DEPARTMENT OF PLANETARY SCIENCES
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PTYS 594A: PLANETARY GEOLOGY FIELD PRACTICUM

Death Valley, California

29 March - 2 April 2006

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cover credit: photo of Death Valley from mikelevin.com

PTYS 594A: PLANETARY FIELD GEOLOGY PRACTICUM

Death Valley 29 March - 2 April 2006

<u>Wednesday 29 March:</u>

7:00 am   Meet at LPL loading dock.

8:00 am   Depart LPL. Drive N on Cherry to Speedway, proceed W to I-10, take I-10 W towards Phoenix. In Phoenix take AZ 101 Loop N (exit 133B) to US 60/Grand Ave. (exit 11). Take 60 W toward Wickenburg. ~7 miles after the junction with 74 turn left into the Hassayampa River Preserve (near mile marker 114).

11:30 am Lunch at Hassayampa River Preserve. Observe pupfish in creek?

12:30 pm Continue N on US 60 to Wickenburg. Take 89 to US 93 N/W toward Kingman. Join I-40 W to Kingman. In Kingman take Stockton Hill Road (Exit 51) N out of town toward Red Lake Playa.

4:30 pm   **John Keller will talk about Red Lake Playa and giant dessication polygons.**

5:30 pm   Continue N on Stockton Hill Road to Pierce Ferry Road. Turn right, drive 5 miles to sharp left bend in road, turn right.

6:00 pm   Camp in the Joshua Tree forest (staying off the Hualapai Indian Reservation). **Eric Palmer -- fireside chat on Gold Basin meteorite strewn field**

<u>Thursday 30 March:</u>

8:00 am   Break camp. Drive W on Pierce Ferry Road to US 93 and turn N toward Las Vegas.

10:00 am Arrive Hoover Dam. Park in lot on E side of the dam, walk out to overlook. **David Choi will talk about Hoover Dam.**

10:30 am Continue on US 93. Exit to NV 146 W at Henderson (exit 61). Follow I-215 W to I-15 (exit 10B) travel S to NV 160/Blue Diamond Rd. (exit 33) towards Pahrump. Bear right on Blue Diamond Rd. to Spring Mtn Ranch State Park or beyond to Red Rock Canyon National Conservation Area.

11:30 am Lunch stop.

12:30 pm Return to NV 160. Take NV 160 W through Pahrump, turn W onto NV 372, which becomes CA 178. At Shoshone turn N on CA 127, travel 2 miles then turn W on CA 178 and into the southern end of Death Valley. Drive N on Badwater Rd.

3:30 pm   Stops along Badwater Rd:
Overlooking Shoreline Butte, **Jason Barnes will talk about Pleistocene lakes and the history of Lake Manly.**
Near Mormon Point, **Colin Dundas will talk about the gravel fans**
Robin Van Auken will talk about desert pavement
Maki Hattori will talk about desert varnish
At Badwater, **Naydene Hays will talk about the prominent turtlebacks.**

6:00 pm   Camp at Furnace Creek, Sunset, or Texas Spring campground (or Mesquite Spring if we're ahead of schedule).

Friday 31 March:

8:00 am   Break camp, continue N on CA 190 to Ubehebe Crater where **Diana Smith will talk about the crater and phreatic explosions.**

10:30 am Drive S on dirt road to Racetrack Playa, stopping along the way for **Veronica Bray will talk about the Tin Mountain landslide** and **Mike Bland will talk about the chaos in the rocks of the Tucki Mountains.**

12:30 pm Lunch stop at Racetrack Playa, where **Brian Jackson will talk about the playa and the mystery of the stones.**

2:30 pm   Return along dirt road to Grapevine and head S on CA 190.

4:30 pm   Stop at Salt Creek where **Catherine Neish will talk about the desert pupfish.**

5:00 pm   Continue S on CA 190, park at the entrance to Artists Drive, and walk to Ventifact Ridge (W side of Badwater Rd.), where **Eve Berger will talk about ventifacts.**

5:30 pm   Drive N to Mushroom Rock, near the exit to Artists drive, where **Yuan Lian will talk about salt weathering.**

6:00 pm   Camp (Furnace Creek, Sunset, or Texas Spring campground)

Saturday 1 April:

8:00 am   Break camp. Drive S on CA 190 to Badwater Rd./CA 178 and continue S to Devil's Golf course. Walk out onto the salt flat where **Kathryn Gardner will talk about evaporite formation and the zonation of evaporites in Death Valley** and **Kevin Stube will talk about microbial life in hypersaline environments.**

10:00 am Continue S on Badwater Rd/CA 178, If it is in good condition, take the dirt road (Harry Wade Rd.) to CA 127 and turn N on CA 127 for a few miles to the snowball Earth site. Otherwise follow CA 178 to CA 127 and head S ~20 miles to the site.

11:30 am **Curtis Cooper and David Minton will talk about the snowball Earth theory and the evidence found in this area.** Continue discussion over lunch.

2:00 pm   Drive S on CA 127 to Baker and take Kelbaker Rd into Mojave National Preserve to Kelso and on to the Kelso dunes.

4:00 pm   **John Moores will talk about the Kelso dunes** and experimentation can ensue.

5:30 pm   Camp in Mojave National Preserve. (If we're running ahead of schedule we could push on to Amboy crater and camp in Joshua Tree on Saturday night.)

Sunday 2 April:

8:00 am   Break camp. Continue S on Kelbaker Rd. past I-40 to the National Trails Highway, drive W a few miles to Amboy Crater. Hike over lava field to the cinder cone.

9:00 am   **Maria Banks will talk about the crater and cinder cones.**

10:00 am Drive E on the National Trails Highway and turn S on Amboy Road, following Amboy road into Twentynine Palms. Turn S on Utah Trail and follow it into Joshua Tree National Park, where it becomes Park Blvd. Turn left onto Pinto Basin Rd and follow it through the park to Cottonwood Springs Rd., which exits the south of the park and leads to I-10. Stop for lunch either before leaving the park or along I-10.

12:00 pm Take I-10 E to Tucson.

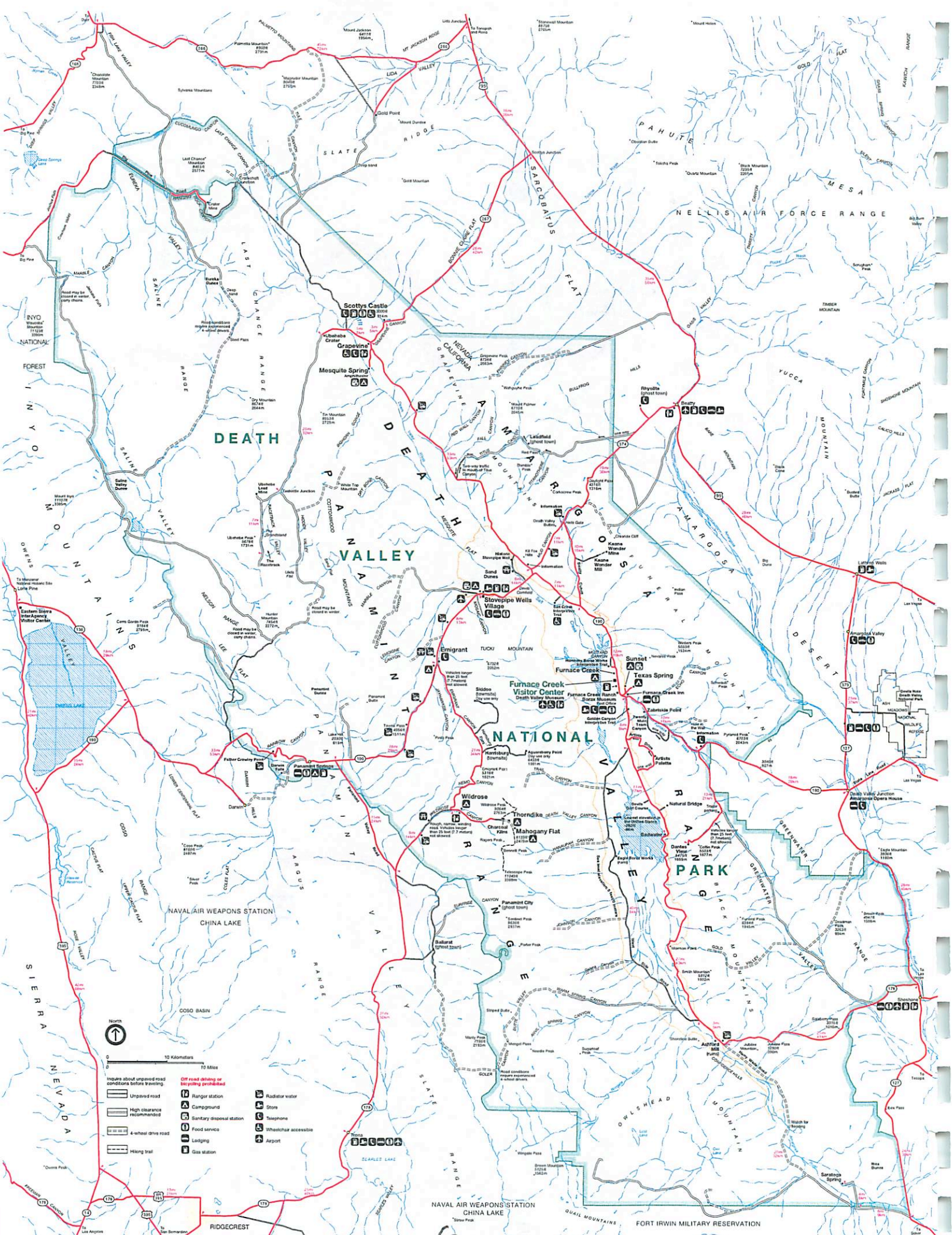7:00 pm   Arrive Tucson, unpack and return vehicles.

