plain sediments that grade laterally into coastal plain, marginal marine, and marine deposits. Abundant amounts of petrified wood, oyster beds containing millions of fossils, and coal are all found in the Dakota.
Tropic	Slope	90	260	The blue-gray Tropic Shale represents deposition of muds in the deeper waters of the Western Interior Seaway. The upper Tropic becomes sandy as it grades into the overlying Straight Cliffs Formation.
Straight Cliffs	Cliff	85	600	The Straight Cliffs Formation represents the final regressive phase of the Cretaceous Western Interior Seaway and consists of four distinctive members. In ascending order, the Tibbet Canyon member is a shallow marine sandstone; the Smokey Hollow member consists of lagoonal and flood plain shales and sandstones; the John Henry member comprises deltaic and fluvial shales, coals, and sandstones; and the Drip Tank member is a fluvial deposited, coarse-grained sandstone.
Wahweap	Cliff	82	500	The Wahweap is composed of mudstones and siltstones interbedded with sandstones and conglomerates, accumulated in fluvial, flood plain, and lacustrine environments.
Kaiparowits	Cliff/Slope	76-74	800	The Kaiparowits Formation consists of drab gray to olive-gray shales and subarkosic sandstones, the lacustrine deposits on a subsiding alluvial plain. The Kaiparowits Formation cuts deeply into the eroded upper Wahweap Formation. The sediment is believed to be derived from southeastern California and south-central Nevada.

Unit	Exposure	Age (mya)	Thickness (m)	
Canaan Peak		74-65	140	The close of the Cretaceous Period was punctuated by the K-T global extinction event. Sevier orogenic events had ended towards the end of the Cretaceous, and the Sevier Highlands were gradually reduced by erosion during early Paleogene. Renewed mountain building from the Laramide orogeny started at the end of the Cretaceous, partitioning the Sevier foreland basin into a series of internally drained, non-marine, depositional basins bounded by basement-cored uplifts. Large lakes began to occupy the inter basins, while uplifted areas produced by the Laramide orogeny became the main source of sediments, which filled the basins. The Canaan Peak Formation contains the K-T boundary, and is composed of conglomerates of quartzite and felsic volcanic clasts deposited in a coarse braided-fluvial system. The sediment is sourced from the same region as the Kaiparowits.
Grand Castle		65-60	230	The Grand Castle Formation is made of conglomerates of quartzite and limestone clasts. The lower and upper conglomerate members represent gravelly braided-river deposits, whereas the middle sandstone member formed in a sandy braided-fluvial system. Petrographic analysis, in conjunction with southeast paleoflow directions, indicates that the Wah Wah and Blue Mountain thrust sheets were the source areas for the Grand Castle Formation.
Pine Hollow		60-40	70	The Pine Hollow Formation is a mixed gray, purple and red deposit of mudstone, limestone, and lenticular sandstones and conglomerates. The common incision of sand and conglomerate channels combined with ephemeral lakes and playas suggests a medial alluvial environment with fluctuating base level.
Claron	Cliff	40-30	640	The Claron Formation consists of sandy limestone from fluvial, deltaic, and lacustrine deposits. The grain size of rocks in this formation decreases upward from coarse sandstone and conglomerate to fine-grained, calcareous sandstone and mudstone. Limestone is dominant in the upper part of the Claron Formation. Paleocurrent data indicate flow toward the southeast, south, and southwest. Lacustrine deposits of the Claron Formation overlap paleotopographic highs of the Pine Hollow basin and indicate cessation of Laramide deformation by middle Eocene.

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Lava Tubes – In Utah and Around the Solar System

Corwin Atwood-Stone

Lava tubes are caves formed during lava flow events – usually pahoehoe. When lava flows in a channel the top can freeze over, and freezing can continue in on all sides of the flow, forming a cylinder. When there is enough insulation the tube will stop contracting at its present size. Over time flow will decrease and won't fill the tube anymore. Lava tube caves often have flat-ish floors from a low level of flow freezing out in place – this last flow may have transitioned to a'a which accounts for the more rubbley texture of some tube floors.

Portions of lava tube ceilings sometimes collapse forming skylights. These make great entrances to caves, and are also very important for studying them on other planets.

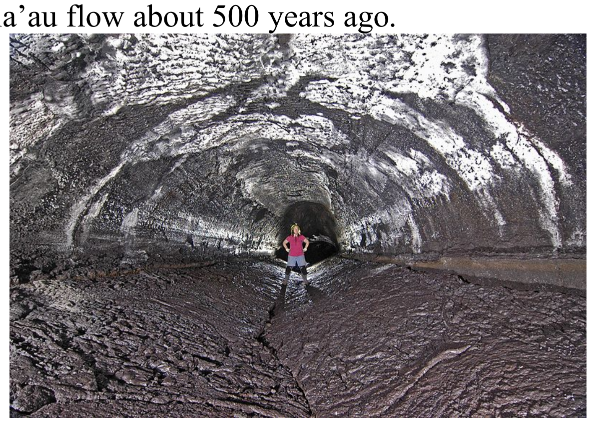
Lava Tubes on Earth

Mammoth Cave – our location.

This cave has about 2200 ft of passages and four chambers, with several exits. Found in the Marysvale volcanic field – which went extinct ~ half a million years ago, and was active as much as 30 million years ago. Flowing water also helped to sculpt this cave about 2000 years ago. Just so you know, we will be sharing this cave with bats.

Kazumura Cave – on Kilauea.

This is the longest lava tube on earth with over 40 miles of passages, and 101 entrances. Parts of this tube are 3600 ft deep, making it also the deepest flow on earth. This was formed by the Aila'au flow about 500 years ago.



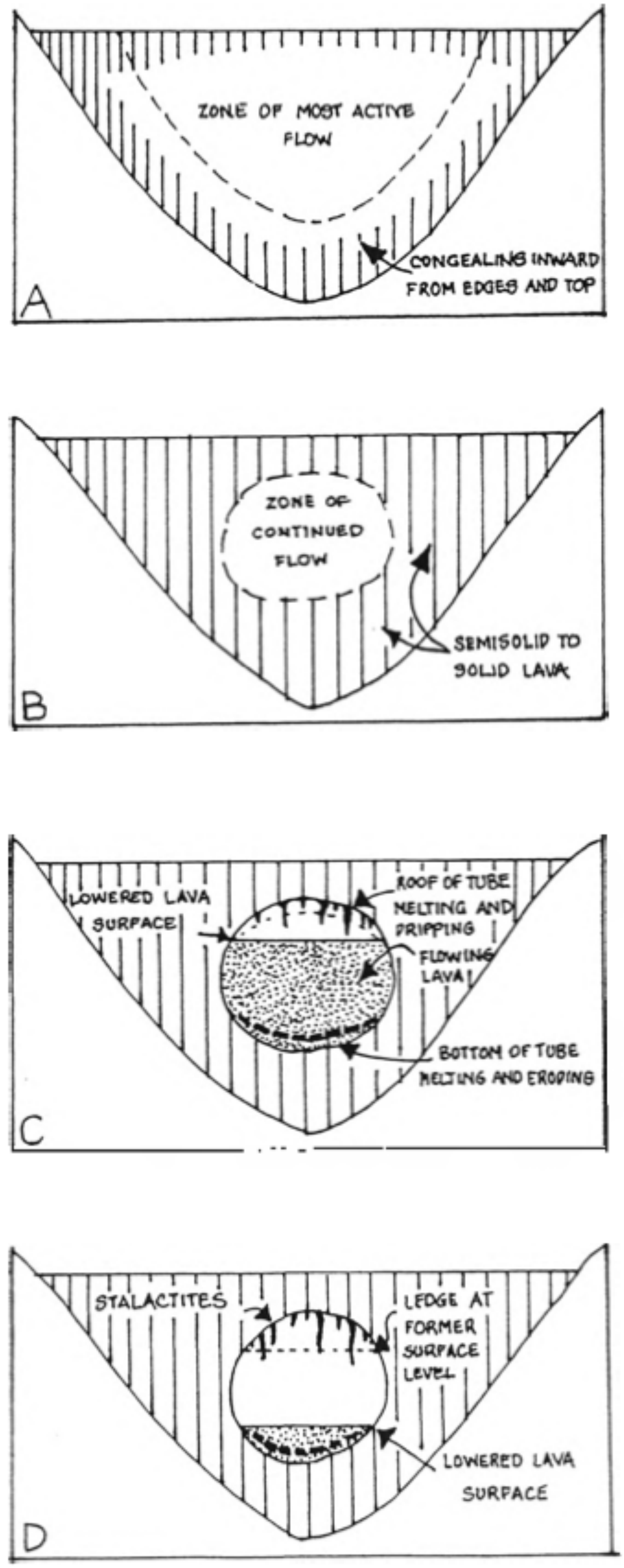


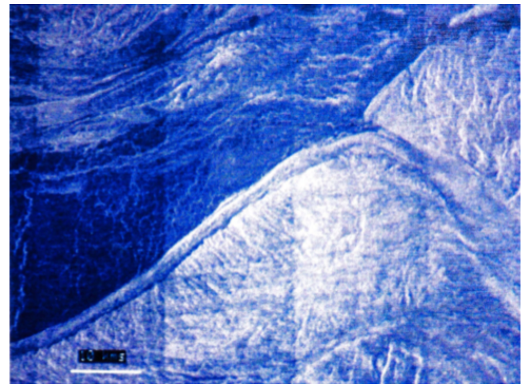
Diagram of lava tube formation from Melville 1994

Thurston Lava Tube - Hawaii

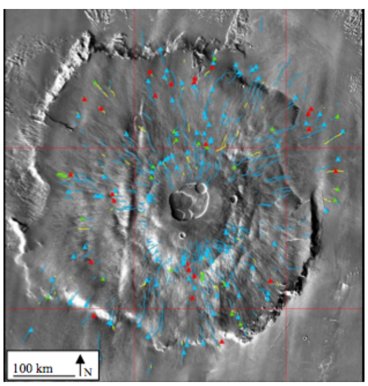
Terrestrial Scale: On Earth lava tubes can be up to about 20 meters wide – although they are usually much smaller, and up to tens of miles long. These tubes are wide spread over the Earth – from Hawaii to Utah to Australia and most places in between.

Planetary Connection:
Lava tubes are also found in many places in our solar system like Venus, Mars, the Moon and possibly elsewhere.

Venus: Low resolution makes looking for skylights difficult, however it is believed that many crater chains on Venus may be associated with massive lava tubes. Another type of evidence is the feature seen to the right, a long ridge which appears to be the equivalent of an inverted lava tube seen in the Undara area of Australia. However in this case the feature is ~2km wide. A similar origin has been proposed for some sinuous rilles on the lunar surface. (Melville 1994)



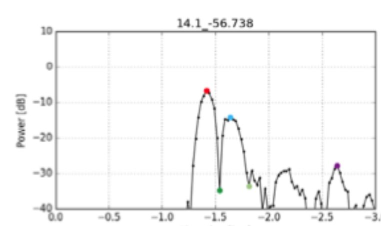
From Melville 1994



Blue lines are mapped tubes, green are associated fans. From Richardson et al. 2009.

Mars: On Mars lava tubes have been known to exist for a long time – identified in high quality images both as collapsed depressions showing former tubes, and from chains of skylights. These tubes are in some places very well mapped, and often their terminations have fans of lava coming out of them as seen to the left. These features are of great interest to astrobiologists as a possible habitat for life on Mars.

Moon: Lava tubes are known form similar data for the moon. Additionally recent work has been done, by Haruyama et al. 2017, directly examining tubes that are inferred from skylights. To do this they have been using the Lunar Radar Sounder on board the Kaguya orbiter. Examining an area in the Marius hills with a believed tube known from skylights they looked for precise types of double echos in the radar data that indicate a subsurface void. Their results suggest that this is an intact tube that is in some areas 120 meters tall and runs for tens of kilometers. Similar work using gravity data from GRAIL also suggests intact lava tubes. These lunar tubes are of great interest because they may be able to serve as mostly premade habitats for early lunar settlers. Haruyama pointed out at LPSC that we could even hold a future Olympics in this tube.



Red and blue points show the two distinct echos.

