LMU
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FAKULTÄT FÜR GEOWISSENSCHAFTEN
DEPARTMENT FÜR GEO- UND UMWELTWISSENSCHAFTEN
GEOLOGIE

LMU Geology and Tectonics Field School

A geological field trip in the central portion of the North American Cordillera

Students' road logs

September 16th – 30th, 2008

Leader: Prof. Anke Friedrich

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Simon Riedl

September 16

Frenchman Mts., Lake Mead, Hoover Dam, Transition Zone

The target of the first field trip day was to leave Las Vegas (NV) towards east, heading for Grand Canyon Village (AR) on the Colorado Plateau, with en-route stops at Frenchman Mountain, Lake Mead and Hoover Dam.

Frenchman Mountain

- **N 36° 11' 55.7" / W 115° 0' 30.5"**
- **elevation: 650 m**
- time: 10:00 am

Leaving Las Vegas on E Lake Mead Boulevard. Road 147 leads to the northern flank of Frenchman Mountain after ~3km. There is a small parking lot, but cullet on the ground inhibits easy parking, so cars have to stay on the road and pull over. The well accessible key part of the outcrop is located ~50m south of the road.

Frenchman mountain is built of the sandstone and limestone sequence from the early Cambrian to the Triassic, with the bedding layers dipping about 50° to the east. On the western foot of the mountain, the Great Unconformity between these phanerozoic rocks and the underlying proterozoic basement (granite, granulite, schist) is exposed. On the contact, the Precambrian granite shows strong alteration and is straight cut off, forming an erosional discordance with the overlying light grey sandstone Cambrian unit (Tapeats ss.). Eastward (upsection) follows a more erodible mudstone shale unit (Bright Angel Shale), recognizable as a smooth little valley right before the western hillside of Frenchman Mountain raises up.

About 2km eastwards, at the eastern flank of Frenchman Mountain, the distinctive red sandstone formation of the lower Triassic (Moenkopi) is exposed and is then followed by the Aztec Sandstone unit of the Jurassic (equivalent of Navajo Fm.).

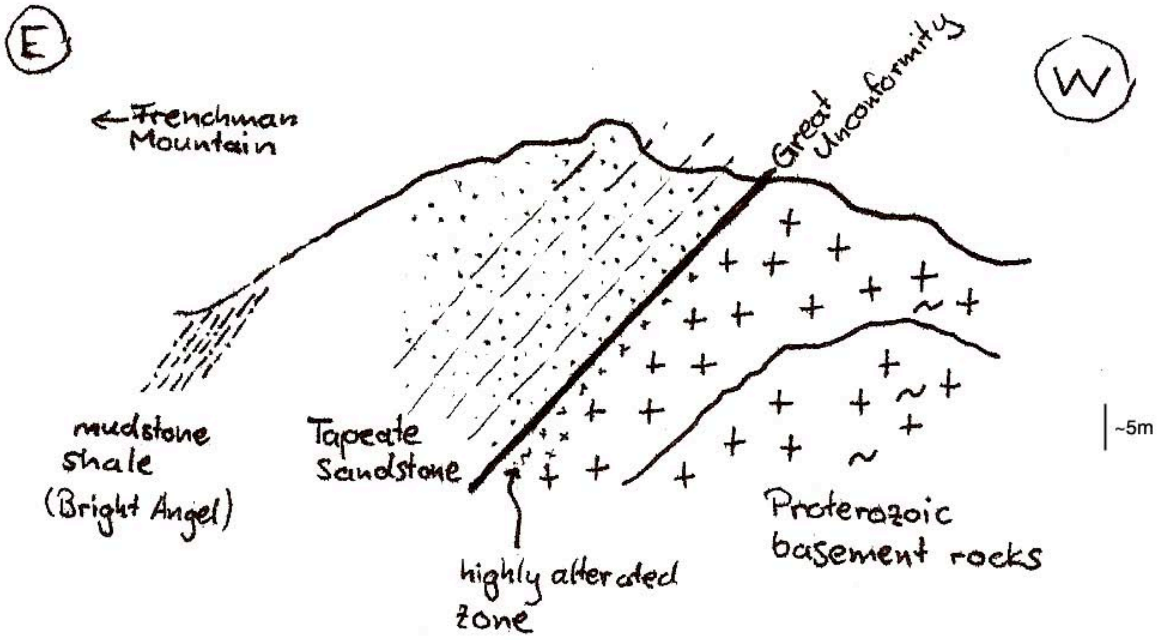

Fig. 1: Sketch showing the Great Unconformity, view towards south.

Fig. 2: Key part of the outcrop, showing the Great Unconformity, view toward south.

Fig. 3: View of the Great Unconformity. Left unit: Tapeats sandstone; right unit: proterozoic basement.

Fig. 4: Close-up view: proterozoic basement rocks (granite).

Fig. 5: Close-up view: Tapeats sandstone beds above the Great Unconformity.

Lake Mead

Lake Mead

- time: 12:20 am

Farther southeast, the overlying exposure of volcanic units shows volcanic activity after the Jurassic. After entering Lake Mead National Park at 12:10 PDT and driving southbound along the western shore of Lake Mead, lake deposits are exposed above the discussed units. Lake Mead itself is a large reservoir impounded by the Hoover Dam since 1936.

Lake Mead – Alan Bible visitor center

- **N 36° 0' 35.0" / W 114° 47' 44.3"**
- **elevation 500 m**
- time: 1:15 pm

Alan Bible Visitor Center, located at the southwest shore of Lake Mead, permits a large-scale overview of the lake with its surrounding geology. The mountains adjoining the lake there are Pliocene to Miocene surficial deposits and volcanic rocks. The sequence is best visible at the Fortification Hill (east to southeast of Lake Mead); it consists of coarse, red Miocene sandstones on the foot, overlain by a large basaltic lava flow (Fortification Hill basalt). Located further east are the Black Mountains, where Miocene plutonic and volcanic rocks are exposed (Wilson Ridge pluton), as well as some proterozoic metamorphic and plutonic units. Beyond the north-western shore of Lake Mead and some tertiary hills, ranges made of Kaibab and Moenkopi Formation (Permian to Triassic) can be seen in the distance. The hill in front of the lake (on its south-eastern shore) is made of Tertiary ignimbrite rocks.

Due to the higher lake in the 1980s, a white ring of evaporites is exposed all along the shore.

The mountains are divided by a series of northeast-southwest to north-south striking normal faults and strike-slip faults. The units close to the faults are partly folded and tend to show high dip angles, in contrast, units with higher distance are dipping very gently towards east.

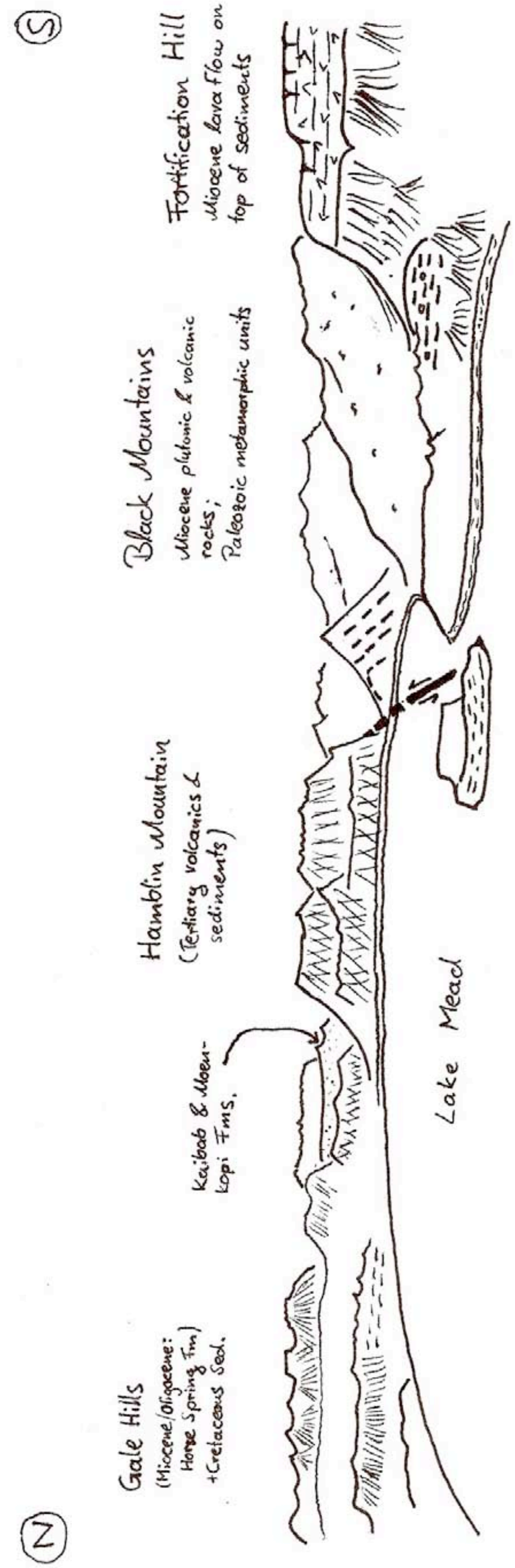

Fig. 6: Sketch: Lake Mead panorama, view towards NE.

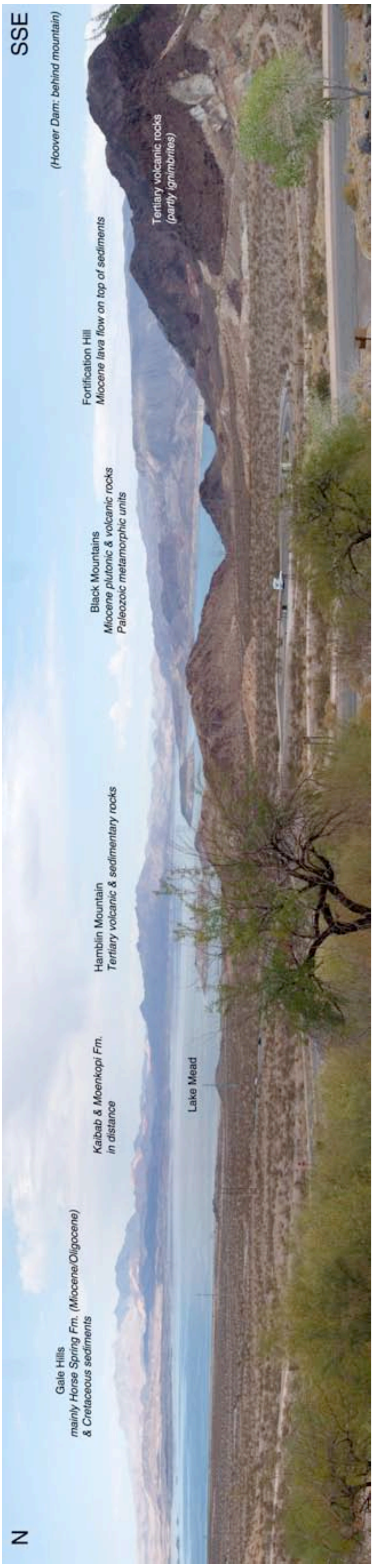

Fig. 7: Lake Mead panorama, view towards NE.

Again, the first main goal is to identify the units, recognize the new sedimentary and the plutonic rock units as well as the known units in the distance and the main structures. Then, make implications for geological history. (Crustal extension in the Tertiary explains the volcanics as well as the deformation. Incision of Colorado River forms today's morphology.)

Hoover Dam

Hoover Dam

- **N 36° 0' 52" / W 114° 44' 11"**
- **elevation: 360 m**
- time: 2:30 pm

The Hoover Dam is located at the very south of Lake Mead. To the south, Colorado River continues in a narrow, about 0.7km wide valley. The mountains at Hoover Dam consist of Tertiary volcanic lava flows. On top, mainly on the western side of the valley, a tuff unit is exposed. Dominating structures are northwest-southeast striking normal faults, which cut through the lava flows.

Driving southeast, the volcanic units are onlapped by alluvial fan deposits (with debris flows and channel fills clearly visible at street side-cuts).

Fig. 8: Hoover Dam; view towards SW. Volcanic deposits are visible in the background. The white fringe above Lake Mead marks the former lake level.

View over Colorado River

- **N 35° 52' 58.7" / W 114° 37' 2"**
- **elevation: 550 m**
- time: 2:55 pm

The alluvial fans continue to the south. The units underneath seem to be proterozoic basement again.

Significant are the volcanic rocks at Hoover Dam and the onlap of the alluvial fans. Enlarged alluvial deposits can be a result of a base level drop-down; the whole landscape is dominated by erosion. The exposure of basement rocks (?) implies that the whole rock sequence could be exposed again farther west, stepping upwards. Goal is to examine the upcoming transition zone from Basin & Range to Colorado Plateau.

Transition from Basin & Range to Colorado Plateau

- time: 3:15 pm
- weather: heavy rainfalls

While driving towards east, the elevation rises stepwise. In a staircase-like shape large depositional basins alternate with steep areas, where the basement rocks and the overlying sequence are exposed again.

These basins are dominated by deposition - a key difference to the Colorado Plateau, which is dominated by erosion.

- time: 5:15 pm
- elevation: ~2000m

Driving on the Colorado Plateau, some Quaternary Volcanoes (San Francisco Peaks) can bee seen in the distance.

- time: 7:30 pm
- elevation: ~2000m

Arrival in Grand Canyon Village.

Addisu Adugna Eba

September 17

Grand Canyon Stratigraphy

After spending the night in Grand Canyon National park camping site, the group traveled to the Canyon where the Stratigraphy including the Great Unconformity is clearly observed.

South rim of the Grand Canyon

- **N 36° 3' / W 112° 5'**
- **elevation: 2202**
- time: 9:30 am
- weather: sunny

Fig. 1: The succession of sedimentary strata with layers.

From fig. 1 the deep incision of the Grand Canyon and the layers of sedimentary strata are clearly observed.

The top most light colored and cliff forming layer is the Kaibab Limestone with an estimated thickness of about 100 m. The underlying reddish brown colored cliff forming layer is the Coconino Sandstone. It has an approximated thickness of about 140 meters. The layer below the Coconino Sandstone is greenish gray colored, gentle slope forming and an approximated thickness of 130 m is the Hermit Shale.

South Kaibab Trail

- **N 36° 3' / W 112° 5'**
- **elevation: 2200m**
- time: 9:40 am
- weather: sunny

Hike down the South Kaibab Trail, approximately to the top of the Coconino Ss. (~1980m).

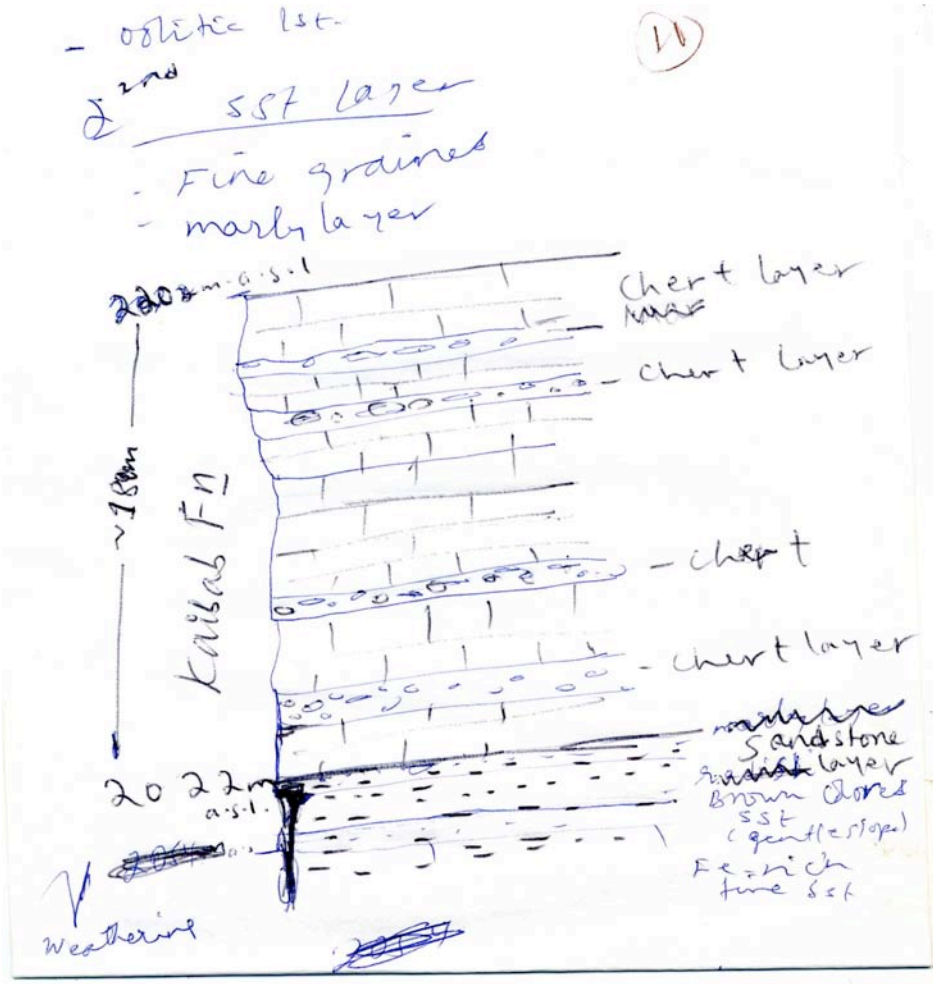

Fig. 2: Stratigraphic column of the upper part of the South Kaibab Trail.

The Kaibab formation consists of layers of mainly fossiliferous limestone alternating with more chaotic ones, which indicate cycles of changing water depths and energy. Along the lowermost 2-3 switchbacks we can observe chert nodules that show the original coral structure in the middle and are isolated. These nodules are due to silicization at a later stage.

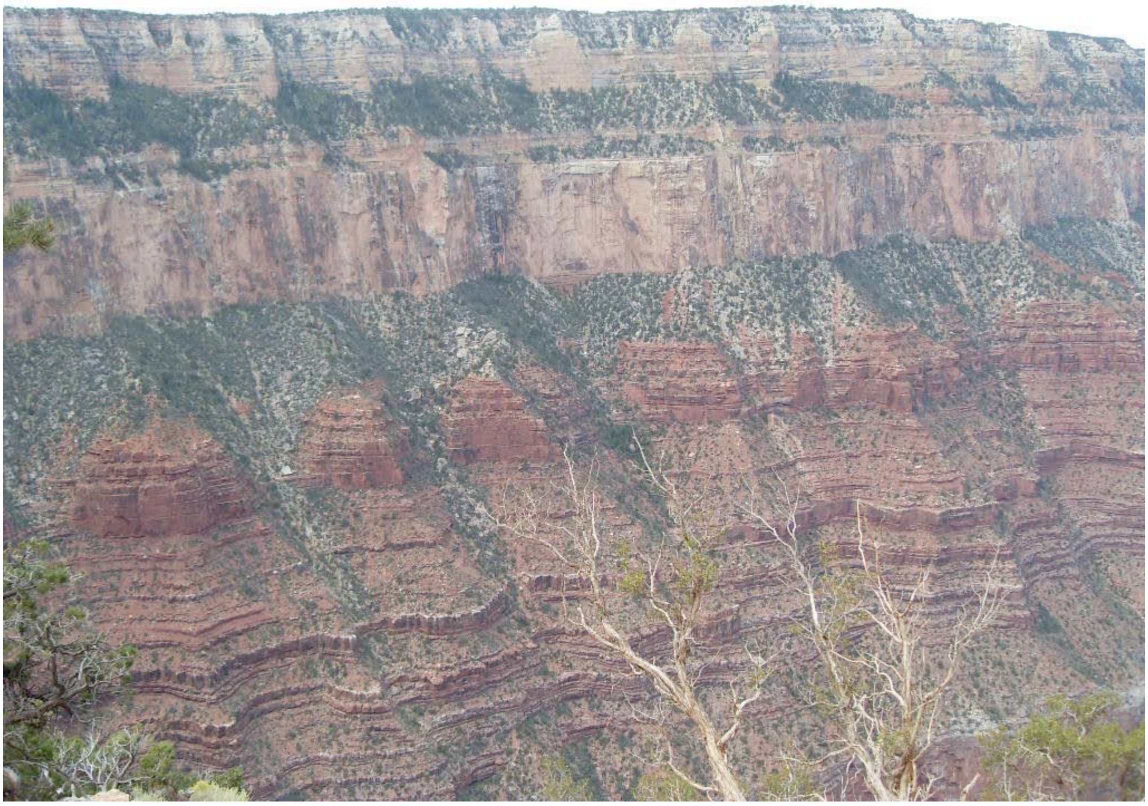

Fig. 3: Stratigraphic sequence as seen from the South Kaibab Trail looking west into a side canyon.

The canyon heading towards the trailhead (fig. 3) is likely fault-controlled: notice the steep straight wall of Redwall Limestone on the W side, while the E side is mmore jagged. Eastern slope also shows significant jointing parallel to the canyon. Small-offset fault at the base of the trail switchbacks might align with this canyon too.

Desert View

- **elevation: 2255 m**
- **14 :52**

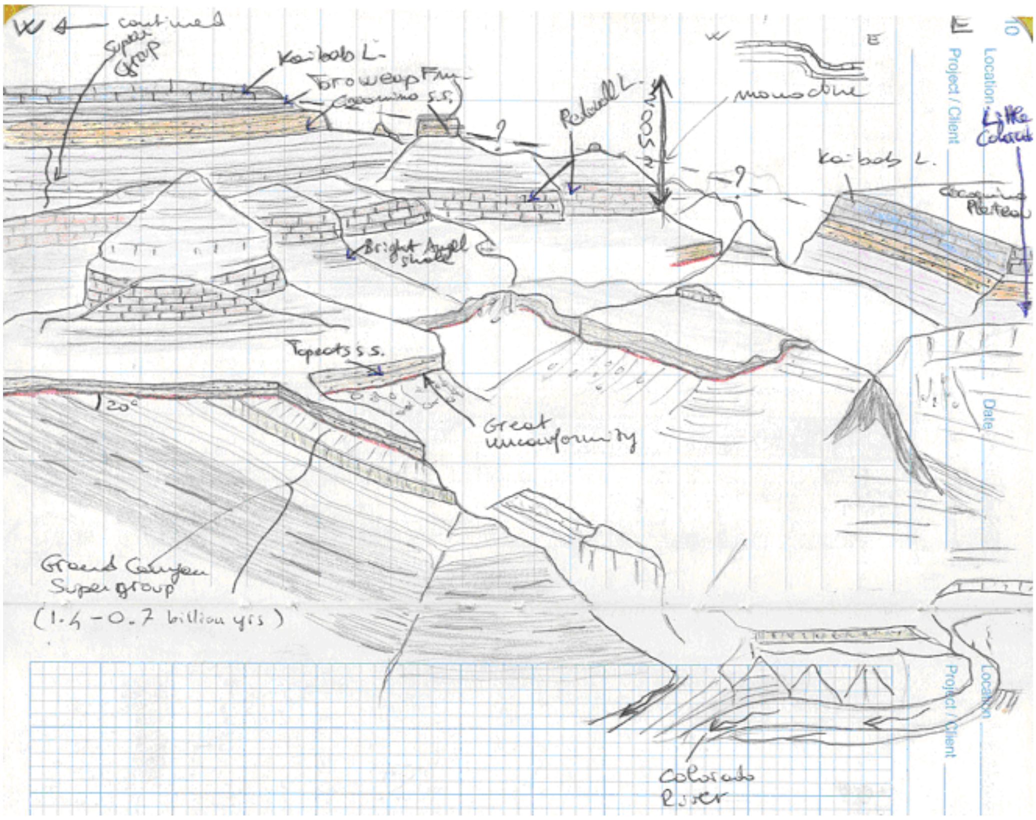

Fig. 4: Sketch of the view from Desert View point.

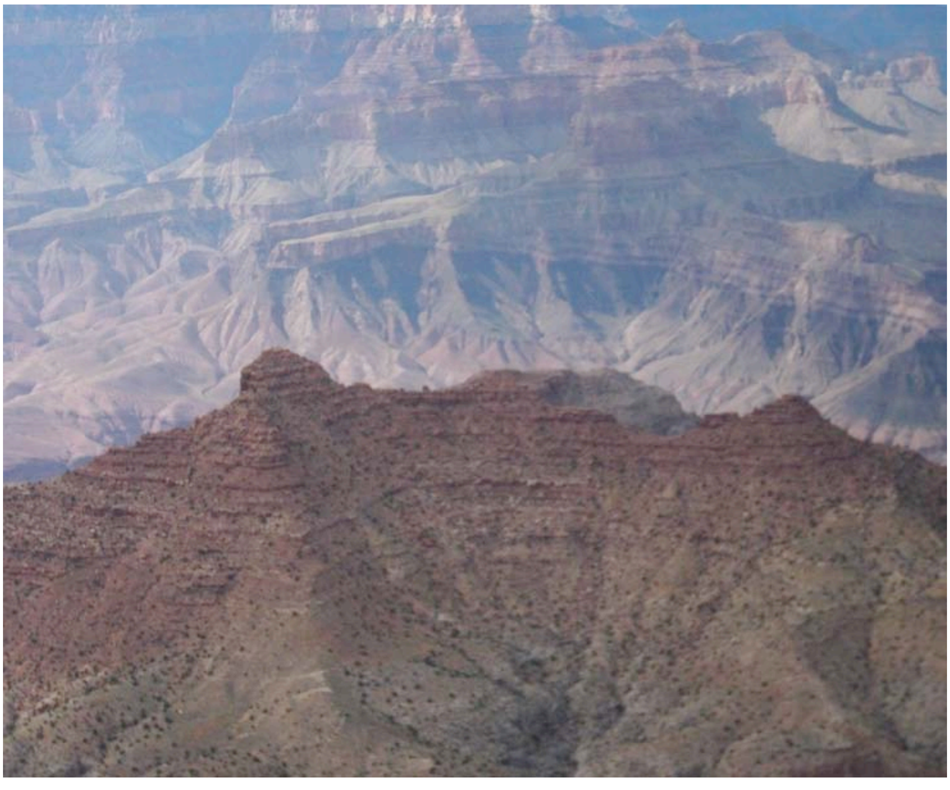

Fig. 5: The lower dark colored layer is from the Grand Canyon super group.

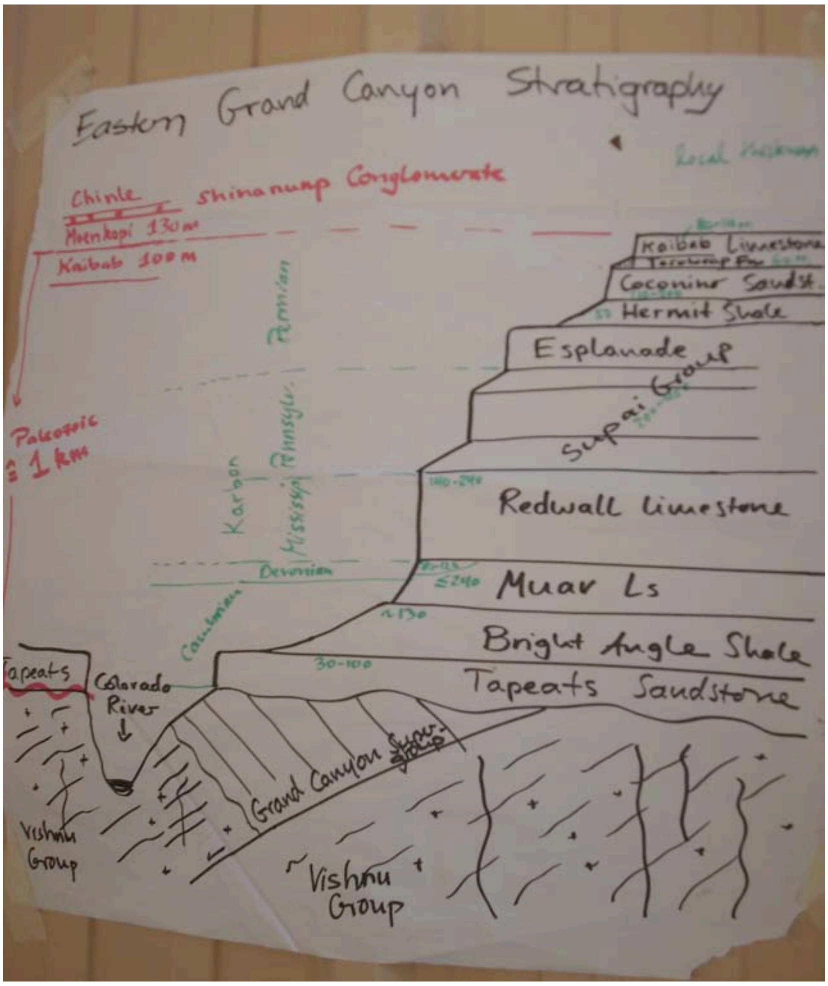

Fig. 6: Sketch of the Eastern Grand Canyon Stratigraphy (summary).