Day 1

Map 1 (Arizona overview):

Grand Canyon Natl Park
Hopi Indian Reservation
93
Mount Tipton 7148 ft
Mount Floyd 7441 ft
Kendrick Peak 10418 ft
Humphreys Peak 12633 ft
Bill Williams Mountain 8800 ft
Hualapai Peak 8417 ft
Kaibab Natl Forest
40
ARIZONA
Pine Peak 7225 ft
Coconino Natl Forest
Mingus Mountain 7815 ft
Chevelon Butte 6945 ft
Crossman Peak 5100 ft
Granite Mountain 7295 ft
Prescott Natl Forest
Agua Fria Natl Mon
17
North Peak 7449 ft
Mazatzal Peak 7903 ft
CALIFORNIA
Pikes Peak 3177 ft
Mount Ord 7128 ft
Black Mesa 3832 ft
Twin Peaks 3382 ft
17
East End 4067 ft
McDowell Peak 4034 ft
10
10
Phoenix
17
Pass Mountain 3312 ft
Signal Peak 7812 ft
Kofa Natl Wildlife Refuge
Quartz Peak 2177 ft
85
Montezuma Peak 4354 ft
Castle Dome Peak 3788 ft
8
10
Crozier Peak 4273 ft
8
Yuma
Newman Peak 4506 ft
Desert Peak 2608 ft
Javelina Mountain 3912 ft
10
Customs Station
Cimarron Peak 4108 ft
Tucson
Cabeza Prieta Natl Wildlife Refuge
Organ Pipe Cactus Natl Mon
Kitt Peak 6875 ft
0 ———— 40.64 mi

Map 2 (Phoenix metro):

Sun City West
19 20 24 25 gf
51
32 34
Surprise
W BELL RD
gf
22
17
26 28
31
36 L
38
Youngtown
Sun City
17
E BELL RD
39
40
Peoria
10 12
N 51ST AVE
8 9
E SHEA BLVD
7 ft gf
W NORTHERN AVE
Glendale
17
gFL
44
45 43
Luke Air Force Base
g
Paradise Valley
46
Litchfield Park
51
Scottsdale
17
4 135 gf
201
124 126 128
Tolleson 3
Phoenix
AZ-202 LOOP
87
Goodyear
129
85
133 136 140
1 Bac
Tempe
Mesa
W BUCKEYE RD
17
195
IL
60
60 gf
196
143
E BASELINE RD
S 51ST AVE
S RURAL RD
AZ-101 LOOP
56
Gilbert
10
57
South Mountain Park
10
Chandler
58
Estrella Mountain Reg Park
60
61
S MARICOPA RD
164
W BELTLINE RD
Butterfly Mountain 4119 ft
Sierra Estrella Wilderness
E RIGGS RD
267
Montezuma Peak 4354 ft
ARIZONA
587
347
175
0 ———— 5.93 mi

Map 3 (Kingman area):

Chloride
ARIZONA
66
93
JAGERSON AVE
Kingman Airport
68
Golden Valley
STOCKTON HILL RD
N BANK ST
51
40
gfL
53
40
59
Kingman
0 ———— 3.05 mi

3

Day 2

Day 3

DEATH VALLEY NATIONAL PARK

INYO NATIONAL FOREST

NELLIS AIR FORCE RANGE

DEATH VALLEY

PANAMINT RANGE

AMARGOSA RANGE

GRAPEVINE MOUNTAINS

FUNERAL MOUNTAINS

BLACK MOUNTAINS

GREENWATER VALLEY

AMARGOSA DESERT

SIERRA NEVADA

PANAMINT VALLEY

SALINE VALLEY

OWENS VALLEY

NAVAL AIR WEAPONS STATION CHINA LAKE

FORT IRWIN MILITARY RESERVATION

OWLSHEAD MOUNTAINS

QUAIL MOUNTAINS

Scottys Castle

Ubehebe Crater

Grapevine

Mesquite Spring

Stovepipe Wells Village

Sand Dunes

Emigrant

Furnace Creek Visitor Center
Death Valley Museum

Furnace Creek Ranch
Borax Museum

Furnace Creek Inn

Texas Spring

Sunset

Zabriskie Point

Artists Palette

Natural Bridge

Badwater

Dantes View

Harrisburg

Wildrose

Thorndike

Charcoal Kilns

Mahogany Flat

Panamint City (ghost town)

Ballarat (ghost town)

Beatty

Rhyolite (ghost town)

Leadfield (ghost town)

Ashford

Shoshone

Amargosa Valley

Death Valley Junction
Amargosa Opera House

Eastern Sierra InterAgency Visitor Center

Father Crowley Point

Panamint Springs

Darwin

Ridgecrest

Lone Pine

Death Valley Buttes

Keane Wonder Mine

Keane Wonder Mill

Telescope Peak

COSO BASIN

DIRTY LAKE

SEARLES LAKE

Legend

Inquire about unpaved road conditions before traveling.

Off road driving or bicycling prohibited

Unpaved road

High clearance recommended

4-wheel-drive road

Hiking trail

Ranger station
Campground
Sanitary disposal station
Food service
Lodging
Gas station

Radiator water
Store
Telephone
Wheelchair accessible
Airport

North

0   10 Kilometers
0   10 Miles

Day 5

Freeway
Paved Road
Graded Dirt Road
Mojave Road
Gas
Water
Restrooms
Information Center
Trailhead
Telephone
Campground

40 miles to Las Vegas from Primm

PRIMM

NIPTON

SEARCHLIGHT

95

NEVADA
CALIFORNIA

HALLORAN
SUMMIT

CIMA DOME

15

BAKER

62 miles to Barstow from Baker

CINDER CONES
& LAVA BEDS

CIMA

NEW YORK MOUNTAINS

163

ZZYZX

SODA
DRY
LAKE

Cedar Canyon Road

LANFAIR VALLEY

PIUTE RANGE

Mid Hills

Hole-in-the-Wall

Mojave Road (4x4)

KELSO
DUNES

KELSO

Providence
Mountains
State
Rec Area

MITCHELL
CAVERNS

GOFFS

FENNER

GRANITE MOUNTAINS

37 miles to Needles from Fenner

50 miles to Barstow from Ludlow LUDLOW

40

JOSHUA TREE NATIONAL PARK

PALM SPRINGS

Oasis Visitor Center

Cottonwood Visitor Center

Black Rock Canyon

West Entrance Station

North Entrance Station

Entrance Station

Keys View

Hidden Valley

Keys Ranch

Barker Dam

Indian Cove

Fortynine Palms Oasis

Oasis of Mara

Ryan Mtn.

Sheep Pass

Lost Horse Mine

Jumbo Rocks

Geology Tour Road

Belle

White Tank

Cholla Cactus Garden

Ocotillo Patch

Cottonwood Spring

Cottonwood Campground

Bajada Nature Trail

Lost Palms Oasis

Eagle Mountain

SAN BERNARDINO MOUNTAINS

LITTLE SAN BERNARDINO MOUNTAINS

HEXIE MOUNTAINS

PINTO MOUNTAINS

PINTO BASIN

COTTONWOOD MOUNTAINS

EAGLE MOUNTAINS

COXCOMB MOUNTAINS

SHEEP HOLE MOUNTAINS

COACHELLA VALLEY

INDIO HILLS

MORONGO VALLEY

YUCCA VALLEY

JOSHUA TREE

DESERT HOT SPRINGS

CATHEDRAL CITY

RANCHO MIRAGE

PALM DESERT

INDIO

COACHELLA

DESERT CENTER

North

5 Kilometers

5 Miles

Off-road driving is prohibited

Hiking trail
Unpaved road
4-wheel-drive road

Ranger Station
Interpretive Trail
Campground
Group campground (reservations required)

Picnic area
Medical facility
Self-guiding trail
Drinking water

Transition Zone

Wilderness

10

Editor's Note --

Fellow fieldtrippers,

Well, I don't have much to say this time around. Chalk it up to neglect and apathy regarding my editorial freedom over this page.

The last time LPL visited Death Valley was in October 2000. Judging from the pictures posted online of that trip, it looks like everyone had a great time, learned a lot about geology and other topics in the field, and did not die, contrary to what the destination name implies.