Elsewhere: It is believed that lava tubes should form in the highly volcanic conditions of Io, and possibly be reused regularly. Future missions may use skylights in active tubes to constrain the eruption temperatures of lava here to learn about composition (Davies et al. 2016). Possible collapsed cryovolcanic lava tubes have been examined on Triton (Kargel & Strom 1990).

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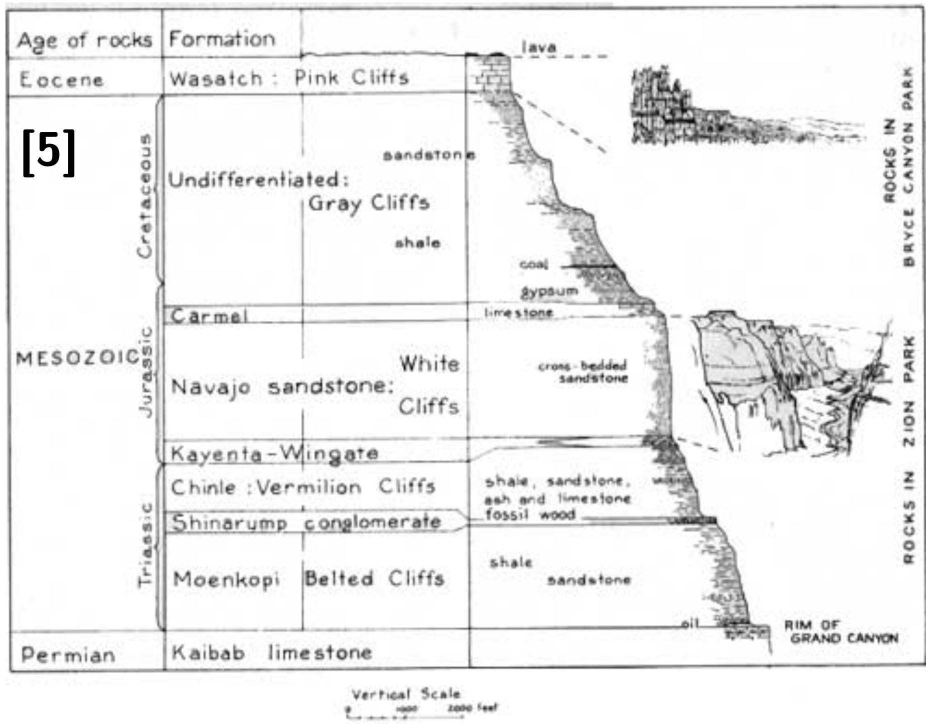
The Geology of Bryce Canyon National Park

Thaddeus Komacek, LPL/University of Arizona, tkomacek@lpl.arizona.edu

Stratigraphy

1940:

[5]

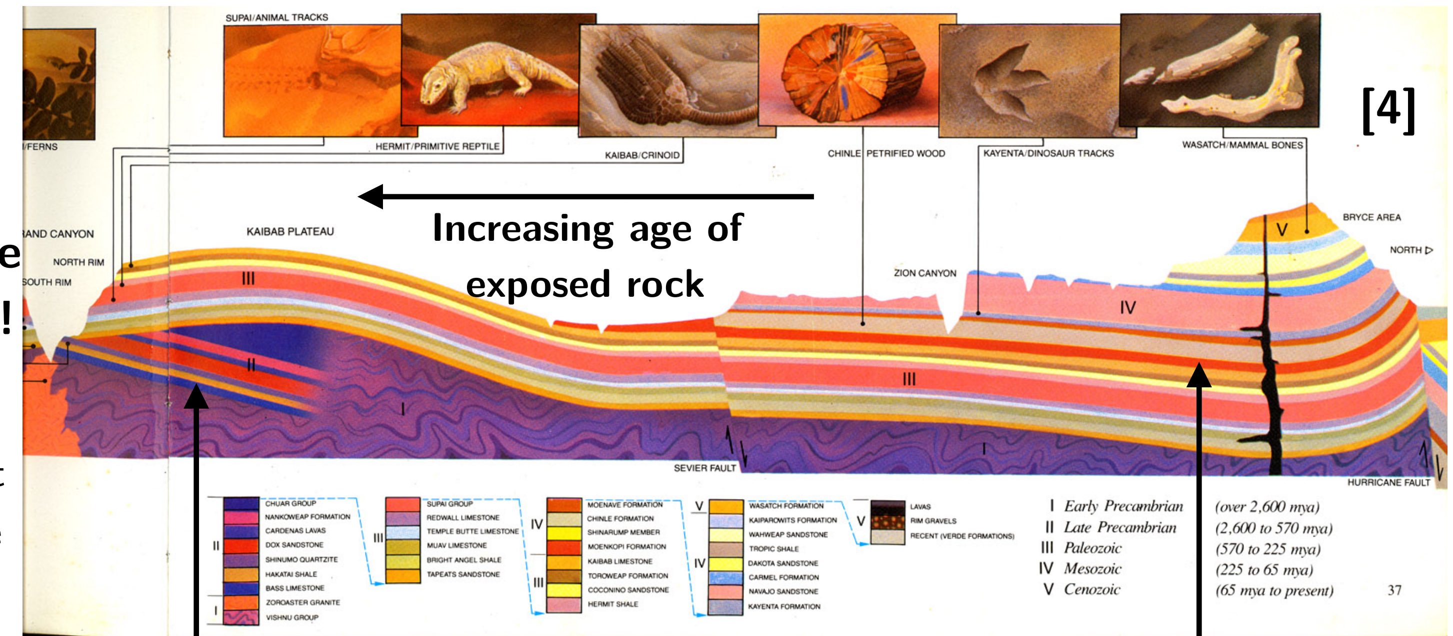


Bryce NP has the youngest exposures in the grand staircase!

These exposures are eocene-age, but were thought to be much older when the park was founded

Context: "Grand staircase"

[4]



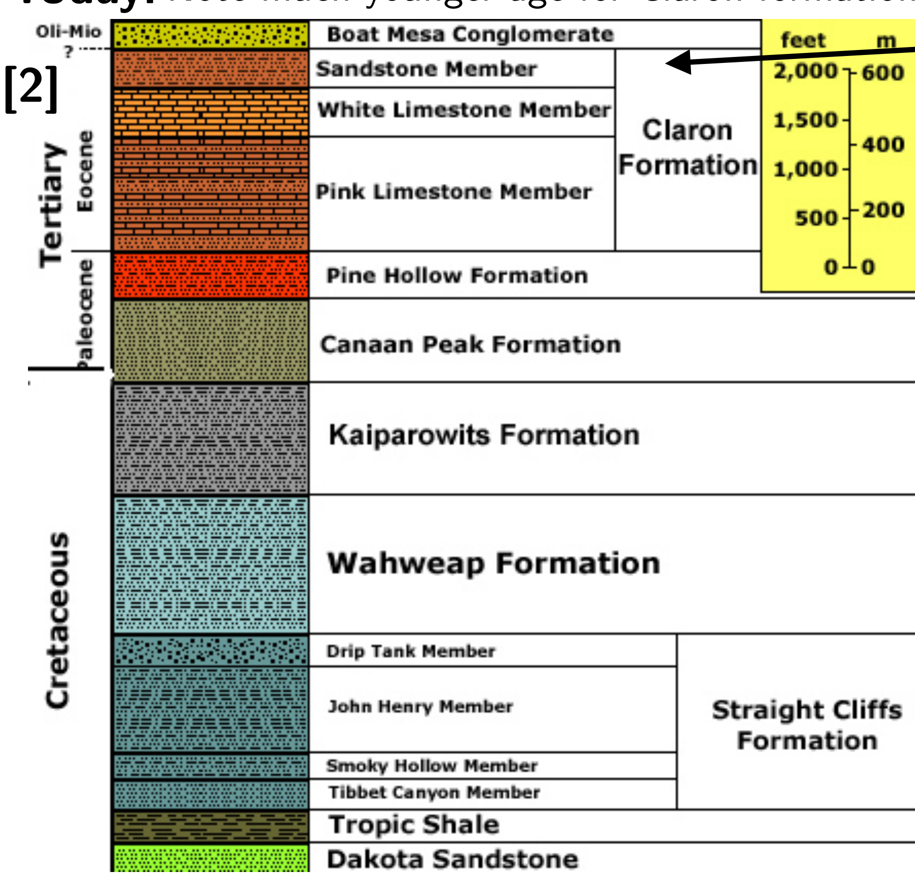
Laramide orogeny/uplift (~66 Ma)

Throughout: fluvial modification (<5 Ma)

Recent extensional faulting (~15 Ma)

Today: Note much younger age for Claron formation!

[2]



Erosion of this member forms hoodoos

Sandstones/ conglomerates from river deposition

Mudstones from alluvial floodplains

Shales/sandstones (inc. hadrosaur fossils)

Variety of alluvial environments (fluvial, paralic, marine) due to western interior seaway

Formation clues: nearby table cliffs

Table cliffs at 10,000 ft but same formation due to uplift at Paunsaugunt fault

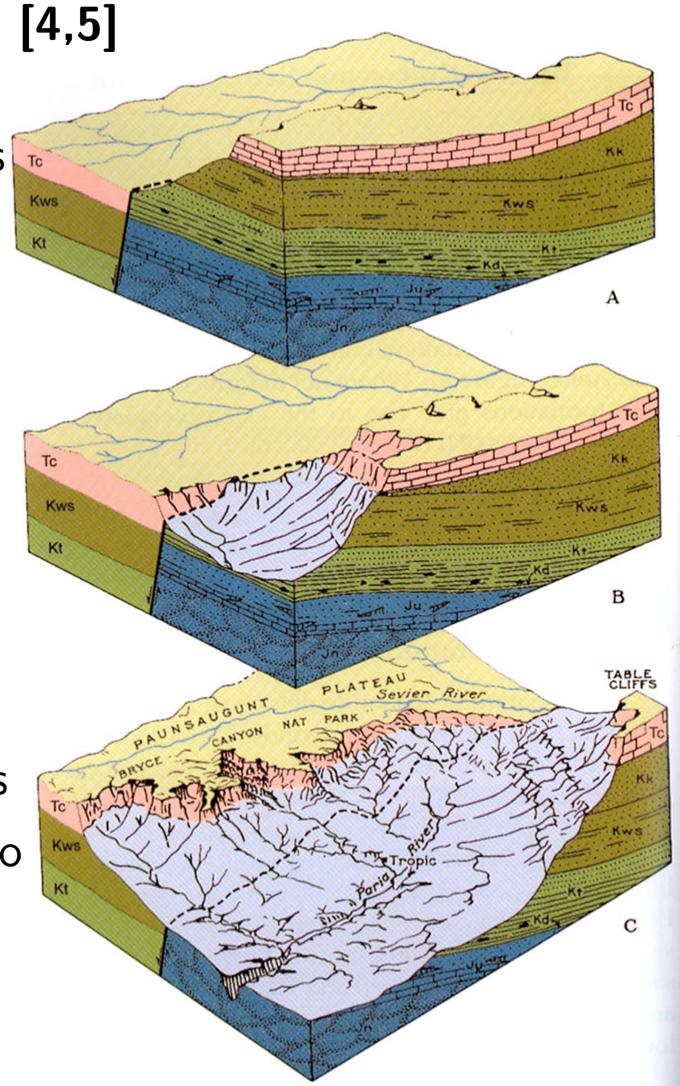
[6]

Note that Bryce lies on the western boarder of the paleo-sea

Formation of Bryce Canyon

Geology of Bryce Canyon National Park, Utah

[4,5]



Movement along Paunsaugunt fault moves eastern blocks 2,000 ft above western

Paria river erodes rocks along both sides of fault (but mainly on east side)

Paria river and tributaries erode rock down to Navajo sandstone, forming Paria amphitheater