Manuel Lindstädt

September 17

East Kaibab Monocline

A monocline is a step-like fold consisting of a zone of steeper dip within an otherwise horizontal or gently-dipping sequence.

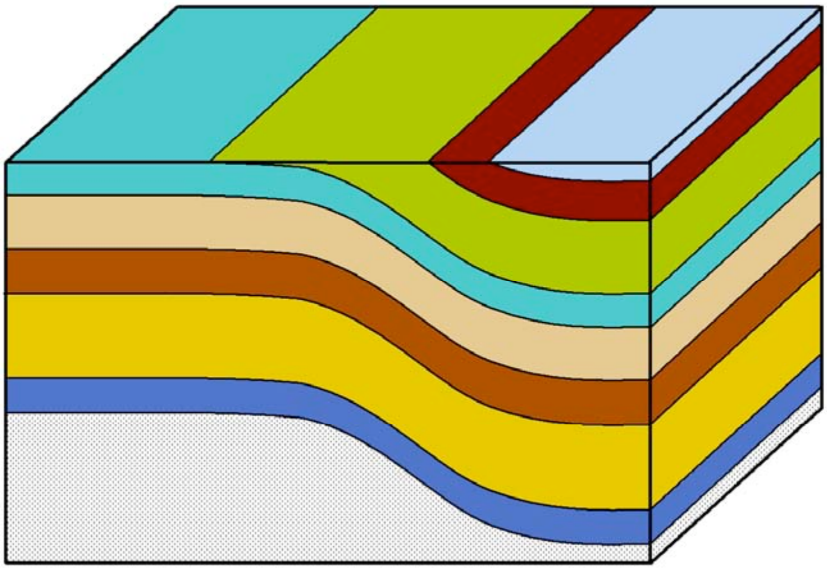

Fig.1: Monocline

The East Kaibab Monocline has formed during the Laramide Orogeny around 65 million years ago. It is one of the Colorado Plateau's main structural features and has had its faulted Basement revealed by erosion in the Grand Canyon. It extends from the San Francisco Peaks volcanic field, Arizona, north 150 miles to Bryce Canyon, Utah. South of the Grand Canyon the monocline has several branches which make abrupt changes of strike. The main monocline, paralleled by the Butte fault, runs north across the eastern end of the Grand Canyon. A minor branch, paralleled by the Cremation fault, runs northwest into the Grand Canyon from Grandview Point. The Colorado River follows the strike of these major structures and may have had a subsequent origin in a belt of weak Triassic strata swinging south around the plunging Kaibab arch. The Little Colorado may have developed later in a similar belt at the foot of the East Kaibab monocline. The differences in altitude of the beds on varied sides of the monocline are about 400 meters. The main flexure trends east, some segments strike northwest, north, and northeast.

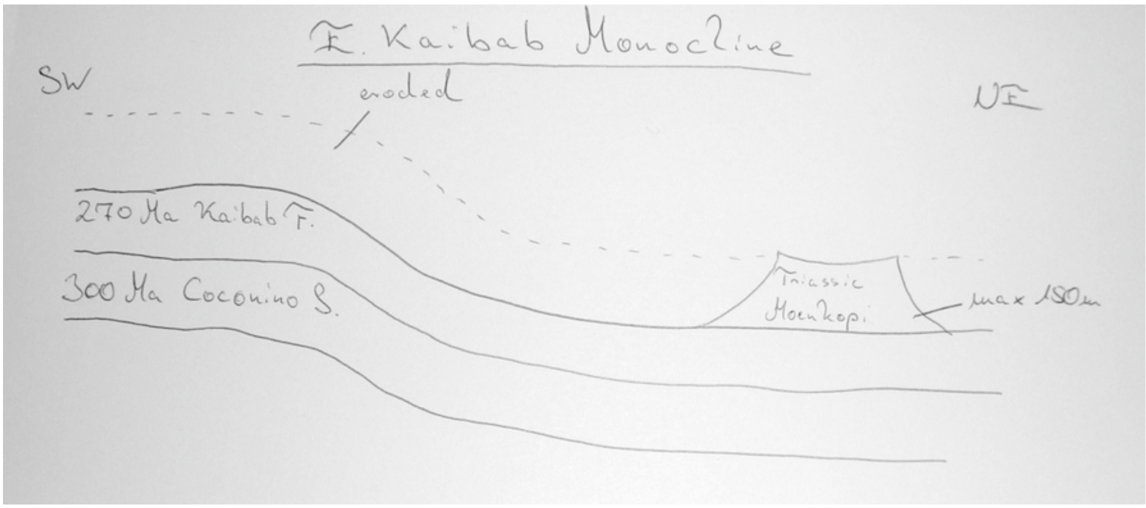

Fig.2: Sketch showing the east Kaibab Monocline

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Fig.3: East Kaibab Monocline (as seen from Desert View)

In Fig. 3 you can see the difference in elevation between the western and eastern segments.

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Johanna Rüther

September 18

Little Colorado River, San Francisco volcanic field, Sunset Crater, Wupatki National Monument

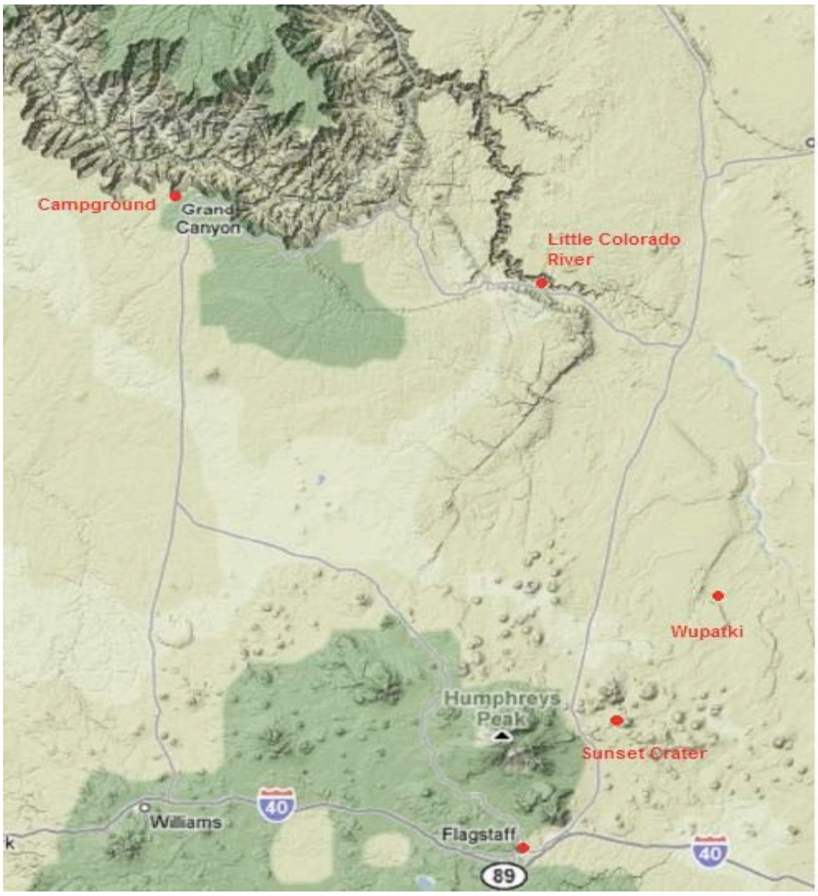


Fig. 1: Overview map of the regular stops.

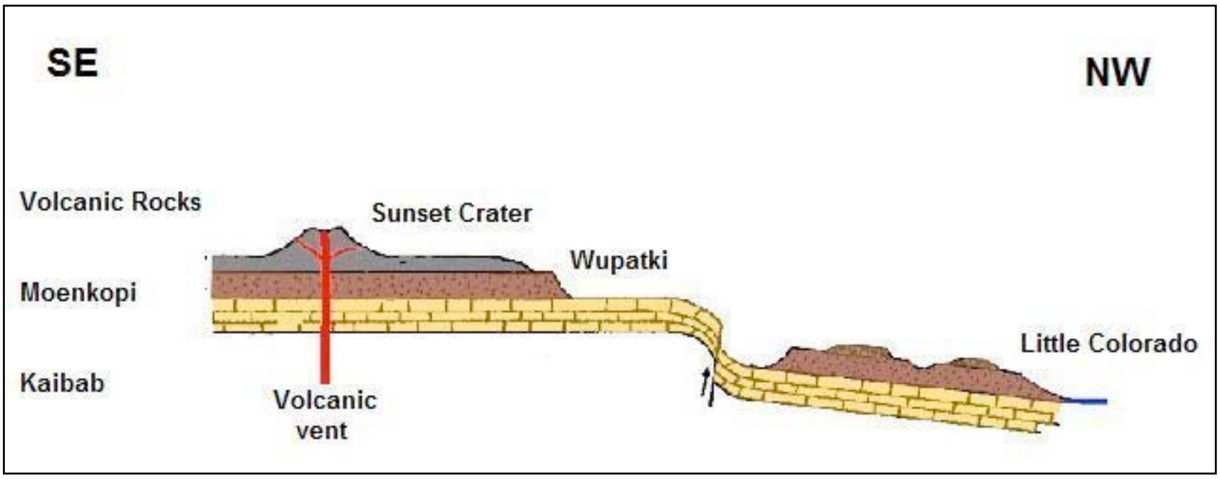


Fig. 2: Sketch of the profile from the Sunset Crater to the Little Colorado river with the characteristic geological units.

Little Colorado Canyon

The region is called Kaibab plateau. Characteristic is the Kaibab Limestone, which is maximal 80 to 110 meters thick. It is a Permian formation
(270 Ma). On the one hand there are the cliffs in the canyon, but on the other hand there is also a monocline structure at this location.

State highway 64

- **N: 35.94 / W: 111.65**
- **elevation: 1642m**
- time: 10:30 a.m.
- weather conditions: cloudy, raining

One can see horizontal layers of limestone, which are eroded by the Little Colorado River. The thickness of the visible columns is about 150 meters. There is a change of slope and cliffs in the rocks. The river is a meandering one with characteristic undercut slopes and slip-off slopes.

At the top ground surface many rounded, unsorted fluvial rocks are deposited. They are younger than 6 Ma.

The East Kaibab Monocline is a step-like fold with a difference of 600 meters in elevation. This structure is similar to the Echo Cliffs, which are located in the North of this outcrop. The East Kaibab Monocline strikes north to south.

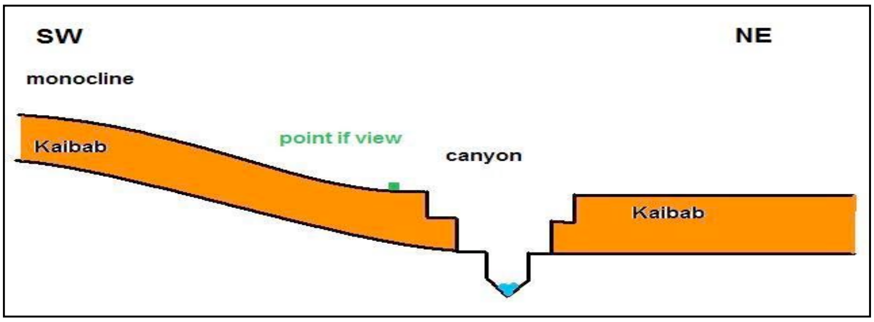


Fig. 3: Sketch of the profile at the stop.

Fig. 4: View into the Little Colorado Canyon; Kaibab Formation outcrops.

Painted Desert

Navajo Nation, highway 89 in direction to Flagstaff

- **N: 35.78 / W: 111.45**
- **elevation: 1400m**

Here Moenkopi Sandstone outcrops. It is a Triassic formation with maximum 300 meters thickness. The age of the rocks is 240 Ma. They dip to north, with 10° dip.

List of unclear issues:
Why are the rocks dipping? Where is the fault? Or is there another monocline? Because of the lower elevation combined with the younger rock formation it is necessary to have one of these possibilities!

San Francisco volcanic field

The volcanism in this area is not older than 6 Ma. It is not caused by extension. There are two theories about the reason of volcanism: The first one says that it is caused by a stationary hot spot. The second one explains the volcanism by the transition zone between the Basin and Range Province and the Colorado Plateau, which is located here. The change from very thin earth crust to very thick earth crust results in ascending heat from the mantle, what induces melting magma. The faults, which created the Colorado Plateau, serve as a pipeline for the rising magma.

This volcanic field consists of many cinder cones and one big stratovolcano, the San Francisco Peaks. It is comparable to Mt. St. Helen. The volcano's magma stems from the crust and the mantle. The magma is composed of basalt, andesite and dacite, which indicate intermediate to acid volcanism.

Fig. 5: View from Painted Desert to the volcanoes of the San Francisco volcanic field.

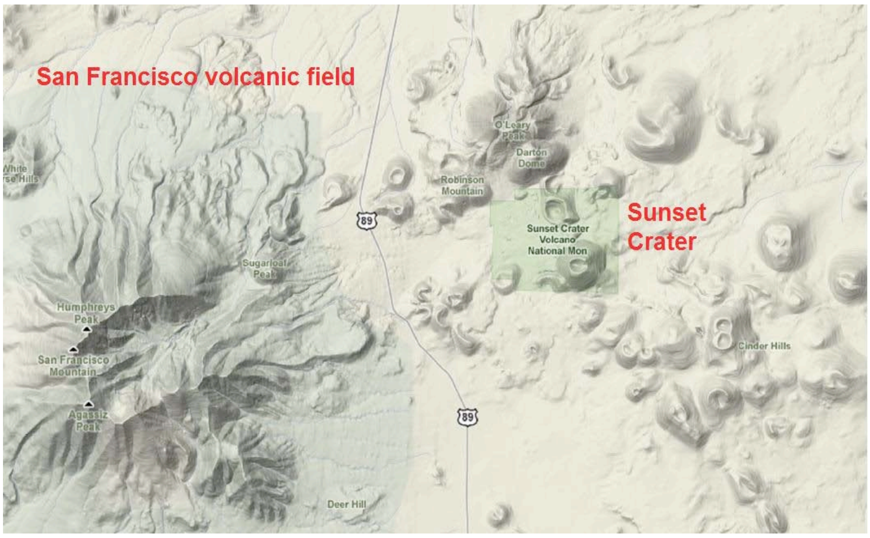


Fig. 6: Landscape map of the San Francisco volcanic field with the San Francisco Peaks and the Sunset Crater Volcano National Monument.

Sunset Crater Volcano National Monument - Bonito Lava Flow

- **N: 35.21 / W:111.31**
- **elevation 2106m**
- time: 2 p.m.
- weather conditions: cloudy

This volcano is very young. The first eruptions took place in the years of 1064 and 1065 A.D.

The lava flow covers an area of 5 km^2 and is up to 30 meters thick. The volcano is 305 meters high and the crater is 91 meters deep. There are 1 billion tons of erupted material.

The Bonito Lava is an Aa-lava with high viscosity and high silica content. It is very sharp-edged. The high porosity of the rocks caused by the bubbles in the texture suggests a high volatile content in this lava.

Fig. 7 : View to Bonito Lava Flow in the Sunset Crater National Monument.

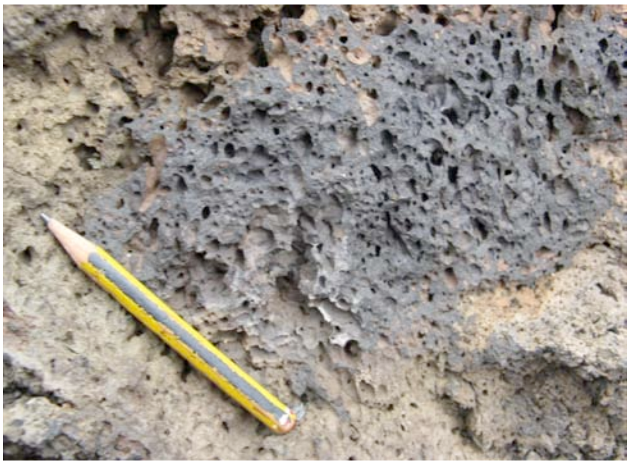


Fig. 8: Aa- lava of the Bonito lava flow.

Sunset Crater Volcano National Monument - Sunset Crater

- **N: 35.21 / W:111.31**
- **elevation: 2142m**
- time: 2:15 p.m.

There is no possibility to climb the crater, but one can walk around on a trail at the foot of the volcano.

The cinder cone is built of erupted cinder, ash and scoria.

The material has the same chemical content as the Bonito lava flow. The different colours of the cinder are caused by the oxidation of the iron in the magma.

Fig 9: View of the Sunset Crater from the trail; cinder cone and surrounding area .

List of unclear issues:
What is the real reason of the volcanism? There are some theories, but which one is right?

Wupatki Pueblo National Monument

The location is in Painted Desert again. Moenkopi Sandstone outcrops here.
Wupatki Pueblo is a National Monument since the 18th century. Ancient Pueblo People populated this area since 1250. The native Americans lived here for a minimum for three generations. Later the Navajos lived in the settlement, too.
The buildings are unique in this area, because of their sophisticated architecture for their age. The village domiciled till 100 people.
The region is unusual for settlement, because it is very dry (20 cm rain per year). The Pueblo people used the cinder layers of the Sunset Crater to save the moisture in the soil.
The reason of movement of the natives is not solved.

FR 545

- **N: 35.52 / 111.37**
- **elevation: 1493m**
- time: 4 p.m.
- weather conditions: cloudy, windy

At the National Monument there is a trail that leads to different buildings of the monument. The houses are built of sandstone and partially constructed within the rocks still in place. The buildings contain up to three floors.
One can see at the rocks still in situ the evidence of abrasion and aeolian erosion, e.g. in form of ventifacts, honeycomb weathering. Also there is desert varnish visible. At the rocks one can get to see cross-bedding of the layers, too.
A special stop on the trail is a blowhole, which is developed by water erosion. Water ran along cracks in the bedrock and dissolved the Kaibab Limestone, which is beneath the Moenkopi sandstone. These blowholes are characteristic for this area. The air in the hole breathes as a reaction of the changes in temperature and pressure of the above ground air.

Fig. 10: One of the buildings of the Wupatki Pueblo in the National Monument; Moenkopi Sandstone.

Fig. 11: Ventifact of Moenkopi Sandstone integrated in a wall at the

Fig. 12: Honeycomb weathering in the Moenkopi Sandstone at the Wupatki.

Forest service road

- **elevation: 1500m**

By getting more to the West the geology changes from Moenkopi Sandstone to Kaibab Limestone.

List of unclear issues:
Where is the tectonic border? Is here a fault or an monocline?

Doney Mountain

- N: 35.53 / W: 111.38
- elevation: 1554m

The Doney Mountain has a magmatic origin also.

Fig. 13: Landscape map of the area at Wupatki National Monument and Doney Mountain.

List of figures

Vanessa Landscheidt

September 19/20

Black Mesa, Cretaceous, Monument Valley

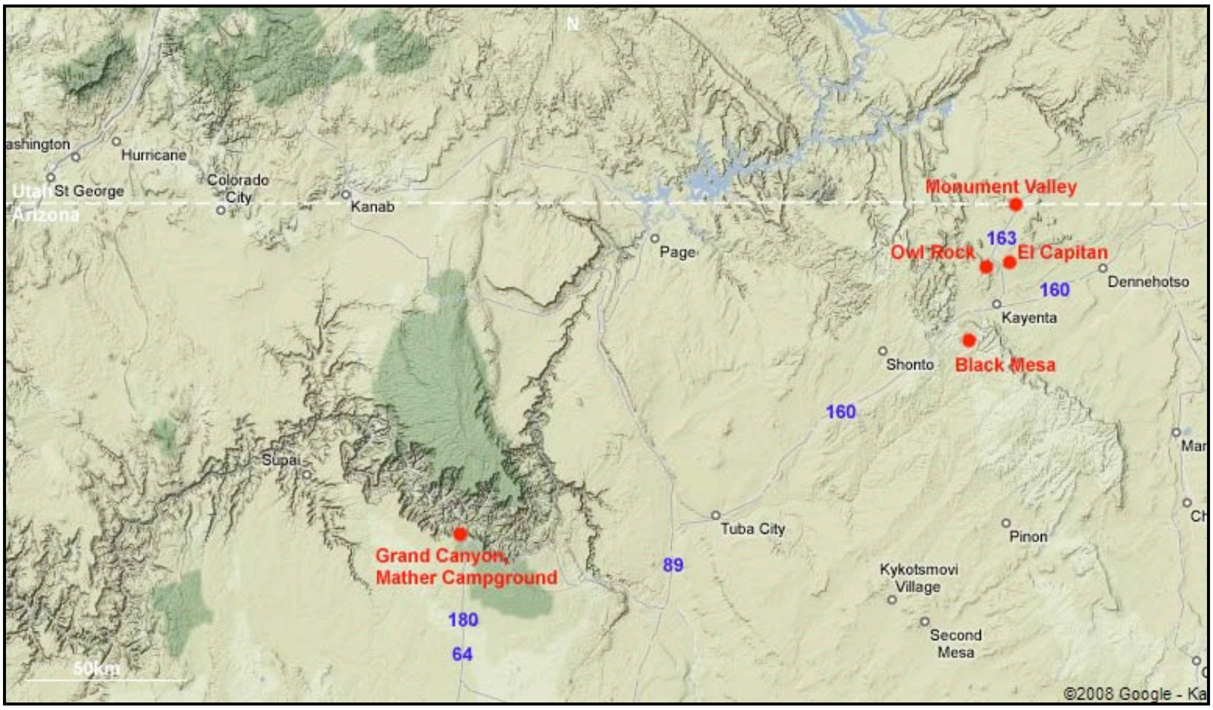


Fig. 1: Route 19th -20th of September 2008.

Cretaceous

Grand Canyon, Mather Campground (Arizona)

The Mather Campground is located nearby the South Rim of Grand Canyon. The campground is accessible by the Highway 180 respectively the Highway 64 (Fig. 2).

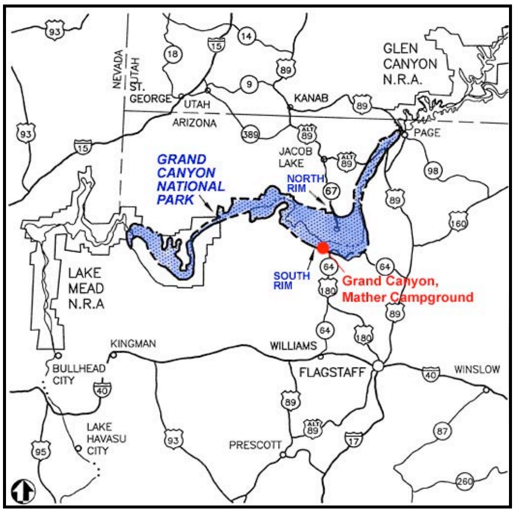


Fig. 2: Map view Grand Canyon.

In the morning of 19th of September there were hold a meeting at the Mather Campground, Grand Canyon.
At first the Eastern Grand Canyon Stratigraphy was merged and completed including time scale and thickness of all geological units. (A detailed geological column of Grand Canyon is found in the handout "Colorado Plateau: sedimentary cover" by Klaus Mayer.)
This followed a talk about the evolution of the Colorado River, and its incision of the Grand Canyon, which has been started 6 Ma ago (Miocene). Dating of the Grand Canyon incision can be done by means of incised sediments and Quaternary basalts. Youngest incised sediments are Triassic formations (Moenkopi, Shinarump Conglomerate, Chinle). The basalts, which belong to the San Francisco volcanic field, overlay sediments inside of the canyon.
Today the Colorado River drains to the West; during late Cretaceous and Tertiary times it drained to the Northeast. The change in direction was caused by basin-range-rifting and the opening of the Gulf of California in the Miocene, which led to morphological modifications and uplift of certain areas (e.g. Rocky Mountains).
(For more in-depth information I refer to the handout "Evolution of River Systems of the Colorado Plateau" by Katharina Aubele.)

In Cretaceous times there were no chance for fluviatile systems to exist, because of broad interior transgression from the Southwest onto the Western craton (Fig. 3). This event is called Zuni transgression (100-80 Ma) and caused the most extensive epeiric sea of Post-Palaeozoic history ("Western Interior seaway") with enormous sedimentary record. The transgression reached a width up to 1000km and a depth of about 400m. In this environment there were deposited conglomerates, sandstones, limestones and shales. Deposition took place in an foreland basin of several mountains in the West, which developed during the Sevier and Laramide orogenies in the Miocene. (For more in-depth information I refer to the handout "Age and deformation styles of the Sevier and Laramide orogenies" by Johanna Ruether.)

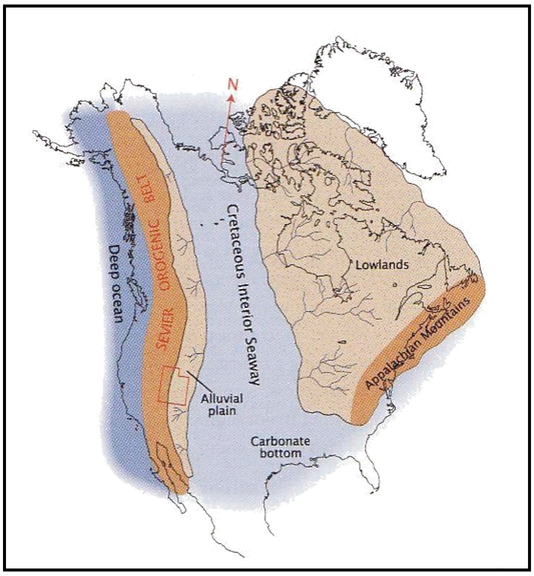


Fig. 3: Geographic map of the United States (Cretaceous).

The reasons for this sea-level highstand are not well known, but the break-up of Pangea and the opening of the Atlantic ocean are suspected to be responsible (Fig. 4).

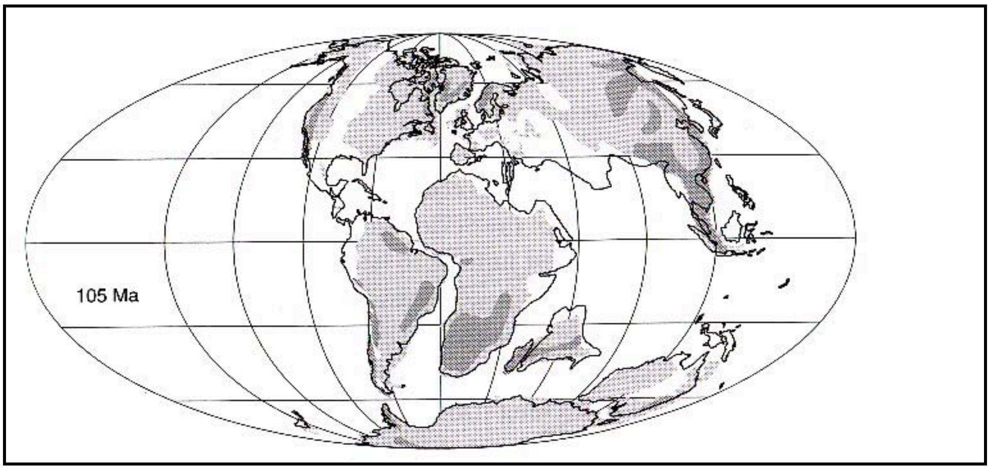


Fig. 4: Global paleographic map (Middle Cretaceous).

Black Mesa (Arizona)

Black Mesa

- **N 36.41 / W 110.20**
- **elevation: 1813 m**

Black Mesa is an elevated area nearby the city of Kayenta. It is located south of the Highway 160. You can reach the mesa easily by drive off the road onto a small, basic parking lot.