Given that we are passing gambler's heaven on the way up to Death Valley, though, I feel obliged to include the latest betting line (as of press time) regarding incidents that may happen on this trip:

CB antenna breaks	6-to-5
Flat Tire	2-to-1
Dead Car Battery	3-to-1
Entrapment of Car by Sand	5-to-2
Entrapment of Car by Mud	9-to-1
Carburetor flambe	11-to-1
Keys locked inside car, a la Ross	12-to-1
Fire Extinguisher Ejection	15-to-1
Brake Caliper Bolt Jettison	20-to-1
Manual Muffler Amputation	25-to-1
We all hate each other by Sunday	Even
We get "lost" in Las Vegas	hopefully
Hoover Dam breaks as we visit	Superman to the rescue!
The CF Jackpot is awarded (ask Jason)	75-to-1
The rocks at Racetrack playa actually race	100-to-1
the Snowball Earth returns	1000-to-1

Anyway, let's just sit back, enjoy the sights, and have a great time out in the field and under the stars.

-David Choi, editor
March 2006

Spaceborne Radar images of Death Valley

Ralph Lorenz
(with Death Valley images from Tom Farr of JPL)

Death Valley is a common test target for spaceborne radars : impressive geology, generally dry (which favors penetration of the ground by microwave energy) and close to JPL. During test campaigns field investigation (e.g. soil moisture etc.) of the imaged areas may be conducted, together with the installation of GPS-located cube corner reflectors (often appear as four-pointed 'overexposed' stars in radar images) for geometric calibration and transponders or receivers for radiometric calibration.

Planetary RADARS
- Long wavelength subsurface sounders (typ 5-50 MHz) : Apollo Lunar Sounder Experiment, CONSERT (on Rosetta), MARSIS on Mars Express, SHARAD on MRO. Future – SELENE, Europa Orbiter, Titan Aerobot
- Microwave Radar imagers (SARs) : Magellan, Cassini, Mini-RF on LRO, Mini-SAR on Chandrayaan. Maybe Mars Scout ? Follow-on Titan orbiter
- Earth Observation : SEASAT (1978) ; Shuttle Imaging Radar SIR (especially SIR-C, 1994 L-band 23cm C-band ; also carried German/Italian X-SAR at 3cm) ; ERS-1, JERS-1, Radarsat

Radar brightness typically correlates with surface roughness at radar wavelength or longer scales, except in low-density, dry (thus transparent) materials, where subsurface scattering may be a strong contributor (similar effects can occur due to buildings or vegetation. Multiple scattering is often evident in the polarization of the signal. Long wavelengths generally penetrate deeper.

Spaceborne radars usually are linearly-polarized ; can transmit and receive in Vertical (VV) or Horizontal (HH) polarization – also 'cross-polarized' HV, VH. NB due to ionospheric effects (Faraday rotation) radio astronomy radars often use circular polarization.

Color mosaic SIR-C images from data take 120.30, look angle 45 deg.
Red : L-band HH : Green L-band HV : Blue C-band HV

Stovepipe Dunes

Furnace Creek fan

Black Mts

Trail Cyn fan

Panamint Mts

Devil's Golfcourse

Badwater

Hanaupah fan

13
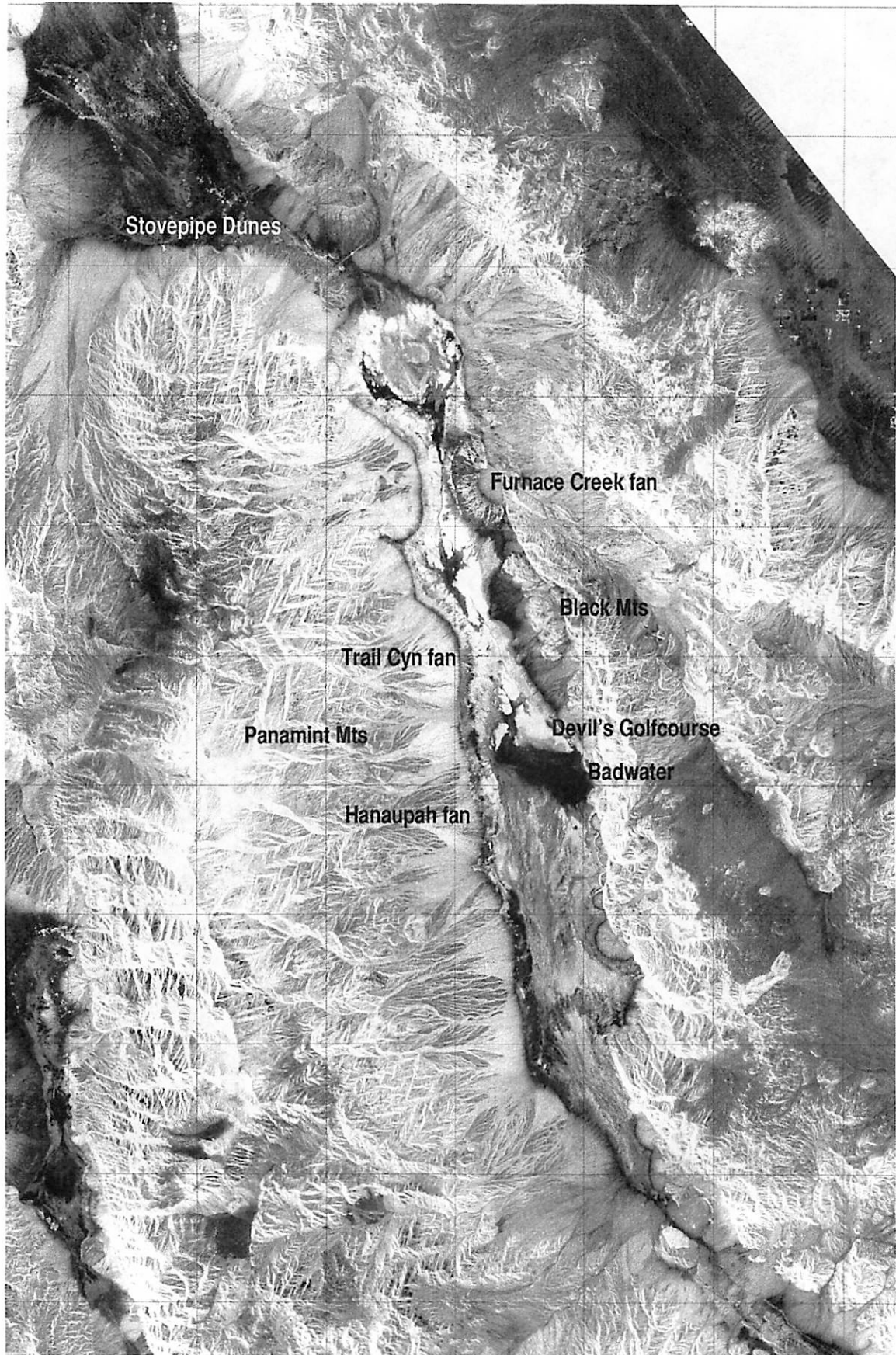
Giant Dessication Polygons
John Keller
Death Valley Field Trip, Spring 2006