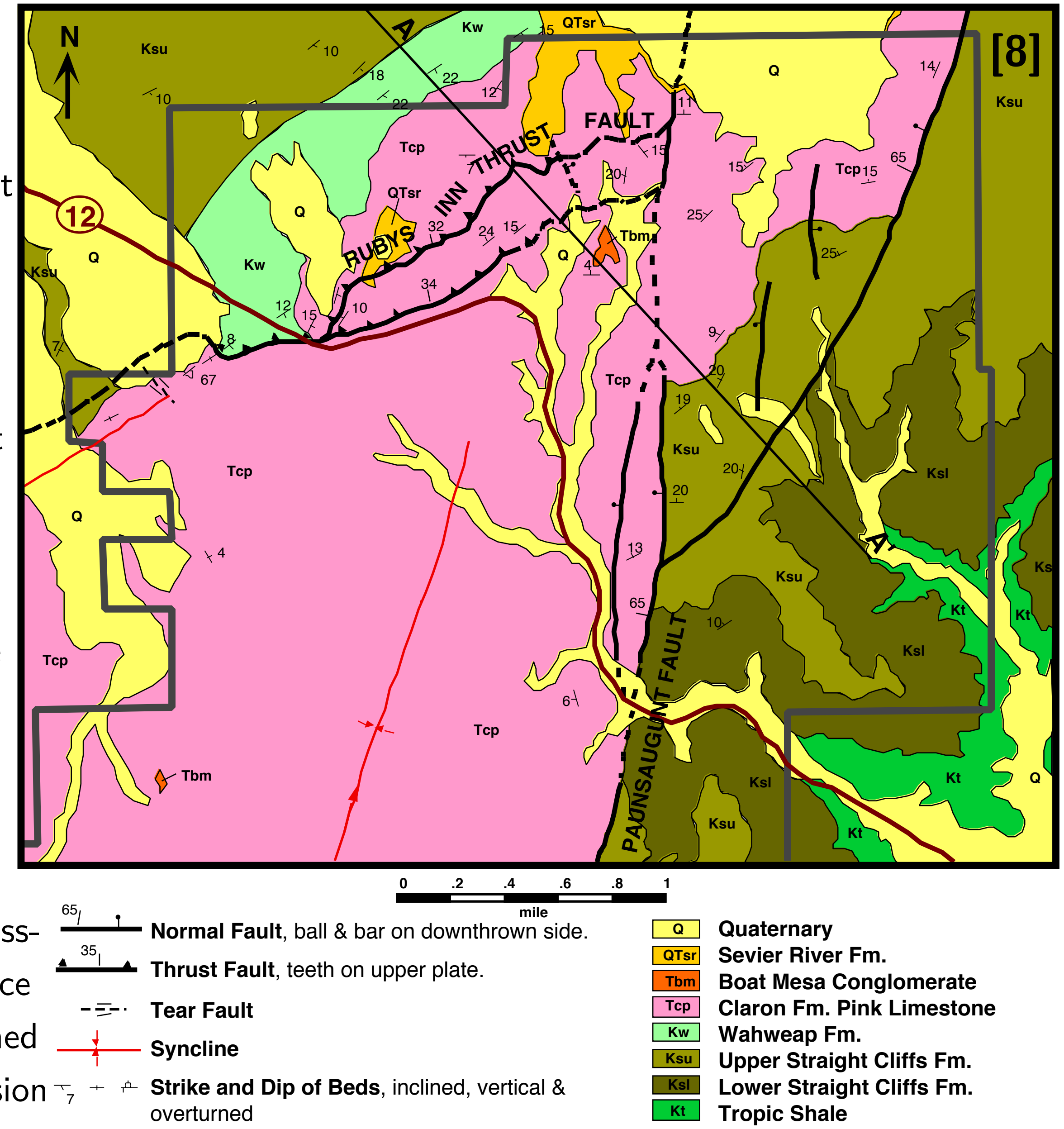
Figure 25. Block diagrams from Gregory (1951, p. 79, figure 42), illustrating the progressive development of the landscape at Bryce Canyon.

Recent tectonics

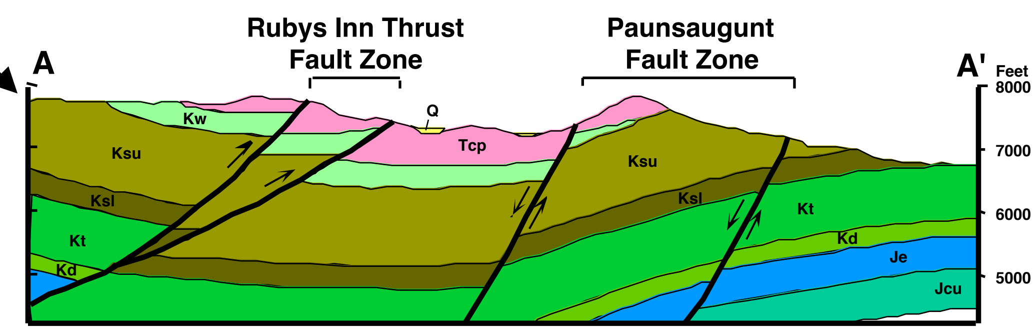
Paunsaugunt fault formed ~5 Ma, up to 1,400 ft displacement

Ruby's inn thrust fault older (~35 Ma), likely reactivated after deposition of the Claron formation

[8]



Evident from cross-section how Bryce "canyon" is formed by headward erosion along the Paunsaugunt fault scarp



Hoodoos

[3]

Erosion which forms them is mainly "frost wedging," enabled by the ~200+ freeze/thaw cycles in Bryce per year [1]

Fun fact: hoodoo colors [7]

Brown/pink/red = hematite (Fe_2O_3), yellow = limonite [$FeO(OH)$]
purple = pyrolusite (MnO_2)

References: [1] *Roadside Geology of Utah*, Halka Chronic, 1990. [2] USGS (**https://3dparks.wr.usgs.gov/coloradoplateau/bryce_strat.htm**) [3] National park service (**https://www.nps.gov/brca/learn/nature/hoodoos.htm**) [4] *Geology of Utah's parks and monuments*, D. Sprinkel et al., 2003. [5] NPS Bryce canyon historical guidebook (**https://www.nps.gov/parkhistory/online_books/brochures/1940/brca/sec1.htm**) [6] **http://www.saguaro-juniper.com/events/2009-07_GrandCanyonZionBryce/Zion_to_Bryce/2009_ZionBryce.htm** [7] *Geology of National Parks*, A.G. Harris et al., 1997. [8] National park service (**https://www.nature.nps.gov/geology/education/Foos/bryce.pdf**)

Hoodoos

Mattie Tigges

- Also called tent rocks, fairy chimneys, and earth pyramids, goblins

Where to find them

- High Plateaus region of the Colorado Plateau
- Badlands regions of the Northern Great Plains
- There is no place in the world where Hoodoos are more abundant than Bryce Canyon

Description

- Pillars of sedimentary rock seem to be “stacked” on one another
  - Limestone- mudstone, siltstone
  - Capped with Dolomite, which is strengthened by magnesium. Erodes slower, so it protects the layers beneath

- Similar to Spiers BUT NOT THE SAME
  - Hoodoos have bulbous layers
  - Spires mostly have a uniform thickness

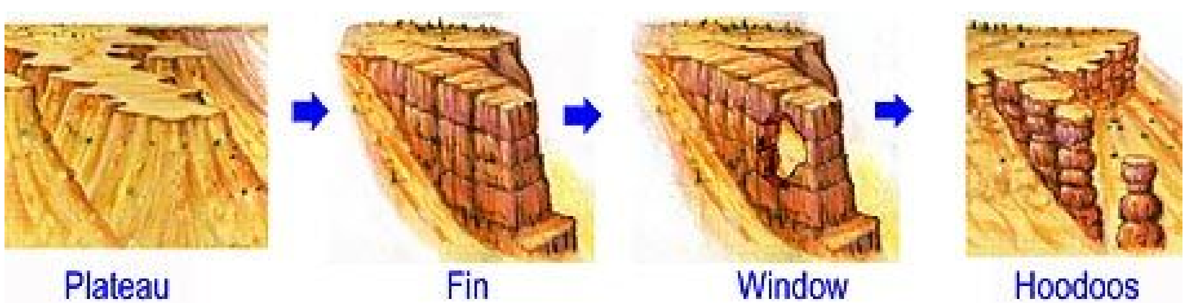
Spires at Canyonlands National Park (NPS)

Hoodoos in Bryce Canyon (NPS)

A few noteworthy Hoodoos:

- Thor's Hammer- currently the tallest at 150 ft
- Queen Victoria (Queen's Garden)
- The Hunter (Agua Point)

Formation



The formation of Hoodoos (NPS)

- Frost wedging
  - Snowmelt settles into cracks in the rock, freezes/ expands, and widens the cracks
  - typically around 200 freeze/ thaw cycles per year
- Acid rain- very slowly dissolves limestone and rounds the edges
- Average rate of erosion is 2-4 feet every 100 years

The bleak future for HooDoos

- The canyon will continue eroding and eventually part of the Servier River will be captured
    - Water Canyon is an example of what we can expect to see happen
- The river running through the amphitheater will speed up erosion

Fallen Hoodoo at Blue Canyon, AZ
(http://www.americansouthwest.net/arizona/blue-canyon/blue12_l.html)

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https://www.nps.gov/brca/learn/nature/hoodoos.htm
https://www.nps.gov/cany/planyourvisit/needles.htm
https://en.wikipedia.org/wiki/Hoodoo_(geology)

BIRDS & ECOLOGY
ZION NATIONAL PARK

Laci Brock
PTYS 594 Spring 2017

California Condors are one of the world's rarest birds.

In the early 1980s, less than 25 of these birds were left, and the species nearly went extinct. A captive breeding program was initiated and was able to successfully keep the species alive. Now the number of California Condors is closer to 400, and Zion is the center of their habitat.

IMPORTANT BIRD AREA (IBA)

Zion National Park (ZNP) is one of over 12,000 IBAs that exist across the world. IBAs are places of international significance which are protected to preserve endangered species, migration and breeding corridors, as well as conserve animal and plant biodiversity. Some notably qualities that make ZNP an IBA include:

- A varied habitat that attracts ~290 different bird species
- Home to breeding Mexican Spotted Owls (endangered), California Condors, Bald Eagles, and Peregrine Falcons
- An abundance of nesting areas on cliff faces, canyons, and caves

Figure 1: A pair of young Mexican Spotted Owls in Arizona
(Image Credit: National Park Service)

Zion Canyon, in particular, is a popular birding destination in Utah from April through October. It is the most popular place to bird watch in the state! We are fortunate enough to be here at the end of April, which starts the peak of spring migration. During this time, an influx of bird species—not normally here—flock to the area to breed and forage for food. One notable species is the peregrine falcon seen in Figure 2.

Figure 2: Peregrine falcons at ZNP prepare for nesting on cliff faces in early March. These falcons were once on the endangered species list, but their numbers have since recovered due to captive breeding programs. (Image Credit: Division of Wildlife Resources, ZNP)

As of March 2017, several climbing routes were temporarily closed at the park (e.g., trails leading to Angels Landing, Mountain of the Sun, The East Temple) to prepare for the arrival of breeding peregrine falcons. The closures reflect 15 years of data collected in the park from monitoring breeding behaviors of these birds.

Did you know?

Peregrine Falcons are the fastest animal on the planet. They can reach speed of 200 mph when diving in the air to hunt for food.

Nearly 80% of the bird species seen in ZNP can be seen here at Zion Canyon. Figure 3 shows a screenshot of species counts from eBird. eBird is a citizen science platform used for identifying and reporting bird species. The Cornell Lab of Ornithology at Cornell University manages eBird. It is free to join and use. Contributions from bird nerds, nature enthusiasts, and beginners alike report sightings and enable ornithologists to study bird migration and the impacts from climate change. In the month of April alone, 149 different bird species have been identified near Zion Canyon.

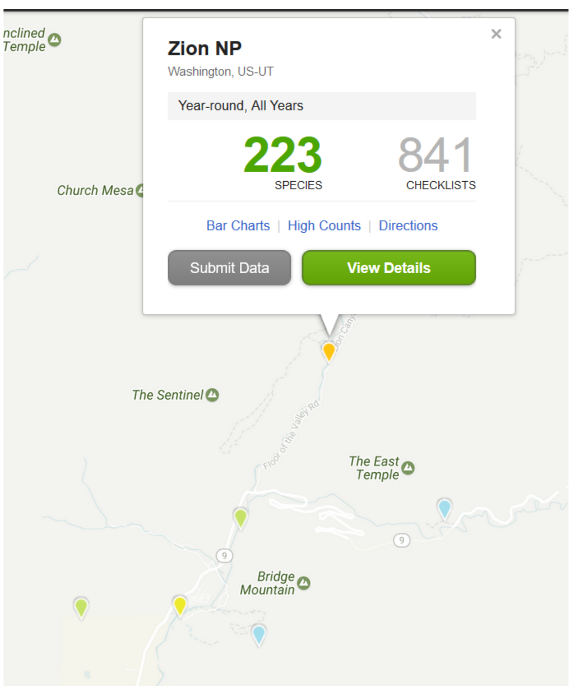


Figure 3: Species count at Zion National Park near our current location. There has been a total of 223 species seen, and visitors to the area have submitted 841 checklists of birds. (Image Credit: eBird)

RIPARIAN CORRIDORS

ZNP supports four different types of life zones: *desert, riparian, woodland, and coniferous forest*. The rim of Zion Canyon is a desert habitat, but the canyon floor is a rich riparian zone watered by the North Fork of the Virgin River. Riparian zones reside at the interface between terrestrial and aquatic ecosystems, typically only composing a small segment of the landscape. These areas supply plentiful food and water sources for birds and other animals, providing an ecologically important route for migrating species.

