Name: ________________

Field trip guide to
Death Valley National Park

Geology of the National Parks
San Francisco State University
March 22-26, 2002

DRIVING DIRECTIONS

Distance	Odometer	Directions
0 miles	0 miles	Leave SFSU at 8:30 a.m.
		Right on 19th Ave. toward San Jose
		Continue south on Highway 280 toward San Jose
44 mi.	44 mi.	Exit Highway 85 South toward San Jose
22 mi.	66 mi.	Merge onto Highway 101 South toward Gilroy
25 mi.	91 mi.	Near Gilroy, exit to 152 East toward Los Banos
48 mi.	139 mi.	Exit to 5 South toward Los Angeles
126 mi.	266 mi.	Exit 46 East toward Wasco
25 mi.	291 mi.	Exit 99 South toward Bakersfield
20 mi.	311 mi.	Exit 58 East toward Tehachapi/Mojave
42 mi.	353 mi.	Take 2nd exit into the town of Tehachapi
		Fill up gas tanks, regroup, leave together
		Return to 58 East toward Mojave
18 mi.	371 mi.	In Mojave, take 14 North/East toward Trona
19 mi.	390 mi.	Exit small road to East (right turn) toward Johannesburg/Randsburg (Randsburg Road)
25 mi.	415 mi.	Turn right onto 395 South toward Johannesburg
2 mi.	417 mi.	Drive past the town of Johannesburg about 1/2 mi.
		Turn left onto small road toward Trona (Death Valley Road)
23 mi.	440 mi.	Turn right onto 178 East toward Trona
42 mi.	482 mi.	Turn right onto small road to Wildrose/Emigrant Pass
19 mi.	501 mi.	Turn right onto dirt road to Aguereberry Point
6 mi.	507 mi.	**STOP 1**: Aguereberry Point for overlook of Death Valley
6 mi.	513 mi.	Return to main road, turn right toward Death Valley
12 mi.	525 mi.	Turn right onto 190 East toward Stovepipe Wells
35 mi.	560 mi.	Drive through Stovepipe Wells, past Furnace Creek
		Turn left into the Texas Springs campground
1 mi.	561 mi.	Drive to Group Site K at the back of the campground
		Arrive 6:30 p.m.

Stop descriptions and figures are taken from the U.S. Geological Survey and National Park Service web site *Geology of Death Valley National Park* [http://www2.nature.nps.gov/grd/usgsnps/deva/deva1.html]

DEATH VALLEY NATIONAL PARK

Death Valley. The name is foreboding and gloomy. Yet here in this valley, much of it below sea level, or in its surrounding mountains you can find spectacular wildflower displays, snow-covered peaks, beautiful sand dunes, abandoned mines and industrial structures, and the hottest spot in North America.

G.K. Gilbert, a geologist who worked in the area in the 1870s, noted that the rock formations were "beautifully delineated on the slopes of the distant mountains, revealing at a glance relations that in a fertile country would appear only as the results of extended and laborious investigation." The rock layers that Gilbert noticed comprise a nearly complete record of the earth's past, but that record has been jumpled out of sequence. The reason is that the rock layers that form the mountains are very ancient, but only in recent geologic time have they risen.

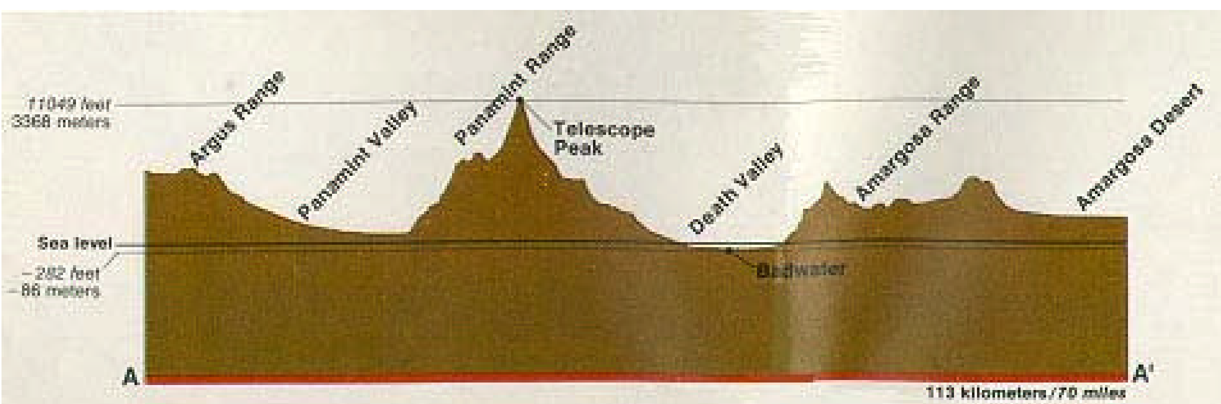
Even as the mountains rose, erosion began to wear them down. An example of this is the formation of the alluvial fans. Intermittent streams, resulting mostly from the bursts of infrequent rains, rush down the steep canyons scouring boulders, soil, and other debris and pushing and carrying the whole mass with it and then depositing it on the valley floor at the canyon's mouth. Because of the faulting in Death Valley, the vertical rise from the lowest point to the top of Telescope Peak is one of the greatest in the United States.