Viking identified giant cracks clustered around the outflow channels in Acidalia, Elysium, and Utopia in the northern hemisphere of Mars. Around Utopia, the average width of these trough features was 2 km with an average depth of 20 m. Giant polygons defined by these troughs have an average diameter of 30 km. These polygons are much larger than similarly shaped polygons formed on Earth through processes of dessication, ice wedging, and lava cooling. References and a more detailed discussion will be provided in a separate handout on the fieldtrip.
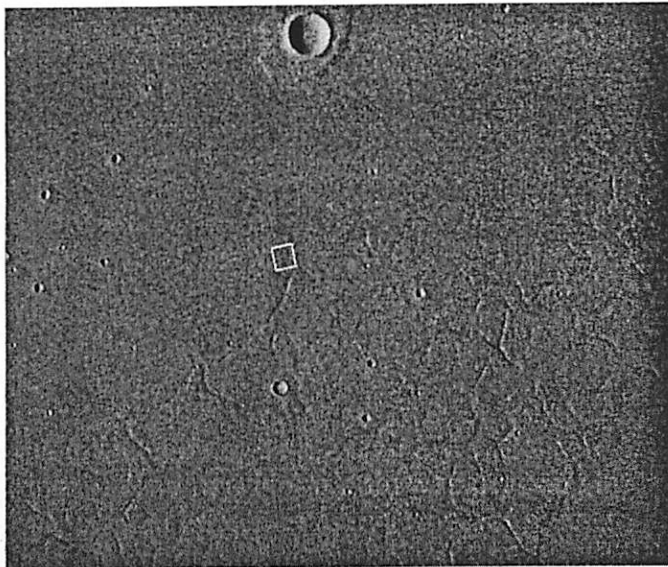
Viking image of polygons.
White square (31.4°N, 245.8°W) shows location of MOC image to the right.
Impact crater at top is 8.3 km in diameter.
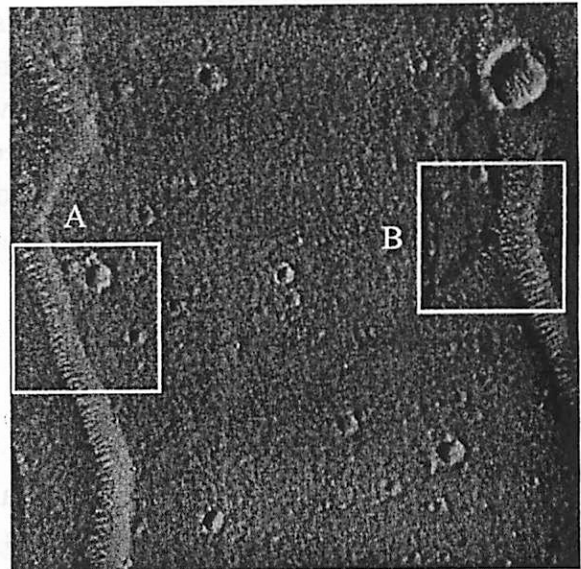
PIA01469 – MOC image of troughs.
Image is 3.4 km wide.
White boxes show location of images below.
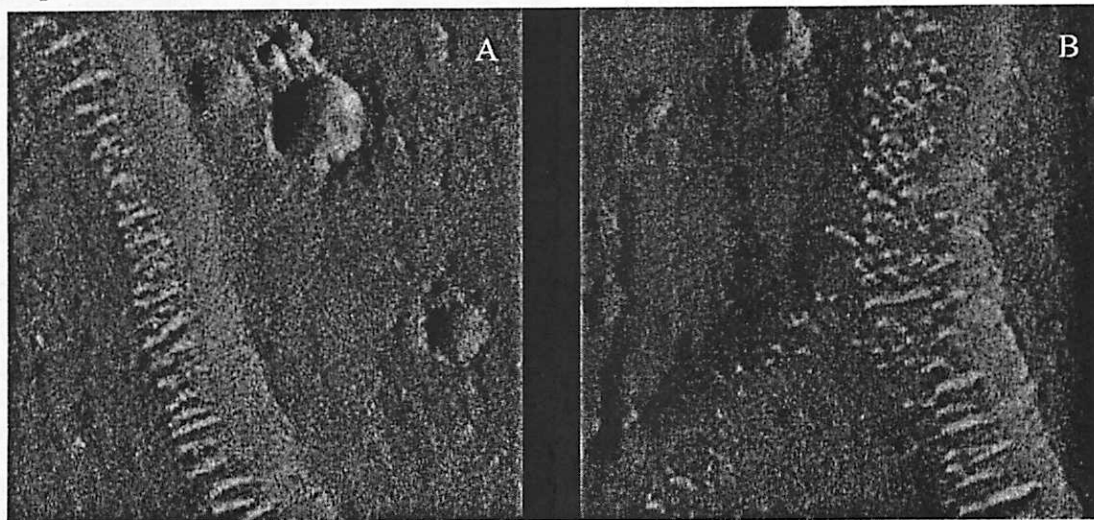
PIA01470 – Closeup of MOC images of troughs.
Resolution is 3.4 meters per pixel and image is 0.87 km wide.
Shows evenly spaced, wind-blown drifts within the troughs.

Gold Basin Meteorite Strewn Field
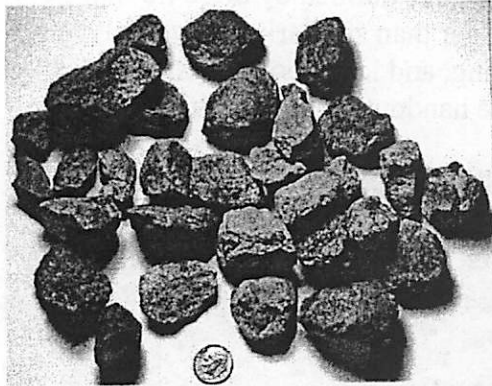
Intro

On 24 Nov 1995, Prof Jim Kriegh (Emeritus, U of Az) was looking for gold using a metal detector. He came upon a few fragments of an L4 meteorite which became part of the largest meteorite field outside of Antarctica. Over the next several years, formal teams collected over 4500 samples with private collectors reporting an additional 2000 specimens. Collectors have gathered meteorites from over 225 km^2 without finding the limits to the field [1].

Details [1]

Name - Gold Basin

Meteor Classification
- Breccia of L fragments

Petrologic Classification - 4

Location - Gold Basin, NW Arizona

Terrestrial Age - 15,000 +- 600 years
(Late Pinedale portion of the Wisconsin Glaciation)

Space Exposure Age - 15 - 30 Ma [4]

Total Original Mass - 168.7 kg

Weathering - 30% to 35% oxidized

Kinetic Energy - estimated 5 to 50 kilotons of TNT. The lack of a crater and degree of spreading indicates atmospheric explosion
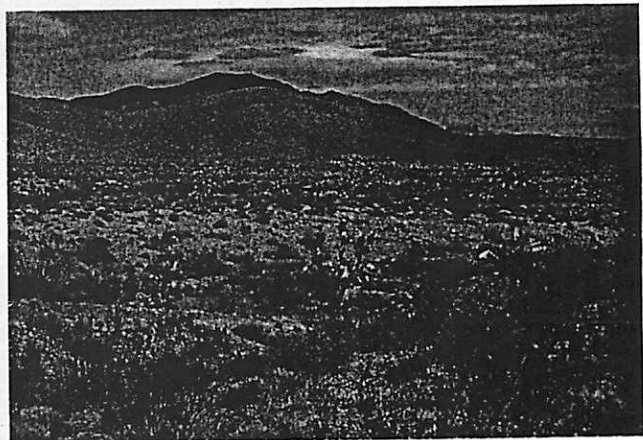
Five other meteorites were found during the search for Gold Basin meteorites:

King Tut (L5)
Golden Rule (L5)
White Hills (Mesosiderite)
White Elephant (L4)
Temple Bar (Carbonaceous)

Eric E. Palmer
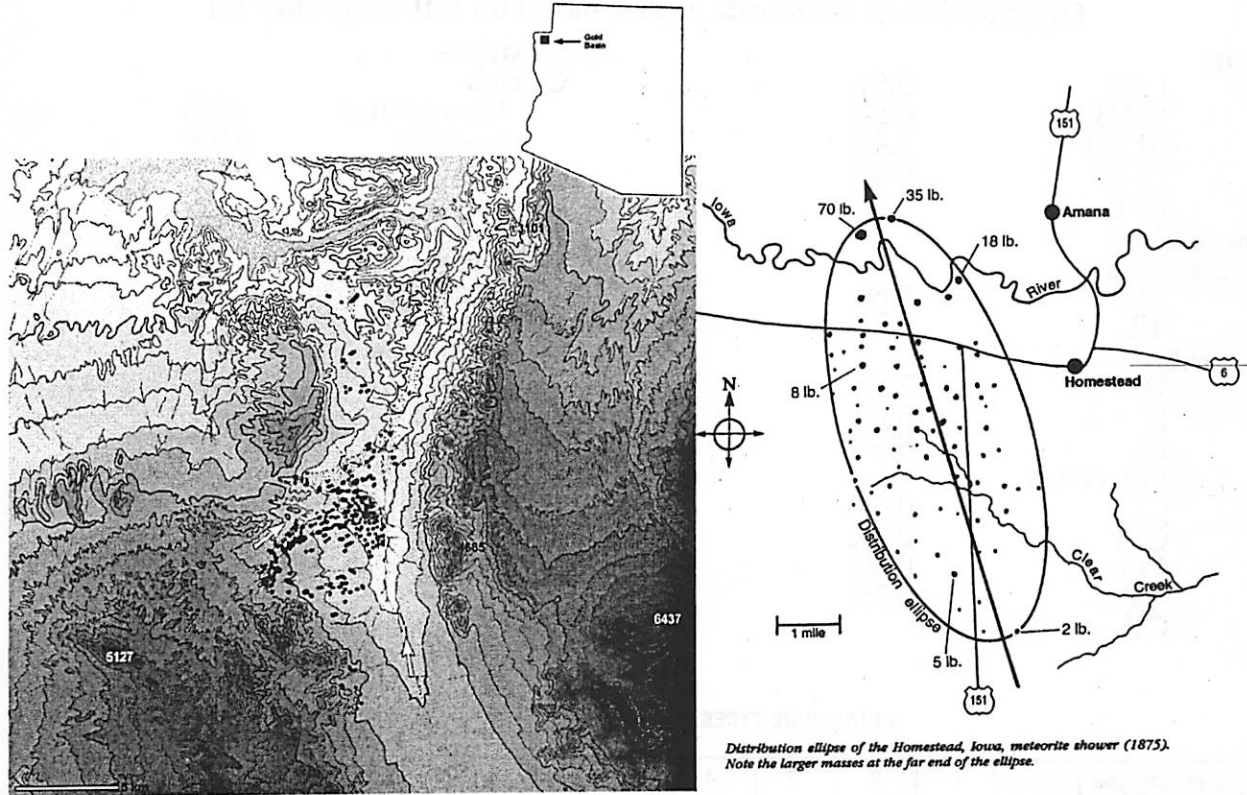
Distribution ellipse of the Homestead, Iowa, meteorite shower (1875). Note the larger masses at the far end of the ellipse.