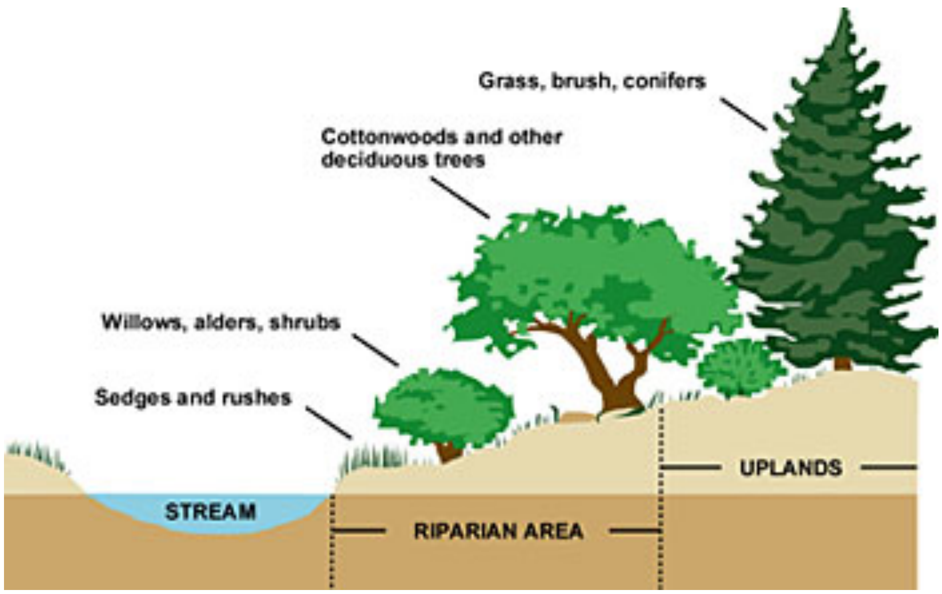


Figure 4: Riparian vegetation, such as cottonwood trees that can be seen around Zion Canyon, thrive in these zones and provide a suitable habitat for birds and other wildlife. (Image Credit: University of Nevada Cooperative Extension)

Riparian zones are ecologically important for other reasons as well. Vegetation in these regions enrich the soil with nutrients, essentially acting as a natural biofilter. Unfortunately, riparian zones are easily impacted by human activities (e.g., industrial and residential development, hunting, mining, agriculture) and are sensitive to climate change. Human-induced changes to riparian zones in ZNP have also caused a displacement of keystone predators, further degrading the ecosystem. Beschta and Ripple (2011) conducted research on the influence of mountain lions in Zion and found decreasing mountain lion populations coupled with increasing mule deer populations over time have impacted riparian plant communities.

BIRD CHECKLIST

Attached is a Bird Checklist for ZNP. Directions for using the checklist are listed within it. All the species that have been seen in the park are listed by:

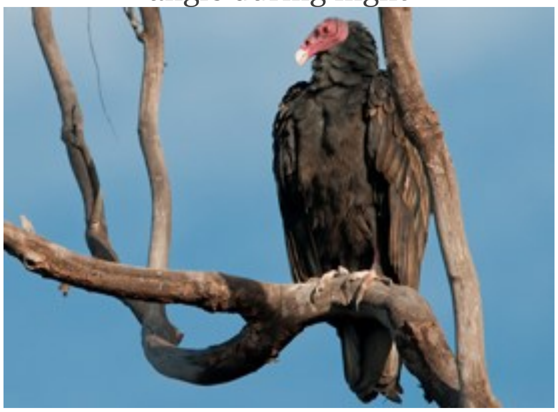
- the type of bird
- what season the bird can be seen in
- how common the bird is for that season
- the type of habitat the bird lives in

The easiest way to identify a bird is to observe it by sight AND sound, though that does not always happen. Observing a bird's behavior and noting its habitat also contribute to identification. However, bird identification is easier than it sounds at times. Many birds look nearly identical in appearance and often have a similar call (see Figure 5).

Figure 5: Sharp-Shinned Hawks (left) and Cooper's Hawks (right) can be incredibly different to tell apart. Cooper's Hawks are generally larger and have rounder tails compared to Sharp-Shinned Hawks, but this can be a tricky ID in the field, especially because both hawks live in the same habitat. (Image Credit: Audubon Society)

All of the birds previously described can be seen in our area today. On the next page are some photos of additional birds to keep an eye out for. (Image Credit: All About Birds)

Turkey Vulture
Smaller than California Condors; V-shaped angle during flight



Wild Turkey
Foraging on the ground for food

Broad-Tailed Hummingbird (male)
In flight, makes loud trill sound from wings; will perch and guard food sources

Black-Chinned Hummingbird (male)
Difficult to see purple gorget unless in sunlight; slender compared to broad-tail

Violet-Green Swallow
Fly in groups, often over bodies of water in search for insects

Steller's Jay
Intelligent and noisy; forges in tree canopys but will investigate forest floor for food

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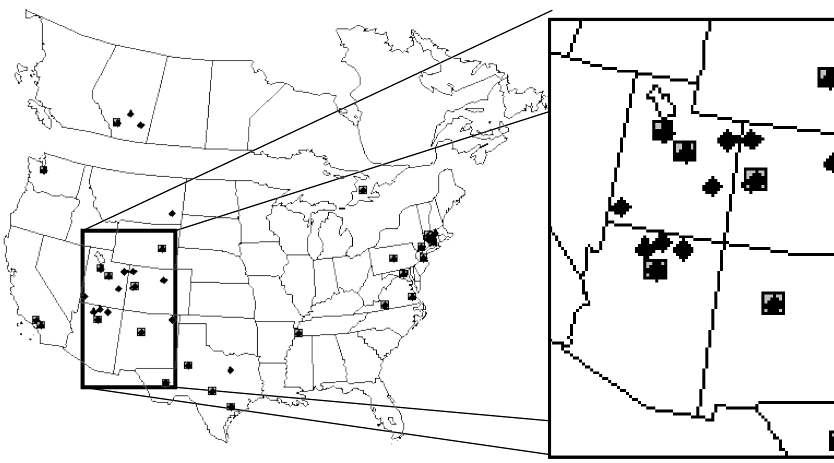
[2] Beschta, R. J., & Ripple, W. J. (2012). The role of large predators in maintaining riparian plant communities and river morphology. Geomorphology, 157(158), 88-98.
[3] eBird (www.eBird.org)
[4] National Audubon Society (www.audubon.org)
[5] Wikipedia (www.wikipedia.org)
[6] Zion National Park (www.nps.org/zion)

Dinosaur Tracks!

Donna Viola

A therapod track north of Moab, UT. Dinosaur tracks are a form of trace fossil: unlike dinosaur bones, which are mineralized and preserved, tracks preserve evidence of where dinosaurs once stepped.

Image credit: Utah Geological Survey

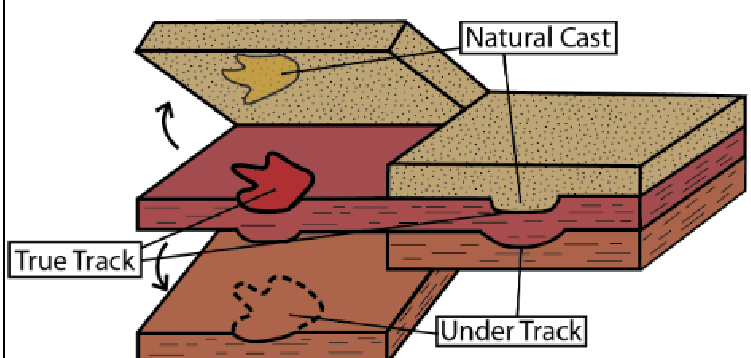


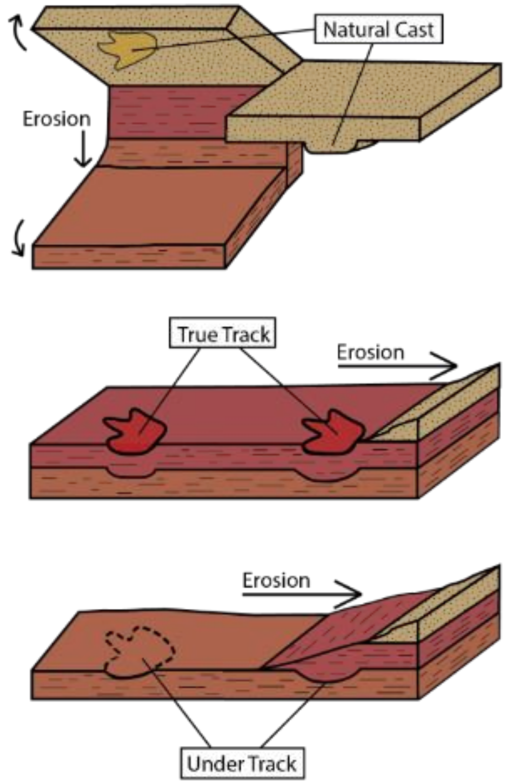
Where do we find dinosaur tracks?
Arizona: Glen Canyon National Recreation Area, Petrified Forest National Park, Wupatki National Monument
Utah: Potash Road Tracks (Moab), Red Fleet Reservoir Tracksite (Vernal), Sauropod Tracksite (Moab), Warner Valley Tracksite (St. George), Coral Pink Sand Dunes
Map from drscavanaugh.org

Formation of dinosaur tracks:

(1) A dinosaur is just going around, minding its own business, and happens to leave behind some footprints, compressing the sediment below its claws. In fact, this dinosaur might even be heavy enough to compress a deeper level of sediment! (These can form into "under tracks".)
(2) Sometimes, the sediment with the dinosaur's footprint will dry out and harden. Now, it can act as a mold!
(3) Under the right depositional conditions, the imprint might get filled in with more sediment (or a "natural cast". The natural cast tends to preserve more detail than the under track.)

Image credit: nps.gov





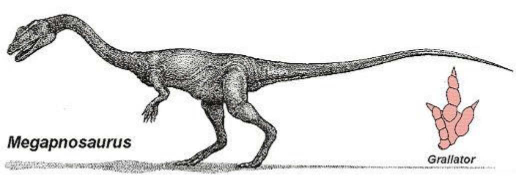
Erosion of dinosaur tracks:

(1) Erosion of the layer containing the "true track" and the "under track". The only remaining evidence that a dinosaur was here is the natural cast (commonly found in less-erosive overhangs).
(2) Erosion of the "natural cast" layer. The true track is preserved!
(3) Erosion of both the natural cast and true track layers. Only the under track is preserved, with less detail than either the natural cast or true track would have had.

Image credit: nps.gov

In Zion National Park, dinosaur tracks tend to be difficult to get to, but are most abundant in the Kayenta and Moenave layers (Jurassic period). Two types of footprints are found here:

Grallator!



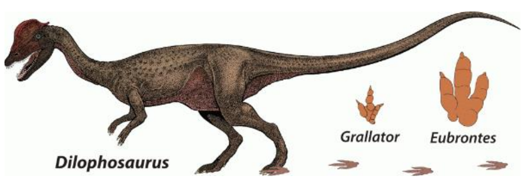
- footprint is small, ~2-6 inches long

- 3-toed, left by a dinosaur walking on two legs.

- Candidate dinosaur: Megapnosaurus. 70-lbs, 10 feet long, carnivore.

Image credit: Utah Geological Survey

Eubrontes!



- footprint is larger, ~10-20 inches long

- 3-toed, left by a dinosaur walking on two legs.