Black Mesa belongs to the Colorado Plateau. Its rocks consist of Cretaceous brackish to marine sediments (Fig. 5). Opposite to Black Mesa one can see towards North an unsymmetrical basin surrounded by lower Triassic ranges (Fig. 6) By looking on the geological map there can be observed more similar dome structures and basins in the whole area. These structures are caused by deformative processes in Tertiary times.

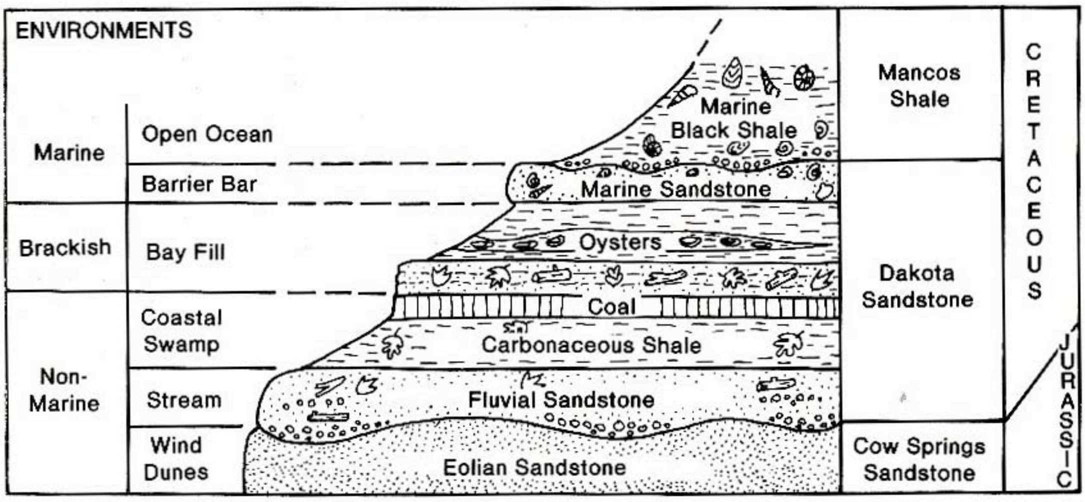


Fig. 5: Marine transgression in the Black Mesa area.

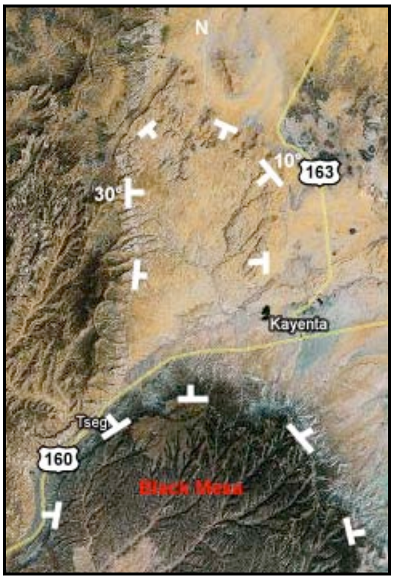


Fig. 6: Map view Black Mesa.

El Capitan and Owl Rock (Arizona)

- **N 36.49 / W 110.14**
- **elevation: 1692 m**

Both El Capitan (Fig. 7) and Owl Rock (Fig. 8) are part of the Navajo volcanic field in the Four Corners region. One can find them 15 km north of Kayenta alongside the Highway 163.

Fig. 7: El Capitan.

Fig. 8: Owl Rock.

They consist of magmatic rocks, which intruded during the Palaeogene (50-25 Ma) into Triassic-Jurassic formations (Chinle Fm, Wingate Ss). The surrounding sediments meanwhile are eroded, so that nowadays just the prominent intrusions can be seen.

Monument Valley (Arizona and Utah)

Monument Valley is kind of a National Park, which belongs both to Arizona and Utah. It is part of the Colorado Plateau. Monument Valley is well-known by its significant remnants (Fig. 9). The erosional forms are results of an uplift and a following activity of a meandering river. These landscape forms can be divided by their size in mesas, buttes and spires (largest to smallest). Nowadays there is no fluviatile system, so that erosion is mainly limited to eolian processes and erosion by temperature change.

Fig. 9: Monument Valley.

The rocks of Monument Valley are composed of Permian and Triassic rocks. The principal layers are Organ Rock Formation, DeChelly Sandstone, Moenkopi Sandstone and Shinarump Conglomerate (oldest to youngest) (Fig. 10). The predominant (deep) red colour dues to the arid conditions during deposition.

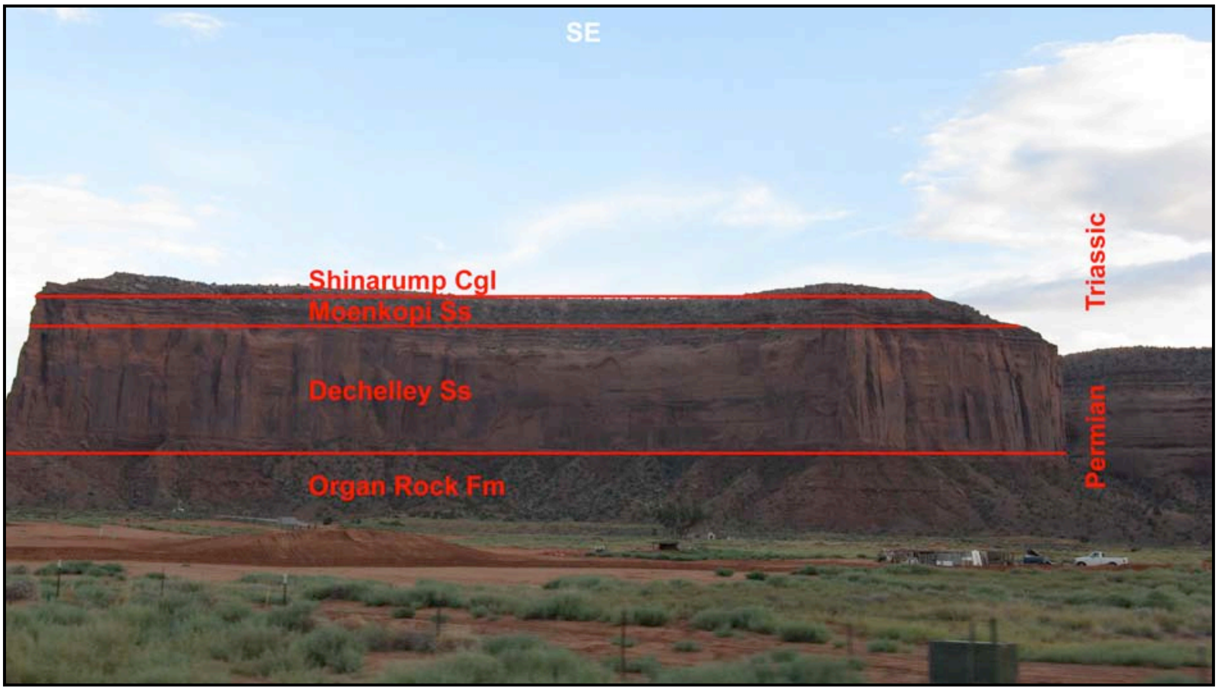


Fig. 10: Profile Monument Valley.

The basement of Monument Valley is build up by the Organ Rock Fm. This formation consists of fine-grained (mudstone, fine sandstone) and soft sediments, which produce plain slopes. The overlaying DeChelly Sandstone is the result of eolian deposition identifiable by its cross bedding. DeChelly Sandstone is responsible for the prominent, vertical forms, which make Monument Valley recognisable. The following unit is Moenkopi, which is mainly composed of sandstone and secondarily of mudstone. It is capped by the Shinarump Conglomerate; an inhomogeneous and poorly sorted sediment.

Monument Valley, Campground

- **N 37.01 / W 110.19**
- **elevation: 1581 m**

The morning of the 20th of September also was shaped by a meeting including considerations on the South-eastern Utah Stratigraphy (tab. 1) and working on profiles.

Cretaceous		Mancos Shale	(0 - > 1000m)
		Dakota Sandstone	(≤ 200m)
Jurassic		Morrison Formation	(400-900m)
		Entrada Sandstone	(300-800m)
	Glen Canyon Group	Navajo Sandstone	(> 600m)
		Kayenta Formation	(200m)
		Wingate Sandstone	(350m)
Triassic		Chinle Formation	(800-1000m)
		Shinarump Conglomerate	(0-200m)
		Moenkopi Formation	(100-350m)
Permian		Dechelley Sandstone	(0-400m)
	Cutler Group	Organ Rock Formation	(300-700m)
		Cedar Mesa Sandstone	(500-700m)
		Halgaito Formation	(400-700m)
Carboniferous (Pennsylvanian)	Hermosa Group		(1000-2000m)

Tab. 1: Southeastern Utah Stratigraphy.

Figures

Fig. 1: http://maps.google.de/ (modified)

Fig. 2: http://www.nps.gov/grca/planyourvisit/directions.htm (modified)

Fig. 3: Hintze, L. F. (2005): Utah’s Spectacular Geology, Department of Geology, Provo

Fig. 4: Baldridge, W. S. (2005): Geology of the American Southwest, Cambridge University Press, Cambridge

Fig. 5: Nations, D., Stokes, W.L. (1988): Geology of Utah, Utah Museum of Natural History & Utah Geological and Mineral Survey, Salt Lake City

Fig. 6: http://maps.google.de/ (modified)

Fig. 7: © Vanessa Landscheidt (2008)

Fig. 8: © Vanessa Landscheidt (2008)

Fig. 9: © Vanessa Landscheidt (2008)

Fig. 10: © Vanessa Landscheidt (2008)

6

Tsegaye Mekuria Checkol

September 20

Monument Valley, Raplee anticline, Goosenecks.

Goulding's Campground, W of Monument Valley

- **N 32^o.42' / W 109^o.32'**
- **Elevation: 1523 m.**
- 8:00

First thing in the morning we saw a mass of blocks of Organ Rock shale formation near the camp that are affected by mass wasting.

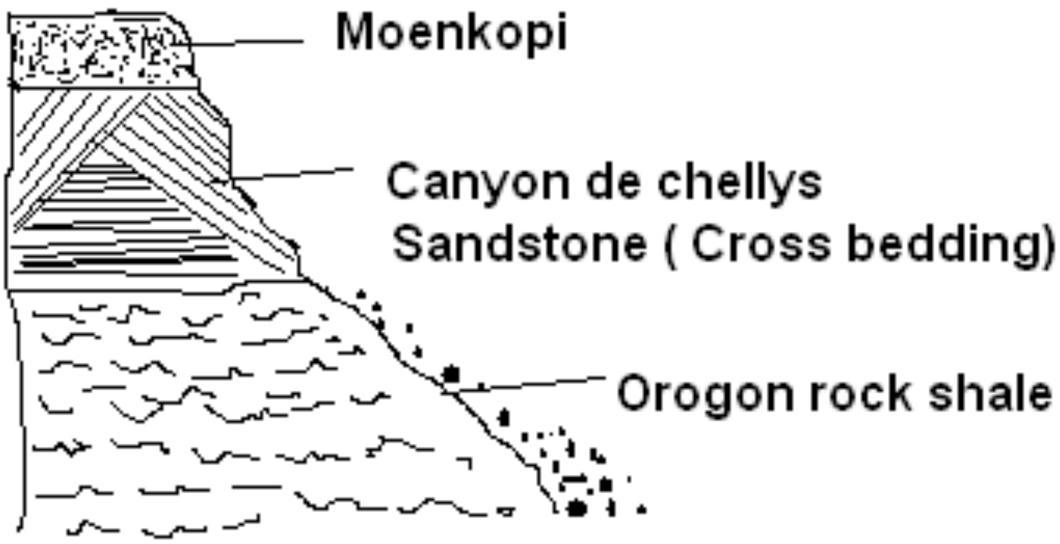


Fig. 1: showing the mass wasting of the rock sequence.

Monument Valley Overview

- **N 37°.04' / W 100°.04'**
- **Elevation: 1661 m.**

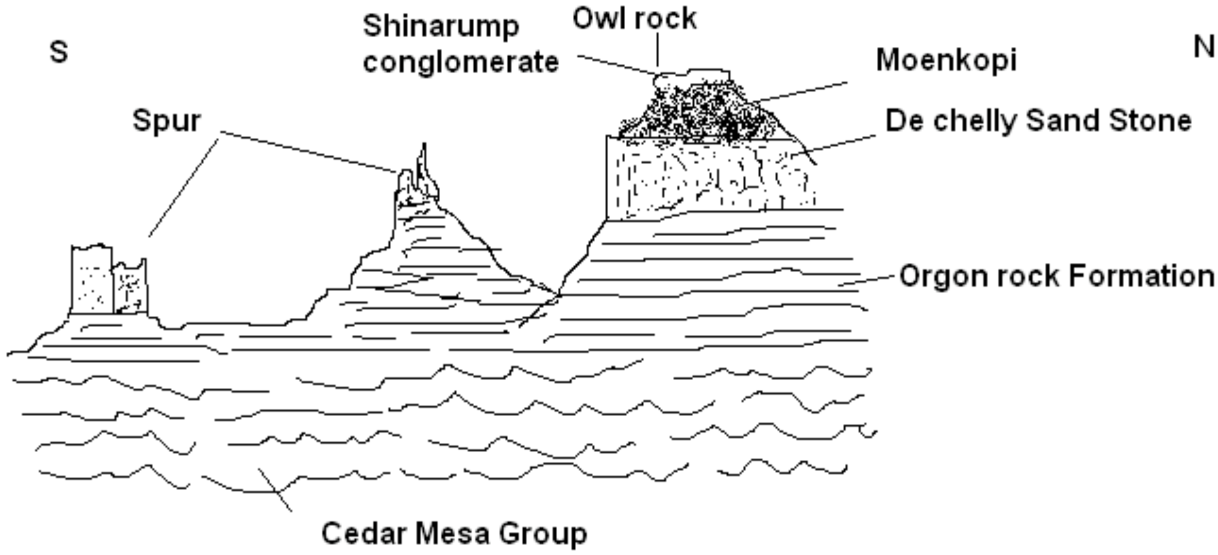


Fig. 1: Sketch of Monument Valley

Fig. 2: Monument Valley as seen from roadside, 5-6 miles NE of Monument Valley Junction.

We have discussed how these rock spurs could be formed using the following explanatory diagram:

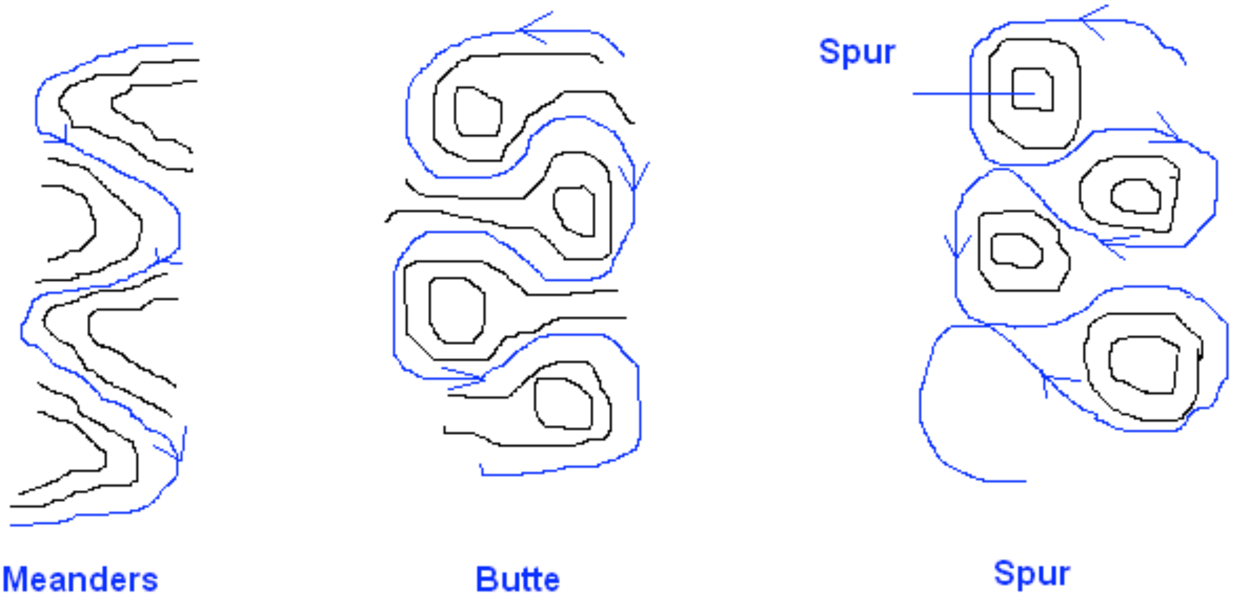


Fig. 4: Spur formation: spurs are what is left over from river meanders.

Cedar Mesa and "The Comb"

- **N 37°.04' / W 100°.04'**
- **Elevation: 1428 m.**

Roadside stop just west of "Mexican Hat": view of "The Comb" (this part of the structure here is actually named "Raplee anticline").

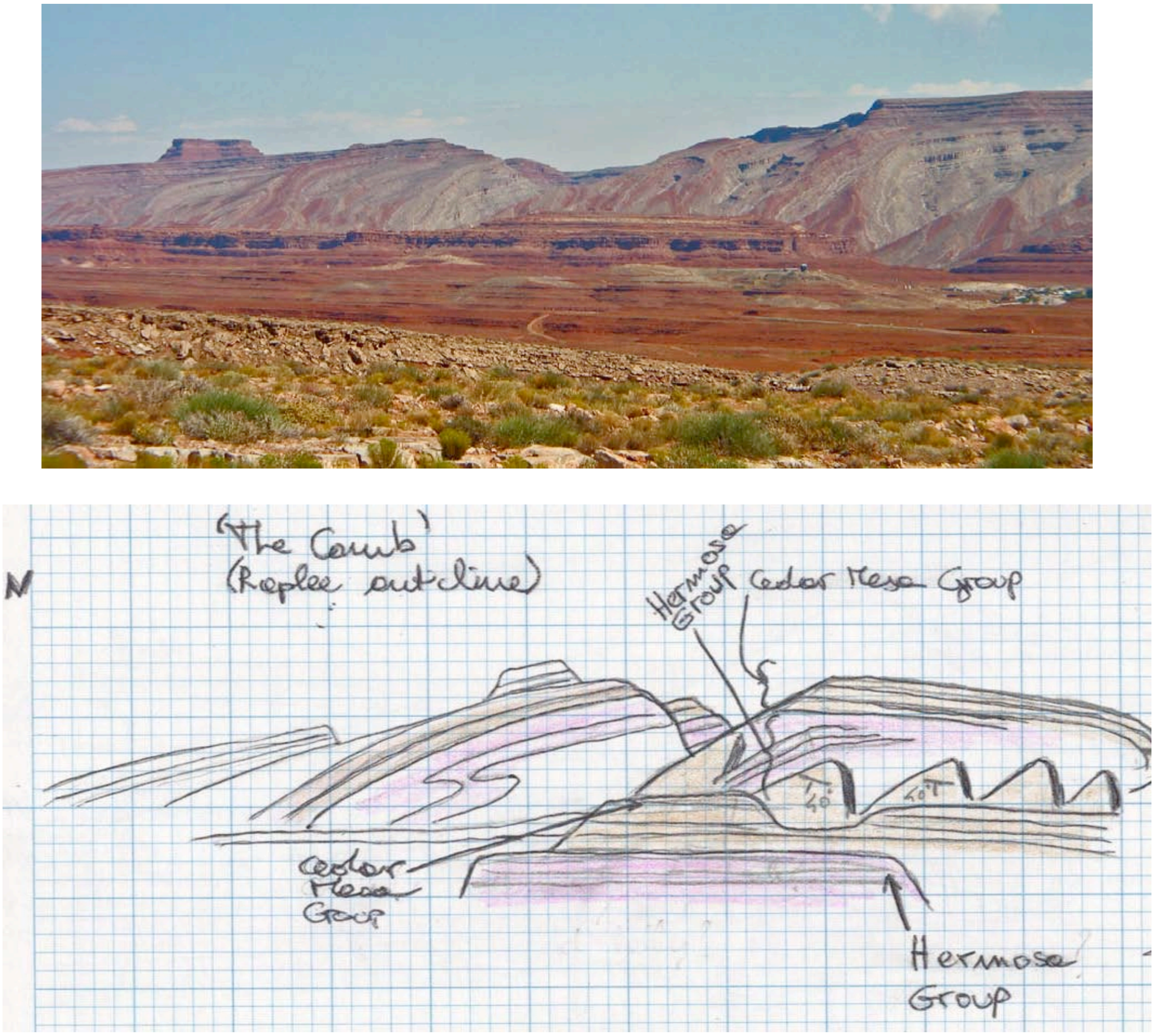


Fig. 5: Photo and sketch of the Raplee anticline, looking east.

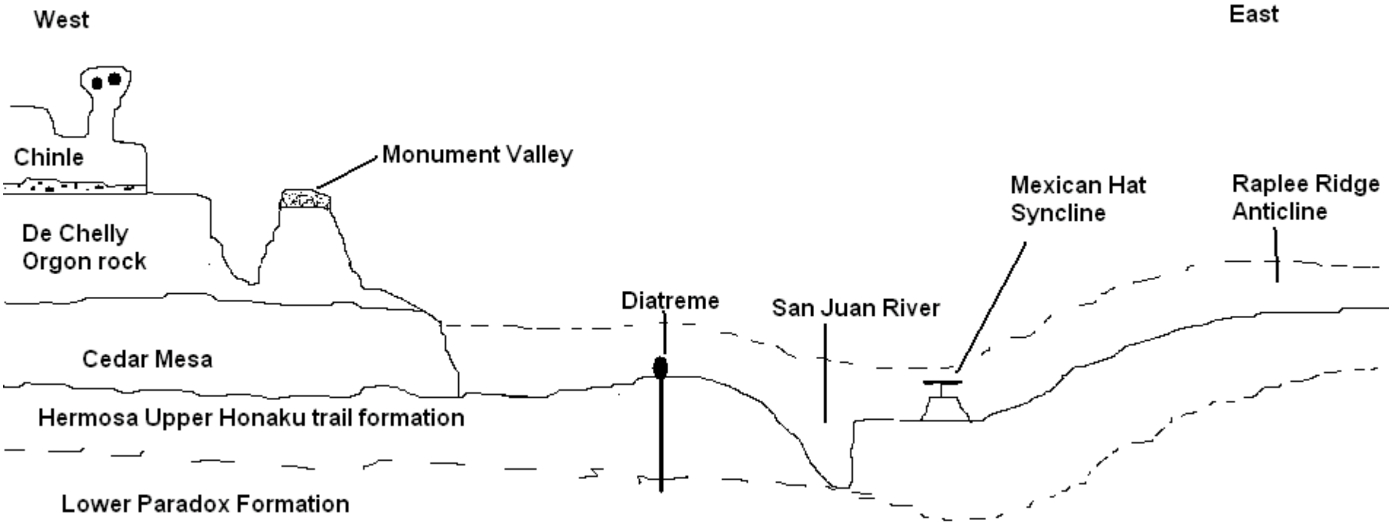
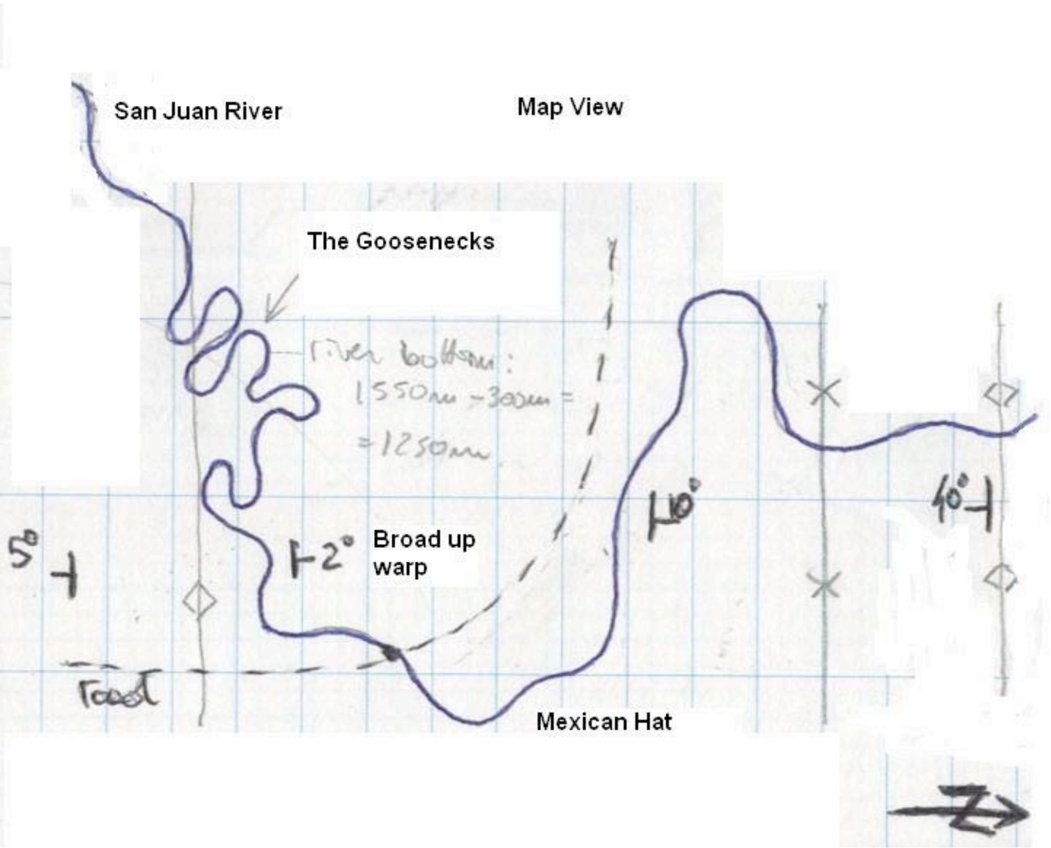


Fig. 6: stratigraphy and structure between Monument Valley and Mexican Hat.

Goosenecks, San Juan River

- **N 37°.17.46' / W 109.92.76'**
- **Elevation: 1517 m.**

Fig. 3: Photo of the Goosenecks, and map view sketch of the area.



The Comb (Raplee anticline).

- **N 37°.16' / W 105°.40'**
- **Elevation: 1344 m.**
-

View from the road towards Bluff just before crossing over The Comb itself.

From here we have a view of the cross-section of this structure. From the fact that part of the stratigraphic sequence appears to be missing and that we are in a valley in between small ridges, we can suspect the presence of a fault that lowers the Chinle-Navajo sequence with respect to the Hermosa Group.

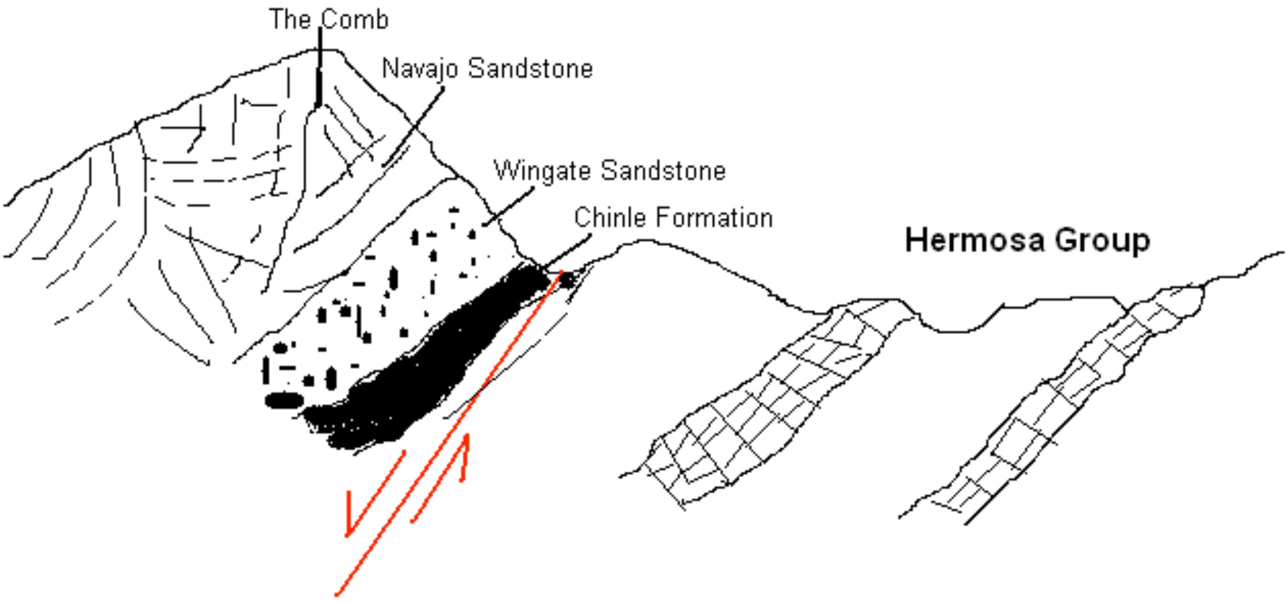


Fig. 9: Sketch showing the layout of the Comb.