The locations of individual finds of Gold Basin meteorites. Mountainous terrain restricts collection [1].	An example of an unhindered strewn field. You can see that the heavier meteorites travel the furthest [2].
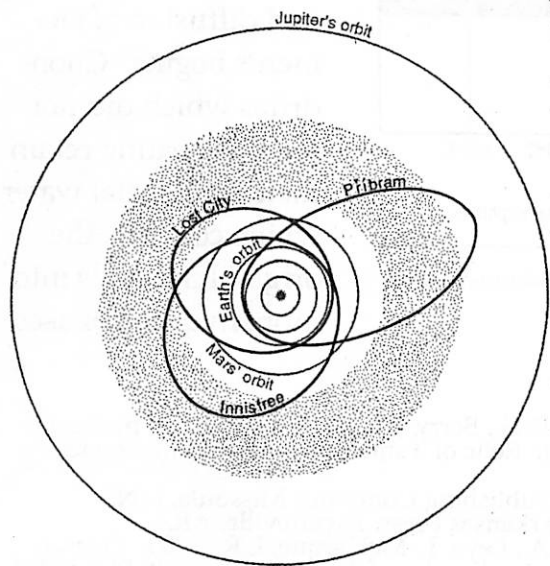
Orbits of the Pribram, Lost City, and Innisfree meteorites, all of which had their aphelions within the asteroid belt.

The Prairie Network (1964-1974) was designed to detect fireballs and locate meteorite falls. They photographically detected and recovered three meteorites. Using the trajectory recorded on the photographs, they were able to reconstruct the orbits of these three ordinary chondrites, as shown in the figure [2]. You can see the orbits intersect the main asteroid belt, but have a higher eccentricity. It is possible that the asteroid fragments were kicked out by Jupiter's Kirkwood gap.

Distribution of Meteorite Types, based on fall frequency [3]

Irons

I AB	0.8%
II AB	0.5%
III AB	1.4%
IV A	0.4%
IV B	0.1%

Chondrites

Enstatite

EH	0.6%
EL	0.7%

Ordinary

H	33%
L	38%
LL	8%

Carbonaceous

CI	0.6%
CM	2.2%
CO	0.6%
CV	0.7%
CR	

Achondrites

Ca rich

Howardites	2.2%
Eucrites	3.0%
SNC	0.6%

Ca poor

Aubrites	1.1%
Diogenites	1.1%
Ureilites	0.5%

Stony Irons

Mesosiderites	0.7%
Pallasites	0.4%

PETROLOGIC TYPES

Chemical Type		1	2	3	4	5	6	7
	Chondrule Texture	Absent	Sparse	Abundant / Distinct		Increasingly/Indistinct		Melted
Enstatite Chondrites	E							
Ordinary Chondrites	H L LL							
Carbonaceous Chondrites	CI CM CV CO							

<150°C　<200°C　400°C　600°C　700°C　750°C　950°C

← Increasing aqueous alteration　　Increasing thermal metamorphism →

Note: The temperature scale shows the approximate temperatures required to produce the distinguishing textures, revealing something of the early heating histories of the chondrites.

Chondrites can be typed based upon their amount of aqueous and thermal alteration. As the temperature gets closer to melting the melting point, grain boundaries become indistinct and diffusion of elements begins. Chondrites which did not see this heating retain their primordial water which converts the original minerals into more hydrous phases.

References
[1] Kring, D.A., Jull, A.J., McHargue, L.R., Bland, P.A., Hill, D.H., Berry, F.J., 2001. Gold Basin meteorite strewn field, Mojave Desert, northwestern Arizona: Relic of a small late Pleistocene impact event. Meteorit. & Planet. Sci. 36, 1057-1066.
[2] Norton, O.R., 1994. Rocks from Space. Mountain Press Publishing Company, Missoula, MN.
[3] Sears, D.W.G, 1988. Thunderstones. The University of Arkansas Press, Fayetteville, AR.
[4] Wieler, R., Baur, H., Jull, A.J.T., Klandrud, S.E., Dring, D.A., Leya, I., McHarque, L.R., 2000. Cosmogenic helium, neon, and argon in the large Gold Basin chondrite (abstract). Meteorit. Planet. Sci. 35 (Supl) A169-A170.
[5] Hill, D. Meteorite or Meteorwrong: The past to identification. Poster.

Have you ever wondered if that "interesting rock" is a meteorite?
Further classification of meteorite type requires sophisticated analytical techniques. When in doubt ask a meteoriticist.

Here are some clues that are used to help distinguish real meteorites from terrestrial rocks and manmade materials.

- **Does the rock have a fusion crust?**
This is a thin, black coating formed as a meteorite passes through Earth's atmosphere. Fusion crust weathers to a rusty-brown color the longer it is exposed to oxygen and water. Don't be fooled by black desert varnish that is very common in desert regions or slags that have a "melted" appearance.

- **Does the "fusion crust" look different than the interior of the rock?**
It should be smooth and not too rough or frothy. It won't necessarily *look* melted.

- **Is the sample magnetic?**
Most meteorites are very magnetic and are easily found with metal detectors. But many meteowrongs such as iron-bearing rocks and metal debris are magnetic, too. If the sample is not magnetic, does it have a fusion crust? Some rare meteorites are not noticeably magnetic.

- **If the sample is dense (heavy for its size), is it metallic?**
The densest meteorites are the iron-nickel and stony-iron type. Stony meteorites may or may not seem heavier than common rocks. Some rocks and slag are very dense.

- **Iron-nickel meteorites will exhibit a diagnostic criss-cross "Widmanstätten" pattern when etched with a special acid mixture.** This is best done in a laboratory.

- **Do you see small flecks of metal inside the sample?**
This is a very important feature of ordinary chondrites. These are sometimes confused with glints of light reflected from crystal faces. Use a magnifier or microscope to check.

- **Are there chondrules (tiny, 1mm diameter, spheres) visible in the interior?**
These may or may not be easily discernable depending on the meteorite type. (Iron-nickel meteorites and some rare stony meteorites don't have chondrules).

magnetite

vesicular basalt
Washington University in St. Louis

Iron debris

concretions
Washington University in St. Louis

Typical Meteowrongs: Iron tools, mill balls, slag, magnetite, hematite, iron-rich rocks, basalt, volcanic rocks, clinkers, river rocks, concretions.

Typical Meteorites

outer surface

broken interior

iron-nickel meteorite

Fresh, black fusion crust — Weathered fusion crust

Metal flecks & chondrules

Stony meteorite

Cut & etched iron-nickel meteorite

Rare stony meteorite: no chondrules, not very magnetic.
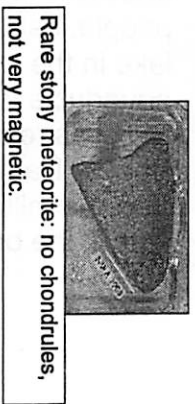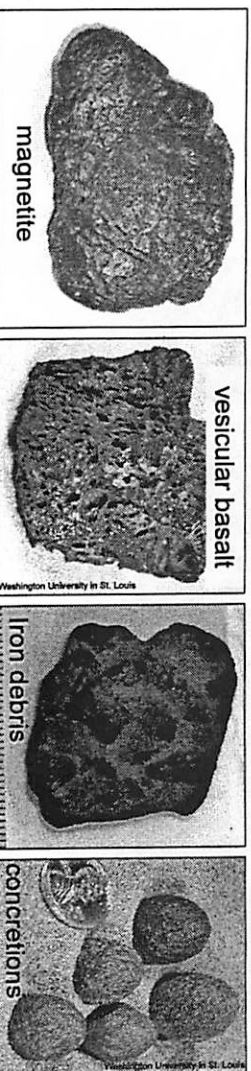
- **Does the rock have vesicles or gas bubbles?**
Very few meteorites have vesicles large enough to see.

- **Does the sample have large, colorful crystals?**
Meteorites generally lack large, colored crystals like those seen in geodes.

- **Does the sample have sedimentary texture?**
Meteorites do not exhibit layers or cemented grains or pebbles.

- **Is the rock colored (red, purple, blue)?**
Meteorites are not very colorful. Colors in terrestrial rocks are often formed from mineral rich fluids (water).

- **Are there other rocks like this one in the area?**
If so, this is a clue there might be a reasonable geological explanation as in magnetite and concretions.

Hoover Dam? But I just met her!

by David Choi

Introduction

The Hoover Dam is one of the world's great engineering feats. It is a gravity-arch dam that is located along the border of Arizona and Nevada. Lake Mead is the artificial reservoir created by the dam. The dam is named after President Herbert Hoover, where as the reservoir is named after El-wood Mead, manager of the construction of Hoover Dam.