- Candidate dinosaur: Dilophoosaurus. Up to 1000 lbs, 20 feet long, carnivore.

Image credit: Utah Geological Survey

Note: Since dinosaur bones aren't found in the same places as dinosaur tracks, the tracks get their own names. And since some dinosaur tracks can look very similar, these two types of tracks are associated with potential, *candidate* dinosaurs.

Theropods	Ornithopods	Prosauropods	Sauropods	Ankylosaurs	Stegosaurs	Ceratopsians

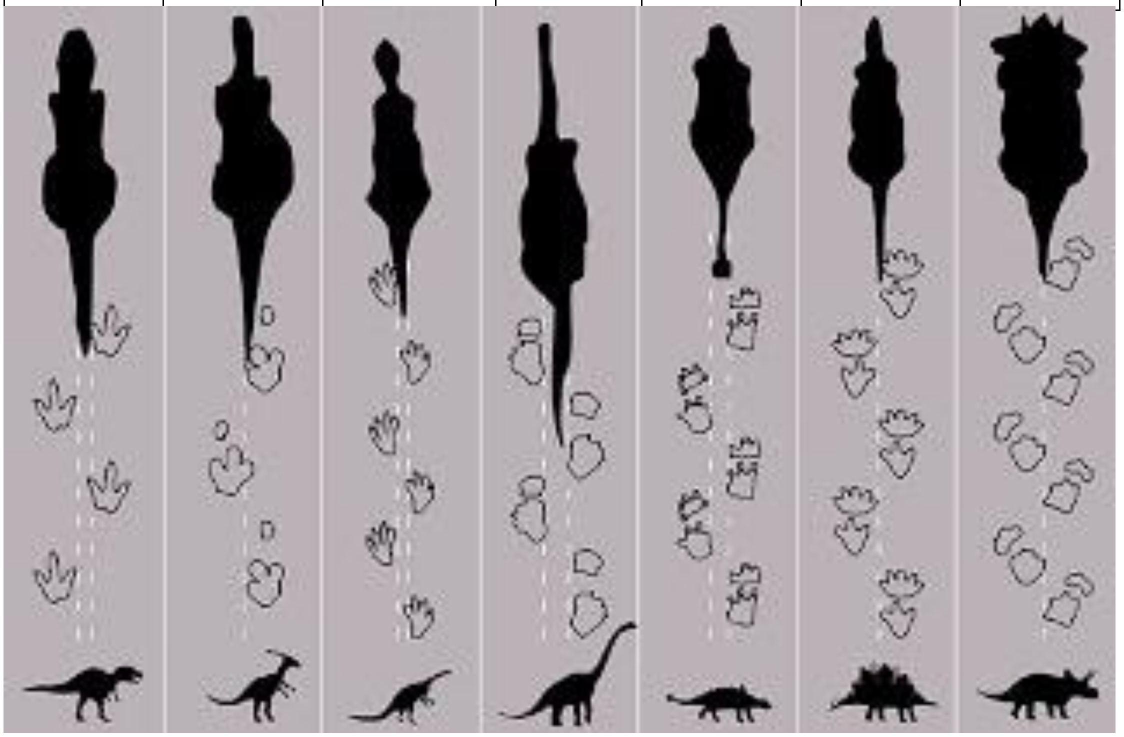
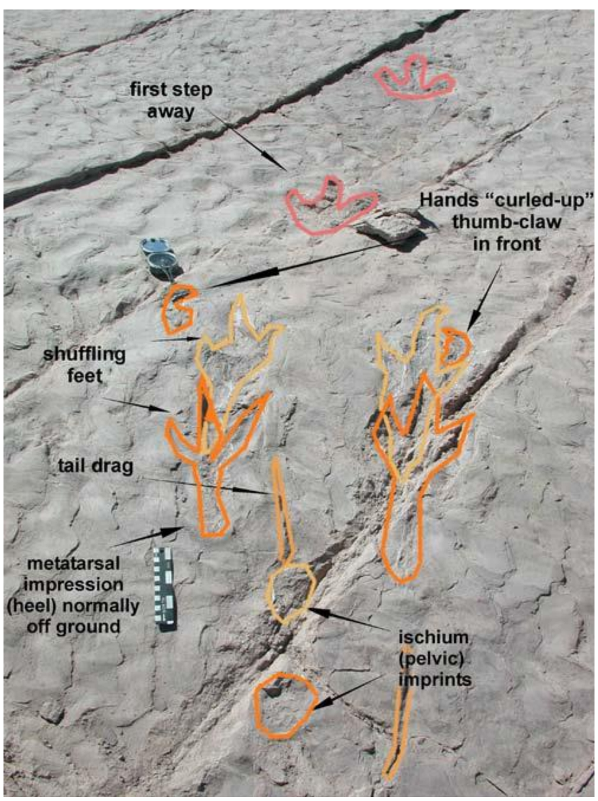


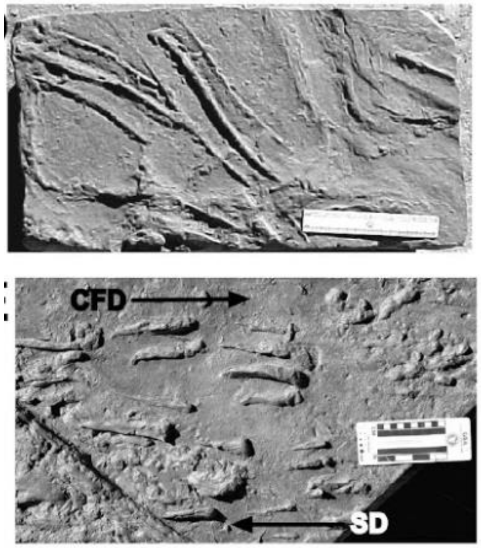
Image credit: geo.utep.edu



"Squatting Dinosaur"

Discovered in 2004 at the St. George Dinosaur Discovery Site at Johnson Farm. Note: handprints show how the dinosaur positioned its hand/claws. Fossil imprints of dragging tails are also rare.

Most tracks at this site are in a Moenave sandstone layer (early Jurassic).



"Swim tracks"

Also discovered at the St. George Dinosaur Discovery Site at Johnson Farm, first identified in 2001.
Grallator-type tracks formed from the claws of dinosaurs scraping the walls while in water. CFD = current flow direction, SD = swim direction.

Image credit: Milner et al., 2006.

Planetary analogs??

Image credit: topleftdesign.com

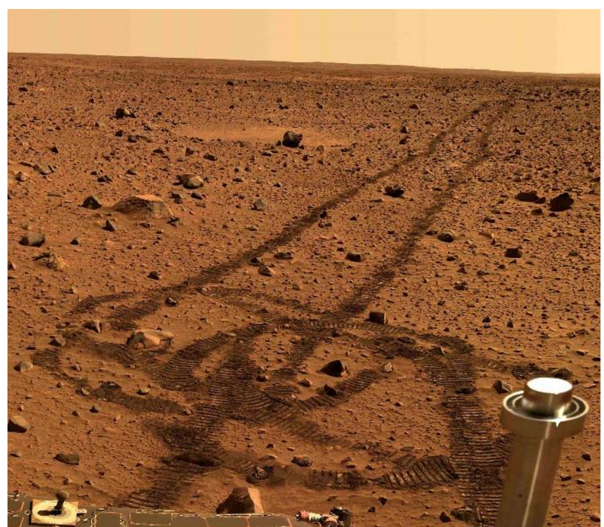
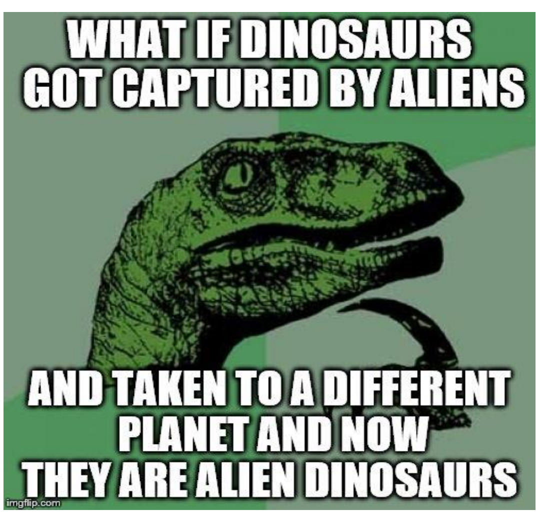


Image credit: NASA



Anthony John Garnello

Vermillion Cliffs Field Guild, PTYS 594a, Spring 2017

Introduction

The Vermillion Cliffs National Monument was established on November 9th, 2000, by President Bill Clinton, and encapsulates the nearby monument Coyote Buttes and is centered by the southern edges of the Paria Plateau. The most noticeable feature of the Vermillion cliffs is its namesake: rolling and brilliantly striking cliffs of red and pink Navajo Sandstone. The characteristic red color comes from iron oxide found inside the predominant minerals that filled the quartz pores during the lithification process. Dating back to the Jurassic Period, the most striking geologic group of the Vermillion Cliffs, Navajo Sandstone, was formed from the deposition of sand in a large, arid erg on the Western portion of Pangaea.

By Erikvoss at English Wikipedia, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=7012061

Some famous locations around the Vermillion Cliffs include Native American Pueblos dating back 12,000 years, complete with scattered structures, houses, and petroglyphs. The area was next explored in 1776 by a group of Spanish Missionaries (in an expedition known and documented as the Dominguez-Escalante Expedition) looking for a land-route linking modern-day Santa-Fe, New Mexico, to Monterey, California. While their expedition was a failure in that they never reached Monterey, the documentation and maps kept along the way were used as part of the Old Spanish Trail, which was a heavily used trade route between Pacific Coast Settlements and New Mexico. In fact, the Highway 89A follows much of this old wagon route near the Vermillion Cliffs National Monument.

History

The Vermillion Cliffs were part of a heavily used trade route between Utah and Arizona during the 19th Century. The Mormon pioneer and Missionary Jacob Hamblin were largely responsible for documenting and exploring the region. This route was also used to access Lee's Ferry, operated by Mormon Leader John Lee, as the first and most accessible method to reach either side of the Colorado River. For an interesting historical side-note about John D. Lee, Google the Mountain Meadows Massacre. The Mormon religion played multiple roles in the exploration of this area, including in the maintenance of the Honeymoon Trail, which brought young Mormon couples up to St. George's Temple in Utah to exchange wedding vows. Though, it was predominantly the Mormon explorers and missionaries who established wagon routes connecting Utah and Arizona, some of which the Highway 89A routes through still today. Pre-dating the Mormon exploration of the area is the Dominguez-Escalante Expedition of 1776, in which a group of Spanish Missionaries sought to connect modern-day Santa Fe, New Mexico with Monterey, California.

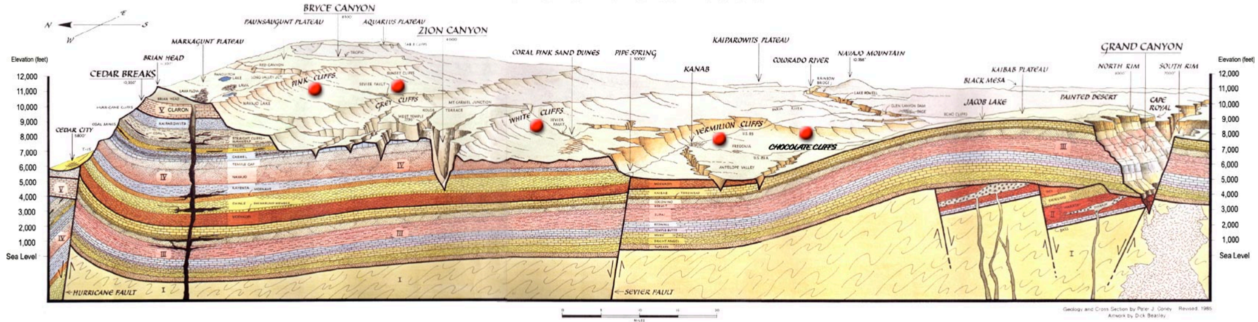
Before the documented exploration by Spanish and Mormon missionaries in the early 19th Century, this area was home to many Native Americans. Dating as far back as 12,000 years ago, there still remains plenty of scattered Pueblos, villages, burial sites, and one of the highest numbers of rock-art petroglyphs in any nationally protected area.

http://roadslesstraveled.us/

Geology

The Vermillion Cliffs are part of the second "up" Grand Staircase of the Colorado Plateau, making it the second oldest strata visible as you make your way up to Bryce Canyon from the Grand Canyon.