Marcel Roenisch

September 21

Castle Valley, Moab fault, Arches National Park

Castle Valley

Castle Valley, Viewpoint from La Sal Mountains

- **N 38°34' / W 109°17'**
- **elevation: 2194 m**
- time: 10:30 am

The viewpoint shows Castle Valley and its stratigraphy. A few marker horizons are pretty well distinguishable. The structure is an anticline and the axis is dipping to the west. Anticlinal and synclinal structures in this region are caused by salt tectonics. The updoming of the Entrada layers in the Arches N.P. is recognizable in the far distance in view direction.

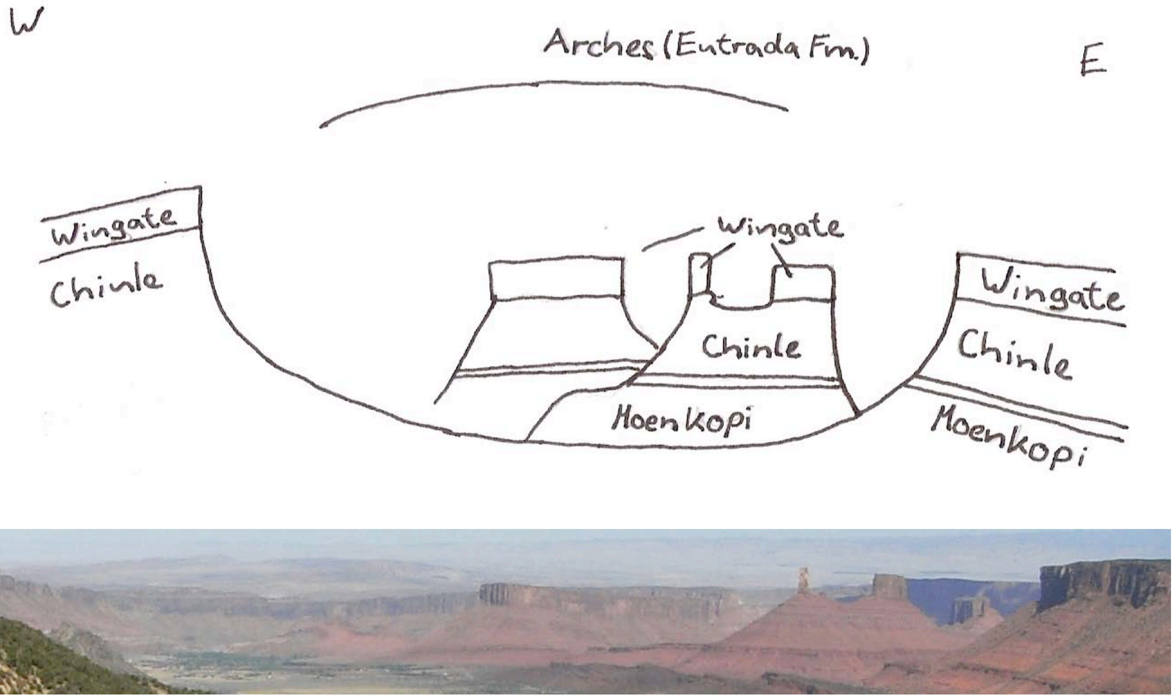


Fig. 1: Castle Valley Overview scatch and photo.

Castle Valley basement, Crossroads to Cisco

- **N 38°41' / W 109°21'**
- **elevation: 1242 m**
- time: 11:15 am

The basement consists of alternating layers of arcosic Sandstone, mudstone, gypsum and other salt carbonates. This formation belongs to the Cutler group, but due to a lateral facies change it is much thicker and changes in composition. The depositional environment was on a coastal plane with varying see level and the sediment source was close by. It could have been the ancestral Rocky Mountains in the late carboniferous.

Moab fault

Moab Valley, Arches N.P. entrance

- **N 38°37' / W 109°37'**
- **elevation: 1224 m**
- time: 02:00 pm

Salt doming in this region is accommodated by the Moab fault. The salt domes belong to the Paradox Fm. and were deposited in basins near the Ancestral Rocky Mountains. The layers in the Moab valley are thinning towards the salt structures and were deposited in different angles because the salt dome got steeper over time.

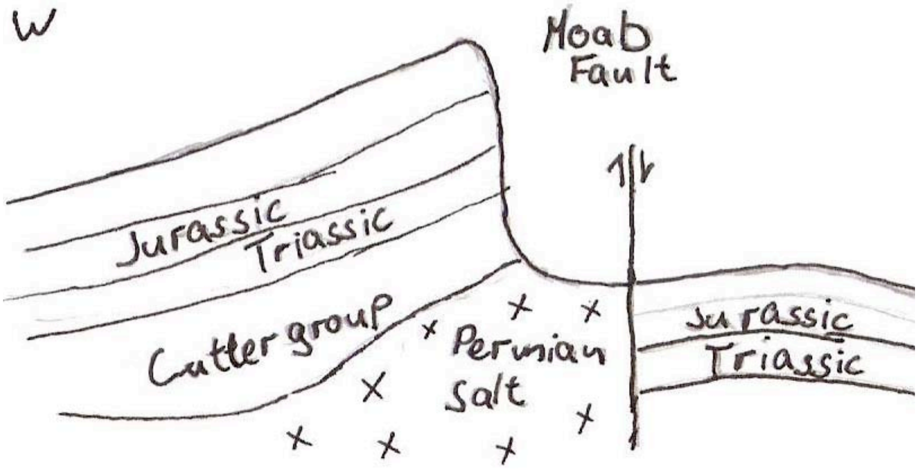


Fig. 2: Schematic crossection of Moab fault.

There is dense faulting at the Arches N.P. entrance. This area belongs to the northern Moab fault zone, where it makes a step to the east. It creates a slight listric faulting.

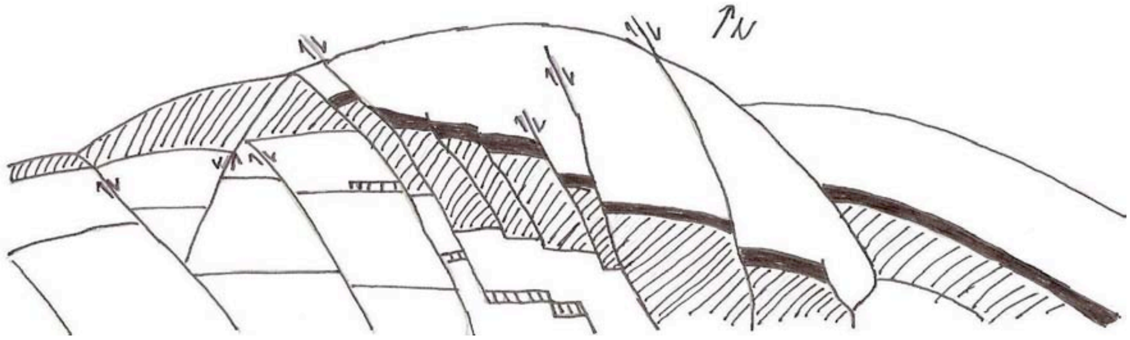


Fig. 3: Dense faulting.

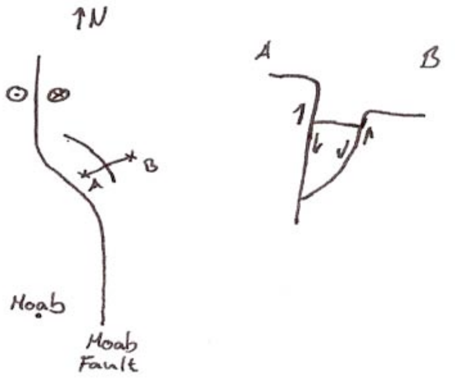


Fig. 4: Schematic map view of the Moab region and cross-section of dense faulting.

Arches National Park

Arches National Park, Salt Valley

- **N 38°42' / W 109°34'**
- **elevation: 1530 m**
- time: 03:00 pm

The salt valley was created by salt doming and erosion of the joints that formed in the layers above the dome.

Fig. 5: Salt Valley evolution.

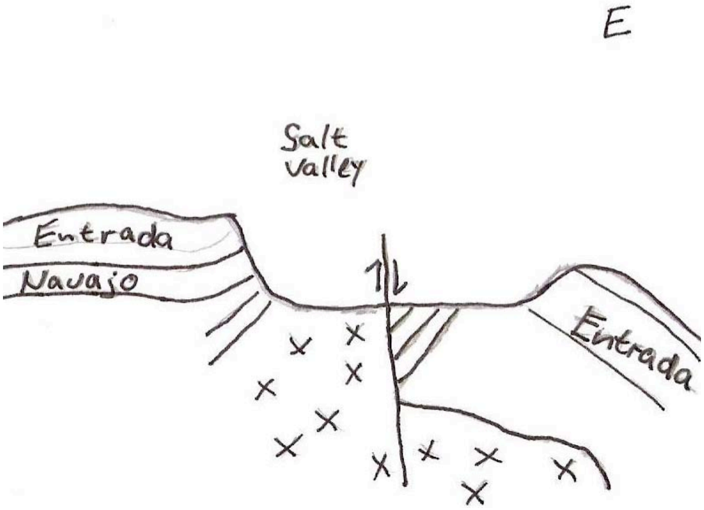


Fig. 6: schematic cross-section of Salt Valley.

Further to the north are the fin structures, which are still-standing features of the above mentioned joints and the early stages of arches.

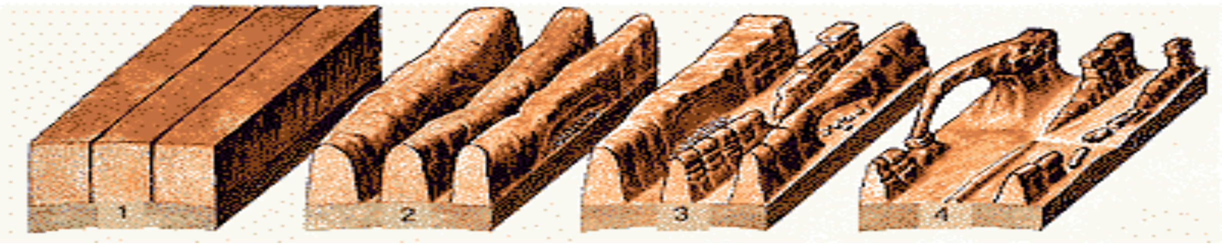


Fig. 7: Schematic evolution of joints to fins to arches.

Klaus Mayer

September 22

Goblin, San Rafael Swell, Cretaceous, Wasatch

Goblin Valley State Park

Valley of the Goblin, Viewpoint

- **N 38.57 / W 110.69**
- **elevation: 1503 m**
- 9:30 am
- weather: warm, sunny, almost clear

The State Park "Goblin Valley" in Utah is known for its numerous mushroom-shaped rock formations. These rock formations in the Entrada Sandstone result from the following processes:

After the erosion of overlying sediments, the relief of the strain caused an uplift and an orthogonal joint system developed. The measured major dip directions of the joints are 210° and 280°. A minor dip direction that can be measured is 165° These joints are zones of weakness, where further erosion and weathering could followed.

The alternating layers of shale, siltstone and sandstone are an evidence for the change in facies due to transgression and regression. The Entrada Formation deposited in the Jurassic, where there was less topography in this area and aeolian sedimentation alternated with marine sedimentation due to the west-eastward change in facies, caused by the orogeny in the west. The deposition of that time can be compared with recent processes of sedimentation in Saudi Arabia. The different sediments, that have been deposited, for example in tidal channels, or in the ebb and flow of tides, have a different resistance to weathering and erosion. The erosion of these sediments can be compared with the erosion of granite, where the edges weather faster, due to greater surface, and spherical forms develop.

That for, these "goblins", that have an average height between 1-4 m develop, when erosion-resistant layers lie above softer siltstone and sandstone.

Fig. 1: Goblins in the "Valley of the Goblins" State Park.

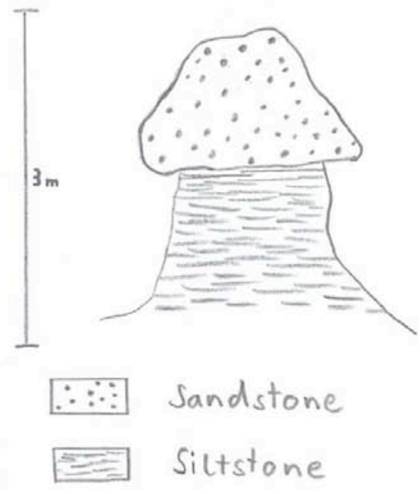


Fig. 2: Sketch of a Goblin.

San Rafael Swell

San Rafael Reef, Viewpoint

- **N 38,93 / W 110.42**
- **elevation 1370 m**
- time: 1:00 pm
- weather: warm, little cloudy, sunny

Fig. 3: San Rafael Reef, view to the south.

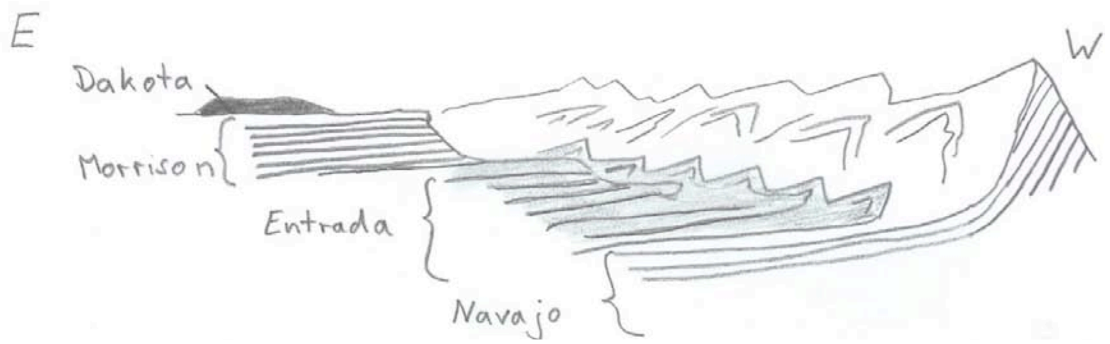


Fig. 4: Sketch of the layers of the San Rafael Reef.

Fig. 5: San Rafael Reef, view to the north.

The San Rafael Reef, as eastern edge oft the San Rafael Swell, is located northwest of "Valley of the Goblin" and part of the Colorado Plateau. The swell is a large geologic feature, an anticline, where due to the Laramide orogeny, the layers were faulted and moved upwards. In the anticline, that is steeper in the east, jurassic sediments from the Dakota Sandstone, Morrison Formation, Entrada Formation to the Navajo Sandstone are exposed and undergo erosion and weathering since that time. The age of that cliff is Eocene.

In this outcrop, the Entrada Formation consists of shale and is less resistant to weathering. The uplifted layers form so called tablelands.

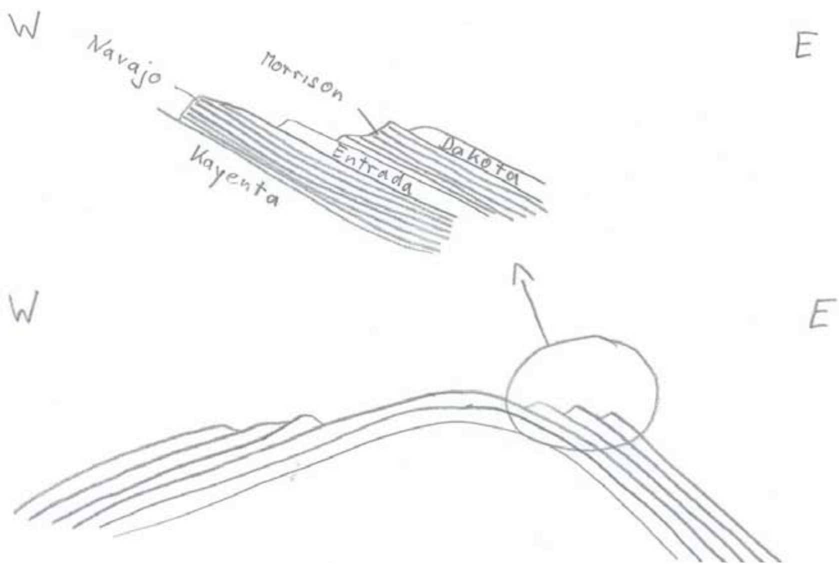


Fig. 6: Cross section trough the anticline with enlargement (above) of the San Rafael Reef.

Cretaceous

Carbon Country

- **N 39.74 / W 110.86**
- **elevation 1872 m**
- 3:20pm
- weather: warm, sunny

Fig. 7: NW dipping (~15°) alternating cretaceous layers of coal and fluvial sandstones.

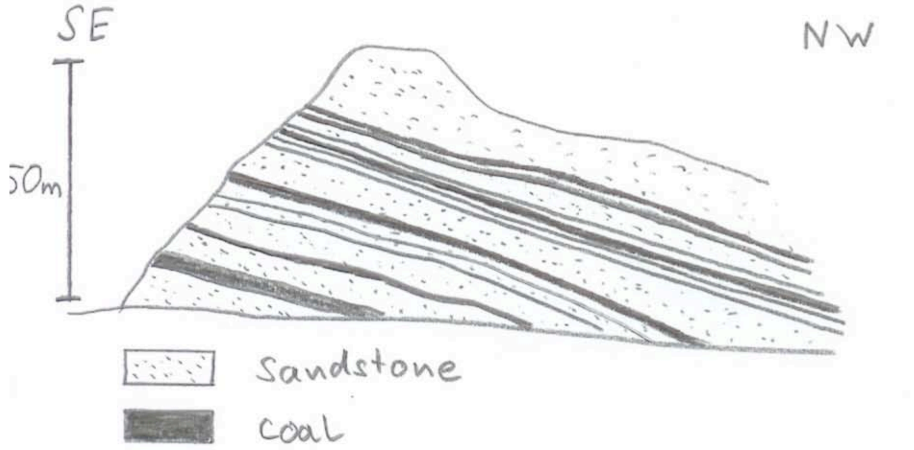


Fig. 8: Sketch of the alternating cretaceous layers.

The transition from late Cretaceous to Tertiary is characterised by a change in sedimentation from fluvial fine sands to poorly sorted coarse sands and terrestrial conglomerate. The uplift of the Colorado Plateau led to a generally northward movement of the Sevier belt foreland basin.

During the Cretaceous, this region in the northwest of the Colorado Plateau was partially under marine influence but also deposition of sediments in swampy, warm areas as well as floodplain sedimentation of fine sands and fluviatile sedimentation of old river systems. The formation of coal led to the establishment of the coal industry in Utah. Besides coal, oil as well as gas resources have their origin in the cretaceous sediments of this area. Numerous rigs are located on the way north to the city of Price.

The transition zone where these layers were deposited lies in between the Basin & Range Province in the west and the Colorado Plateau in the east.

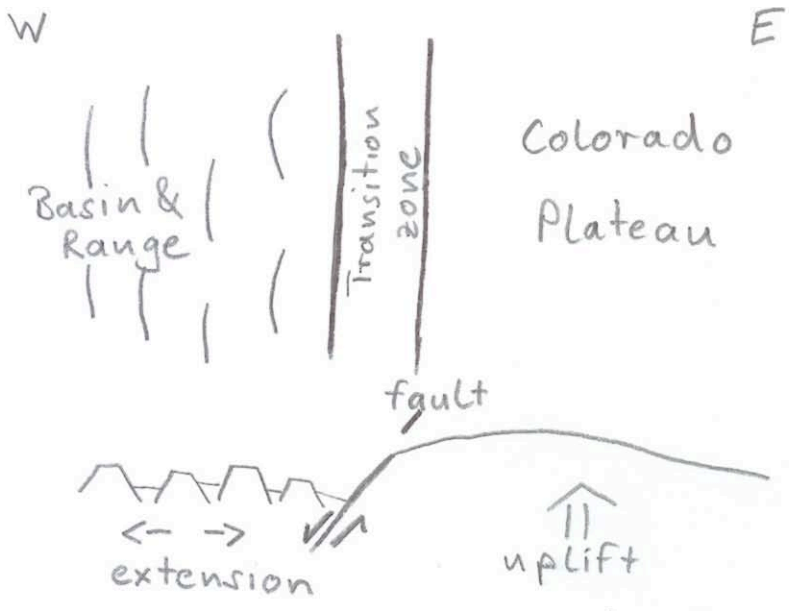


Fig. 9: View and cross section trough the southwest of the USA.

Wasatch

Wasatch hinge line

- **N 40.03 / W 111.34**
- **elevation 1479 m**
- 4:40pm
- weather: warm, little cloudy

The Wasatch fault is the north south striking, 400 km long, active normal fault, which is the hinge line between the uplifted and eroded Colorado Plateau in the east and the Basin & Range Province in the west. The offset between the hanging wall and the footwall is approximately up to 12km. The Wasatch Mountains east of the fault are tilted to the east. With an average uplift of 1mm per year, the fault has a big potential to cause earthquakes. Earthquakes even with high magnitudes, as they already occurred several times in the past.
The basin area west of the fault is filled with playa sediments of the ancient Lake Bonneville and the Salt Lake.

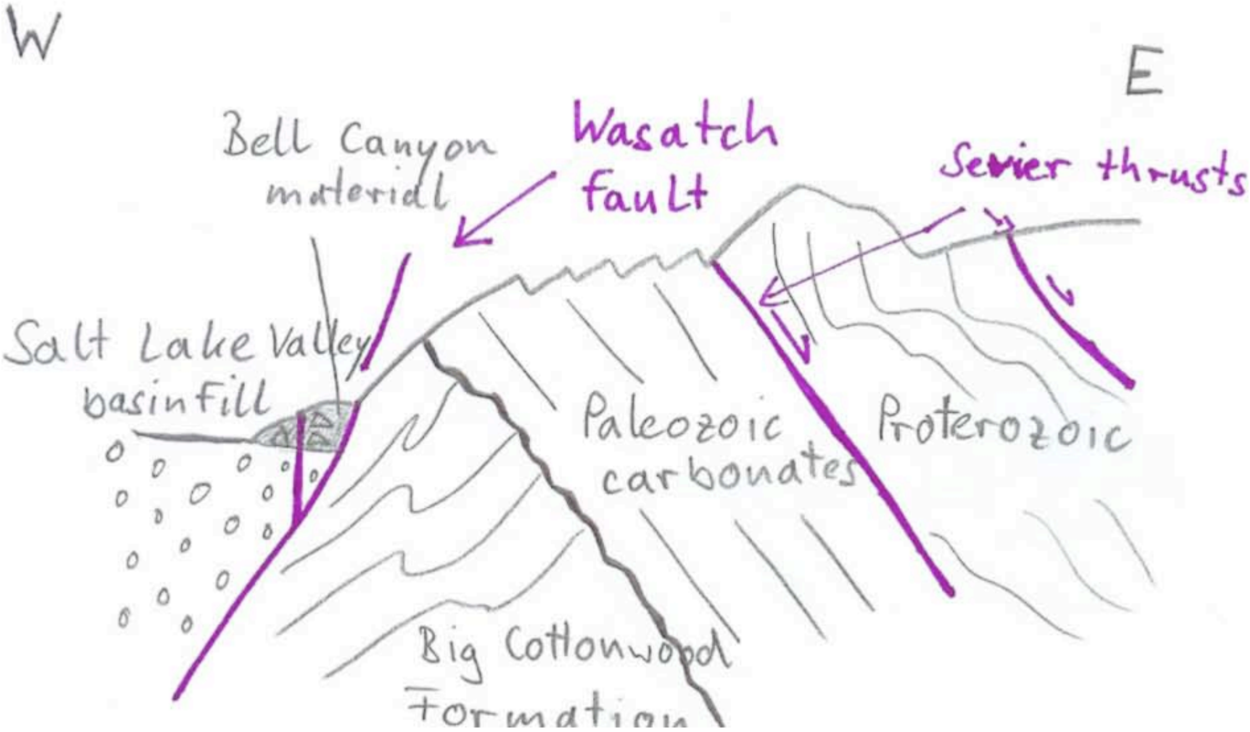


Fig. 10: Simplified cross section trough the Wasatch Fault.

University of Utah - LMU Geology Student BBQ
Salt Lake City, September 23rd, 2008

Anna Pöhlmann

September 24

Little Cottonwood Canyon, Sevier age thrust, Alta Stock, Contact Metamorphism, Bell Canyon Moraine

Stratigraphy of the Wasatch Range near Salt Lake City

Tab. 1: Stratigraphy of the Wasatch Range

Mio-/ Pliocene	Little Cottonwood Granite (30,5 Ma)	
Oligocene	volcanic tuffs and conglomerates	
Cretaceous	sandstones, siltstones, carbonates	500 m
Jurassic	Nugget Sandstone (equ. of Navajo Sandstone)	400 m
	Ankarch Formation redbeds (equ. of Chinle Formation)	150 m
	Thaynes Formation limestones, shales, bright red shale, siltstones	
Triassic	Woodsite Formation	
Permian	Carbonates	700 m
Pennsylvanian	Weber Quartzite	500 m
Mississippian	limestones, dolostones, quartzites of the Oquirrh Basin	1500 m
Devonian	carbonates and tintic quartzites	600m
Cambrian	Mutual Formation (purple red shales and quartzites)	800 m
Late Proterozoic	Mineral Fork Tillite	1000 m
	Big Cottonwood Formation (equ. of Grand Canyon Supergroup), quartzites, shales	0-5000 m
Early Proterozoic	Farmington Canyon Complex (equ. of Vishnu Shist), gneiss and shists	

Little Cottonwood Canyon

The Little Cottonwood Canyon lies approximately 20 miles south of central Salt Lake City and can be reached via the Little Cottonwood Road, which eventually leads up to the skiing resorts of Alta and Snowbird.

The canyon is a glacial trough and was formed during the last ice age (30.000 to 10.000 years ago). Near its mouth one can find the Little Cottonwood Stock, an intrusion consisting of quartz monzonite.

Viewpoint close to the Albion Point Campground

- **N 40°34' / W 111°35'**
- **elevation: 2845 m**

The viewpoint lies approximately 10 miles up the road in the Little Cottonwood Canyon next to the skiing resort Alta.

The exercise is to sketch the view towards the NW (see Fig. 1 and 2).

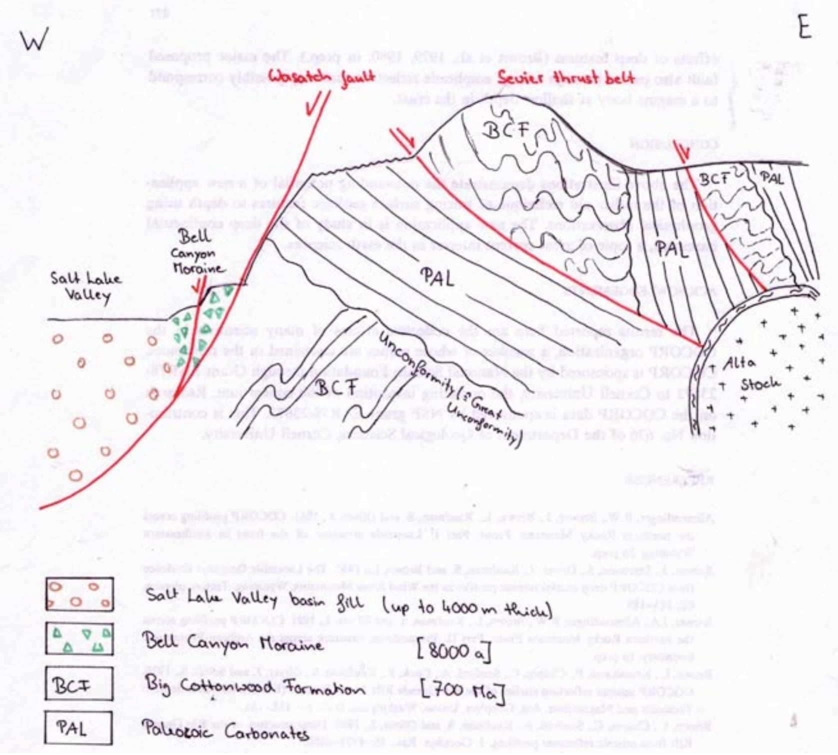


Fig. 1: Simplified sketch in NW' direction.