History

In 1922, a commission was formed to begin planning out the dam; the government's representative on that commission was Herbert Hoover, then-Secretary of Commerce. The need for a dam was pressing in the face of flood control and the desire for a fair allocation of Colorado River waters. In November of 1922, the Colorado River Compact divided the 7 states with interests in the river (CO, NM, UT, WY, NV, AZ, and CA) into an Upper and Lower Basin, and the states in each Basin were left to work out an agreement on how to share the water. Construction of the dam began in 1931, and after nearly 5 years, 96 deaths, $49 million dollars ($676 million after inflation), and 3.33 million cubic meters of concrete, the project was completed in 1936. The sub-compacts spelling out how water would be divided weren't completed until the 1940s and 50s.
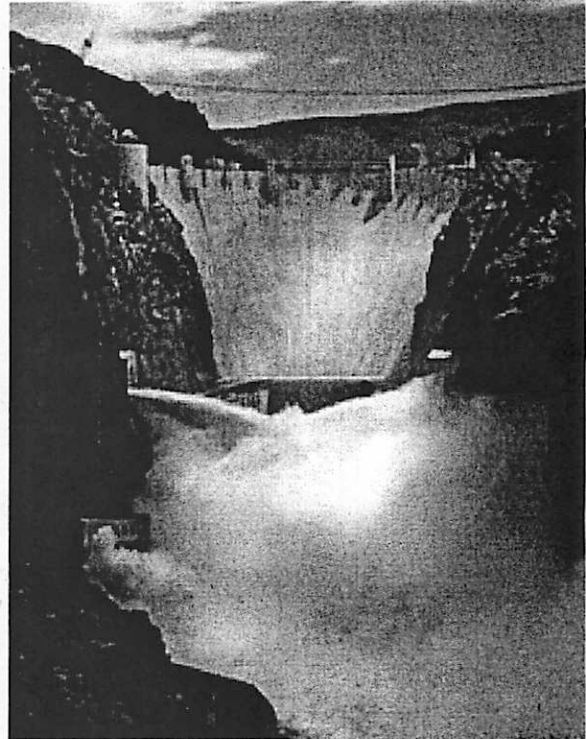
Current Status

Right now, Hoover Dam's hydroelectric power plant generates energy for Southern California, Arizona, and Nevada. It produces enough clean energy for nearly 1.3 million people. Lake Mead, the largest man-made lake in the United States, provides water via aqueducts to Nevada and California, and provides recreation to millions of visitors. Hoover Dam itself is a tourist attraction, with nearly a million visitors each year. Unfortunately, the booming population growth of Las

Vegas and Phoenix have caused strain on U.S. Highway 93, which is the principal road linking these two cities and itself goes on top of Hoover Dam. This led to the **Hoover Dam Bypass Project**, where workers are now building a concrete-steel composite arch bridge (the first of its kind in the USA) nearly 840 feet above the water, and 1500 feet downstream from the dam. When it is completed in 2008 (hopefully), all vehicular thru traffic will be diverted to the bridge, and the road on top of the dam will be pedestrian traffic only.

Effects of Dams on rivers in general

1. Stream Flow -- sediment transport by a river out to sea is decreased in general. This will cause the reservoir to fill up with sediment over time, whereas water released downstream will be relatively sediment-free. Furthermore, the cutting power of the stream is enhanced, resulting in downstream channel erosion and tributary headcutting. Flood control has resulted in the reduction of the formation of point bars, oxbows, and secondary channels, and a stabilization in the primary channel.

2. Biological Impact -- dams serve as a barrier to migration for aquatic life that swim up-stream in order to spawn. Fish ladders have been built as a way for these fishes to make it upstream, but questions have been raised regarding their effectiveness. Furthermore, because water released downstream is relatively sediment-free, stream beds downstream are relatively rocky, which does not bode well for aquatic plant life.

3. Water Quality -- the establishment of a deep reservoir will typically lead to thermal stratification of the lake during summer months. This will usually cause the lake to be divided into an upper, well-oxygenated, warm layer (the *hypolimnion*), floating over a cold, oxygen-deprived layer (the *epilimnion*). Discharges of water from the dam can be from this lower layer, which can have detrimental effects on downstream ecosystems.

Effects on the Colorado River

1. Lake Mead Sediments

While the dam has led to flood control and regulation of water flow, one consequence is that silt carried from the Rocky Mountains is deposited in Lake Mead as the river flow slows down at the barrier. Thus, the reservoir has been gradually filling up with silt. Furthermore, the water released from the dam is relatively silt-free, causing increased channel-cutting power downstream.
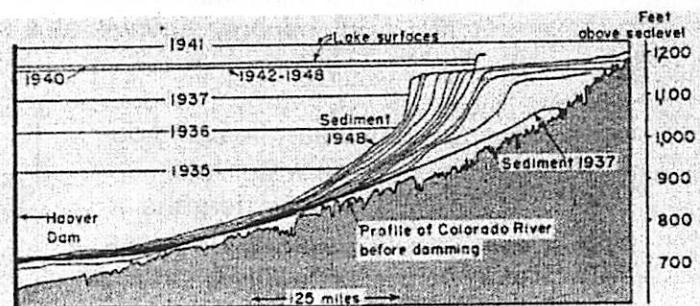
Fig. 1 Successive profiles of the body of sediment gradually filling the basin of Lake Mead, determined by annual surveys. (After C. P. Vetter.)

2. Flood Control

Before the construction of Hoover Dam, the Colorado River would typically flood every spring and summer from the snowmelt. This would have a negative effect on agricultural communities in California, Arizona, and Mexico. Spillways are essentially outlets that let out water behind a dam without the water going through the turbines. The spillways have only been used twice at the Hoover Dam. Once in 1941 as a test, and once in the summer of 1983 due to a snow-melt flood. The 1983 flood was caused by unusually heavy snowfall during the river combined with a faster-than-average melt, and already above average reservoir levels. The subsequent flood damage downstream of the Hoover Dam caused hydrologists to revise their flood prediction methods and reservoir release schedules.

3. Effect on wildlife

a. According to a study by Eugenio Aragon-Noriega and Luis Calderon-Aguilera, damming of the Colorado River has affected the nursery area of a certain species of blue shrimp in the Upper Gulf of California. As the dam has regulated the flow of water downstream, less than 1% of the "virgin flow" reaches the mouth of the river. Through sampling of the nursery region for shrimp larvae, they were able to determine that larvae abundance was inversely correlated with river salinity.
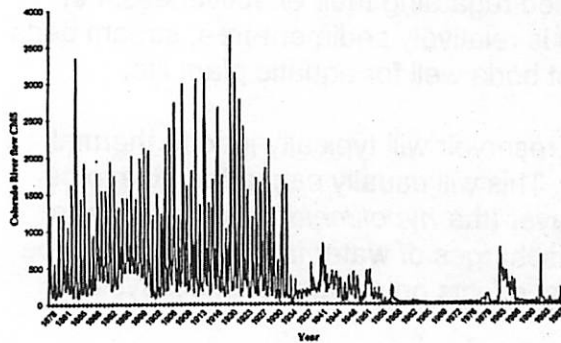
Figure 1. Record of mean monthly Colorado River flow from 1878 through 1998 in cubic meters per second (CMS) (U.S. Bureau of Reclamation, www.yra.lc.usbr.gov).

b. According to a study by Rodriguez et al. (of the Dept. of Geosciences at UA), the increase in salinity at the estuary of the Colorado River has negatively affected a certain species of bivalve mollusk that was once abundant in the area. Through a paleontological and geochronological analysis of mollusk fossils, the researchers determined that this mollusk once flourished in low-salinity waters away from the river's mouth, and now only survives as a small population near the mouth of the river.

c. The reduction of water flow and decrease in silt entrained in the water has harmed the Colorado River delta near the Gulf of California. This has resulted in a loss of natural wetland habitat for wildlife. The loss of flooding events has also resulted in the loss of riprarian (near river bank) plants and trees along the Colorado that were dependent on periodic floods for survival.
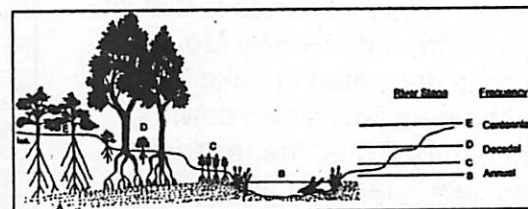
Figure 4. Geomorphic and ecological functions provided by different levels of flow. Water tables that sustain riparian vegetation and that delineate in-channel baseflow habitat are maintained by groundwater inflow and flood recharge (A). Floods of varying size and timing are needed to maintain a diversity of riparian plant species and aquatic habitat. Small floods occur frequently and transport fine sediments, maintaining high benthic productivity and creating spawning habitat for fishes (B). Intermediate-size floods inundate low-lying floodplains and deposit entrained sediment, allowing for the establishment of pioneer species (C). These floods also import accumulated organic material into the channel and help to maintain the characteristic form of the active stream channel. Larger floods that recur on the order of decades inundate the aggraded floodplain terraces, where later successional species establish (D). Rare, large floods can uproot mature riparian trees and deposit them in the channel, creating high-quality habitat for many aquatic species (E).

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4. Misc.

a. *Turbidity currents* are cases in which inflowing water has a greater density due in part to entrained/suspended material. One of the best known ones exists in Lake Mead, where it can extend for nearly the entire length of the lake. These currents are certainly a factor forming the bottom deposits in the reservoir.

b. Because Lake Mead is such a large reservoir, the water chemistry of the impounded water may differ from fresh inflowing water for quite some time. Furthermore, the presence of density currents can create a complicated pattern of chemical stratification.

Efforts at Restoration

Several Colorado River Indian tribes in Arizona have begun attempts to restore the natural aquatic habitat along the Colorado River by using part of their water allotment. As of 2001, nearly 500 acres had been restored, with more in the works. More restorations are taking place in national wildlife refuges south of Lake Mead along the Colorado.

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Geologic Ghosts of Climate Changes Past

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ABSTRACT

During glaciations, Death Valley becomes Lake Manly. Shorelines are visible on a nearby outcrop. I also discuss a new review paper on global sea level change.

Subject headings: Lake Manly – Climate Change – Ice Age – 30m Thick Glaciers

1. INTRODUCTION

Earth's climate is a roller coaster. For the past 2.2 million years our planet has been locked in an ice age that features glaciations intersperced with brief interglacial periods like the present. There have been 8 glacial cycles in the past 650,000 years (1).