The Grand Staircase



(Public Domain, https://commons.wikimedia.org/w/index.php?curid=314356)

The characteristic red color is part of the Navajo Sandstone group, which is a Geological formation as part of the Glen Canyon Group, and dates back to the early Jurassic Period (191-174 million years ago). The Navajo Sandstone group is Eolianite, meaning that it formed by the lithification (compaction and cementation) of sediment deposited by wind. This sediment came in the form of sand dunes that used to dominate this region (known as a dune sea) on Pangea.

The wide ranges of colors visible on these cliffs come predominantly from the following three minerals: Hematite (mineral form of iron(III) oxide, reddish brown), Goethite (iron-bearing hydroxide used in brown pigments) and Limonite (second of two principle iron ores, and is yellowish brown in color). These minerals seeped into and filled the pore spaces of the quartz sand during the lithification process. The other primary color of the Navajo Sandstone group is white, which came about from a bleaching process by acidic groundwater comprised of hydrocarbons. Where the sandstone has its reddish color is where this reducing groundwater mixed with oxidizing groundwater, causing the iron to precipitate out and into the sand. This process resulted in large spatial variations in type and proportion of precipitates, which resulted in the color patterns seen throughout the cliffs. Another additional feature of this widely variable precipitation process is the formation of layers/columns of ironstone. This ironstone is much less susceptible to weathering than the surrounding sandstone, which enabled the formation of many ledges, towers, and even arches, found inside the park.

http://www.truckcampermagazine.com/

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Some 8,000 feet above sea level a peregrine falcon cruises from its perch atop Zion's high plateau. A flock of band-tailed pigeons note its approach and bolt on noisy wings into a stand of ponderosa pines. The falcon careens over the edge of its looming sandstone world and drops roughly 2,000 feet along a sheer rock wall; white-throated swifts scatter to give it space. At the base of the cliffs the raptor's flight becomes more horizontal. From the pygmy forest of pinyon and juniper, pinyon jays squawk their disapproval, and further down, along the Virgin River, a black-headed grosbeak eyes the peregrine from the cover of a big cottonwood. Soon, the falcon's shadow is streaking across searing desert terrain, where a roadrunner abandons its pursuit of lizards to avoid becoming prey itself.

Amazingly, a peregrine falcon can be within a talon's grasp of each of Zion's major habitats during a flight lasting only a few minutes.

In Zion National Park, a diversity of environments is compressed into a relatively small space. While birdwatchers lack the peregrine falcon's luxury of 100 mile per hour, you can still visit Zion's different habitats within a day.

Try to experience the varied landscapes of Zion. You will likely be impressed with their stunning beauty and with the many bird species that occupy them.

Habitats

D Desert sagebrush and blackbrush areas, including grassy canyon bottomlands; e.g. Huber Wash, Coalpits Wash, parts of Chinle Trail, and fields around Springdale.

R Riparian woodlands along the Virgin River and its tributaries.

P Pinyon-juniper woodlands, including the sloping sides of Zion Canyon, possibly with interspersed scrub oak thickets.

E Evergreen woodlands—including fir, ponderosa pine, aspen, and associated vegetation—plus mountain meadows, side canyons, and canyon walls; such as the upper parts of the West Rim Trail, Potato Hollow, Hidden Canyon, and much of the Kolob Canyons area.

W On or near water areas, including the Virgin River and tributaries, Kolob and Blue Springs Reservoirs, and Springdale Ponds.

A Birds may be seen in almost any habitat type.

Abundance

c Common, seen most days in correct season and habitat.

u Uncommon, seen in low numbers in correct season and habitat

r Rare, no more than a few sightings per year.

s Sporadic, may be numerous in some years and entirely absent in other years.

x Accidental, seen no more than a few times or reported but not well documented.

- Species not known to occur in this season or data not available.

* breeds in Zion
**recently introduced to nothern Arizona

This checklist contains 290 bird species.

	Spring	Summer	Fall	Winter	Habitat
Loons & Grebes					
☐ common loon	r	-	r	-	W
☐ pied-billed grebe	u	r	u	u	W
☐ horned grebe	x	-	r	r	W
☐ eared grebe	c	-	c	u	W
☐ western grebe	r	-	r	-	W
☐ Clark's grebe	x	-	-	-	W
Pelicans & Cormorants					
☐ American white pelican	x	-	r	-	W
☐ double-crested cormorant	r	x	-	-	W
Herons, Ibises & Storks					
☐ American bittern	x	-	x	-	W
☐ great blue heron	u	r	u	u	W
☐ great egret	r	-	x	-	W
☐ snowy egret	u	-	r	-	W
☐ cattle egret	r	-	r	-	W
☐ green heron	r	-	r	-	W
☐ black-crowned night heron	r	r	r	r	W
☐ white-faced ibis	u	-	r	-	W
☐ wood stork	-	x	-	-	W
Vultures					
☐ turkey vulture*	u	c	u	x	A
☐ California condor**	r	u	u	r	E/P
Swans, Geese & Ducks					
☐ tundra swan	-	-	-	x	W
☐ snow goose	r	-	r	-	W
☐ Canada goose	r	-	r	u	W
☐ wood duck	u	-	u	u	W
☐ green-winged teal*	u	r	c	u	W
☐ mallard*	c	c	c	c	W
☐ northern pintail*	u	-	u	u	W
☐ blue-winged teal	u	r	r	r	W
☐ cinnamon teal	c	u	c	u	W
☐ northern shoveler	u	-	u	u	W
☐ gadwall	u	-	u	u	W
☐ American wigeon	u	-	u	u	W
☐ canvasback	u	-	u	u	W
☐ redhead	u	-	u	r	W
☐ ring-necked duck	c	-	c	u	W
☐ lesser scaup	u	-	u	u	W
☐ long-tailed duck	-	-	-	x	W
☐ surf scoter	-	-	-	x	W
☐ white-winged scoter	-	-	x	-	W

	Spring	Summer	Fall	Winter	Habitat
☐ common goldeneye	u	-	u	u	W
☐ bufflehead	u	-	u	u	W
☐ common merganser*	u	r	u	r	W
☐ red-breasted merganser	u	r	u	r	W
☐ ruddy duck	u	-	u	u	W

Osprey, Eagles, Hawks & Falcons

	Spring	Summer	Fall	Winter	Habitat
☐ osprey	r	-	r	x	W
☐ bald eagle	r	r	r	u	W
☐ northern harrier	u	r	u	u	D
☐ sharp-shinned hawk*	u	u	u	u	E/P/R
☐ cooper's hawk*	c	c	c	c	E/P/R
☐ northern goshawk*	r	r	r	r	E
☐ common black-hawk	r	r	-	-	R
☐ red-shouldered hawk	-	x	-	x	R
☐ broad-winged hawk	x	-	-	-	R
☐ Swainson's hawk	r	r	r	-	D/E
☐ zone-tailed hawk	-	x	x	-	R
☐ red-tailed hawk*	c	c	c	c	A
☐ ferruginous hawk	r	r	r	r	D/P
☐ rough-legged hawk	u	-	u	u	D
☐ golden eagle*	u	u	u	u	D/E/P
☐ American kestrel*	c	c	c	c	D/E/R
☐ merlin	-	-	r	r	P/R
☐ peregrine falcon*	u	u	u	u	A
☐ prairie falcon	r	r	r	r	D/E

Pheasants, Grouse, Turkey & Quail

	Spring	Summer	Fall	Winter	Habitat
☐ ring-necked pheasant*	r	r	r	r	D
☐ dusky grouse*	u	u	u	u	E
☐ wild turkey*	c	c	c	c	E/R
☐ gambel's quail*	u	u	u	u	D/R

Rails & Cranes

	Spring	Summer	Fall	Winter	Habitat
☐ Virginia rail*	r	r	r	r	W
☐ sora*	r	r	r	r	W
☐ American coot*	u	r	u	c	W
☐ sandhill crane	-	-	-	x	W

Shorebirds

	Spring	Summer	Fall	Winter	Habitat
☐ black-bellied plover	-	-	-	x	W
☐ snowy plover	-	x	-	x	W
☐ semipalmated plover	r	-	r	-	W
☐ killdeer*	u	u	u	u	D/W
☐ mountain plover	x	-	-	-	D
☐ black-necked stilt	u	-	x	-	W
☐ American avocet	u	-	r	-	W
☐ greater yellowlegs	u	-	x	-	W
☐ lesser yellowlegs	r	-	x	-	W
☐ solitary sandpiper	r	-	r	-	W
☐ willet	u	-	-	-	W
☐ wandering tattler	-	-	x	-	W
☐ spotted sandpiper*	u	u	u	r	W
☐ long-billed curlew	x	-	-	-	W
☐ marbled godwit	r	-	-	-	W
☐ sanderling	x	-	-	-	W
☐ western sandpiper	u	-	u	-	W
☐ least sandpiper	u	-	u	-	W
☐ Baird's sandpiper	x	-	x	-	W
☐ pectoral sandpiper	x	-	x	-	W
☐ long-billed dowitcher	u	-	x	-	W
☐ common snipe	u	x	u	u	R/W
☐ Wilson's phalarope	r	-	r	-	W
☐ red-necked phalarope	r	-	r	-	W
☐ red phalarope	x	-	-	-	W

Gulls & Terns

	Spring	Summer	Fall	Winter	Habitat
☐ Franklin's gull	r	-	-	-	W
☐ Bonaparte's gull	x	-	x	-	W
☐ ring-billed gull	u	-	r	r	W
☐ California gull	u	-	r	-	W
☐ herring gull	x	-	x	x	W
☐ Caspian tern	x	-	x	-	W
☐ Forster's tern	r	x	x	-	W
☐ black tern	-	x	-	-	W

Pigeons & Doves

	Spring	Summer	Fall	Winter	Habitat
☐ rock pigeon	r	r	r	r	D/R
☐ band-tailed pigeon*	x	u	x	-	E
☐ white-winged dove	x	-	-	-	R
☐ mourning dove*	c	c	r	r	A
☐ inca dove	x	x	x	x	R

Cuckoos & Roadrunners

	Spring	Summer	Fall	Winter	Habitat
☐ yellow-billed cuckoo	-	r	r	-	R
☐ greater roadrunner	u	u	u	u	D

Owls

	Spring	Summer	Fall	Winter	Habitat
☐ barn owl	r	r	r	r	P/R
☐ flammulated owl*	r	r	r	-	E/P
☐ western screech-owl*	u	u	u	u	E/R
☐ great horned owl*	u	u	u	u	A
☐ northern pygmy-owl*	u	u	u	u	E/P/R
☐ Mexican spotted owl*	u	u	u	u	E
☐ long-eared owl	x	-	-	-	D/P
☐ short-eared owl	-	x	-	-	P
☐ northern saw-whet owl	s	s	s	s	E/R

Goatsuckers

	Spring	Summer	Fall	Winter	Habitat
☐ lesser nighthawk	-	r	-	-	D
☐ common nighthawk	u	u	u	-	A
☐ common poorwill*	u	u	u	-	D/E//P
☐ Mexican whip-poor-will	r	-	-	-	R

Swifts

	Spring	Summer	Fall	Winter	Habitat
☐ black swift	r	-	r	-	R
☐ Vaux's swift	x	-	x	-	R
☐ white-throated swift*	c	c	c	r	A

Hummingbirds

	Spring	Summer	Fall	Winter	Habitat
☐ broad-billed hummingbird	-	-	x	-	R
☐ blue-throated hummingbird	-	x	-	-	R
☐ magnificent hummingbird	x	x	-	-	R
☐ black-chinned hummingbird*	c	c	c	-	A
☐ Costa's hummingbird*	u	r	-	-	D
☐ Anna's hummingbird	x	x	-	-	D/R
☐ calliope hummingbird	r	-	r	-	E/R
☐ broad-tailed hummingbird*	u	u	u	-	E
☐ rufous hummingbird	-	r	u	-	E/R