Fig. 2: Picture, taken in NW' direction, compare to Fig. 1.

The Sevier Orogeny (late Cretaceous to early Tertiary) results in a thrust belt where the western plate is subducted under the eastern plate. The beds generally dip to the NW, but some blocks close to the Wasatch fault are tilted backwards and therefore dip to the East.

Tectonic development

We then try to get a bigger picture of the tectonic setting of SW-USA over time.

The Paleozoic setting (deep sea –shelf–craton environment) results in varying thicknesses of the deposited sediments with estimated 1000 m on the craton, 3000 m at the shelf area and up to 12.000 m in the deep sea (see Fig. 3).

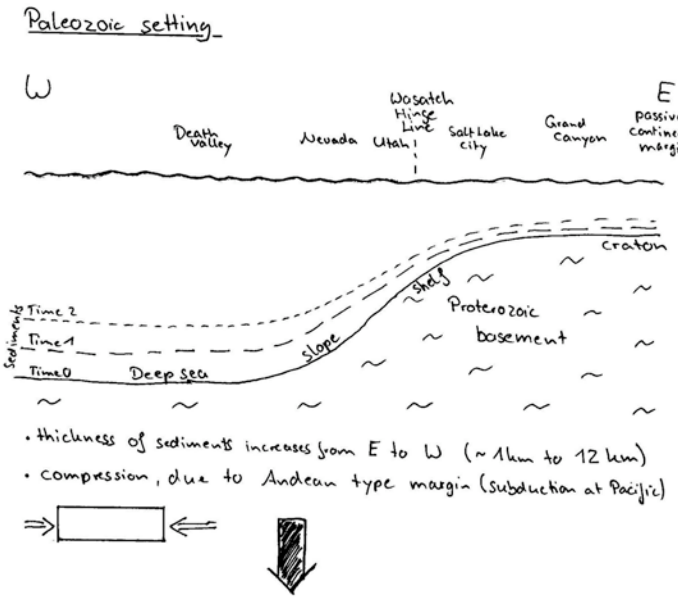


Fig. 3: Paleozoic setting of SW-USA.

The development of an Andean type margin leads to compression and a completely different Cretaceous setting (see fig. 4).

The Sevier-style deformation west of the Wasatch Hinge Line is a classical foreland fold-and-thrust belt. The orogeny is sediment-controlled and called a thin skinned deformation. East of the Wasatch Hinge Line on the contrary there is Laramide style deformation (see Fig. 5).

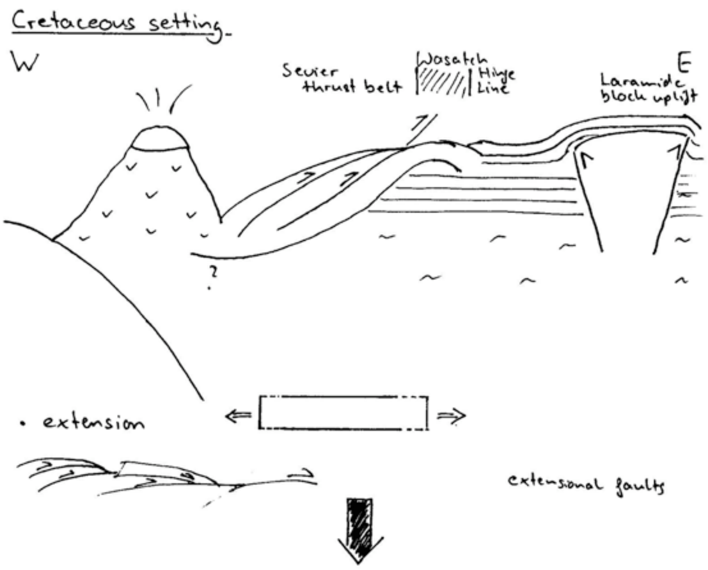


Fig. 4: Cretaceous setting of SW-USA.

It can be described as a block uplift (due to compressional forces) and occurs when thrusting is not possible. The orogeny is therefore basement controlled with only a thin sediment cover and is called a thick skinned deformation. Examples of the Laramide style deformation are the East Kaibab Monocline and several other monoclines on the Colorado Plateau.

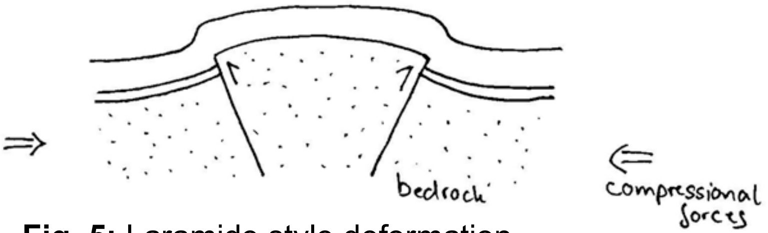


Fig. 5: Laramide style deformation.

Following the compression extensional forces started to work in the Tertiary (Oligocene, 36 Ma) and resulted in a setting active until now.

The transition zone between the Basin-and-Range Province (passive margin, shelf) and the Colorado Plateau (craton) is called the Wasatch Hinge Line. It is the frontal most Sevier thrust and therefore the eastern most normal fault.

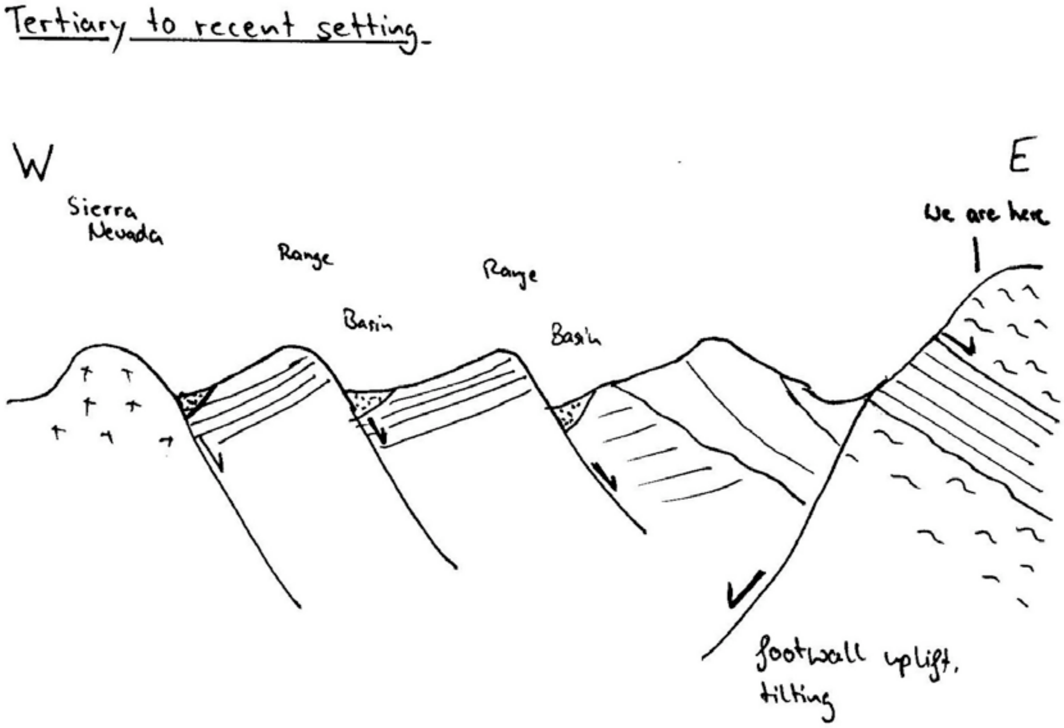


Fig. 6: Tertiary to recent setting of SW-USA.

The basins, also called playas, are filled with quaternary sediments from the lakes. They develop along the extensional faults.

Contact metamorphism of the Alta Stock

- **N 40°35’ / W 111°37’**
- **elevation 2945 m**

After the viewpoint stop we made a short hike in a western direction up the mountain slope to get a closer look at the contact metamorphic aureole of the Alta Stock. The Alta stock is a Tertiary (~38 Ma) granodiorite that intruded into Paleozoic dolostone and produced a well-defined, first-class example of an aureole. The minerals include talc, tremolite, forsterite and periclase and also borate minerals in skarn deposits around the stock. In the skarns and marbles one can find also minerals like forsterite, malachite, diopside, phlogopite and brucite.

On the walk we first pass a light grey, granitic rock with a high percentage of quartz and Biotite and little pyroxene. On some of the fissures assemblages of big (up to 1 cm) amphiboles (probably Hornblende) were found. Further up the path the rocks change to whitish-grey granulite that contains garnets and the layering of elongated minerals (micas) indicates a small degree of metamorphism. It is intercepted by layers of a dark, very fine grained rock (probably Hornfels).

Bell Canyon Moraine

Road 210, S Wasatch Blvd, along the Wasatch Mountain front

Approximately 2 miles north of the Little Cottonwood Canyon we make a short road-side stop to take a look at the Bell Canyon and the Cottonwood Moraine. The later is smaller and has an age of 14.000 years. It covers sediments from the Lake Bonneville Highstand and therefore has to be younger. The Bell Canyon Moraine is bigger and is offset by a younger fault with a maximum displacement of 14 m. The radio carbon dating of the offset soils gives an age of 8000 years.

Fig. 7: Bell Canyon Moraine with the offset clearly visible in the middle of the picture.

Laura Wagenknecht

September 24/25

Basin and Range, Lake Bonneville, Salt Flats

Basin and Range

The Basin and Range extension started in the Oligocene, 36 Ma ago. The basins correspond to playas and are filled with quaternary lake sediments. The ranges are Graben and Halfgraben structures, which developed on normal faults. The structures are back tilting with about 20-40° but even overtilting is possible. Some of them contain still active faults.

Development of Basin and Range

Palaeozoic

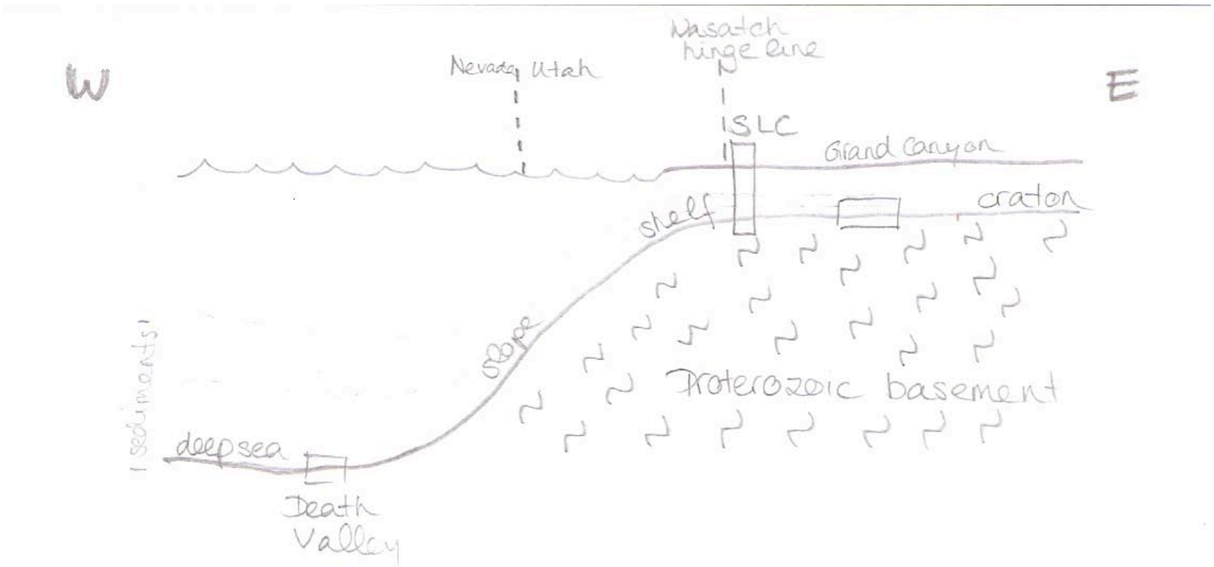


Fig. 1: Thickness of sediments increase from East to West.

Cretaceous

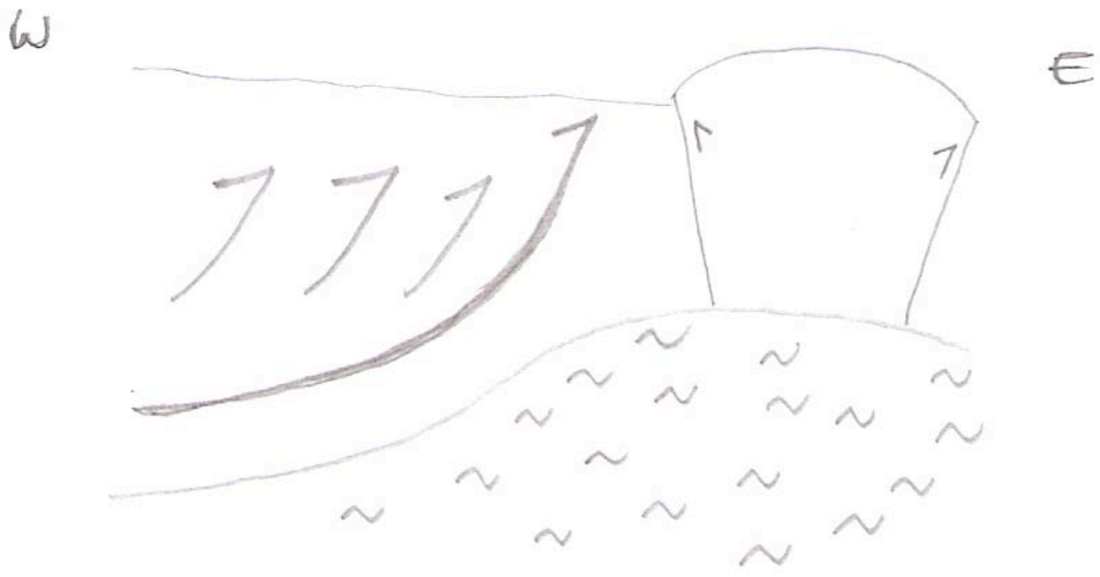


Fig. 2: Sevier style: thin skinned foreland – fold and thrust style (east).
Laramide style: thick skinned (west).

Tertiary

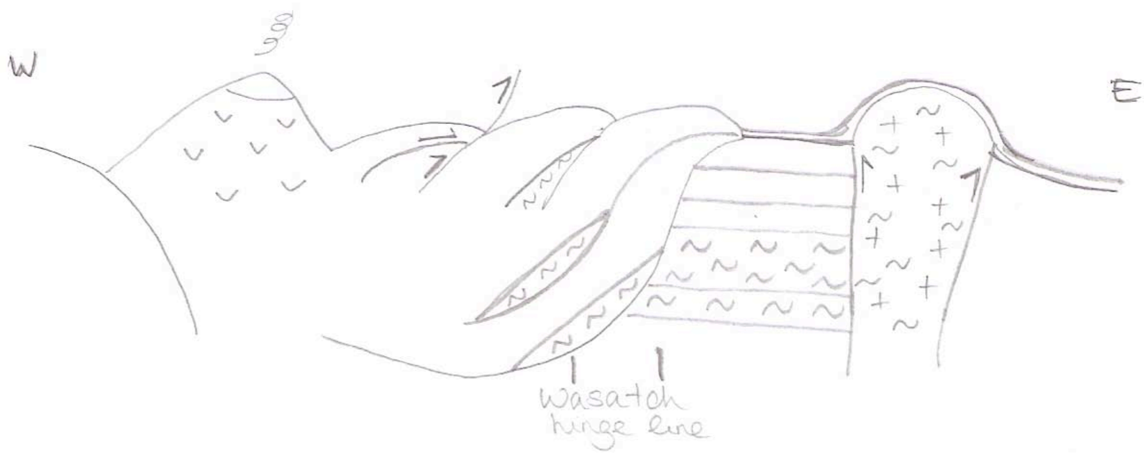


Fig. 3: Wasatch Hinge Line:

1. Transition zone between craton and passive margin shelf
2. Wasatch Hinge Line separates the Sevier thrust belt in the west and the Laramide style uplift in the east
3. Transition zone, Colorado Plateau/ Basin and Range correspond to eastern most normal fault

Tertiary to recent settings

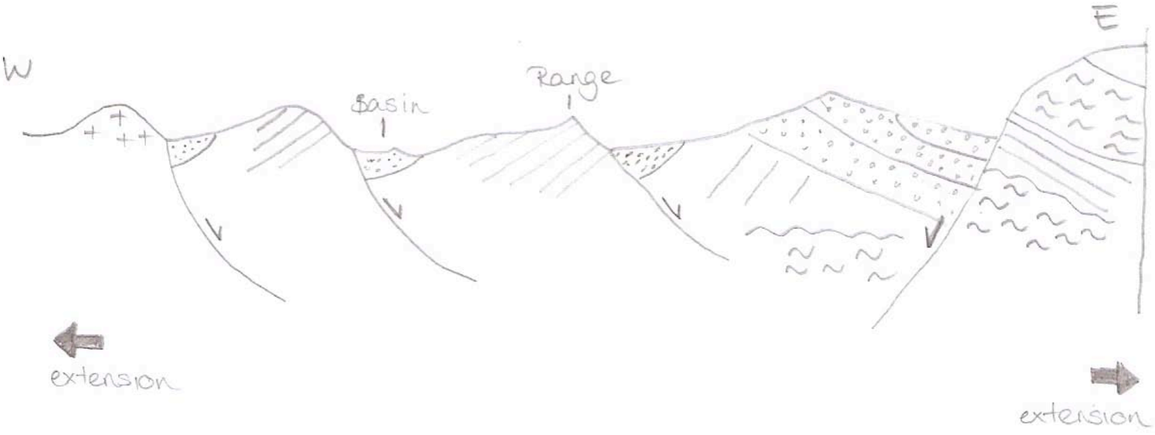


Fig. 4: Gravitational collapse: the over thickened crust got chopped up (comparison to Tibet).

Contact of tertiary granite with proterozoic carbonatic silicates

- **N 40° 35' / W 111°37'**
- **elevation: 2945m**
- Contact metamorphoses
- Granite: light grey colour, high concentration of quartz, low concentration of pyroxene
- Carbonatic silicate: black colour, content of biotite, pyroxene and feldspar.

Cottonwood moraine

- Alongside Wasatch Hinge line
- 14000 years old (younger than lake Bonneville highstand)
- There is a young fault through the moraine. The offset averages at its maximum 14m. It seems to be a young fault.
- The same displacement is present in a terrace further down.
- Radiocarbon dating got the age of the offset, which is 8000 years.

Lake Bonneville/ Salt flats

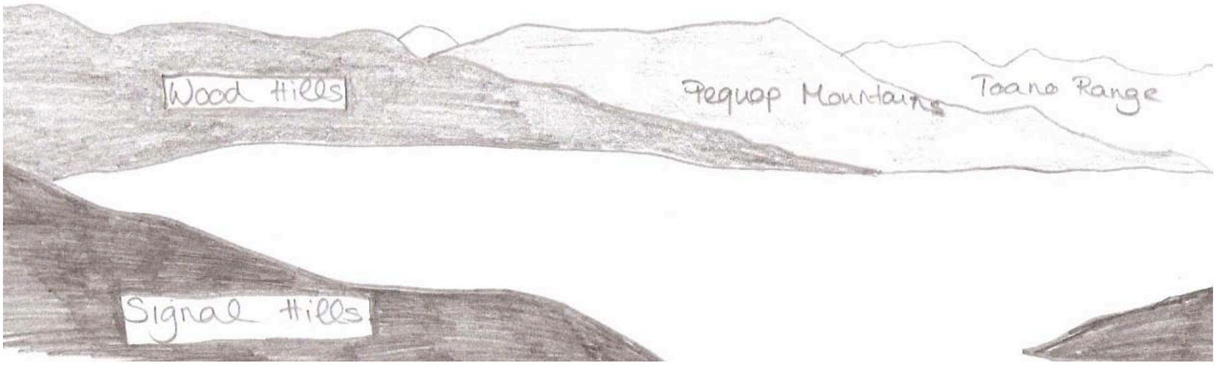
Lake Bonneville is an Pleistocene lake. The lake Bonneville highstand was 17000 years ago and was 113m higher than today's lake level.

The lake left huge salt flats. But not all the water left the lake by evaporation. Some of the water spilled out of the lake during the natural dam break at the Redrock-Pass in the north.

<u>Viewpoint at Angel's Creek Campground, westward of Wells</u>

- **N 41° 02' / W 115° 03'**
- **elevation: 2060m**
- East Humboldt Range

The ranges are running in multi-plane north-south. Between the ranges, in the flats, fans deltas, playa sediments and salt flats are located. The ranges consist mostly of Palaeozoic bedrock.



Laure Hoeppli

September 25/26

Basin and Range 2, Crescent Valley, Wells Earthquake

Basin and Range 2

View point at Angel Creek campsite

- **N 41° 02' / W 115° 03'**
- **elevation: 2060 m**
- time: 10:00 am
- weather: sunny and warm

Why is the Great Salt Lake salty?

The water flows in the lake but cannot get out. Because of the arid climate in this region, the evaporation is high and it doesn't rain much. So the water evaporates and the salt concentration in the lake increases and the water is saturated with salt.

Basin & Range

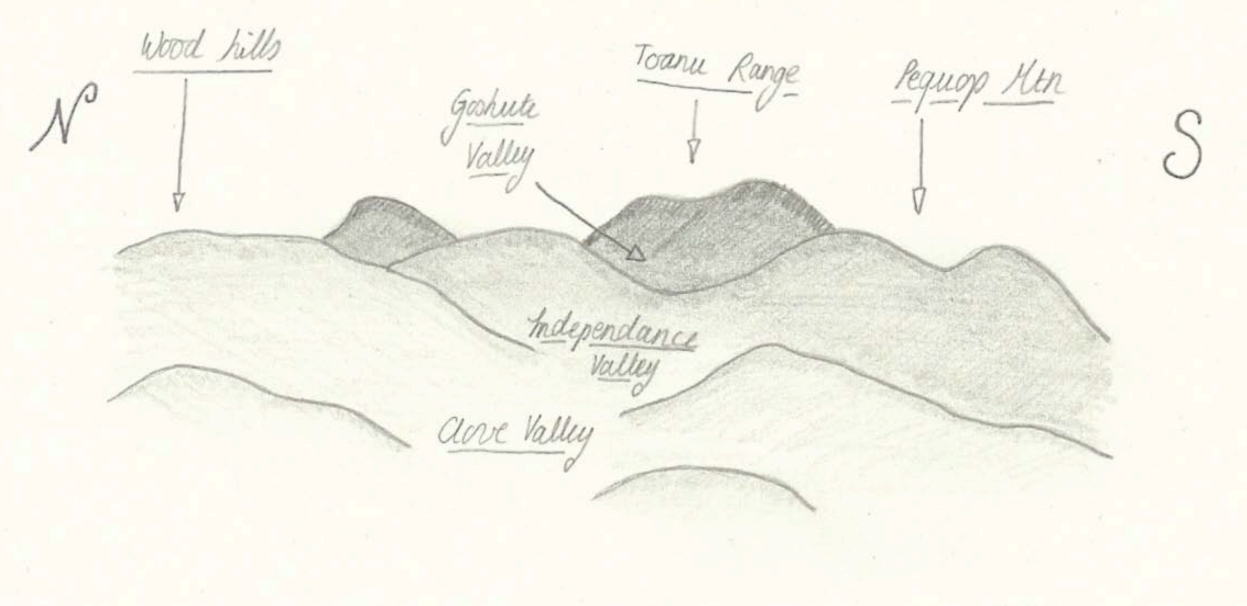


Fig. 1: The Basin and Range from Angel Creeks view point. We can see five different ranges and also basins.

The ranges are elongated hills following a N-S direction. They are composed of either tertiary volcanic rocks or a combination of Ordovician and Silurian rocks. The basins are filled with various sediments (alluvial fans, deltas, playas, salt) arriving from the ranges.

We can find various earths' precious minerals in the Nevada part of this province, like gold, silver and oil.

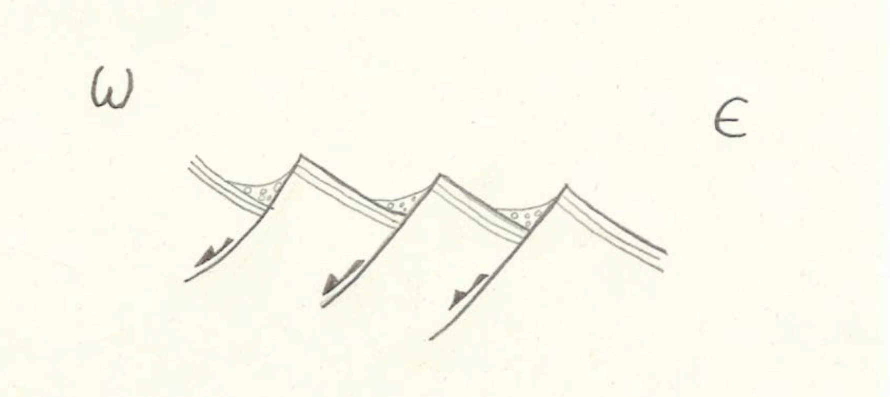


Fig. 2: Profile of the Basin and Range province. The basins will be filled up with the material eroded from the ranges.

Three prominent lake levels in this area: Lake Bonneville was for 17000 years about 4240 feet above today's lake level and for 14000 years when the dam broke, Lake Gilbert for 11000 years with 4250 feet above today's level.

Crescent Valley

Fig. 3: Playa, alluvial fans and triangular facets on a range in Hot spring, Crescent valley.

View point at Hot springs, east of Crescent Valley

- **small road east of Crescent Valley, on McDaniel Ave., Nevada**
- **N 4°24´ / W 116°30´**
- elevation: 1450 m
- time: 1:00 pm
- weather: sunny and warm

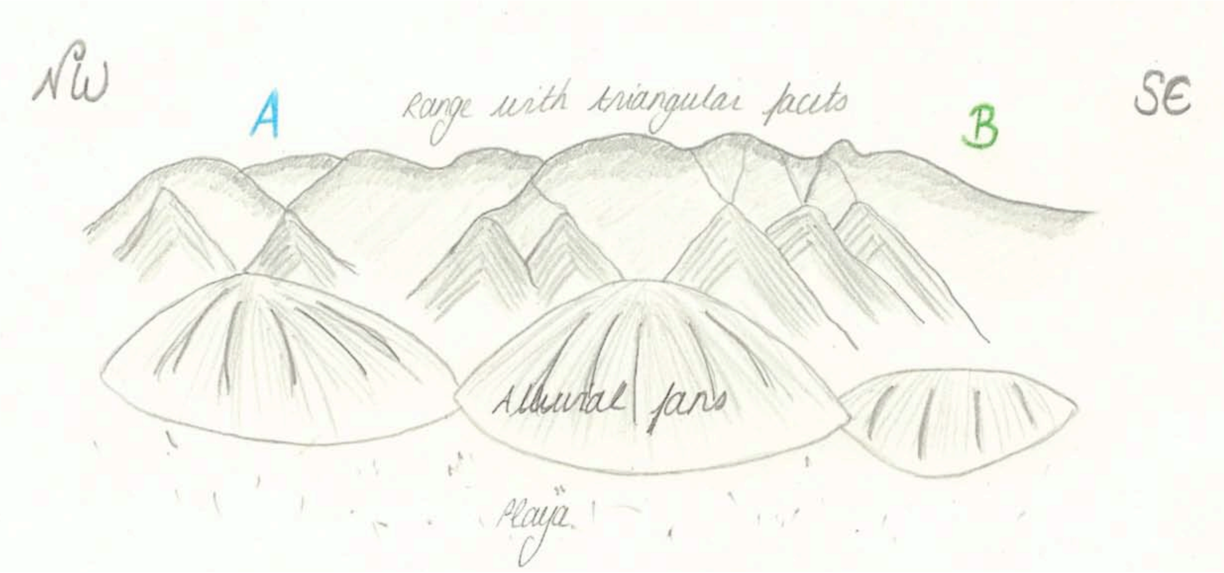


Fig. 4: View of the Cortez Mountains from the Hot Spring view point with the different erosions and sedimentations type in a basin/range pair.