During the most recent glaciation, and very probably many of the glaciations before that, the climate of Death Valley and the rest of what is presently the Mojave desert, was cooler and wetter. This particular area was much less of a desert, and hence water that fell as precipitation here or upstream of here did not evaporate faster than it accumulated. Since Death Valley is a closed depression, the accumulation led to the build up of a lake in the valley. Similarly, lakes formed in Owen's Valley, China Lake, Searles and Panamint Valleys.

The lake in Death Valley is called Lake Manly after a dude that rescued some other dude in the 1850s. The lake extended 90 km in a north-south direction, ∼ 8 east-west, and 600 feet deep. On an outcrop called "Shoreline Butte", numerous horizonal terraces demarcate Lake Manly's Pleistocene shorelines. The shoreline features were created by wave action against the surrounding rocky terrain.

The Death Valley and surrounding areas would have been North America's Great Lakes of the Pleistocene, given that what we now call the Great Lakes was under the Laurentide ice sheet.

Numerous other aspects of Earth's geology can only be understood in the context of the glacial/interglatial cycle of the Pleistocene. In particular, the sea level changes that normally occur on long timescales have instead been frequent and high in amplitude during the past 2.2 million years. Global sea level was $100m$ lower during the last glaciation, and could be $100m$ higher again if all of Earth's ice caps were melted.

Sea level changes were a hot topic on the previous trip, the one in Baja California, so I thought I might babble on about some new sea level change information that was brought to light by a paper in the 2005 November 25 *Science* (?). Determination of paleo sea levels is decidedly nontrivial owing to continuing tectonic effects, erosion, and deposition. A new method, backstripping, attempts to compensate for these effects:

> Backstripping is an inverse technique that can be used to quantitatively extract sea-level change amplitudes from the stratigraphic record. It accounts for the effects of sediment compaction, loading (the response of crust to overlying sediment mass), and water-depth variations on basin subsidence. Tectonic subsidence at a passive margin is modeled with thermal decay curves and removed to obtain a quantified eustatic estimate in the absence of local tectonic complexities. (Miller et al.)

For instance Chesapeake Bay, the future home of Field Trip Leader Turtle, is a river valley system during glaciations that becomes inundated in interglacial periods.

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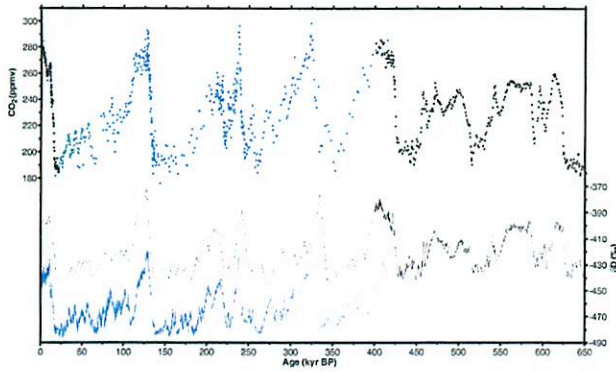
Fig. 1.— Paleo-CO2 levels for the past 650,000 years from an Antarctic ice core. Siegenthaler et al. found a strong correlation between CO2 and temperature, though it is not clear which is forcing the other.

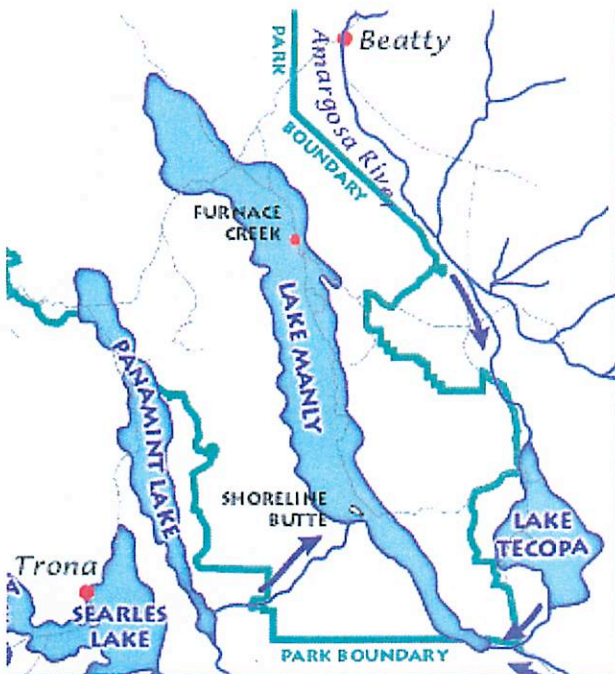Fig. 3.— Shoreline butte, on which the Pleistocene shoreline of Lake Manly can be seen.

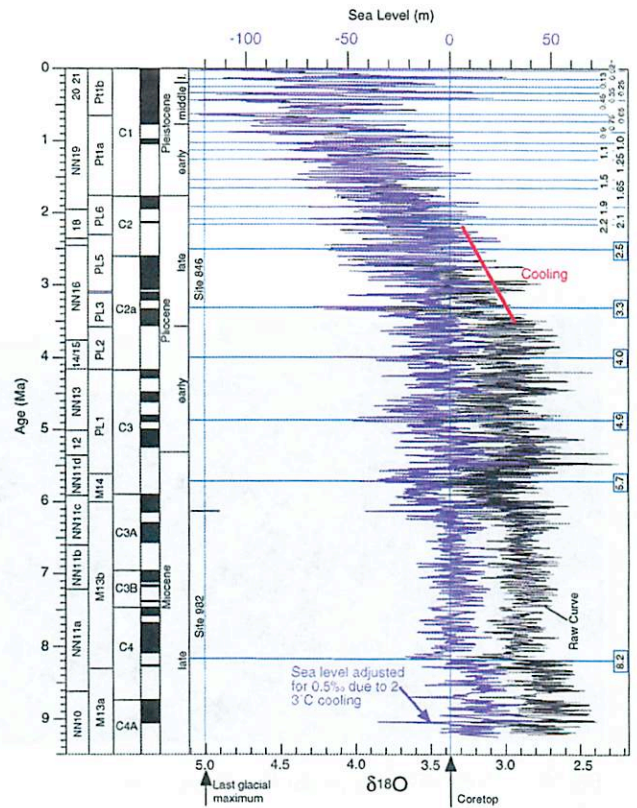Fig. 2.— Geography of Pleistocene Lakes in the Mojave Desert area.

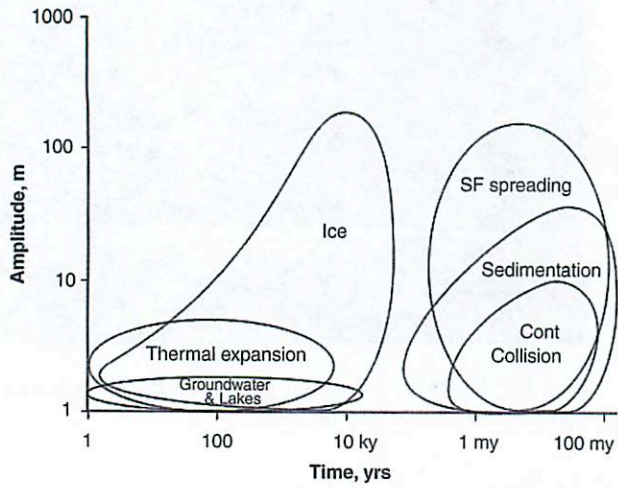Fig. 4.— Amplitudes, timescales, and sources of sea level change. From Miller et al.

Fig. 5.— Backstripping record of global sea level for the past 100 million years.

Fig. 6.— View of Chesapeake Bay from orbit.

Gravel Fans Near Mormon Point
Colin Dundas

An **alluvial fan** is a "fan-shaped accumulation of sediment traversed by stream flow or debris flow channels." A **bajada** results when multiple alluvial fans merge into a single unit. (Leeder, *Sedimentology and Sedimentary Basins*)

Formation and Morphology:

Alluvial fans result when material flowing from a relatively small **catchment** (drainage area) expands into a larger, flatter area. The flow velocity drops and material is deposited. This tends to form a characteristic fan shape around the point of intersection, since the deposition of material in one area will channel later flow elsewhere, resulting in even, fan-shaped distribution. The topography which leads to alluvial fans is often associated with faulting, which can produce the steep, undissected slopes needed.