DESCRIPTIONS OF GEOLOGY STOPS

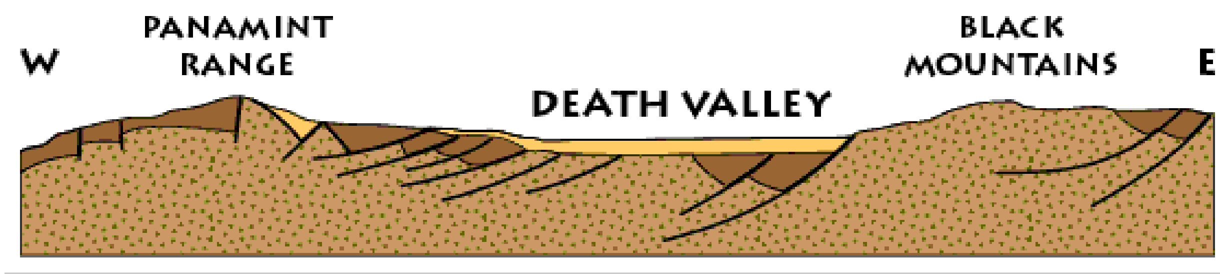
<u>Day 1 — Friday, March 22</u>

STOP 1 — Aguereberry Point

<u>Topographic cross-section</u>



Structural cross-section



Questions to answer
Sketch the Furnace Creek alluvial fan. Include the Black Mountain range front, vegetation, streams, and the change in color at about mid-fan.

Day 2 — Saturday, March 23

STOP 2 — Titus Canyon

Ancient rocks - youthful mountains

The deep, narrow gorge of Titus Canyon cuts into the steep face of the Grapevine Mountains. Although the mountain range was uplifted quite recently, geologically-speaking, most of the rocks that make up the range are over half a billion years old.

Tropical seas

The gray rocks lining the walls of the western end of Titus Canyon are Cambrian age (570-505 million years old) limestones. These ancient Paleozoic rocks formed at a time when Death Valley was submerged beneath tropical seas. By the end of the Precambrian, the continental edge of North America had been planed off by erosion to a gently rounded surface of low relief. The rise and fall of the Cambrian seas periodically shifted the shoreline eastward, flooding the continent, then regressed westward, exposing the limestone layers to erosion.

Most of California, Oregon, and Washington states had not yet joined what we now call North America. Death Valley lay at the equator, submerged beneath the tropical sea for much of the Cambrian period. Click here to see the location of Death Valley through time.

Limey layers

Although some of the limestone exposed in the walls of Titus Canyon originated from thick mats of algae (stromatolites) that thrived in the warm, shallow Death Valley seas, most of the gray limestone shows little structure. Thousands of feet of this limey goo were deposited in the Death Valley region. You'll see similar limestone layers if you visit Lake Mead National Recreation Area or hike to the bottom of the Grand Canyon.

Questions to answer

What is a breccia?

What cement is holding the collapse breccia together? Where did it come from?

Sketch two different fault types you find in Titus Canyon

How do the alluvial fans differ on the west and east side of Death Valley? Draw two sketches showing the differences.

What does desert varnish tell you about the alluvial fan sediments?

STOP 3 — Ubehebe Crater

At the edge of Ubehebe Crater, you'll be greeted by an eerie, surreal landscape. All is quiet now, but imagine yourself transported to a time just over two thousand years ago......Following weaknesses in the Earth's crust, searing basaltic magma rose upward. A fault along the base of Tin Mountain, responsible for uplift of the entire mountain range, lay in the path of the molten mass, providing an easy escape route to the surface.

<u>Fire and water</u>
Magma worked its way through the fault-weakened rock where it met water-soaked bedrock and alluvial fan sediments. In an instant, water flashed to steam. A sudden, violent release of steam-powered energy blasted away the confining rock above. A dense, ground-hugging cloud of rocky debris surged out from the base at up to 100 miles/hour, decimating the landscape.

The largest of these eruptions produced Ubehebe Crater, over a half a mile wide and 770 feet deep. Up to 150 feet of rock debris mantles the countryside near the site of the explosion. Over a dozen other explosion craters and tuff rings in the Ubehebe Crater field are the result of this type of hydrovolcanic eruption.

STOP 4 — Racetrack Playa

<u>The mysterious sliding rocks of Racetrack Playa</u>
The level surface of this parched basin provides the backdrop for one of Death Valley's most intriguing geological puzzles, the mysterious sliding rocks of Racetrack Playa. Scattered across the extraordinarily flat surface of Racetrack Playa, far from the edges of the surrounding mountains are boulders, some up to 320 kg (705 lb), and smaller pieces of rock. Stretching behind many of the stones you'll see grooved trails. Some are short, some long, some straight, some curvy. Clearly, these rocks must gouge furrows as they slide across the playa surface, yet no living person has ever witnessed these amazing rocks move! What makes these rocks skid as

much as 880 meters (2890 ft.) across the flat playa surface? Recent scientific sleuthing provides some answers.

<u>The playa surface</u>

Racetrack Playa is an almost perfectly flat dry lake bed nestled between the Cottonwood Mountains to the east and the Last Chance Range to the west. During periods of heavy rain, water washes down from nearby mountain slopes onto the playa, forming a shallow, short-lived lake. Under the hot Death Valley sun, the thin veneer of water quickly evaporates, leaving behind a layer of soft mud. As the mud dries, it shrinks and cracks into a mosaic of interlocking polygons.