The range of the Cortez Mountains has the same structures like all ranges. The erosion in those arid regions occurs because of the wind and water. It is hard to imagine enough water in those deserts plains to erode something. But because of the aridity of the climate, when it's raining, the water is not absorbed by the soil but stays on the surface and flows over everything. It is the same mechanism that created canyons in Arizona. The eroded material flows downhill in form of alluvial fans that extend to a large or a small surface, depending on the type of material eroded. In the basin there is a playa. A playa is a temporary lake formed because of a flash flood. The sediments are fine-grained and can form cracked-mud or tepee when the salt concentration is high.

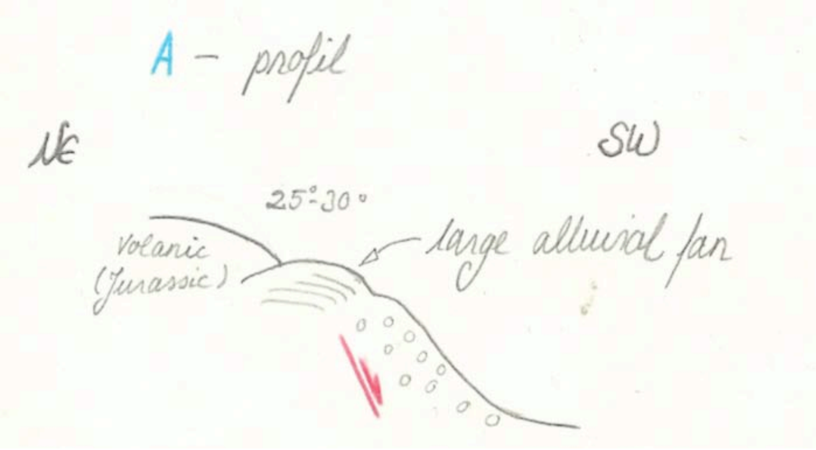


Fig. 5: Alluvial fan of the Cortez Mountains. Here volcanic rocks are eroded. Because of the softness of those rocks, the alluvial fan is large and the angle between the range and the alluvial fan is low.

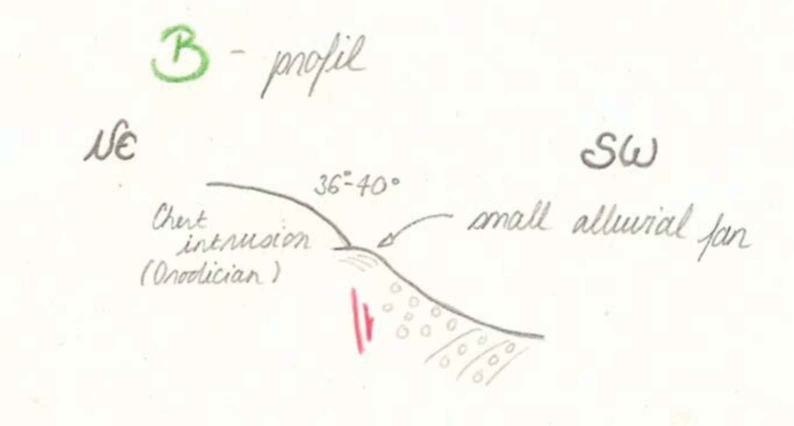


Fig. 6: Alluvial fan of the Cortez Mountains. Here chert intrusions are eroded. Because of the hardness of those rocks, the alluvial fan is small.

The bigger alluvial fans are made of vulcanite and the smaller one of chert intrusions. Of course, time plays also a role in the size of the alluvial fans.

The angle between the range and the alluvial fan is also influenced by the rock type composing the range. When there is more erodible material, the sinuosity of the flow of the alluvial fan is also high. So the alluvial fan will flow further in the basin.

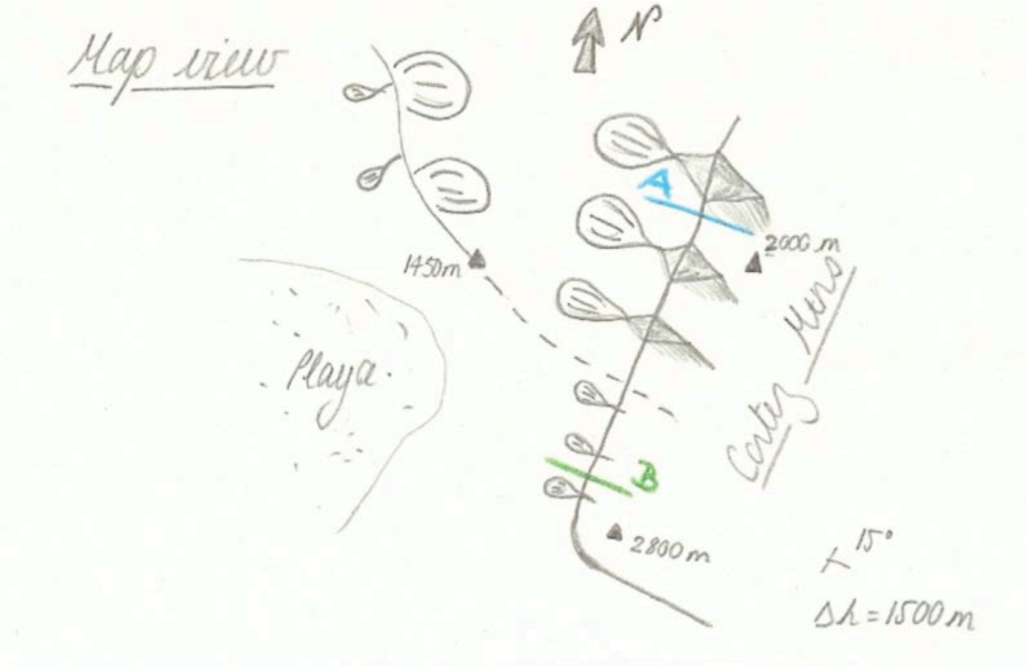
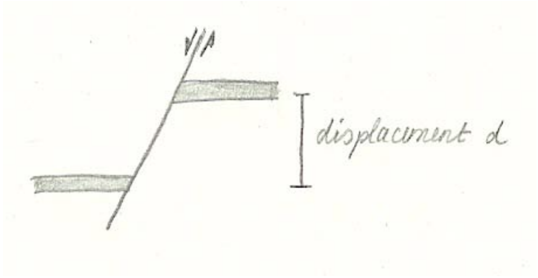


Fig. 7: Map view of the Hot spring province. The Hot springs are on the point with 1450m. The sketch demonstrates the difference of rocks in the Cortez Mountains

range and also the different types of sedimentations in the basin (triangular facets, large and small alluvial fans and playa).

Rule of thumb:
Sediment deposition due to the gravity.



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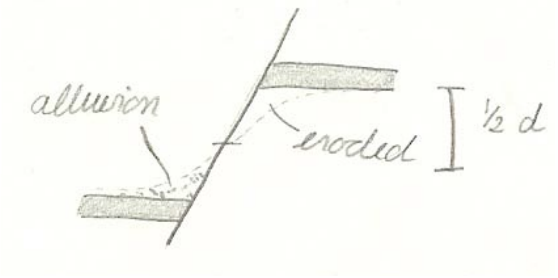

Fig. 8: Displacement on a range because of a normal fault.

Fig. 9: After time, the area of the displacement will be eroded and produce an alluvial fan down.

Fourmile Canyon entrance

- **Cortez Mountain, near the old gold mine. Arriving trough a dirt road not on the map.**
- time: 4:00 pm
- weather: sunny and warm

Alluvial fan is an offset and is eroded by a younger fluvial system that created a alluvial / fluvial scarp (from Pleistocene). The fault scarp is very steep with 45° dip.

Fig. 10: View of the alluvial fans on the entrance of Fourmile Canyon.

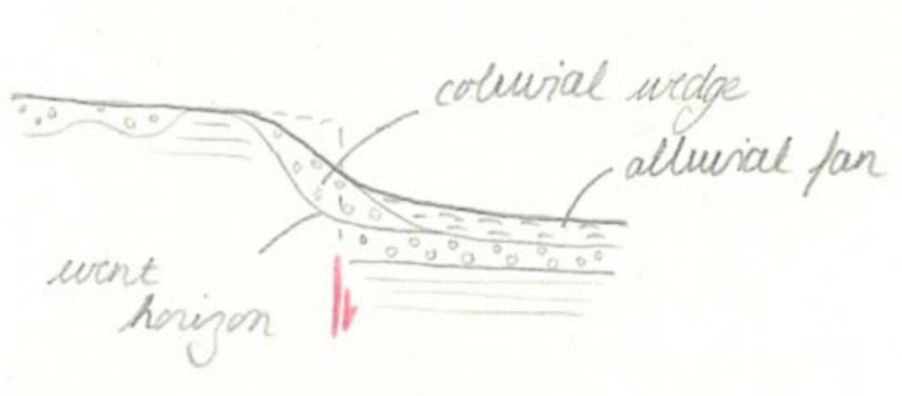

Fig. 11: Colluvial wedge at the entrance of Fourmile Canyon.

A colluvial wedge is a triangle of sediments deposited at the bottom of a low-grade slope.

The colluvial sediments are transported by gravity and the alluvial sediments by water. So they are frequently found together.

An event horizon is the scar of an event that happened in this area. It can be a fire, an overflow in a flash flood or an earthquake. The erosion due to this event cut the older layers and let after him a different morphology. An event horizon helps to prove that a big catastrophe happened on that place. We also can find out when it happened.

Fig. 12: New and old alluvial fans at the entrance of Fourmile canyon.

Wells Earthquake

Fig. 13: The old town of Wells destroyed by an earthquake on February 2008, the 21st with a magnitude of 6.0 on the Richter scale.

Which side of the valley is an active fault?

An active fault is a fault that had an activity in a recent period of time. In the Basin and Range province, it can be recognized because of the morphology of the ranges.

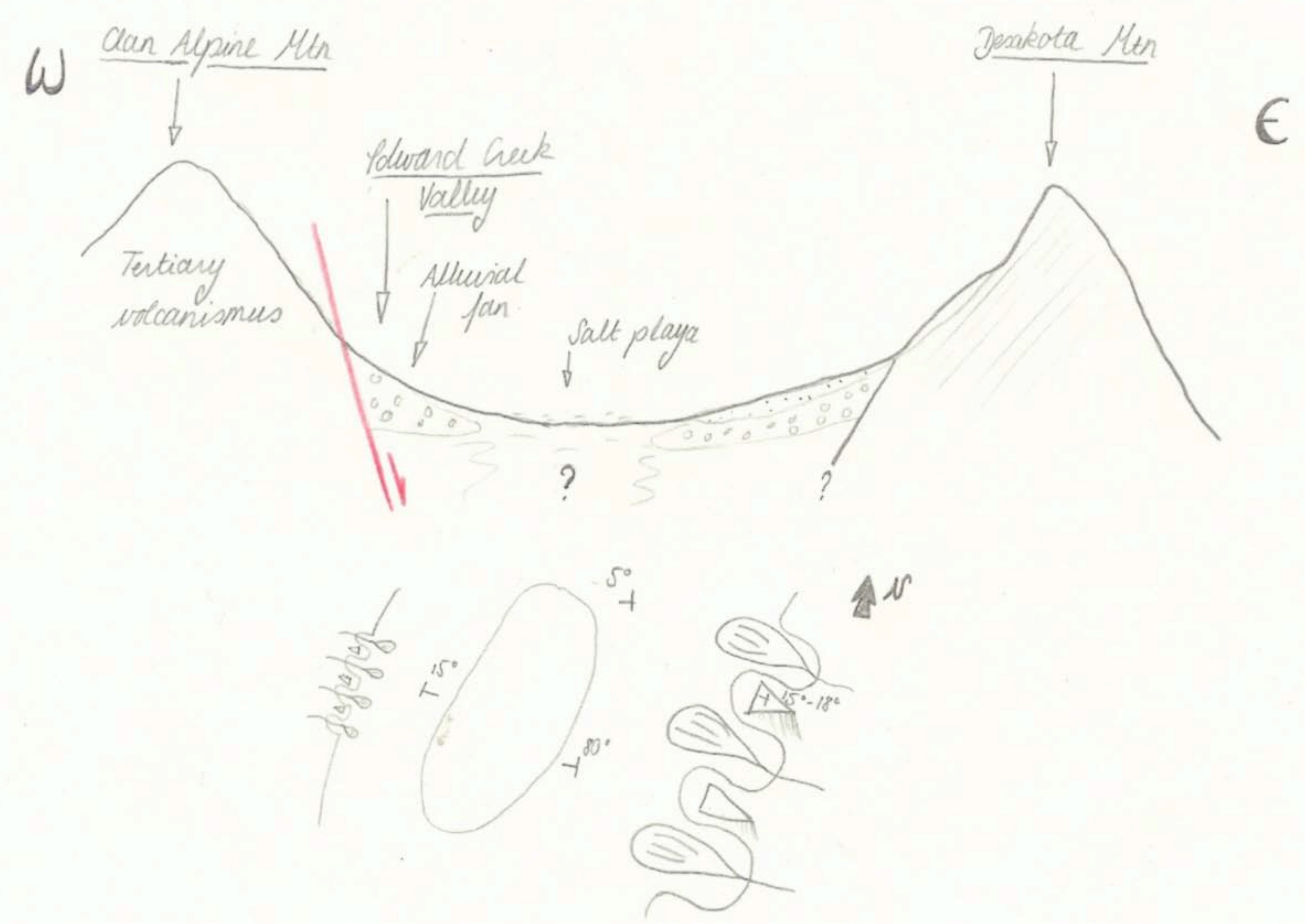

Fig. 14: Profile and map view of the Edward Creek Valley. The active fault is drawn in red.

Earthquake fault

- **On the loneliest road (Hwy 50), Fairview peak, Nevada.**
- **N 39° 17' / W 118° 07'**
- **elevation: 1385 m**
- time: 1:00 pm
- weather: sunny and warm

Earthquake in December 1954 with a magnitude of 7.3 on the Richter scale. Due to the arid climate, the erosion is limited so the fault scarp is always visible.

A fire occurred in 2001 and created an event horizon in this area because the burned soil is easy to recognize.

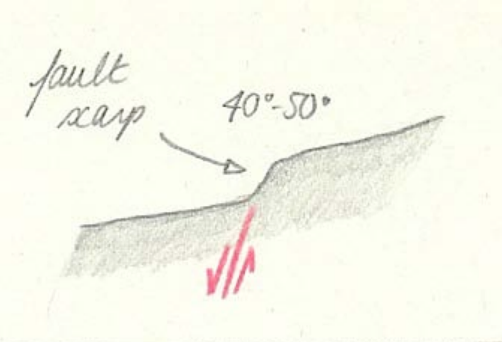

Fig. 15: The fault scarp and the normal fault of the earthquake of December 1954.

Fig.16: The fault scarp of the earthquake of December 1954.

Measurements on the earthquake fault

- **N 39° 13' / W 118° 08'**
- **elevation: 1982 m**

The age of the event is known. In those cases when it isn't, it can be determined by dating coal from fires.

The fault is a straight surface but traverse a complex topography, therefore the fault trace is not straight. It is thought that this fault is listric.

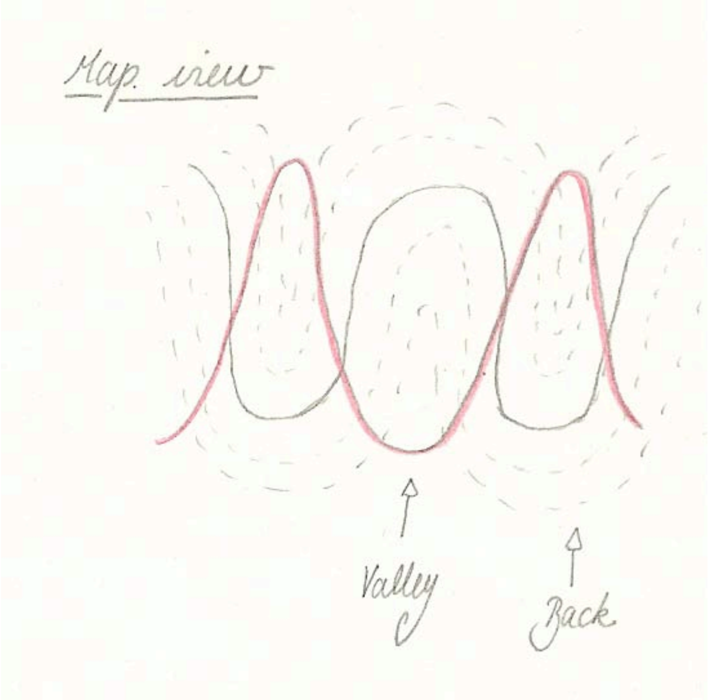

Fig. 17: The fault (in red) due to the earthquake of December 1954 is cutting a complex topography (in grey) in the mountains.

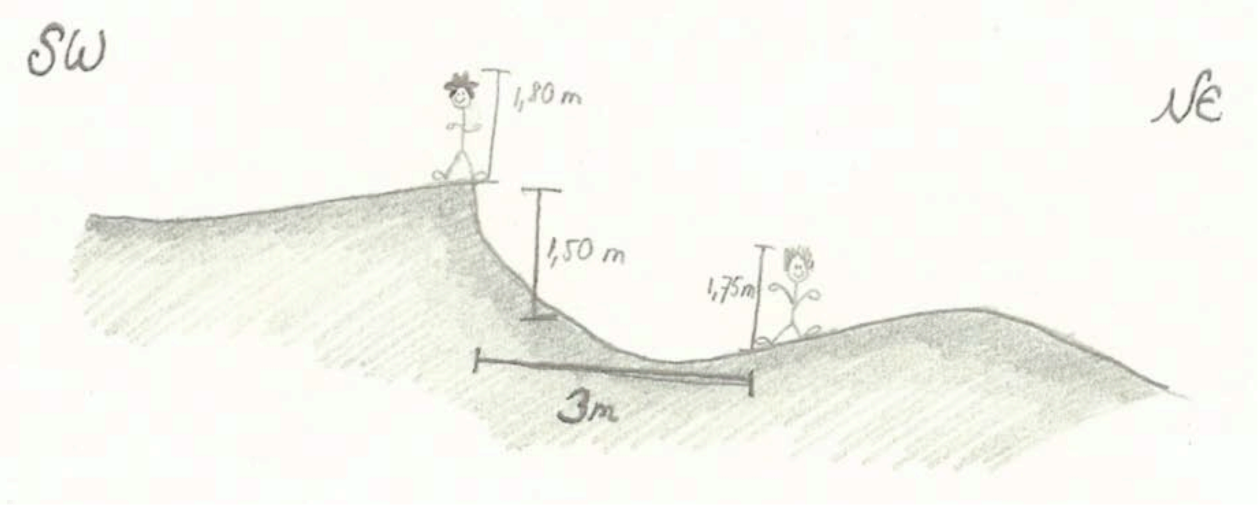

Fig. 18: Exercise of tectonic. Measurements of the fault scarp.

Calculation the offset

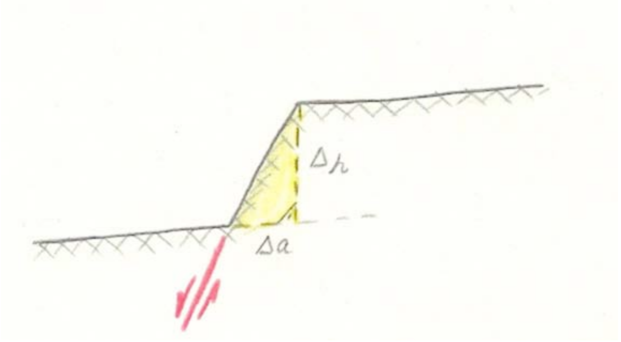

Fig. 19: Offset on the fault scarp.

From Pythagoras: $\boxed{Offset = \sqrt{\Delta h^2 + \Delta a^2}}$

Katharina Aubele

September 27

Austin, Middlegate, Fairview Peak

Austin

- **N39° 29' 30.74'' / W117° 04' 12.67''**
- **elevation: 2008 m**

We spent the night of September 26 in the former mining town of Austin, NV. As one of the few former mining towns, Austin has managed to survive, mainly on tourism. We did not discuss geological issues here.

Middlegate

- **N 39° 24' 48.03'' / W118° 39' 20.36''**
- **elevation: 1190 m**

After having spent the night in Pony Canyon Motel, Austin, we headed further south on the interstate I-50 to Middlegate. At the Ponyrail Pass Station in Middlegate, we had a historical stop and talked about the tertiary volcanics that cover the area. As these volcanics form a quite thick section, our assumption is that since they have been deposited, there presumably was only minor extension going on along the faults in this area. Otherwise, much more of the volcanic deposits would have been subject to erosion due to the relative uplift of the footwall parts of the faults.

List of unclear issues:

- How thick is the volcanic section?
- What is the exact composition of the volcanics?
- Is it possible to derive the source of the volcanics?
- Have the volcanics be dated? Is there a more precise age, than "tertiary" and how have they been dated?

Edward Creek Valley

From Middlegate, we made our way through Edward Creek Valley, which we crossed from north to south. The assignment was to determine which side of the valley showed stronger and/or more recent fault activity. The criteria that we used to make a first order statement were (1) visibility of triangular facets along the foot of the valley-bordering mountain ranges, (2) size of alluvial fans that had been shed from the ranges and degree of interfingering between the fans, (3) visible fault scarps, (4) topography on either side of the valley.

Along the way through the valley, we came to the conclusion, that in the northern part, the fault on the western side of Edward Creek Valley was more active than the eastern fault. Several arguments lead to this assumption: (1) there were more and more pronounced triangular facets on the western side and they also seemed to be more aligned than the ones on the eastern side of the valley, (2) the alluvial fans were smaller on the western side than on the eastern side as far as the northern part of the valley is concerned, (3) according to the map, the highest peak along the range on the western side is 300ft higher in elevation than the highest peak along the eastern range.

Farther to the south, it seemed like fault activity would jump from the western to the eastern side of Edward Creek Valley, again this assumption is based on the above mentioned criteria.

For further explanation, see Appendix, figures 1.1 and 1.2.

List of unclear issues:

- How high are erosion rates in the valley?
- How high are the precipitation rates in the area?
- Where would one look for dateable material to date an event horizon?
- When was the last earthquake event along one of the faults?
- How could that event be dated?

Fairview Peak

- **N39° 13' 29.80'' / W118° 09' 10.46''**
- **elevation: 2520 m**

From Edward Creek Valley, we continued to Fairview Peak, where very well preserved fault scarps that resulted from earthquakes in the 1950's are visible. The scarps run N-S and show an offset of approximately 3m. The dip of the free-face of the fault is about 40 to 50° to the east. Along the fault, the effects of topography on the apparent dip of the free-face are rather astonishing.

The units that have been cut by the fault are mainly debris flow deposits and colluvium such as poorly sorted breccias, which enhances the chance of creating landslides subsequent to fault activity.

In 2001, there was a major fire in this area, providing a unique event horizon for future geoscientists to date these offsets as being older than the creation of burnt soil etc. due to this fire. For further information, see Appendix, figures 1.3, 1.4 and 1.5.

List of unclear issues:

- Would it be possible in the future to relate the offset of the fault to several earthquakes, that happened shortly after one another or could one not distinguish between the individual earthquakes?
- If no, why?

Research Center Bishop, CA

- **N37° 22' 03.09'' / W118° 23' 44.37''**
- **elevation: 1270 m**

We spent the next nights in the Research Center in Bishop, CA.

Appendix

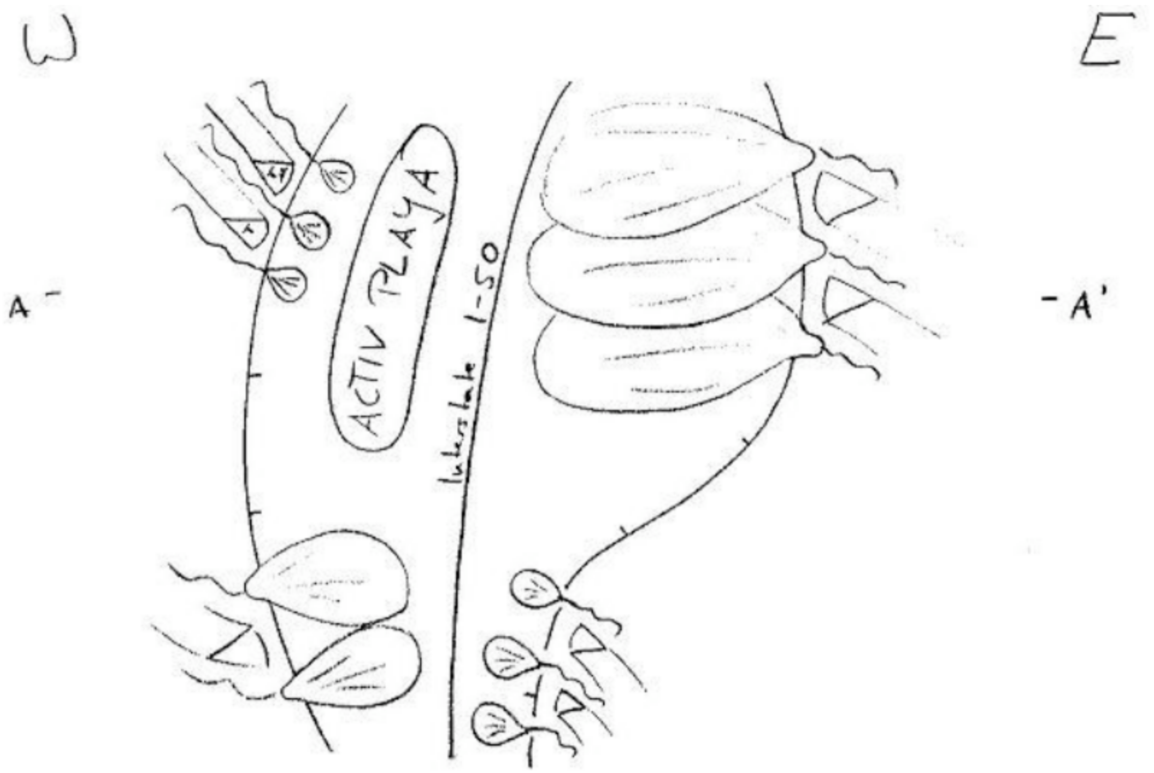

Figure 1.1: Map view of Edward Creek Valley (schematic).

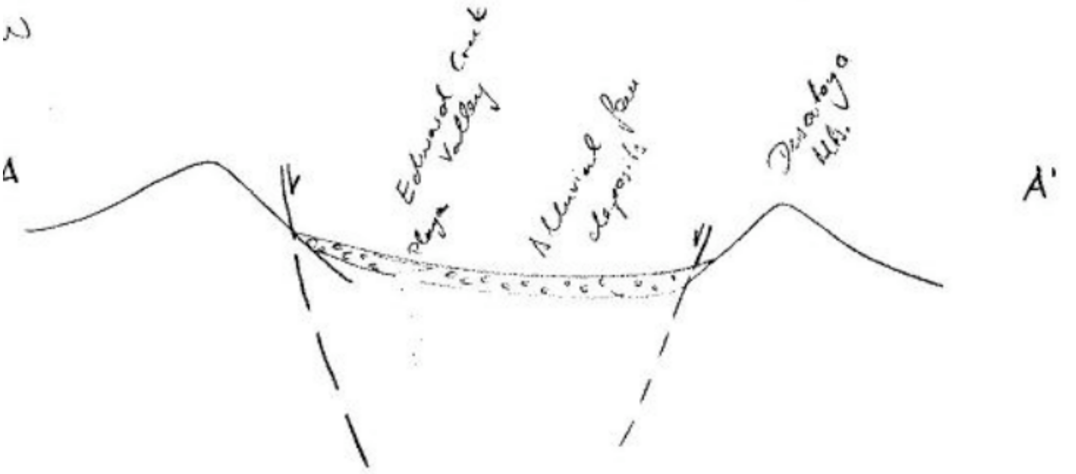

Figure 1.2: Schematic cross section of Edward Creek Valley.