Kingfishers

	Spring	Summer	Fall	Winter	Habitat
☐ belted kingfisher*	u	u	u	u	R/W

Woodpeckers

	Spring	Summer	Fall	Winter	Habitat
☐ Lewis' woodpecker	x	-	r	r	E
☐ acorn woodpecker	x	r	-	-	E
☐ red-naped sapsucker*	c	u	c	s	E/P/R
☐ Williamson's sapsucker	-	-	r	r	E/P
☐ ladder-backed woodpecker	r	r	r	r	D/R
☐ downy woodpecker	u	u	u	u	E/P/R
☐ hairy woodpecker*	c	c	c	c	E/P/R
☐ three-toed woodpecker	-	-	-	x	P
☐ northern flicker*	u	u	u	c	E/P/R

Flycatchers

	Spring	Summer	Fall	Winter	Habitat
☐ olive-sided flycatcher*	u	u	u	-	E
☐ western wood-pewee*	u	c	u	-	E/R
☐ willow flycatcher*	r	r	-	-	R
☐ Hammond's flycatcher	r	-	r	-	E/R
☐ dusky flycatcher*	u	u	u	-	E/P/R
☐ gray flycatcher*	u	u	-	-	P

	Spring	Summer	Fall	Winter	Habitat
☐ cordilleran flycatcher*	u	u	-	-	E/R
☐ black phoebe*	u	u	u	u	R
☐ eastern phoebe	x	-	x	-	R
☐ Say's phoebe*	c	c	c	u	D/R
☐ vermilion flycatcher	x	x	-	-	R
☐ ash-throated flycatcher*	u	c	-	-	E/P/R
☐ Cassin's kingbird*	u	u	r	-	P/R
☐ western kingbird*	c	c	u	-	D/R
☐ eastern kingbird	x	-	x	-	P/R
☐ northern shrike	-	-	-	r	D
☐ loggerhead shrike	r	-	r	r	D/E

Vireos

	Spring	Summer	Fall	Winter	Habitat
☐ Bell's vireo*	-	r	-	-	R
☐ gray vireo*	u	u	-	-	P
☐ plumbeous vireo*	c	c	c	-	E/R
☐ warbling vireo*	c	c	c	-	E/R

Jays & Crows

	Spring	Summer	Fall	Winter	Habitat
☐ gray jay	-	-	-	x	P
☐ Steller's jay*	c	c	c	c	E/P/R
☐ western scrub-jay*	c	c	c	c	P/R
☐ pinyon jay*	u	u	u	u	P
☐ Clark's nutcracker	r	-	r	r	E
☐ black-billed magpie	x	-	-	x	D/P
☐ American crow	r	r	r	r	P/R
☐ common raven*	c	c	c	c	A

Larks

	Spring	Summer	Fall	Winter	Habitat
☐ horned lark	r	-	r	u	D

Swallows

	Spring	Summer	Fall	Winter	Habitat
☐ tree swallow*	c	c	r	-	E/W
☐ violet-green swallow*	c	c	c	-	A
☐ n. rough-winged swallow*	c	u	r	-	R/W
☐ bank swallow	r	-	-	-	R/W
☐ cliff swallow*	u	u	u	-	D/W
☐ barn swallow	r	-	r	-	D/W

Chickadees, Titmice & Bushtits

	Spring	Summer	Fall	Winter	Habitat
☐ black-capped chickadee*	c	c	c	c	E/P/R
☐ mountain chickadee*	c	c	c	c	E/P/R
☐ juniper titmouse*	c	c	c	c	P
☐ verdin	-	-	x	x	D
☐ bushtit*	c	c	c	c	D/E/P

Nuthatches & Creepers

	Spring	Summer	Fall	Winter	Habitat
☐ red-breasted nuthatch*	r	u	r	r	E
☐ white-breasted nuthatch*	u	u	u	u	E/P
☐ pygmy nuthatch*	u	u	u	u	E
☐ brown creeper*	u	r	u	u	D/E/P

Wrens & Dippers

	Spring	Summer	Fall	Winter	Habitat
☐ rock wren*	c	c	c	u	D/P
☐ canyon wren*	c	c	c	c	R/P
☐ Bewick's wren*	c	c	c	c	D/P
☐ house wren*	c	c	r	r	R
☐ Pacific wren*	r	r	r	u	R
☐ marsh wren*	u	-	u	u	R/W
☐ American dipper*	c	c	c	c	W

Kinglets & Gnatcatchers

	Spring	Summer	Fall	Winter	Habitat
☐ golden-crowned kinglet	r	-	-	u	E/P
☐ ruby-crowned kinglet	c	r	c	c	E/P
☐ blue-gray gnatcatcher*	c	c	r	r	D/P

Thrushes

	Spring	Summer	Fall	Winter	Habitat
☐ western bluebird*	c	u	c	u	D/E/R
☐ mountain bluebird*	u	u	u	u	D/E
☐ Townsend's solitaire*	c	u	c	u	E/P
☐ Swainson's thrush	r	-	x	-	E
☐ hermit thrush*	u	c	u	u	E/R
☐ American robin*	c	c	c	c	A
☐ varied thrush	x	-	-	-	R

Mockingbirds & Thrashers

	Spring	Summer	Fall	Winter	Habitat
☐ gray catbird	-	-	x	x	R
☐ northern mockingbird*	r	u	-	r	D/P
☐ sage thrasher	x	-	x	-	D
☐ brown thrasher	x	-	-	x	R
☐ crissal thrasher	x	-	x	-	D/R

Starlings

	Spring	Summer	Fall	Winter	Habitat
☐ European starling*	c	c	c	c	D/R

Pipits, Waxwings & Phainopepla

	Spring	Summer	Fall	Winter	Habitat
☐ American pipit	u	-	u	u	D
☐ Bohemian waxwing	-	-	-	s	R
☐ cedar waxwing	u	-	u	u	R
☐ phainopepla*	r	u	r	-	D/P/R

Warblers

	Spring	Summer	Fall	Winter	Habitat
☐ orange-crowned warbler*	u	u	u	x	E/R
☐ Nashville warbler	r	-	r	-	R
☐ Virginia's warbler*	c	c	u	-	E/P/R
☐ Lucy's warbler*	c	c	-	-	R
☐ yellow warbler*	c	c	c	-	R
☐ yellow-rumped warbler*	c	u	c	u	E/R
☐ black-throated gray warbler*	c	c	u	-	P
☐ Townsend's warbler	-	-	x	-	E
☐ hermit warbler	-	x	-	-	R
☐ Grace's warbler*	c	c	r	-	E
☐ black-and-white warbler	x	x	-	-	R
☐ American redstart	x	x	x	-	R
☐ ovenbird	x	-	-	-	R
☐ northern waterthrush	r	-	x	-	R
☐ MacGillivray's warbler	u	u	r	-	D/R/E
☐ common yellowthroat*	u	r	-	-	R
☐ hooded warbler	-	-	x	-	E
☐ Wilson's warbler	u	-	r	x	R
☐ painted redstart	r	-	-	-	P/R
☐ yellow-breasted chat*	u	r	x	-	R

Tanagers

	Spring	Summer	Fall	Winter	Habitat
☐ summer tanager*	u	u	r	-	R
☐ western tanager*	c	c	c	-	E/R

Towhees, Sparrows & Juncos

	Spring	Summer	Fall	Winter	Habitat
☐ green-tailed towhee*	u	u	u	x	D/E/R
☐ spotted towhee*	c	c	c	c	E/P/R
☐ Abert's towhee*	-	-	r	r	R
☐ rufous-crowned sparrow*	r	r	r	r	D/P
☐ American tree sparrow	x	-	x	-	D/P
☐ chipping sparrow*	c	c	c	r	D/E/P
☐ Brewer's sparrow	r	r	r	r	D/E
☐ black-chinned sparrow*	r	r	r	-	D/P
☐ vesper sparrow*	c	u	c	x	D/E
☐ lark sparrow*	u	u	u	x	D/R
☐ black-throated sparrow*	c	c	r	x	D
☐ sage sparrow	r	x	r	r	D/P
☐ savannah sparrow	u	x	r	r	D
☐ fox sparrow	x	-	x	r	D/R
☐ song sparrow*	c	c	c	c	R/W
☐ Lincoln's sparrow*	u	r	u	u	D/E/R
☐ swamp sparrow	x	-	-	-	R
☐ white-throated sparrow	r	-	r	r	D/R
☐ Harris' sparrow	-	-	-	x	D/R
☐ golden-crowned sparrow	r	-	r	r	D/R

	Spring	Summer	Fall	Winter	Habitat
☐ white-crowned sparrow	r	-	r	r	A
☐ dark-eyed junco*	c	c	c	c	A
☐ chestnut-collard longspur	-	-	x	-	D
☐ snow bunting	-	-	-	x	P
Grosbeaks & Buntings					
☐ rose-breasted grosbeak	r	r	-	-	R
☐ black-headed grosbeak*	c	c	r	-	E/P/R
☐ blue brosbeak*	u	u	u	-	P/R
☐ Lazuli bunting*	c	c	c	-	P/R
☐ indigo bunting*	r	r	-	-	R
Blackbirds, Meadowlarks & Orioles					
☐ red-winged blackbird*	u	u	u	r	R/W
☐ western meadowlark*	u	u	u	r	D
☐ yellow-headed blackbird	r	-	r	-	R/W
☐ rusty blackbird	-	x	-	-	W
☐ Brewer's blackbird*	u	u	u	r	E/R
☐ great-tailed grackle	r	r	-	-	D/R
☐ brown-headed cowbird*	c	c	r	-	A
☐ hooded oriole	r	r	-	-	R
☐ Bullock's oriole*	c	c	r	-	R
☐ Scott's oriole	r	r	-	-	D/P
Finches					
☐ gray-crowned rosy-finch	-	-	-	s	D/P
☐ pine grosbeak	x	-	-	x	E
☐ Cassin's finch*	u	u	u	s	D/E
☐ house finch*	c	c	c	c	D/P/R
☐ red crossbill*	s	s	s	s	E
☐ pine siskin*	u	r	u	u	E/P/R
☐ lesser goldfinch*	c	c	c	u	A
☐ American goldfinch	u	-	u	u	D/R
☐ evening grosbeak	s	s	s	s	E/R
Weaver Finches					
☐ house sparrow*	c	c	c	c	D/R

Do you have an interesting bird sighting? Records are lacking for numerous species. Your observations of uncommon or rare species, or of any birds exhibiting unusual behavior, can provide the National Park Service and the birding community with valuable data. Natural History Observation Cards are available at visitor centers or entrance stations. Below is a checklist of the information needed as a reminder while you're in the field. Please be specific and accurate on your sighting—do not guess—and thank you!

Observation Checklist

Species:

Date:

Time:

Weather:

Location:

Description, habitat, behavior, number . . .