<u>What the trails tell</u>

The shallow furrows and rounded, levee-like ridges that form the "trails" of the sliding rocks are clues that suggest the stones move only when the playa surface is soft and wet. Anyone who has ever slipped in a mud puddle knows that water-drenched mud makes an incredibly slick, low-friction surface. Once an object is put into motion on a very low-friction surface, it may move quite a distance before it stops. Some researchers thought that gravity was the culprit and that the rocks might be sliding downhill on a very, very shallow slope. However, this hypothesis was discarded when it was shown that the northern end of the playa is several centimeters higher than the southern end, so many rocks actually move uphill! Without any witnesses to the sliding rock phenomenon, it's been difficult to prove exactly what makes Racetrack rocks move. Researchers have also been hampered because traces left behind by sliding rocks are short-lived. Small rock trails may be washed away by a single rain storm. Even trails gouged into the playa by the largest boulders last no more than seven years.

<u>A high-tech solution</u>

Researchers noticed that although some trails change direction, most trend in a generally southwest to northeast direction. This is consistent with the direction of the prevailing winds. Could wind really provide the force that sets the largest Racetrack Playa boulders in motion? One recent study used a high-tech approach in an attempt to solve the mystery of the sliding rocks. Detailed measurements using Global Positioning System (GPS) instruments were made of over 160 sliding rocks and their trails.

After analyzing their rock trail map, researchers found that the longest, straightest trails are concentrated in the southeastern part of Racetrack Playa. In this area, wind is channelled through a low point in the mountains, forming a natural wind tunnel. In the central part of the playa two natural wind tunnels focus their energy from different directions. It's in this area that rock trails are the most convoluted. So the evidence suggests that strong gusts of wind and swirling dust devils, in combination with a slick playa surface may set even the heaviest the rocks in motion. Off they go, scooting along downwind until friction slows them down and they come to rest. There the stones wait for the next time when slippery mud and wind spur them into action again.

STOP 5 — Road sign at alluvial fan ~1 mile south of Titus Canyon

Questions to answer

Sketch this alluvial fan and show areas of more and less desert varnish development. Label the active lobe of this fan.

What is alluvium? How does the alluvium differ on the west and east sides of Death Valley?

What is desert varnish?

Day 3 — Sunday, March 24

STOP 6 — Zabriske Point

Unearthly world-Death Valley's badlands

Looking out from Zabriskie Point, you are surrounded by yet another of Death Valley's forbidding, almost unearthly, desert landscapes. These are badlands. Everywhere you look, you see bone-dry, finely-sculpted, golden brown rock. Only the sparsest vegetation can survive in this intricately carved terrain. What processes work to form this spectacular scenery? Surprisingly enough, the story of Death Valley's badlands begins and ends with water.

A muddy beginning

At Zabriskie Point, the badlands are developed on a mudstone foundation (Furnace Creek Formation). Fine-grained sediments (silt and clay) were deposited in one of Death Valley's prehistoric lakes, then were buried by still more sediment, and finally compressed and weakly cemented to form the soft rock called mudstone. If you take a microscopic look, you would see that the clay minerals in the mudstone are shaped like tiny plates. These plates act like roof shingles, preventing water from penetrating the surface. The combination of the almost impermeable mudstone and Death Valley's scant rainfall makes plant growth and soil development nearly impossible.

Water: the continuing sculptor

Now, back to the role of water. At Death Valley rainfall is intense but sporadic. Very long periods of drought are punctuated with drenching downpours. With so little vegetation and no soil, when water reaches the ground, there is nothing to absorb the rainfall. During Death Valley's rain showers, water hits the surface and immediately begins to rush down the steep slopes, sweeping along particles of loosened mud. The rate of erosion can be incredible! Tiny rills are quickly carved into the soft mudstone. The more water in the downpour, the more rills are needed to carry the water away. Rills cut deeper to form gullys. Badlands are the ultimate result-nature's way of efficiently moving lots of water quickly.

STOP 7 — Natural Bridge

Questions to answer

What is fault gauge or fault breccia?

Sketch this low angle normal fault. Include arrows showing the direction of displacement and label the ages of the rocks on either side of the fault.

STOP 8 — Badwater

The oldest rocks - Relics of the Precambrian world in Death Valley

The steep face of the Black Mountains is made up of some of the oldest rocks in Death Valley. These 1.7 billion-year-old Precambrian rocks are the remnants of an ancient volcanic mountain belt with flanking deposits of mud and sand. About 1.8-1.7 billion years ago, these volcanic and sedimentary rocks were severely metamorphosed—altered, recrystallized, and partially remelted by the Earth's internal heat and by the load of overlying younger rocks. The original rocks were transformed to contorted gneiss, making their original parentage almost unrecognizable. 11 million years ago, these venerable rocks were injected with magma that solidified to form the Willow Spring pluton. The diorite to gabbro composition of the Willow Spring pluton blends well with the dark Precambrian gneiss, so you'll have to look carefully to see the contact between the two rock types. The steep face of the Black Mountains rises from the valley floor. Few visitors realize that these mountains are made up of some of Death Valley's oldest rocks.