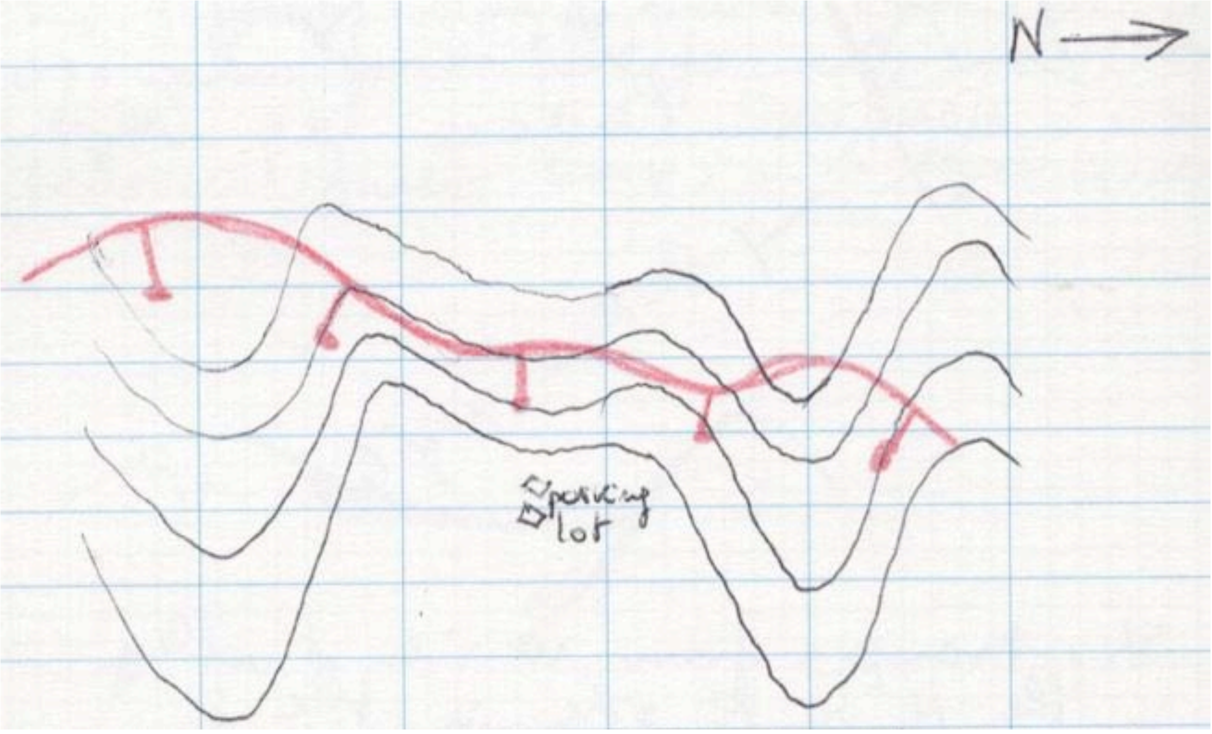

Figure 1.3: Schematic map view of the Fairview Peak fault scarp. The fault surface dips at a steeper angle than the topographic surface, creating the typical outcrop pattern. (Drawing from Sara Carena's field notes)

Figure 1.4: The fault surface looking north. Note cars and persons for scale. (Photo taken by Simon Riedl).

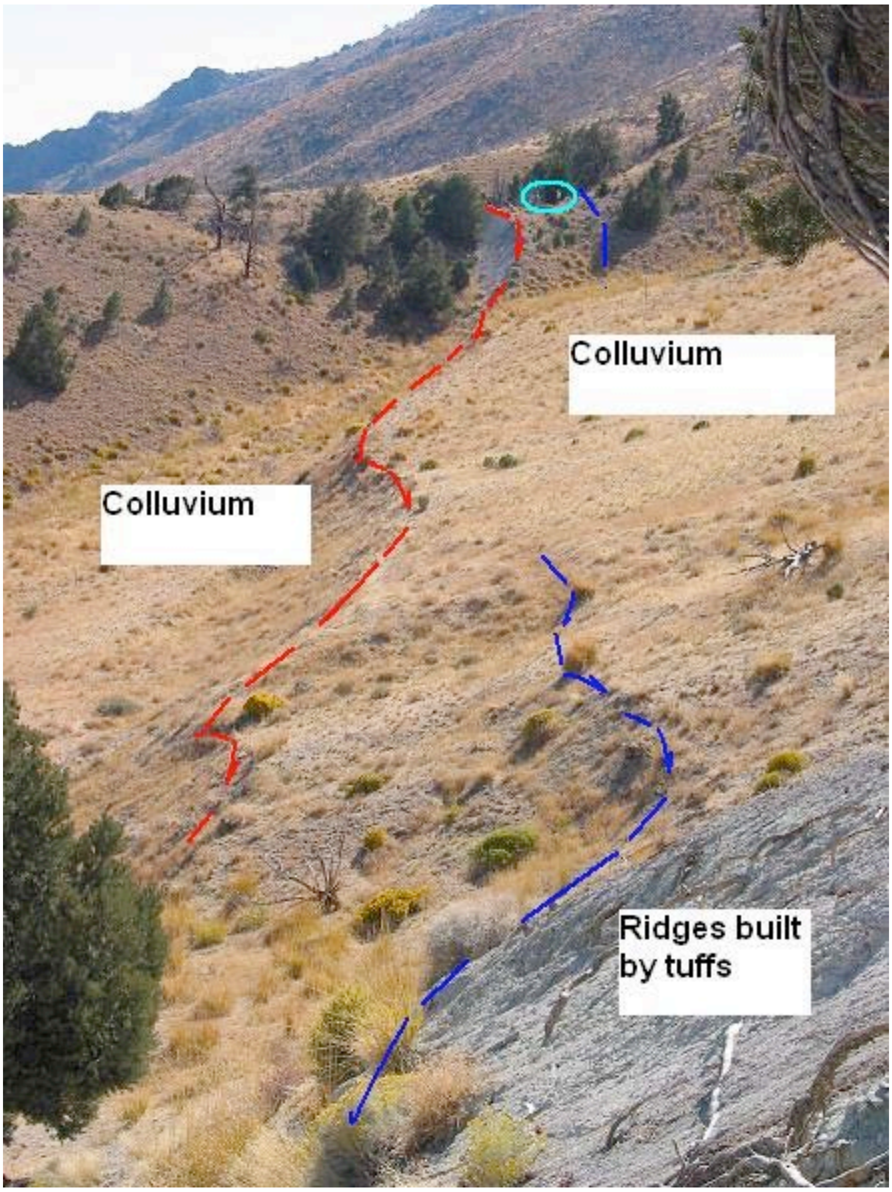

Figure 1.5: Photo of the Fairview Peak fault scarps looking south from a tuff outcrop on the northern ridge. Note that from this angle, the smaller upper scarp (blue) is also visible. Small circle in the background highlights persons for scale. (Photo taken by Sara Carena)

Manuel Hambach

September 27

Long Valley Caldera, Devils Postpile, Mono Craters, Mono Lake

Long Valley Caldera

The Long Valley Caldera is one of the biggest calderas known and covers an area of 32 km long and 17 km wide. The caldera was formed about 750,000 years ago as a large magma chamber erupted and as it was emptied the system collapsed and formed a great topographic depression. The pyroclastic material, which was blown out during the eruption, is called the bishop tuff. In this depression a lake arose: Crowley Lake.

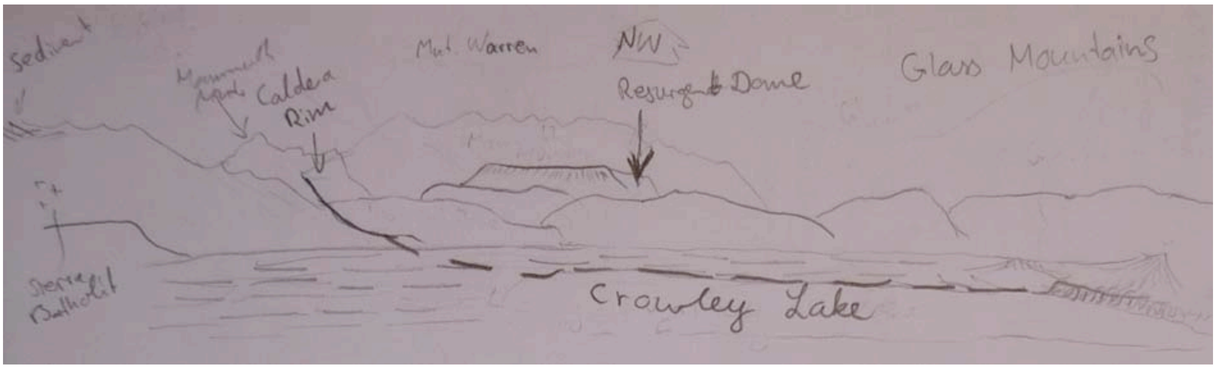

Fig 1: Sketch of Crowley Lake with a northwestern view.

<u>Long Valley Caldera</u>

- **N 37.345 / W 118.442**
- **elevation: 2091 m**
- time: 09:30

We arrive in the south of Crowley Lake, form where we have a great view to the north. On The left hand side in the northwest we can see the Sierra Nevada Batholite. In the north right in the middle of the caldera is a "resurgent dome", a dome, which was lifted up by rising magma and proves that the region is still volcanically active. We have a great view over the Glass Mountains in the northeast.

Devils Postpile National Monument

The formation was created as a 100 m thick basaltic lava flow cooled and was breaking into vertical, multisided shafts called “columnar basalt”. The exact age of formation is not known, but it is younger than 1 million years. Glaciers eroded the top part auf of the formation and left a flat surface behind between 20000 and 11000 years ago.

Devil’s Postpile National Monument

- **N 37.375 / W 119.051**
- **elevation: 2285 m**
- time: 11:40

When we arrive hat the outcrop we are standing at the bottom of the formation looking up a vertical wall of columnar basalt. At the foot of this wall we can also see debris consisting of eroded columns. The joint we see between the columns are cooling joints, which were created when the lava cooled down. The joints arise perpendicular to the surface of the lava flow. The reason why columns are hexagonal is the fact that an angle of 120° between the joints is energetically the most convenient structure. So if we count the sides of the columns we find out that most of them have five or six sides. There are 4 conditions to form columnar basalt:

- slow cooling of the lava
- fine grained material
- homogeneous material
- constant thickness of the lava flow

If we have a closer look at mineralogy of the basaltic rocks we see a fine-grained matrix contain larger crystals of plagioclase feldspar, olivine and pyroxenes.

It is possible to walk up a short patch on top of the formation and look at the glacial formed flat surface. We can find striation and half-moon structures, which tell us the glacier ice came from the north and went to the south.

Fig. 2: View to the east: the columnar basalt on top and the debris at the bottom.

Fig. 3: The top of a six sided column with half-moon structures in it.

Mono Craters

Panum Crater, one of the Mono Craters, is a, about 500 years old, volcanic cone in the south of Mono Lake. Before the magma reached the surface it hit a layer of groundwater, which turned into steam and caused a powerful explosion. Volcanic bombs and ash were thrown over long distances and the outer rim was created by that explosion. Later, after this event took place, magmatic processes were still in progress and the inner plug was formed by pouring out lava, which cooled rapidly and formed the plug dome consisting of obsidian, pumice and rhyolite.

Mono Craters

- **N 37.555 / W 119.049**
- **elevation 2387 m**
- time: 14:45

You can walk two different trails at Panum Crater. The first trail leads up to the plug dome, where you can see massive flows of obsidian, rhyolite and pumice. Most obsidian has the composition of a rhyolite. The condition to create obsidian is a lava flow with few fluids in it, which is cooling very fast. You can also find "stony rhyolite" here, a fine-grained rhyolite that is created when obsidian slowly over a long time. So obsidian only exists for at most 1 million years and crystallizes to rhyolite after that amount of time. At some places there are small crusts of sulphur, which were formed by fumaroles. That means that gas from the magma chamber is rising up to the surface and exits out through the fumaroles.

The second trail goes around the crater in a circle. This outer ring consists of ash and little pieces of pumice. But you can also find alluvial deposits like plutonic rock pebbles, which tell us that before the crater was created an alluvial fan must have been at this place, and that at least some of the fan material came from the Sierra Nevada. As the explosion took place alluvial material was deposited with volcanic products in the outer rim.

Fig. 4: A huge formation of obsidian at the plug dome.

Mono Lake

Mono Lake is a hyper saline lake north of the Long Valley Caldera. It is a terminal lake in which melting water from the mountains around is running, with no outflow. The dissolved salts in the runoffs accumulate in the lake and raise the pH. As in 1941 water from the Mono Lake area was diverted to Los Angeles the lake level rapidly increased. As a result of the falling lake level alkaline sands and lime tuffa towers were exposed.

Mono Lake

- **N 37.576 / W 119.072**
- **elevation 1947 m**
- time: 17:10

To learn about the ecology, animals and plants living in Mono Lake you can visit the Mono Lake Visitor Center southwest of the lake. Here you can find photographs, pictures and rocks of the lake with good explanations of the processes leading to the recent lake level.

Further north at about N 38.004 / W 119.084 you can access the lake's shore by a trail. From a vista point at the end of the trail you can see the tufa towers and birds living at the lake with your own eyes.

Fig 5: Anna Pöhlmann standing next to tufa tower at Mono Lake.

Christoph Kludt

September 28

Owens Lake, Owens Valley, Sierra Nevada, White Mountains, eastern California Shear Zone, Death Valley

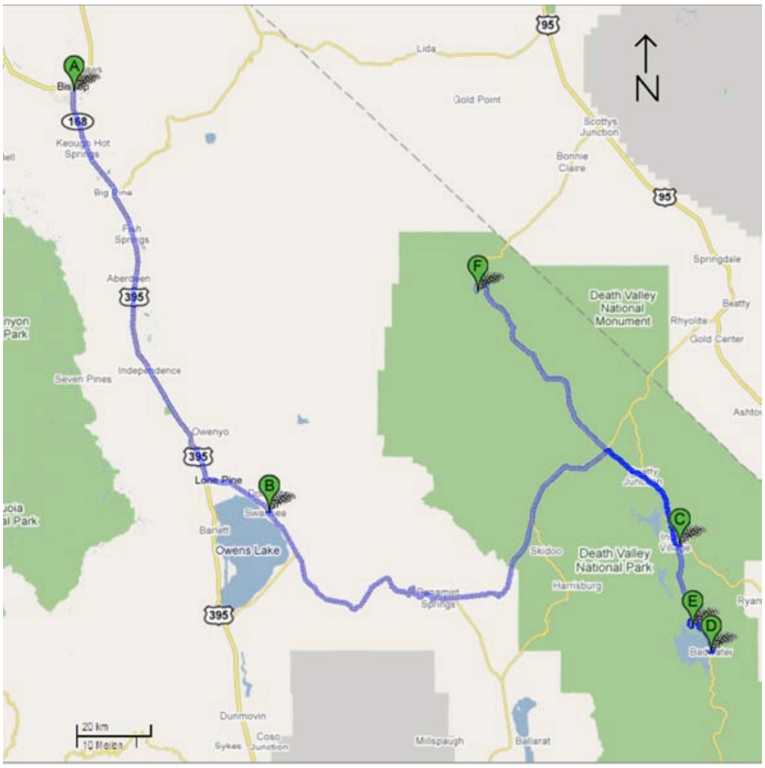

Fig.1: route of the day shown with map from "http://maps.google.de"

A: Bishop White Mountain Research Station

B: Owens Lake view Point

C: Furnace Creek (Death Valley)

D: Badwater

E: Devil's Golf Course

F: Mesquite Spring (campground)

Road Log from A to B:

We started at the White Mountain research station in Bishop at 9:00 am.

After a logistic break we drove along the State Highway 168 and the US Highway 130 in southern direction.

At Lone Pine we turned left on the US Highway 136 which leaded us to our first location.

Owens Valley and Owens Lake

Owens valley is a long narrow valley which is located between the Sierra Nevada in the west and the White and Inyo Mountains in the east and it is the western part of the Basin and Range Province. The valley is formed by extensional forces pulling the region westwards and is a very good example for a classic "Graben" structure.

Owens Lake, view point

- **N 36°31'/ W 117°53'**
- **elevation: 1142 m**
- time: 12:30 am
- weather: sunny and warm circa 100°F

Fig.2: photo from Owens Lake view Point in western direction.

From this view point you can see in western direction the "nearly" dry and salty Owens Lake in the front and the Sierra Nevada in background. The geological and tectonic situation is combined in the sketch of the cross section through the valley.

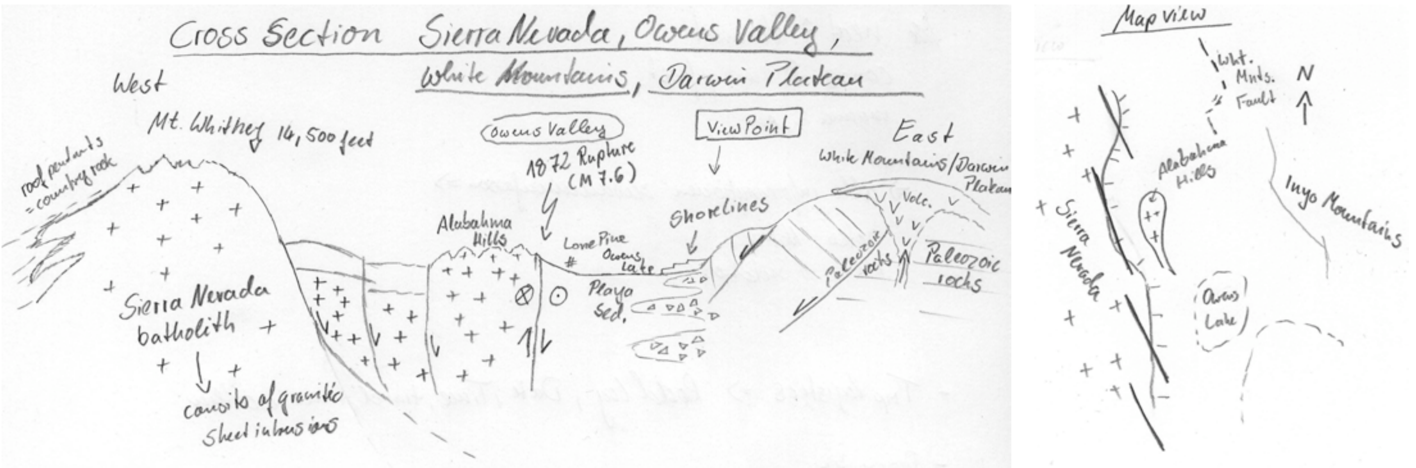

Fig 3: Sketch of cross section and map view.

In this cross section you can see the classical "Graben" structure between the fault at the Sierra Nevada and the fault at the White Mountains at the flanks of the valley. Additional to vertical displacements we have also a horizontal displacement which is about 2-6 km. The Owens Lake itself is a kind of a pull-apart basin structure with a 2 km sediment fill. The entire erosion of the Sierra Nevada until now is about 1-2 km. The core of the surrounding mountain ranges consists of granitic plutons. The granitic rocks exposed in the high mountains are subject to high rates of weathering and erosion and the resultant rocks and sediment have been carried down by water mass movement onto the alluvial fans in the deep valley.
Additional to this the volcanic rocks especially in the eastern part can be used as time-markers and help to date the events in this region.
The displacement in general is caused by the movement of the Walker Lane Belt and the Eastern California Shear zone. The arrangement of those zones is shown in the sketch below.

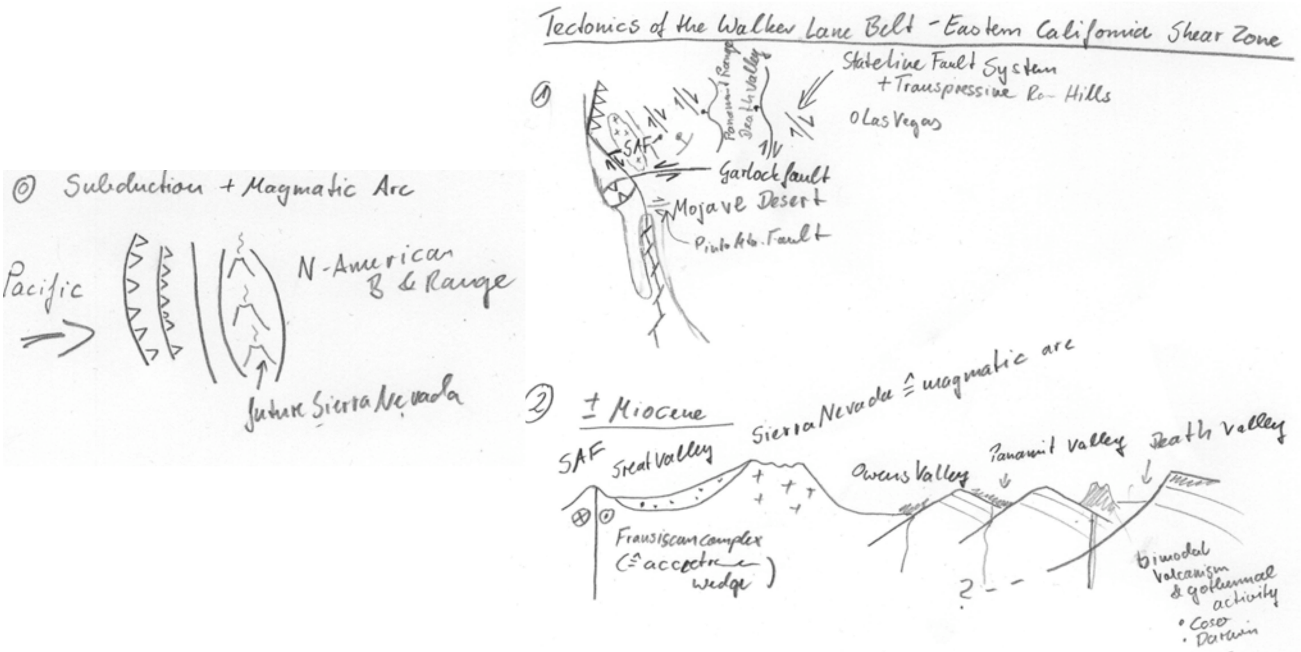

Fig. 4: Development and tectonic of Walker Lane Belt and Eastern California Shear Zone.

The Eastern California Shear zone is composed of a set of NW striking faults and is located south of the Garlock fault in the Mojave Desert. The Walker Lane Belt extends northward from Garlock fault. This major tectonic system includes

Owens and Death Valley and several prominent faults. Furthermore these zones are located at the juncture of Sierra Nevada and the Basin and Range.

Because of this position between those two different tectonic structures this region is deforming in a complex way and the faults in Owens and Death Valley have still a movement of several mm per year.

Road Log from B to C:

After this first geological stop we kept on driving on the US Highway 136 in south eastern direction and then straight ahead on State Highway 190 to the east.

On this way we passed the Panamint Valley and entered the Death Valley National Park.

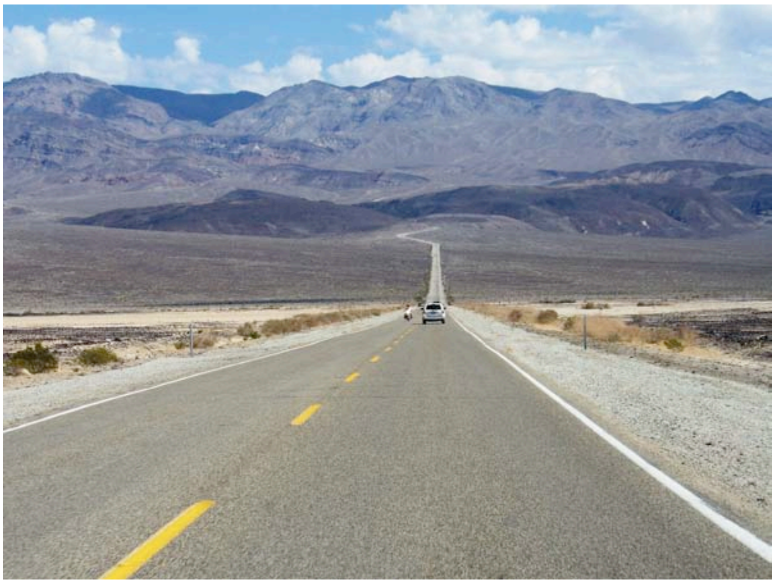

Fig. 5: Panamint Valley on Highway 190.

Road Log from C to D:

At 2:00pm we stopped at Furnace Creek for a logistic stop.

After this we turned right on the State Highway 178 in southern direction to our second geological stop Badwater.

Death Valley National Park

Death Valley is located east of the Sierra Nevada.

The first interesting point is the decreasing elevation of the different valleys we've been driving through. Owens Valley has an elevation of 1000 m, Panamint Valley 800 m and Death Valley 0 m. This effect is caused by the increasing amount of stretching which also causes isostatic compensation and footwall uplift.

Because of this in Owens Valley and Basin and Range we have a "normal" half "Graben" structure, but in Death Valley we have a combination of half "Graben" structure and updoming. This causes the typical metamorphic core complexes and turtleback structures in this valley.

Bad Water, Death Valley

- **N 36°13'/ W 116°46'**
- **elevation: -86 m (below sea level !)**
- time: 3:30 pm
- weather: sunny and warm (110°F)

At this location you can see one typical turtleback structure from Death Valley.

This kind of structure includes a "metamorphic core complex". The first thing which is necessary for the development of a metamorphic core complex is an extension on a fault system. Because of the extension the crust becomes thinner on some places in this area and under these thinner parts of the crust develops isostatic uplift. This up arching of the crust compensates the thinning and brings metamorphic material near to the surface.

Fig. 6: Photo of Badwater turtleback (view in northern direction).

In this case the upper crust is stripped away due to the extension and the middle and lower crust is exposed. The brown and green coloured rocks are ductile deformed Precambrian metamorphic rocks that lie in the footwall of the fault.

Additional to the E-W extension there is also a dextral component in this valley. This component is caused by the pull apart basin structure in this area, which is shown in Fig.7.

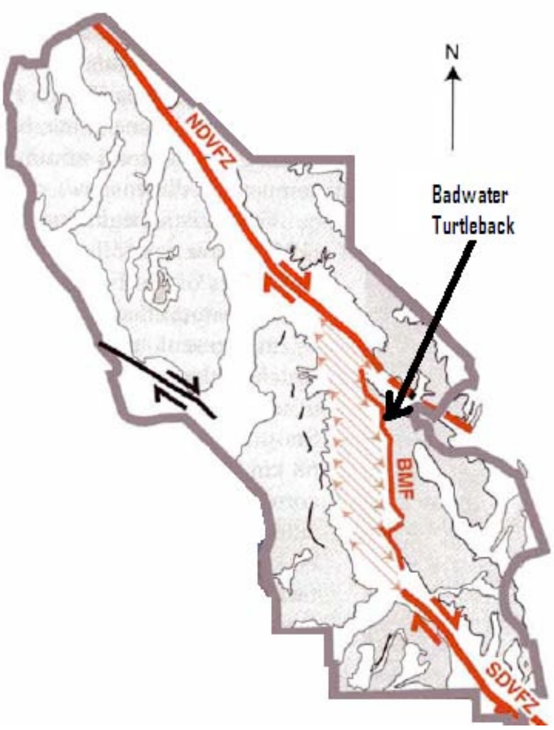

Fig.7: Pull-apart origin of modern Death Valley from "Geology of Death Valley National Park by Miller and Wright".

The slip direction is more/less parallel to the orientation of the turtlebacks.
Another interesting fact is that the erosion rate at this place is much lower than the motion rate of the faults. Because of this you can find a lot of fault planes which have kinematic indicators and help to quantify the motion rates.

The second interesting place at this location is the well shaped alluvial fan which is also located next to Badwater to the south.

Fig.8: Photo of alluvial fan with fault scarps at Bad Water in southern direction.

At the east side of Death Valley you can find small and well shaped alluvial fans with fault scarps. This shape of the fans is caused by the active fault zone on this side of the valley. Compared to the eastern side you can find on the west side large fans as it is shown in Fig.9.