Observer (name, address, phone number):

National Park Service
U.S. Department of the Interior

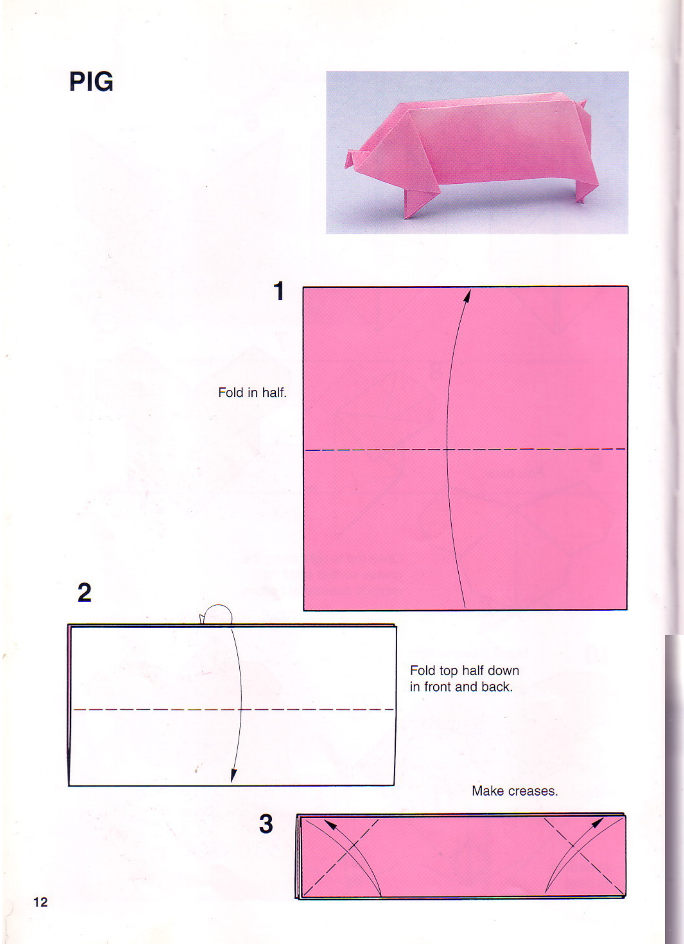
Zion National Park

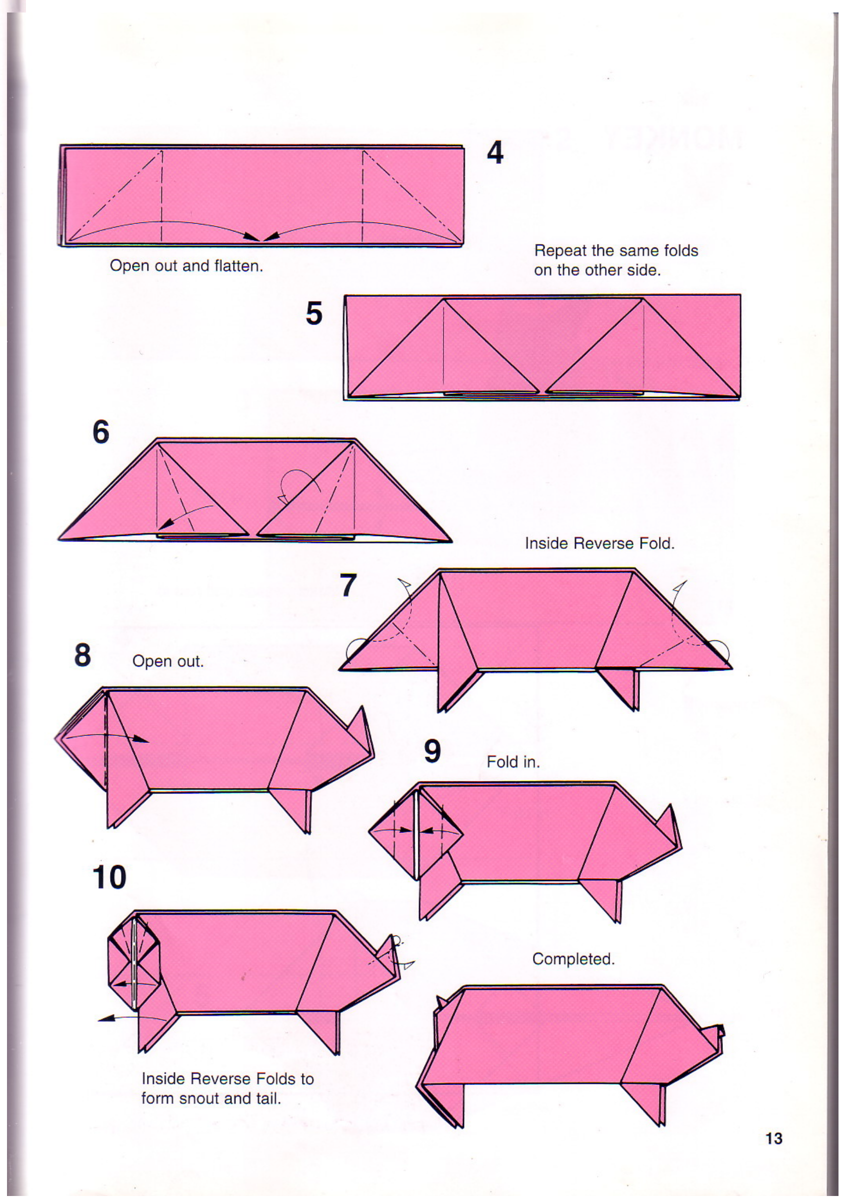
Bird Checklist

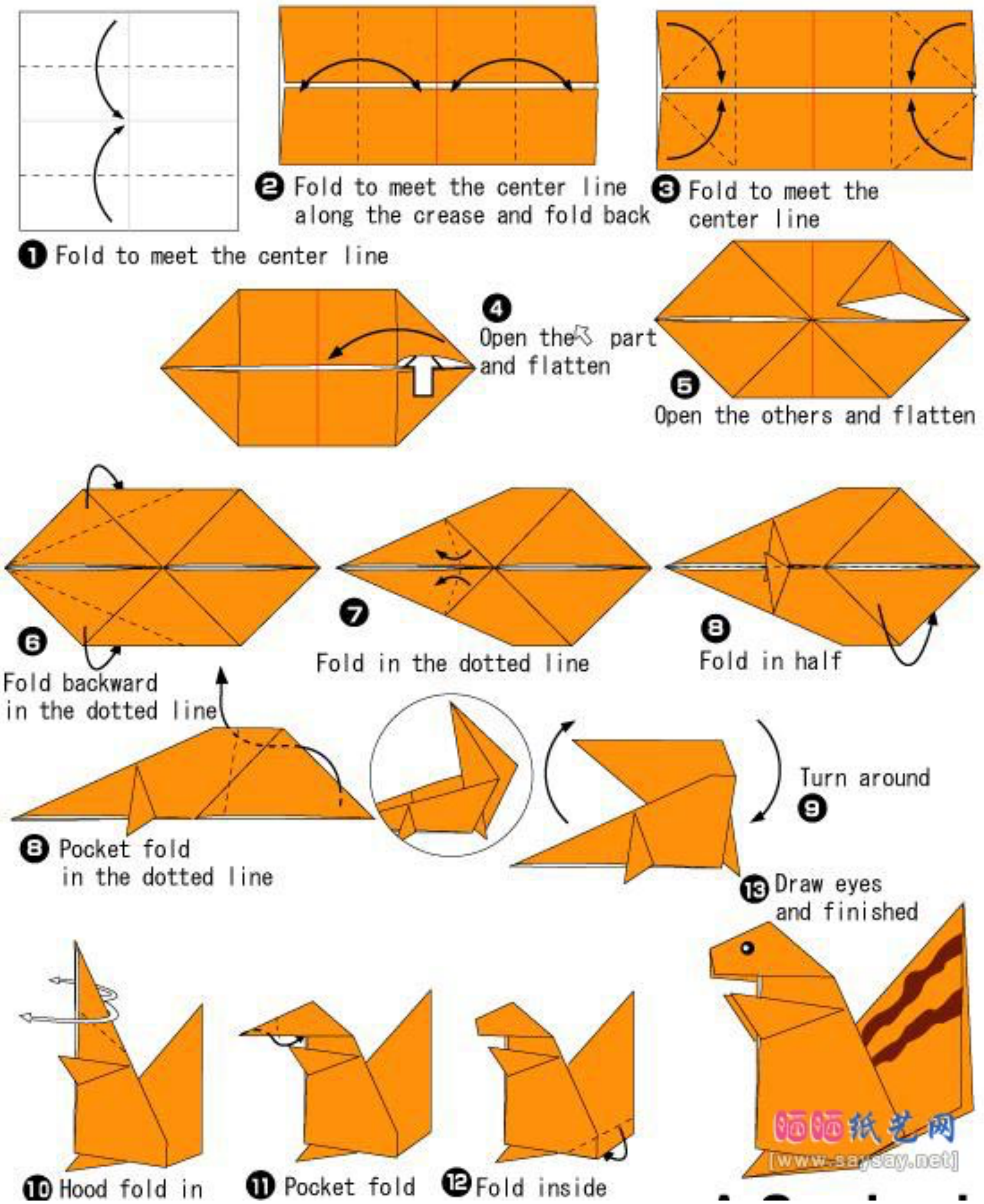
NPS/CAITLIN CECI

Activities!!

http://origamiers.com/wp-content/uploads/2014/03/Very-Simple-Pig-Origami-Instructions.jpg

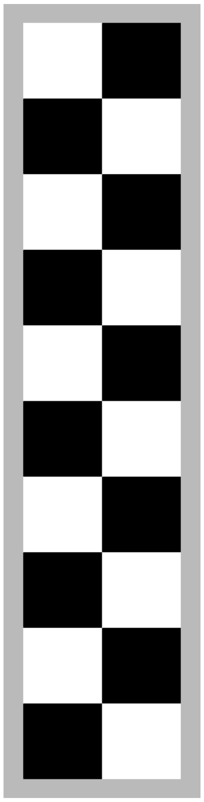






http://origamiers.com/wp-content/uploads/2014/02/easy_origami_squirrel_instructions.jpg

10 cm ruler



ROCK DENSITIES

Material type	Density range (Mg/m^3)	Approximate average density (Mg/m^3)
Sedimentary rocks		
Alluvium	1.96–2.00	1.98
Clay	1.63–2.60	2.21
Gravel	1.70–2.40	2.00
Loess	1.40–1.93	1.64
Silt	1.80–2.20	1.93
Soil	1.20–2.40	1.92
Sand	1.70–2.30	2.00
Sandstone	1.61–2.76	2.35
Shale	1.77–3.20	2.40
Limestone	1.93–2.90	2.55
Dolomite	2.28–2.90	2.70
Chalk	1.53–2.60	2.01
Halite	2.10–2.60	2.22
Glacier ice	0.88–0.92	0.90
Igneous rocks		
Rhyolite	2.35–2.70	2.52
Granite	2.50–2.81	2.64
Andesite	2.40–2.80	2.61
Syenite	2.60–2.95	2.77
Basalt	2.70–3.30	2.99
Gabbro	2.70–3.50	3.03
Metamorphic rocks		
Schist	2.39–2.90	2.64
Gneiss	2.59–3.00	2.80
Phylite	2.68–2.80	2.74
Slate	2.70–2.90	2.79
Granulite	2.52–2.73	2.65
Amphibolite	2.90–3.04	2.96
Eclogite	3.20–3.54	3.37

Udden-Wentworth Grain Size Scale

Size Range	**Name**
>256 mm	Boulder
64-256 mm	Cobble
4-64 mm	Pebble (occasionally subdivided)
2-4 mm	Granule
1-2 mm	Very Coarse Sand
0.5-1 mm	Coarse Sand
0.25-0.5 mm	Medium Sand
125-250 μm	Fine Sand
62.5-125 μm	Very Fine Sand
31.25-62.5 μm	Silt
15.75-31.25 μm	Clay

MOHS HARDNESS SCALE

Index Mineral	Scale	Common Objects
Diamond	10	
Corundum	9	
Topaz	8	
Quartz	7	Steel file (6.5)
Orthoclase	6	
Apatite	5	Glass (5.5) Knife blade (5.1)
Fluorite	4	Wire Nail (4.5) Penney (3.5)
Calcite	3	Fingernail (2.5)
Gypsum	2	
Talc	1	

GEOLOGIC TIME SCALE

Eon	Era	Period	Epoch	Boundary (Ma)	Development of Plants and Animals
Phanerozoic	Cenozoic	Quaternary	Holocene	0.01	Earliest *Homo sapiens*
			Pleistocene	1.6	
		Tertiary	Pliocene	5.3	Earliest hominids
			Miocene	23.8	
			Oligocene	33.7	"Age of Mammals"
			Eocene	55	
			Palaeocene	65	Extinction of dinosaurs and many other species
	Mesozoic	Cretaceous	"Age of Reptiles"	145	First flowering plants
		Jurassic		208	First birds Dinosaurs dominant
		Triassic		248	First mammals
	Palaeozoic	Permian	"Age of Amphibians"	286	Extinction of trilobites and many other marine animals
		Carboniferous: Pennsylvanian		320	First reptiles Large coal swamps
		Carboniferous: Mississippian		360	Amphibians abundant
		Devonian	"Age of Fishes"	410	First amphibians First insect fossils
		Silurian		438	Fishes dominant
		Ordovician	"Age of Invertebrates"	505	First land plants First fishes
		Cambrian		545	Trilobites dominant First organisms with shells
		Vendian	"Soft-bodied faunas"	650	Abundant Ediacaran faunas
Proterozoic	Collectively called Precambrian comprises about 87% of the geological time scale			2500	First multicelled organisms
Archean				3800	First one-celled organisms Age of oldest rocks
Hadean				4600 Ma	Origin of the earth

(From http://sci.waikato.ac.nz/evolution/geological.shtml)