Salty remnants

Beneath the dark shadows of the Black Mountains, a great, extraordinarily flat expanse of shimmering white spreads out before you. You are at Badwater, at -282 feet it is the lowest spot in the Western Hemisphere. Step onto the trail and you'll see that the white expanse is made up of billions of crystals of almost pure table salt! As your feet crunch along the trail that leads onto the valley floor, you are walking on the salty remnants of a much greener, lusher time in Death Valley's relatively recent past.

Not long ago, during the Holocene (about 2000-4000 years ago), the climate was quite a bit wetter than today. So wet that streams running from nearby mountains gradually filled Death Valley to a depth of almost 30 feet. Some of the minerals left behind by earlier Death Valley lakes dissolved in the shallow water, creating a briny solution.

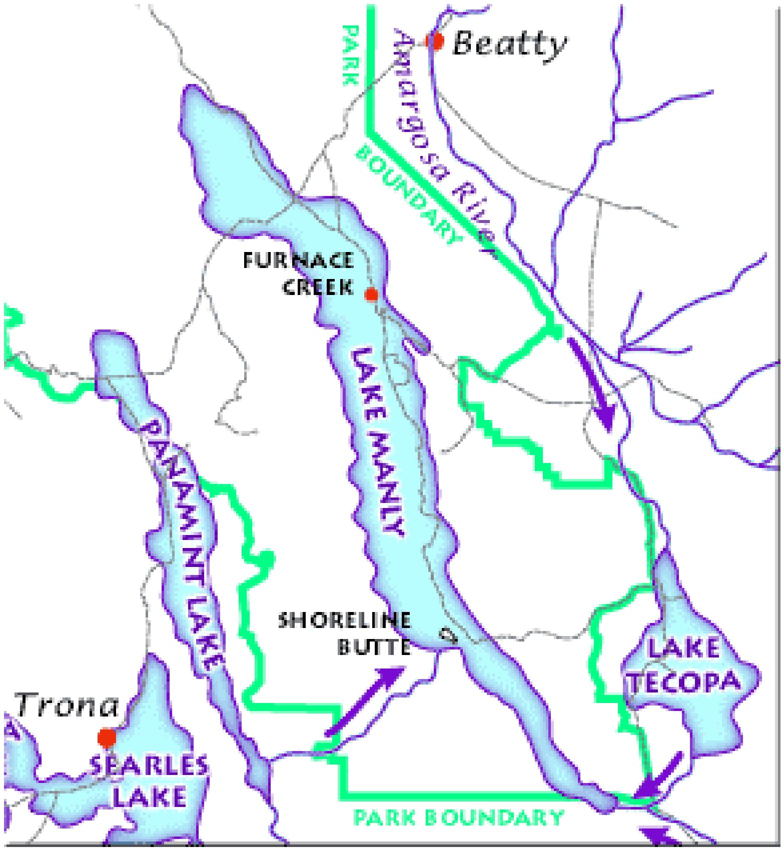
The desert returns

The wet times didn't last. The climate warmed and rainfall declined. The lake began to dry up. Minerals dissolved in the lake became increasingly concentrated as water evaporated. Eventually, only a briny soup remained, forming salty pools on the lowest parts of Death Valley's floor. Salts (95% table salt - NaCl) began to crystallize, coating the surface with a thick crust about three to five feet thick. Here at Badwater, significant rainstorms flood the valley bottom periodically, covering the salt pan with a thin sheet of standing water. Each newly-formed lake doesn't last long though, because the 1.9 inch average rainfall is overwhelmed by a 150-inch annual evaporation rate. This, the nation's greatest evaporation potential, means that even a 12-foot-deep, 30 miles long lake would dry up in a single year! While flooded, some of the salt is dissolved, then is redeposited as clean, sparkling crystals when the water evaporates.

Questions to answer

Sketch the development of a salt saucer starting with polygonal cracks.

STOP 9 — Drive toward Shoreline Butte (several stops along the way)



Ice age Death Valley

During the Pleistocene ice ages, climate cooled and became wetter, glaciers grew in the Sierra Nevada Mountains. Rivers flowed into what are now dry deserts and lakes formed in many of down-dropped valleys of the Basin and Range. Shoreline Butte reveals evidence of a large lake, Lake Manly, that filled what is now the driest desert of the United States. Imagine a time during the ice age, between 186,000 - 128,000 years ago, when Shoreline Butte was an island in a lake nearly 100 miles long and 600 feet deep! Lake Manly and other Pleistocene lakes of the Death Valley region. Note the location of Shoreline Butte at the south end of the Valley.

Waves left their mark

Look carefully and you can see several horizontal lines carved into the northeast flank of Shoreline Butte. These lines are actually flat terraces called strandlines that are cut into the hillside by waves battering the shore. It takes some time for waves to gnaw away terraces like these, so these benches provide records of times when the lake level stabilized long enough for waves to leave their mark on the rock. The highest strandline is one of the principle clues that geologists use to estimate the depth of the lake that once filled Death Valley. Shorelines of ancient Lake Manly are preserved in several parts of Death Valley, but nowhere is the record as clear as at Shoreline Butte. Several lakes have occupied Death Valley since the close of the

Pleistocene Epoch 10,000 years ago, but these younger lakes were quite shallow compared to Lake Manly.

Questions to answer
How does a wine glass canyon form?

Sketch this wine glass canyon and show where the range-bounding fault is located.