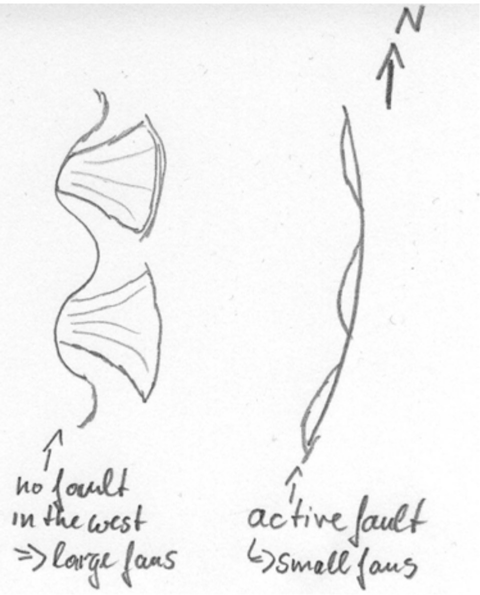

Fig. 9: sketch of the situation in Death Valley.

In the alluvial fan of Bad Water you can find the deposits of debris flows and in some cases sheet flows like shown on the Fig.10.

Fig. 10: debris and sheet flow at the steep Bad Water alluvial fan.

Devil's Golf Course, Death Valley

- **N 36°13'/ W 116°46'**
- time: 4:30 pm
- weather: sunny and warm circa 110°F

At this location you can find a salt crust that contains structures which are typical for a salt playa like this. The surface structure of this salt pan consists mainly of polygon shaped salt blocks and salt pinnacles. The shape of the surface is caused by desiccation whereas the mud beneath the surface dries and causes cracks in the surface.

Fig.11. Devils Golf Course, photo of the surface with salt pinnacles and polygon shaped blocks.

Road Log from E to F:

After this last geological stop for this day we went to the Mesquite Spring campground.

References:

Miller, Marli B. & Wright, Lauren A.; Geology of death Valley National Park second Edition, Kendall/Hunt Publishing Company 2004

Lukas Sundermann

September 28/29

Death Valley, Turtleback, Salt Flat

Death Valley

- **N - S Extension: ca. N 36°37' / W 117°00' to N 35°54' / W 116°44' (app. 50 miles)**
- **elevation: - 85.5 m – ca. 3000 m**
- weather: hot, dry

Tab. 1: Simplified Stratigraphy of the Death Valley / West Vegas region from the Proterozoic to the Tertiary.

Simplified Stratigraphy Death Valley / West Vegas

Tertiary	Vulcanics + Landslides + Alluvial + Lacustrine
Cretacreous / Jurassic	Aztec Ss.(Navajo) Kayenta
Triassic	Chinle Moenkopi
Permean	Kaibab Red Beds
Mississippean / Pennsylvanian	Bird pring Fm. Monte Cristo Limest.
Devonian / Silur	Hidden Valley / Sultan Dolomite Ely Springs Dolomite
Ordovizean	Eureka Quarzite Pogonip
Cambrian	Nopah Bonanza King Fm. Carrara Fm. Zabriskie Fm. Wood Canyon Fm.
Proterozoic	*Great Uncomformity* Stirling Quarzite Johnnie Ibox Noonday Dolomite Pahrump Group
	Crystalline Basement

Death Valley is a pull-apart basin that started to form in the Tertiary as the extension of the area began. It extends approximately 50 miles in N – S direction and is 1 - 4 miles wide. On average it is the hottest place on earth and North Americas lowest at Badwater Basin.

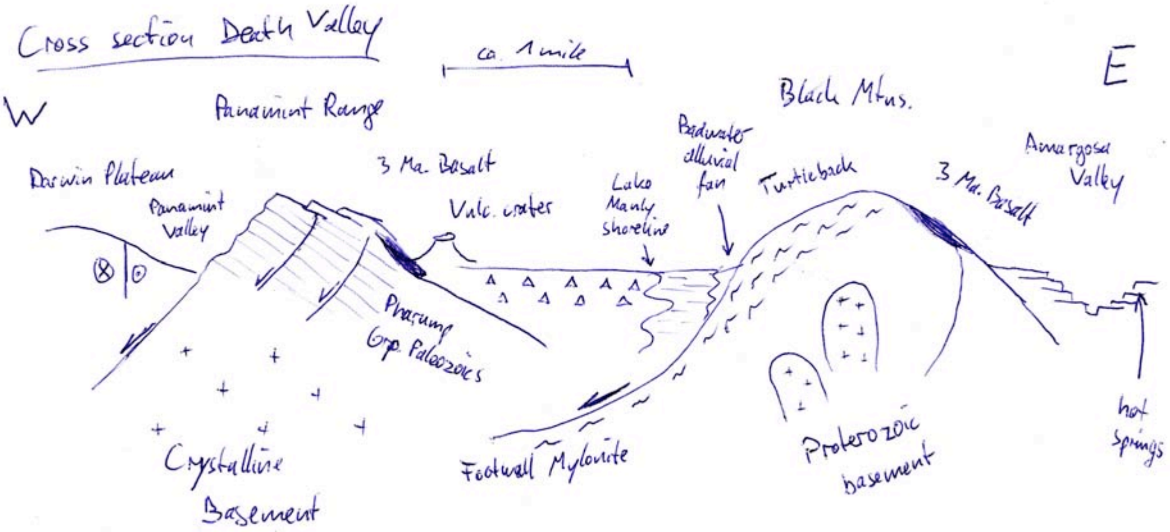

Fig. 1: Simplified cross section of Death Valley from W to E. Due to extreme extension upper sediment layers are stretched and removed, whereas metamorphic rocks of the footwall are situated at the surface nowadays**.**

Devil's Golf Course

- **N 36°17' / W 116°49'**
- **elevation: 0 m**
- time: 17:30
- weather: sunny, hot

Contrary to other salt flats, like those in Utah or elsewhere, the so-called 'Devils Golf Course' salt flat in Death Valley shows a really rough surface. There are no bumps or hills but broken open pieces of salt and clay, which are up to 30 centimetres above the surface. These pieces are quite strong and the whole area looks like an acre.

Fig. 2: The rough surface of the salt flat called 'Devils Golf Course'. View is to the west at sunset.

The salt often exists in forms of connected crystals. These salt layers alternate with layers of brownish and blackish clay. Sometimes there are bigger stones which could originally derive from flooding events or human impacts. Near to the parking lot is a little hole of approximately 1 meter in diameter filled with oversaturated water. Holding your fingers into it and let them dry again results in white, salt-covered fingers, because the salt immediately begins to crystallize out as the water evaporates. It is suggested that there should be more oversaturated water beneath the surface of 'Devils Golf Course'.

Development of the salt flat: Short and heavy rain events dissolve the salt from the mountain ranges all around the valley. According to that, little springs could add forms a puddle at 'Badwater' supports this theory.

After the flooding of the valley a lake exists for a short period. In this time clay gets deposited. Extreme high evaporation rates remove the water again and crystallized salt remains on the ground. Due to the heat desiccation cracks are forming. The tilting of the cracks result to the acre-like surface. Issue: Why is the surface rough at 'Devils Golf Course' and why smooth at 'Badwater'?

Badwater Basin Badwater alluvial fan

- **N 36°13' / W 116°46'**
- **elevation: - 85,5 m**
- time: 14:00
- weather: sunny, hot

Badwater is the lowest point in North America. Once again the surface of the flat is covered with salt. Next to the parking lot is a little spring which forms a puddle. Some hundred meters to the south, Badwater alluvial fan, a textbook example, extends into the salt flat.

Along the big active fault of Death Valley at the eastern side, Badwater alluvial fan is a little and steep fan in contrast to the long and big fans at the western side. The fan is very young and consists of gravel and sometimes even big stones or rocks. Looking up to the mountains behind the fan, the dry bed cuts deep into the rocks and forms a canyon which is called a 'wine glass'-shaped valley.

The fan itself has many channels which often cut into each other after another rain event. The gravel consists of volcanic and metamorphic rocks as the drainage area includes such type of rocks. Thick and layered sediments, old alluvial deposits, are located at both sides of the dry river bed. These part of the alluvial fan is inactive today and gets eroded on every younger rain event.

Natural Bridge

- **N 36°17' / W116°46'**
- **elevation: 110 m**
- time: 11:00
- weather: sunny, hot

Like Badwater, a dry river bed curls through the thick sediment layers of an old and nowadays inactive alluvial fan. Some younger faults cut the sediment layers and nicely eroded half-tubes in the wall indicate recent water activity.

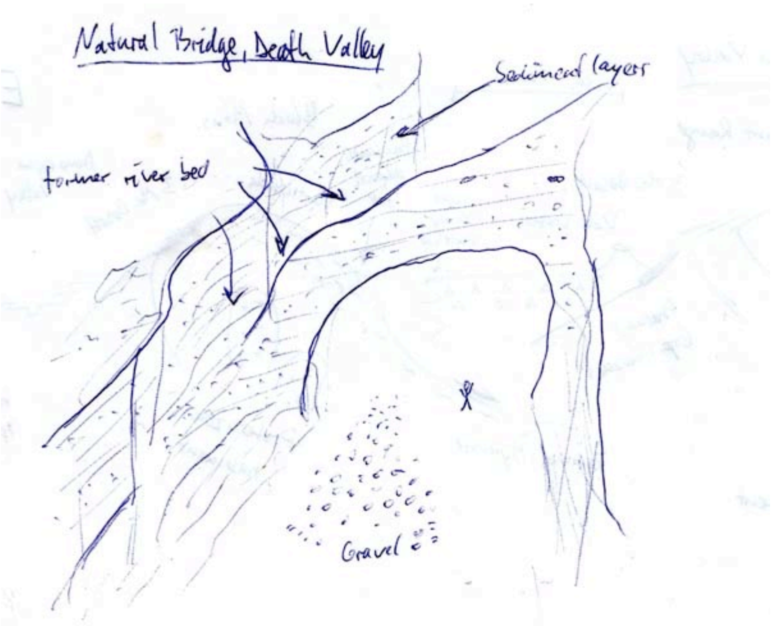

Fig. 3: Sketch of the 'Natural Bridge' with the former river bed on the left side of the N-S directed canyon.

Famous natural bridge is circa 20 minutes to walk from the parking lot. It is approximately 15 meters high and 10 meters wide. Someday the river curved around a nose in the incised sediment. The old river bed can be recognized at the northern side today. After a while the river changed its direction and cuts a hole into the nose, which obviously contains of stronger sediment at the upper part.

On the way up the canyon gravel and stones start to include metamorphic rocks. It indicates a river incision into such kind of material, in this case a metamorphic core complex.

Turtelback

Badwater Turtleback

- **N 36°17' / W116°46'**
- **elevation: 120 m**
- time: 16:00
- weather: sunny, hot

Because of their shape, metamorphic core complexes are known as turtlebacks as well. They consist of ductile deformed material and mylonites at the top. Extreme stretching of the crust and unroofing of the brittle sediments cause isostatic uplift of originally about 20 km deep metamorphic rocks of the footwall. By reason of their genesis they can be found only at the eastern side of Death Valley. Badwater turtlebacks surface approximately indicates the fault plane.

At the top of the incised river bed a sharp boundary between the fan sediment and the metamorphic rock is visible. The sediment consists just of volcanic rocks since there was no outcrop of metamorphic rocks at the time of deposition.

The cracked and broken mylonites at the turtlebacks top show joints striking in different directions. Sometimes the joints are filled with gypsum which originates from the sediment layers above. The metamorphic rocks mostly contain gneiss and schist and show elements of ductile deformation and tectonic activity like delta- and sigma-clasts.

The boundary between sediments and metamorphic rocks dips about 30° to the south and indicates the old detachment zone. It is really sharp. Usually normal faults show angles of 60° which suggests an inactive unroofing process in this case.

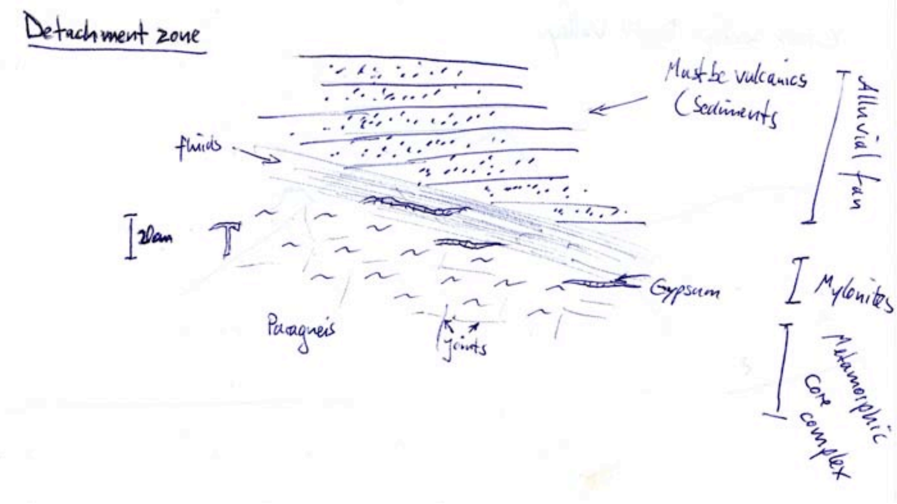

Fig. 4: Detailed sketch of the contact between the older metamorphic rocks and the younger alluvial fan sediments. The normal fault dips to the south.

Frank Biersack

September 29

Natural Bridge, Desert Pavement, Furnace Creek Fault Zone, Amargosa Valley

Natural Bridge

From I 178 a dirt road leads to the big alluvial fan in which the Natural Bridge Canyon is incised. The genesis of the Badwater turtleback (metamorphic core complex) caused the incision of an alluvial fan in its own sediments. The incision left a natural bridge of sediments over the canyon behind.

- **N 36° 17` / W 116° 46`**
- **location: alluvial Fan, Turtleback, Death Valley**
- **elevation: 110 m**
- time: morning
- weather conditions: hot, dry and sunny

We are walking up the incised, dry riverbed in an alluvial fan of an early Quaternary age. Many small faults and cracks can be seen in the sidewalls of the alluvial fan in the canyon. Some of them are widened by the water flush which can be really strong flush floods after a rain incidence. The widened parts look like vertical half pipes. These are indicators of a detachment fault system which is caused by the uplifting genesis of a turtleback under the alluvial sediments. At one point the erosion has left over a natural bridge over the canyon. Probably the material of the bridge is a harder basaltic detritus, so that it could sustain the erosion of the water flush. Further up in the canyon the contact between the alluvial sediments and the metamorphic core complex can be observed. The alluvial fan consists of volcanic rocks that have a breccia character. At the outcrop of the contact zone, which is approximately the middle of the turtleback, you can see that all cracks in the hanging wall ends in the footwall. The footwall is the Proterozoic basement, which surface is a mylonitic green schist.

Fig. 1: Natural Bridge Canyon - the bridge.

Furnace Creek Fault Zone

The stop is on the I 190 direction out of the Death Valley after the Zabriskie-Point formation. The Furnace Creek Fault Zone is one of the two big faults at the Death Valley. It runs from a connection with the Death Valley Fault Zone north-northwestward to the Amargosa Valley.

- **N 36° 24` / W 116° 47`**
- **elevation: 257 m**
- time: afternoon
- weather conditions: hot, dry and sunny

The fault is steeply, dipping with a right (dextral) lateral movement, strike slip fault. It extends for more than 200 km along the western flank of the Funeral Mountains. The total displacement is reconstructed and about 50- 65 km. The Stratigraphy between Miocene and Quaternaryhas a strong angle unconformity. The Miocene is tilted because of the strong shearing mechanisms of the big lateral movement.

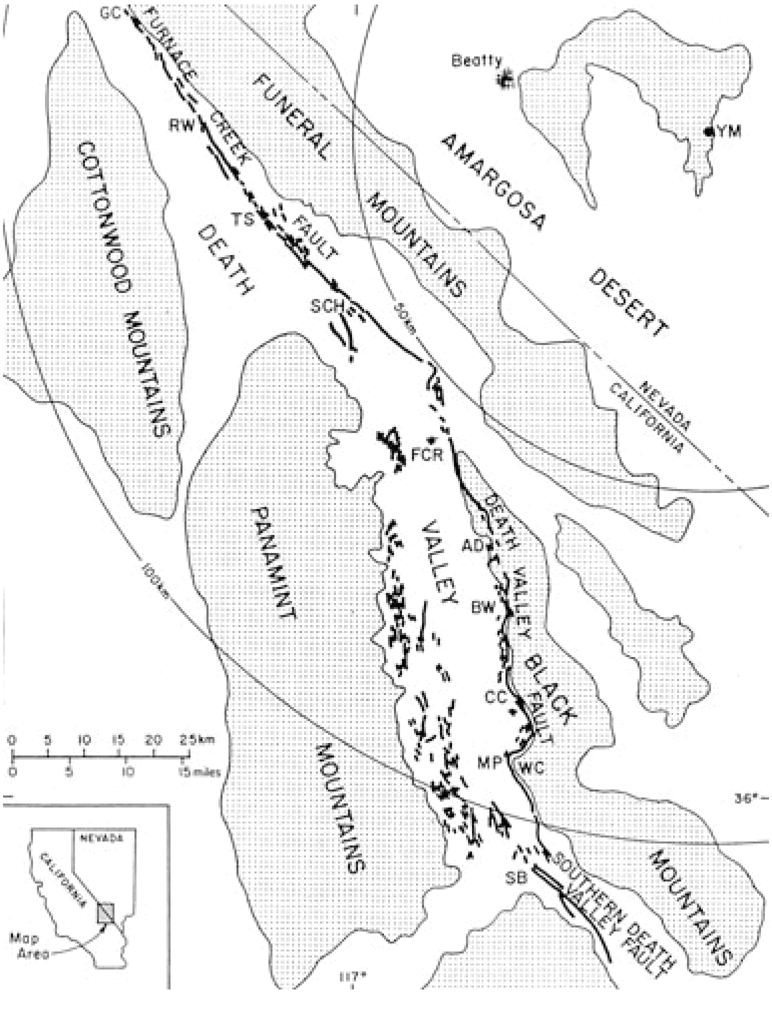

Fig. 2: Overview of the primary tectonic structures around Death Valley.

Desert Pavement

We are on our way to Tecopa Hot Springs, east of the Death Valley National Park. The vegetation is very poor and we are still in the Desert (Hamada) of Nevada. The topography is formed by the Basin and Range structures and the alluvial fans and canyons of the ranges.

- **location: outcrop near the road I 95**
- **elevation: approximately 500 m**
- time: afternoon
- weather conditions: hot, dry and sunny

The outcrop shows an almost 90° tilted sequence of alluvial, Cenozoic Sandstones which are located like a tilted block beside the road. The surface of the layers has streaming ripples and mud cracks as well as load cast structures. So we figured out that we looked upon the top side of the layers, which meant that the layers are not over tilted. Some parts of the layers include bigger clasts. The surface of the block is desert pavement. The fine grains are blown out by the wind and only pebble to cobble size rock fragments are left. They are closely packed and it looks like a puzzle of stones. Some fragments are covered with desert varnish and some have an angular surface because they are shaped by the wind to ventifacts.

Fig. 3: Tilted sandstones.

Fig. 4: Tilted sandstones, load cast structures and desert pavement on the top.

Amargosa Valley

On the I 127 direction Shoshone we have a last stop in the Amargosa Valley.

- **N 36° 14` / W 116° 25`**
- **location: viewpoint**
- **elevation: 675 m**
- time: afternoon
- weather conditions: hot, dry and sunny

The Amargosa Valley is on the border between California and Nevada. Along the valley you can observe at several points the Furnace Creek- and the Death Valley fault zones and their offshoots. A view of the Eagle Rock Mountain, which is surrounded by four playas, let see a big eastward dipping north-south running detachment fault. The Mountain is an isolated fault-block that consists of Cambrian carbonate rocks.

Fig. 5: Eagle Rock Mountain.

Rebecca Kämmerling

September 30

Tecopa Hot Springs, China Ranch, Charles Brown Outcrop

Tecopa Hot Springs

Tecopa Hot Springs is located on a road approximately two miles off State Highway 127, and lies just east of the southern end of Death Valley National Park at an elevation of 1,325 feet.

A hot spring is a spring that is produced by the emergence of geothermally heated groundwater from the earth's crust. The water temperature usually measures between 116 - 118° F.

Fig 1: Hot tub at Tecopa hot springs.

China Ranch – date farm

General summary of Stratigraphy, style and control of tectonic architecture of Western USA. Concluding discussion:

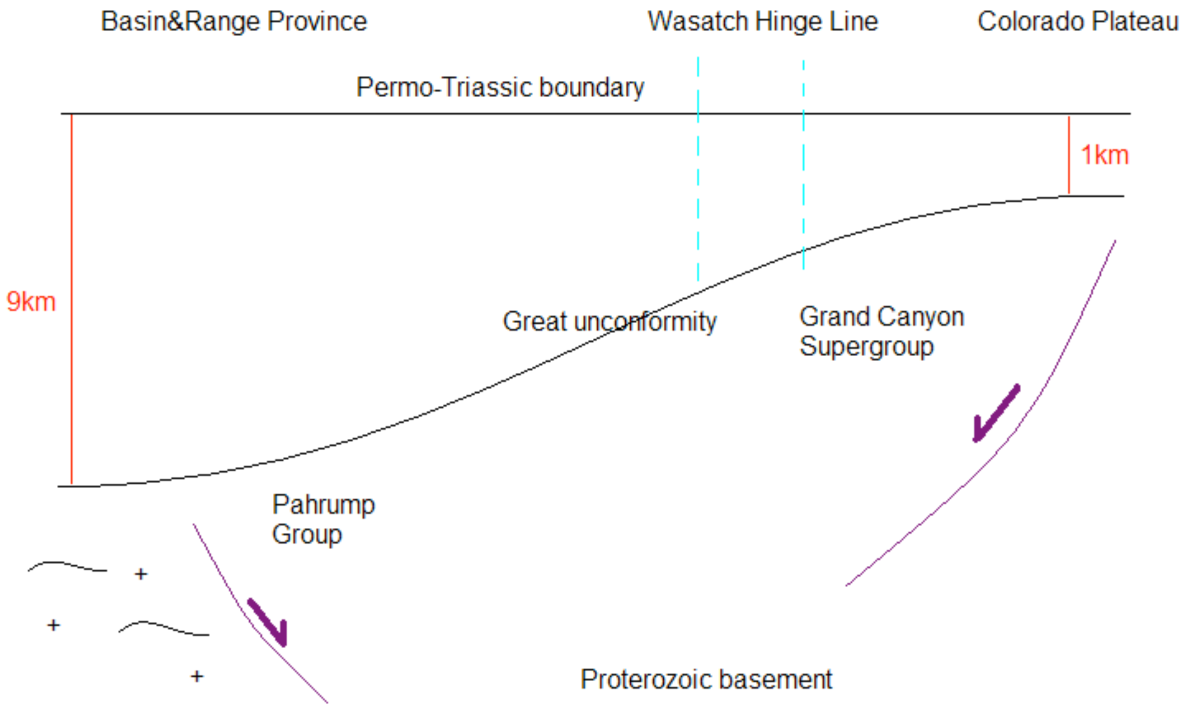

Fig 2: W-E cross section through Basin & Range and Colorado Plateau.

The Colorado Plateau landscape features and landforms include mesas, chimney rocks, arches and deeply incised canyons. In the Basin and Range Province the predominant landforms are narrow north-south ranges flanked by broad sloping alluvial fans that flatten in centre of the wide valleys.

The Colorado Plateau

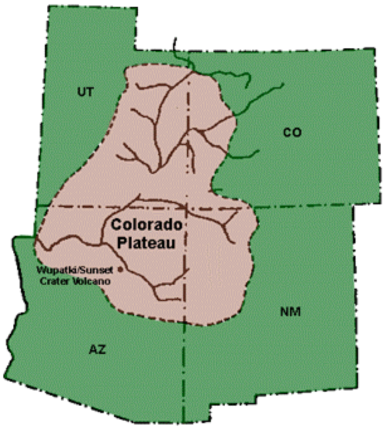

Fig 3: Colorado Plateau area.

- 1,2 - 0,8 Billion years ago: Deposition and tilting of the Grand Canyon Supergroup on the Vishnu Basement → Great unconformity
- Deposition of Paleozoic lime- and sandstones with a general westward thickening
- Triassic: Deposition of Moenkopi, Shinarump and Chinle Formation
- Jurassic and Cretaceous: Deposition, River system: eastward draining
- Late Cretaceous, Early Tertiary (stressed by Laramide Orogeny): uplift of Colorado Plateau
- 14 - 8Ma ago: large scale erosion of younger strata
- <12Ma: Deposition of lake sediments
- ~6Ma: Incision of the Colorado River (westward)

Wasatch Hinge Line

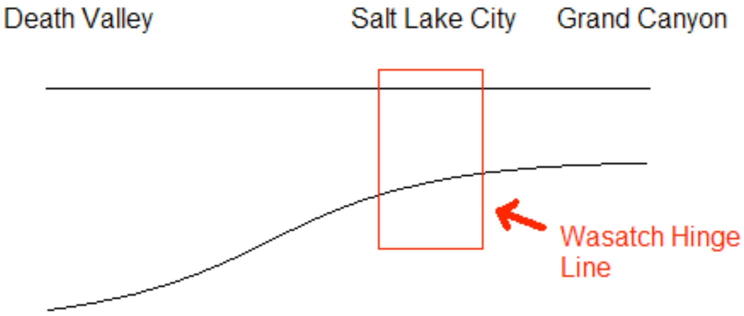

Fig 4: Cross section from Death Valley to Grand Canyon

The Wasatch Hinge Line divides major geologic provinces: the Colorado Plateau-Rocky Mountains from the Basin and Range.

- Proterozoic and Palaeozoic: Separation of 2 continental plates, lateral change in lithology
- Mesozoic: west → Sevier foreland fold- and thrust belt type (thin skinned)
- East → thick skinned Laramide style
- Tertiary: eastern most Basin and Range Province type normal fault
- Quaternary: continued faulting and basin fill

Basin and Range Province

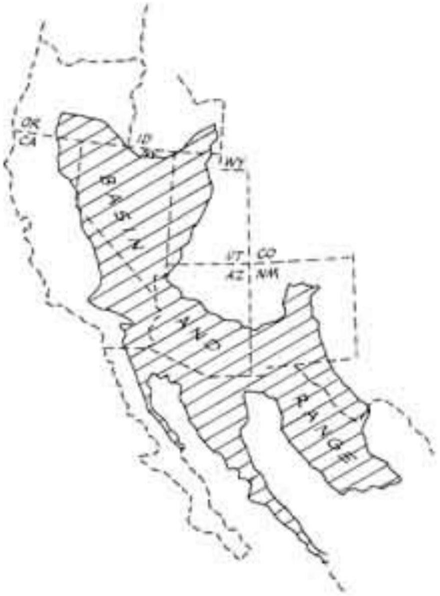

Fig 5: Basin and Range area

- Palaeozoic: limestones + dolomites, uplift → Sandstone (e.g. Eureka-quartzite), subduction → limestone
- Mesozoic: end of passive continental margin (compression), shallow marine depositions, plutonic intrusions, Sevier-style deformation (late Jurassic, Cretaceous)
  Model A: gravitational collapse → early Basin and Range extension (metamorphic core complex)
  Model B: backarc spreading → early Basin and Range extension
- Cenozoic: San Andreas Fault (16Ma) → extension (N-S trending faults) → crust thinned out, blocks tilted eastwards

Charles Brown Outcrop

Charles Brown Outcrop

- **N 35° 59' / W 116° 13'**
- **elevation: 701 m**
- time: 4:00 pm

Fig 6: Outcrop Charles Brown Road

The Outcrop is located along the Charles Brown Highway (CA 178), northeast of the small town of Shoshone, this road-cut exposes the spectacular black band of volcanic glass within the tuff. The layers dip WNW, the black layer consists of obsidian which has a thickness of 1,5 - 2m.

This tuff formed during a pyroclastic flow. The hot, gaseous flow deposited ash and rock fragments along the ancient irregular topography of the region. This thick deposit of ash cooled relatively quickly at the top and bottom, but the ash in the middle was extremely hot (700°C). Due to the overlap, the ash in the middle was melted and obsidian developed. Flattened pumice and vesicles are all aligned at a shallower angle than the black obsidian layer, indicating that the ash flow was deposited on a paleo-slope. The flattened pumice was originally horizontal because flattening is simply due to the weight of the rock above, so the current dip of 15° indicates later tilting.