STOP 10 — Split Cinder Cone

Birth of a cinder cone
Less than 300,000 years ago, a chamber filled with solid crystals and searing molten basaltic rock simmered beneath Death Valley. Magma rose toward the surface, following weaknesses in the Earth's crust. Nearing the surface, the black lava encountered the fractured earth of the Death Valley Fault zone. Lava quickly made its way through the fault-weakened rock and burst out of the valley floor as a fiery fountain of scorching lava and gas. Lava fountains threw blobs of molten basalt hundreds of feet into the air. Although lava erupted at 1200°C (2200°F), most of the molten, airborne globs cooled and solidified to form cinders before reaching the ground. Most cinders fell very near the central vent, building a small cone. What did the initial eruption of Split Cinder cone look like? The image at left of a fountain of fire erupting at Pu`u `O`o cinder cone, Hawaii might help you imagine it.

Cinder by cinder
Most cinders fell very near the central vent. Layer upon layer of volcanic ejecta were deposited, building a higher and steeper cinder cone. Eventually the cone became so steep that the flanks collapsed under their own weight. The collapsing cinders came to rest when the sides reached just the right steepness to keep them stable. This angle, usually about 35°, is called the angle of repose.

Every pile of loose particles has a unique angle of repose, depending upon the material it's made from. Because all volcanic cinders have almost the same angle of repose, cinder cones everywhere develop nearly identical shapes with nice, straight sides rising at an angle of about 35° from the ground. Cinder cones are commonly very symmetrical. Split Cinder Cone may have once looked very much like Pu`u ka Pele cinder cone at right. The birth of this small cinder cone is only part of it's intriguing story. How did this once-symmetrical cone split into two pieces? You'll remember that the basaltic lava that built Split Cinder Cone used rock weakened by a branch of the Death Valley Fault zone. Split Cinder Cone was probably built over a very short time; its birth and death probably spanned less than a few decades. Although the little volcano lay quiet, the Death Valley Fault zone continued to move as it had for almost three million years. The wrenching force of this very active fault pulled one part of the volcano to the southeast, while the other part was pulled toward the northwest. Eventually, the crust could no longer resist the wrenching motion of the fault and the cinder cone began to be ripped into two pieces. Each time the fault moved, the two sides of the cone moved farther apart.

This type of side-by-side fault movement is referred to as strike-slip. Because one side of the cinder cone is being moved to the right, relative to the other side, this fault is a right-lateral strike slip fault. The upper part of the once symmetrical cone has been moved to the right 300 feet (91 meters) relative to the lower part. Features like Split Cinder Cone can be used to determine the rate of movement along the Death Valley Fault zone. The volcanic rock from which the cinder cone is made can be radiometrically dated. Once geologists know the age of a feature cut by a fault, and the distance the two parts have moved apart, the rate of movement on each branch of the fault can be estimated.

Questions to be answered

Label on the aerial photo below the sense on movement on the strike-slip fault that has split this small cinder cone:

STOP 11 — Devil's Golfcourse

<u>Mineral music</u>
It’s an early summer morning. The temperature is rising fast. The air is completely still and the quiet is profound. But, listen carefully and you'll hear a sounds like tiny pops and pings. Bend your ear to the ground and the sound grows louder. The musical sound of literally billions of tiny salt crystals bursting apart as they expand and contract in the heat provides the backdrop for this salty story.

Lakeside property
Not long ago, about 2000-4000 years ago during the Holocene, the climate was quite a bit wetter than today. It was so wet that water gradually filled Death Valley to a depth of almost 30 feet. The ancient peoples of Death Valley must have enjoyed centuries of abundant food in their lakeside homes.

The desert returns
These good times didn't last, however. The climate warmed, rainfall declined, and the shallow lakes began to dry up. Minerals dissolved in the lake became increasingly concentrated as water evaporated. Eventually, only a briny soup remained, forming salty pools on the lowest parts of Death Valley’s floor. Salts (95% table salt - NaCl) began to crystallize, coating the muddy lakebed with a three to five feet thick crust of salt.

Pinnacles
While the saltpan at Badwater periodically floods, then dries, Devil's Golf Course lies in a part of the Death Valley salt pan that is several feet above flood level. Without the smoothing effects of flood waters, the silty salt at Devil's Golf Course grows into fantastic, intricately detailed pinnacles. The pinnacles form when salty water rises up from underlying muds. Capillary action draws the water upward where it quickly evaporates, leaving a salty residue behind. The pinnacles grow very slowly, perhaps as little as an inch in 35 years. Wind and rain continually work to erode and sculpt the salty spires into an amazing array of shapes.

Questions to answer
What does Devil's Golfcourse taste like? Why?

STOP 12 — Ventifact Ridge

Day 4 — Monday, March 25

STOP 13 — Artist's Pallette

Technicolor terrain
The face of the Black Mountains along Artist’s Drive is made up of the multicolored rock of the Artist Drive Formation. Aprons of pink, green, purple, brown, and black rock debris drape across the mountain front, providing some of the most scenic evidence of one of Death Valley’s most violently explosive volcanic periods.

Roller coaster ride
The curvy, one-way, one lane Artist's Drive leads you up to the edge of the Black Mountains. Artist's Drive rises up to the top of an alluvial fan fed by a deep canyon cut into the mountain. As you make your way up to the mountain face you'll dip up and down, roller coaster-like as the road dips into ravines carved into the fan by Death Valley's occasional, but intense flash floods. The narrow road runs high up onto the fan, with views of the strikingly white salty floor of Death Valley in the distance.

STOP 14 — Golden Canyon

A walk up Golden Canyon
You'll have to put on your virtual walking shoes for this field trip as we'll be venturing about a mile into Golden Canyon. This trail provides a beautiful window into the heart of Death Valley. We'll start the mouth of the canyon at 160 feet (49m) below sea level, and gradually climb uphill about 300 feet (91m) within the first mile. Looking out toward the parched basin of Death Valley, it's hard to believe that the force of moving water shapes the intricately carved canyon you are about to enter. As you look at the rocks and landforms around you, what evidence do you see of the work of water?

A view from the canyon mouth
At the entrance to Golden Canyon you have a sweeping view across Death Valley toward the Panamint Mountains. Rising nearly halfway up the steep mountain front of the Panamints are great aprons of rocky debris that spread out toward the valley floor, partially burying this majestic range in its own sediment. If you look closely, you'll notice that this apron of sediment is actually composed of many individual, fan-shaped deposits, each radiating from a deep canyon cut into the mountain front. Death Valley is world-famous for the incredible size, shape, and exposure of these alluvial fans.

At the mouth of Golden Canyon, you are standing on another alluvial fan. Here you can see evidence of how past floods have shaped this fan. Look closely at the rocks nearby, including those that you are standing on. What do you notice about their size? You may notice that large boulders and cobbles have been deposited near the entrance of the canyon. Try to imagine the force of the floods required to move some of these larger boulders!

Flash floods emerging from the narrow, confining walls of Golden Canyon suddenly spread out at the canyon mouth into the open valley below. As the torrent slows down, the water is no longer able to carry its load of sediment, and rapidly deposits a chaotic mixture of poorly sorted debris on the alluvial fan. Farther downslope toward the valley floor, the sediment becomes progressively smaller.

An Abrasive Situation
Not long ago, a paved road wound through Golden Canyon. What happened to the pavement here? In February 1976, a four-day storm dropped 2.3 inches (5.7cm) of rain at Furnace Creek. On the morning of the fourth day, a violent downpour sent a tremendous surge of water, rock, and mud to flow through these narrows. Such sediment-laden floods work like sandpaper, cutting

away and undermining the rocky canyon walls as they speed through the canyon. Pitted against the force of Death Valley's flash floods, Golden Canyon's paved road didn't stand a chance. At this spot, the canyon is especially narrow, so flood waters are constricted and the speed increases. This increase in force is similar to the effect of placing your thumb over the mouth of a garden hose to constrict the flow of water. If you look closely at the walls of the canyon, you will see a coating of mud that indicates the depth of the water that once moved through these narrows. Nearly all of the rock debris that you observed near the mouth of the canyon has been transported by flash floods. The narrow, deep shape of the side canyons of Death Valley indicate that the uplift of the mountains is relatively recent, consistent with other evidence that the landscape of Death Valley is quite young. These relatively rare flood events are so dramatic that their effects can even be noticed within the brief span of a human lifetime. Such geologic forces have been carving the canyons of Death Valley for millions of years, constantly sculpting and changing this desert landscape.

<u>Ancient Alluvial Fans</u>
Look closely at the rock exposed in the canyon walls. Notice that the layers are composed of rocky debris that ranges in size from boulders to fine-grained sand and silt. Where have you seen similar sediment? These layers of poorly sorted conglomerate were deposited six million years ago on an ancient alluvial fan. The loose material was subsequently buried and cemented into solid rock known as the Furnace Creek Formation. More recent uplift and erosion have exposed them to view.

At the time that these rock layers were being deposited, Golden Canyon and the modern basin of Death Valley had not yet formed. What was the source for the material that composes these ancient alluvial fans? These layers of conglomerate become thinner and disappear further to the east. The type of rock material that composes these conglomerates also indicates that the sediment came from the west. It’s thought that the source was part of the bedrock of the Panamint Mountains; the modern counterparts of the ancient fans you are looking at are the gigantic fans of the Panamint Mountains that you observed from the mouth of Golden Canyon. The narrow, deep shape of the side canyons of Death Valley indicate that the uplift of the mountains is relatively recent, consistent with other evidence that the landscape of Death Valley is quite young. These relatively rare flood events are so dramatic that their effects can even be noticed within the brief span of a human lifetime. Such geologic forces have been carving the canyons of Death Valley for millions of years, constantly sculpting and changing this desert landscape.

<u>A Restless Earth</u>
As you look up and down the canyon, what do you notice about the orientation of the rock layers? A basic principle of geology states that sedimentary layers are horizontal when they are deposited. Why do these layers tilt so steeply now? Their steep dip is more evidence of the dynamic geologic forces that have affected the Death Valley area. These tilted rock layers are part of one limb of a giant fold that formed as a result of the crustal stretching that has shaped the Death Valley landscape.

An Ancient Lake

Walking up Golden Canyon involves traveling through an ancient, changing landscape. It's time to again look closely at the rocks exposed in the canyon walls. You'll notice that the conglomerate layers composed of large boulders have given way to a different kind of rock. In contrast, these light-colored deposits are comprised of very small particles of silt and mud. Such fine-grained sediment is typical of debris that is deposited at the bottom of a calm lake. These mudstones are thought to be of similar age to the lower conglomerate. So the boundary between these different rock layers represents a change in the ancient landscape rather than a change in time or climate-you have walked across the alluvial fan and into a lake!

Ripples in Time

Look closely at the surface of the tilted rock layers in this area. Rather than being perfectly flat, some of the surfaces have an undulating pattern. If you are familiar with a lake or sea shore environment, perhaps you have observed similar ripples shaped in the sand. The ripple marks that you see here are further evidence of the ancient lake that once occupied this area; they were created by the movement of water over the loose sediment deposited at the bottom of the lake. The preservation of their delicate pattern required rapid burial beneath another layer of sediment. In other places in Death Valley, fascinating fossil footprints of large mammals have been found in lake deposits of similar age.

Evaporite Minerals

New mineral deposits are currently forming on the floor of Death Valley. Water carries dissolved sodium, chlorine, sulfur, calcium, boron and other elements that have been eroded from the surrounding mountains. The arid climate rapidly evaporates water from the valley floor, concentrating these elements into new minerals such as halite (table salt), gypsum, and borax. Today, the salt flats near Badwater or the Devil's Golf Course are excellent places to observe these interesting formations. At this point in the your hike, you can see deposits of white minerals within the ancient lake deposits. These evaporite minerals formed in the past due to processes similar to those that are currently working on the floor of Death Valley.

Badlands

In the Golden Canyon and Zabriskie Point area, these fine-grained sedimentary rocks have been intricately sculpted to form one of Death Valley's many spectacular landscapes. Plants are very rare here and are usually found only in the canyon washes. Why are these hills so barren? The extreme climate is not the only answer. The story of these 'badlands' begins and ends with water. The ancient lake deposits through which you are walking are quite impermeable because of the clay and mud that they contain. Instead of soaking into the ground, rain quickly runs downhill, washes away any topsoil, and prevents plants from taking root. The combination of impermeable rocks, steep and barren slopes, and sporadic but sometimes intense rainfall leads to high surface run-off. The formation of the numerous gullies and ravines that characterize the badlands is simply Nature's way of efficiently removing so much excess water.

It's All Downhill

In addition to water, the force of gravity is working to carry rock material down to lower elevations. The first step in this process is the fracturing of the rock that occurs mainly because of regional stresses that are affecting the area. Physical and chemical weathering then attack the rock along these zones of weakness. Because of mild winters in Death Valley, freezing and thawing of water is less important here than in colder climates. However, deposits of salt concentrated within the cracks will grow and expand and can further break the rock apart. As the rock is broken down into smaller pieces, water and gravity are able to transport them more easily.

<u>The Red Cathedral</u>
Notice the change from the relatively gentle yellow slopes in the foreground to the steeper red cliffs beyond. This change in topography is due to a difference in rock type. Being more resistant to erosion, the rocks of the Red Cathedral form steep cliffs. These cliffs are composed of conglomerate similar to that exposed near the mouth of Golden Canyon. The conglomerate of Red Cathedral is also interpreted to be deposits of ancient alluvial fans. The red color is produced by the oxidation of iron, similar to the process that forms rust.

STOP 15 — Salt Creek

STOP 16 — Mesquite Flat sand dunes

<u>Sinuous sculptures of sand</u>
Death Valley's most accessible sand dunes are just a few miles from Stovepipe Wells. Tucked into Mesquite Flat in the north end of the park, these dunes are nearly surrounded by mountains on all sides. The primary source of the dune sands is probably the Cottonwood Mountains which lie to the north and northwest. The tiny grains of quartz and feldspar that form the sinuous sculptures that make up this dune field began as much larger pieces of solid rock.

<u>Breaking down bedrock</u>
Even in this parched climate, the effects of weathering take their toll on rock. High in the mountains, which receive quite a bit more moisture than the valley floor, bedrock is broken down into blocks. Flash floods, speeding storm waters that rush down from bare mountain slopes during intense desert storms, grind the rock to smaller pieces as it hurtles toward the valley floor. Eventually large blocks may be jostled around enough to be broken into sand-sized grains. Sand and other sediment usually ends up deposited on alluvial fans or on the valley floor. In Death Valley's climate, it doesn't take long for the sediment to dry out and become exposed to the prevailing northwest winds.

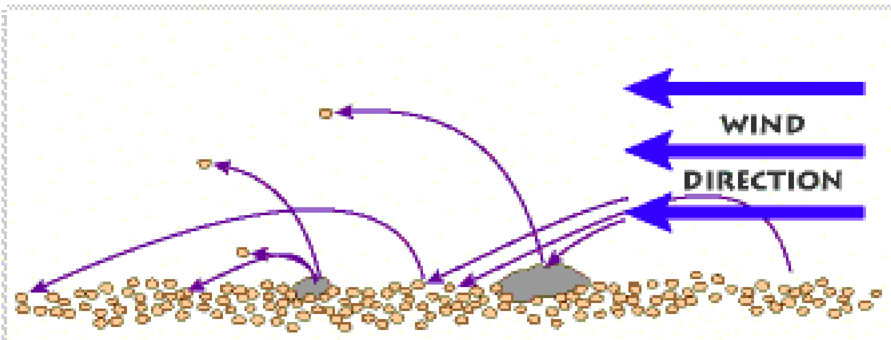
<u>Sand on the move</u>
All it takes is a bit of breeze (16 kilometers/hour or 10 miles/hour) to whisk fine sand into motion. The grains may be suspended in the air, bounce along, or nudged along by impacts from bouncing grains, depending upon the grain size and wind strength. Almost all blowing sand remains within a meter of the surface as it migrates.

<u>Ripples and dunes</u>
Once sand begins to pile up, ripples and dunes can form. Wind continues to move sand up to the top of the pile until the pile is so steep that it collapses under its own weight. The collapsing sand comes to rest when it reaches just the right steepness to keep the dune stable. This angle, usually

about 30-34°, is called the angle of repose. Every pile of loose particles has a unique angle of repose, depending upon the properties of the material it's made of.

The repeating cycle of sand inching up the windward side to the dune crest, then slipping down the dune's slip face allows the dune to inch forward, migrating in the direction the wind blows. As you might guess, all of this climbing then slipping leaves its mark on the internal structure of the dune. The sloping lines or laminations you see are the preserved slip faces of a migrating sand dune.

Saltation



Dune formation

STOP 17 — Mosaic Canyon

The entrance to Mosaic Canyon appears deceptively ordinary, but just a 1/4 mile walk up the canyon narrows dramatically to a deep slot cut into the face of Tucki Mountain. Smooth, polished marble walls enclose the trail as it follows the canyon's sinuous curves.

Following faults
The canyon follows faults that formed when the rocky crust of the Death Valley region began stretching just a few million years ago. Running water scoured away at the fault-weakened rock, gradually carving this remarkable canyon. Periodic flash floods carry rocky debris (sediment) eroded from Mosaic Canyon and the surrounding hillsides toward the valley below. At the canyon mouth water spreads out and deposits its sediment load, gradually building up a large wedge-shaped alluvial fan that extends down toward Stovepipe Wells.

Making marble
Mosaic Canyon's polished marble walls are carved from the Noonday Dolomite and other Precambrian carbonate rocks. These rock formation began as limestone deposited during Late

Precambrian (about 850-700 million years ago) when the area was covered by a warm sea. Later addition of magnesium changed the limestone, a rock made of calcium carbonate, to dolomite, a calcium-magnesium carbonate. The dolomite was later deeply buried by younger sediment. Far below the surface, high pressure and temperature altered the dolomite into the metamorphic rock, marble.

A close-up look at the marble walls of Mosaic Canyon reveals intricately folded layers. The relatively recent uplift of Death Valley's mountian ranges and subsequent erosion have exposed these metamorphic rocks. Mosaic Canyon was named for a rock formation known as the Mosaic Breccia. Breccia is the Italian word meaning fragments. This formation is composed of angular fragments of many different kinds of parent rock, and it can be seen on the floor of the canyon just south of the parking area.

Day 5 — Tuesday, March 26

Pack up camp
Return to SFSU in a.m.

Eon	Era		Millions of years ago	Events in Death Valley
			now	
Cenozoic	Quaternary	Holocene	.01	Alluvial fans, playas, salt pan, dunes form. Continued faulting. Ubehebe volcanic field erupts. 30 ft. deep lake fills valley.
		Pleistocene	1.6	Lake Manly fills valley to 600 ft depth. Continued faulting.
	Tertiary	Pliocene	5.3	Opening of modern Death Valley. Alluvial fans spread into valley Sierra Nevada mountains rise. Rainshadow creates desert.
		Miocene	23.7	Volcanism throughout region. Thick ash deposits accumulate. Onset of major extension in Death Valley region. Basin & Range topography begins to develop.
		Oligocene	36.6	River and lake deposits in local basins. Relatively subdued terrain. UNCONFORMITY
		Eocene	57.8	Erosional smoothing of Death Valley highlands to low plains.
		Paleocene	66.4	
Mesozoic	Cretaceous		144	Pluton intrusion, thrust-faulting and regional uplift follows in Death Valley area. Dune sands and dinosaurs further inland.
	Jurassic		208	Sea withdraws from D.V. area as Sierra Nevada becomes a chain of volcanoes.
	Triassic		245	Shallow marine deposition UNCONFORMITY
Paleozoic	Permian		286	Sporadic influxes of mud alternate with carbonate shelf deposits
	Pennsylvanian		320	
	Mississippian		360	Long period of sediment deposition on stable, passive continental margin. Tropical carbonate platform sedimentation dominates with numerous intervals sea withdrawal and platform emergence. Deposition of nonmarine sediment and partial erosion of marine deposits common during emergence.
	Devonian		408	
	Silurian		438	
	Ordovician		505	Great sheet of pure sand (Eureka Quartzite) briefly interrupts limestone and dolomite accumulation during the Ordovician.
	Cambrian		570	Thick wedge of sediment (siliclastic) deposited on new continental margin Death Valley near equator.
Precambrian	Proterozoic		2500	Continental rifting Glacio-marine deposition. Region covered by shallow to deep seas. Marine deposition. Rapid uplift & erosion UNCONFORMITY Volcanic mtn. chain rocks suffer regional metamorphism
	Archean		3800	No older rocks than 1800 are known in the Death Valley region.
	Hadean		4550	