An important factor in the development of an alluvial fan is the occurrence of a **fanhead trench**, an incised channel near the head of the fan. This concentrates deposition in one area downchannel, and can disrupt the symmetry of a fan. Fanhead trenches result when conditions favor incision (erosion) near the fan; this can occur when stream flow is relatively intense and erosive, and is sometimes associated with climate change.
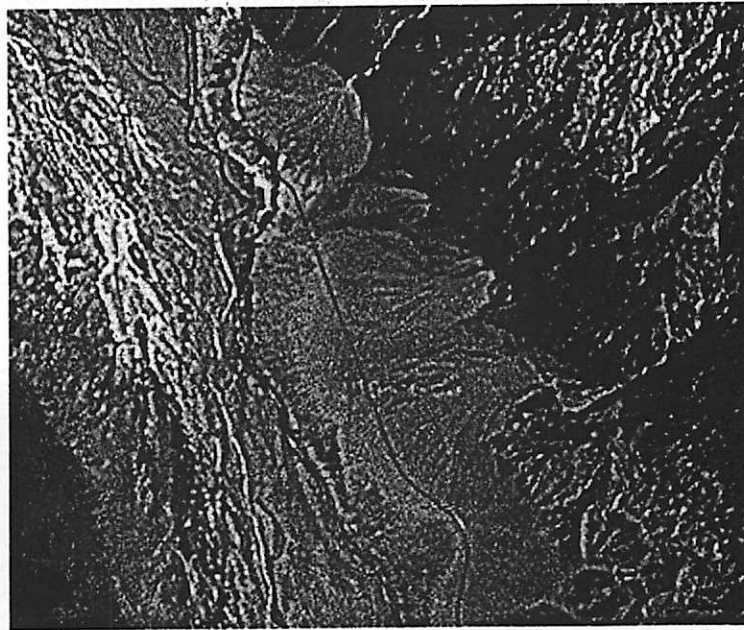
Figure 1: Satellite photo of several alluvial fans in Death Valley, each ~1.5 miles across. Note multiple old channels in each fan. (Image credit Google Maps).

Sediment Transport:

Alluvial fans are often characterized as debris-flow or stream-flow-dominated, although there is a gradation between the two. In stream-flow-dominated fans, rainfall is sufficient to produce persistent streams. The formation of debris-flow-dominated fans is left to the imagination of the reader...

In both types of fan, smaller sediment clasts are generally found further from the source of the fan, since the flow power drops off with distance. However, there will be considerable variation within the deposits of a single fan since the channel and the site of deposition wanders considerably over time.

Death Valley and Mormon Point

Death Valley alluvial fans are in many ways the type example—you can find a picture in most basic geology textbooks. The Mormon Point area has a number of fans, and is also noted for the presence of small risers which are either fault scarps or wave-cut benches. This is still a topic of ongoing research, but it seems clear that both are present in places and have modified some of the fan deposits.

Alluvial Fans on Mars:

MOC and THEMIS images have demonstrated the existence of alluvial fans on Mars. These are generally found in large craters, emanating from alcoves carved into the rims. The fan gradients indicate that they are composed of coarse gravel rather than fine silt, but the mechanics of sediment transport may be slightly different on Mars due to the lower gravity. Moore and Howard argue for fluvial (rather than debris-flow) transport in the large fans they examined, which probably date from the Noachian-Hesperian boundary (about 3.5-4 Ga). Old, exhumed channels appear on the surface. Alluvial fans require multiple events (and thus significant time) to form, implying an extended period of fluvial activity. However, the fans do appear clustered, which indicates either that the target material varies substantially or that the local climate controlled fan formation.
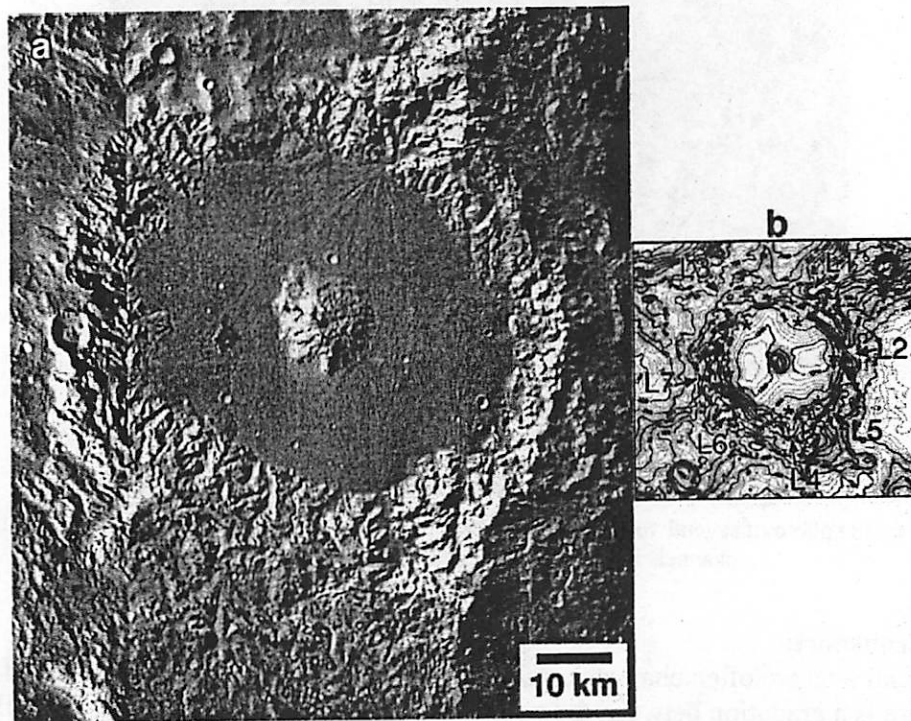
Figure 2: (Moore and Howard, Fig. 5) Martian crater with several alluvial fans on the floor. Note shape of topography in the topo map at right., and small channels incised near the fan heads.
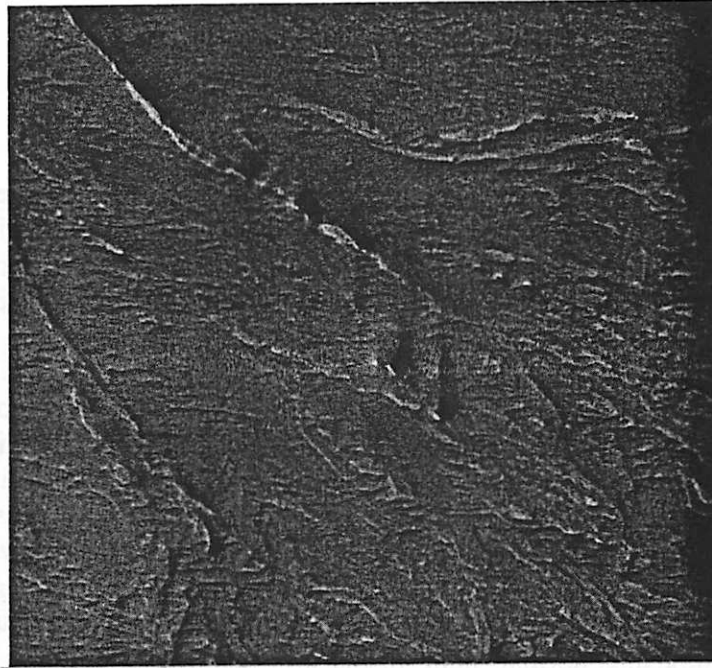
Figure 3: MOC image R1501087, showing the surface of an alluvial fan on Mars. The linear ridges are interpreted as old channels, now preserved in inverted relief. This may be due either to cementation by flowing water, or preferential deposition of fine, easily eroded material outside the channels. HiRISE should provide some clarification of scenes like this.

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Recent fault scarps in Death Valley
Chris Okubo

Location/geometry

The most recently active faults in Death Valley are part of the Northern and Southern Death Valley Fault Zones and Black Mountain Fault Zone (Figure 1). These fault zones are defined at the surface by a through-going series of surface ruptures that extend from the Fish Lake Valley Fault Zone in Nevada to the Garlock Fault Zone in California. The Death Valley and Black Mountain Fault Zones as we see them today are approximately 14 million years old.

The Death Valley and Black Mountain Fault Zone system is comprised primarily of right lateral strike slip faults and normal faults (Figure 2). There is a minor component of thrust faulting in each Fault Zone. The formation of Death Valley is linked to the growth of these fault zones. Death Valley is located within an extensional stepover between the Northern and Southern Death Valley Fault Zones, which primarily accommodate right lateral strike slip displacement. Death Valley is currently developing as a half-graben, bounded on the eastern side by the Black Mountain Fault Zone, which primarily accommodates normal fault displacements. Slip along the Northern and Southern Death Valley Fault Zones drives slip along the Black Mountain Fault Zone by decreasing the horizontal compressive stresses acting in the Death Valley region. This enables normal faulting to occur within the Black Mountain Fault Zone and thereby leading to the growth (i.e. deepening and lengthening) of Death Valley.

Abbrev.	Fault zone name
FLVFZ	Fish Lake Valley
NDVF	Northern Death Valley
BMFZ	Black Mountains
SDVFZ	Southern Death Valley
FCFZ	Furnace Creek
PVFZ	Panamint Valley
GFZ	Garlock
▷	Fault zone boundaries
⊙	Furnace Creek Ranch (FCR)
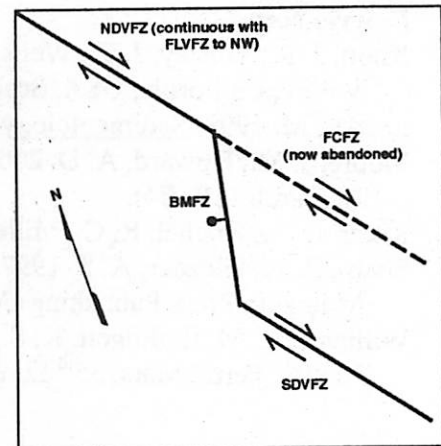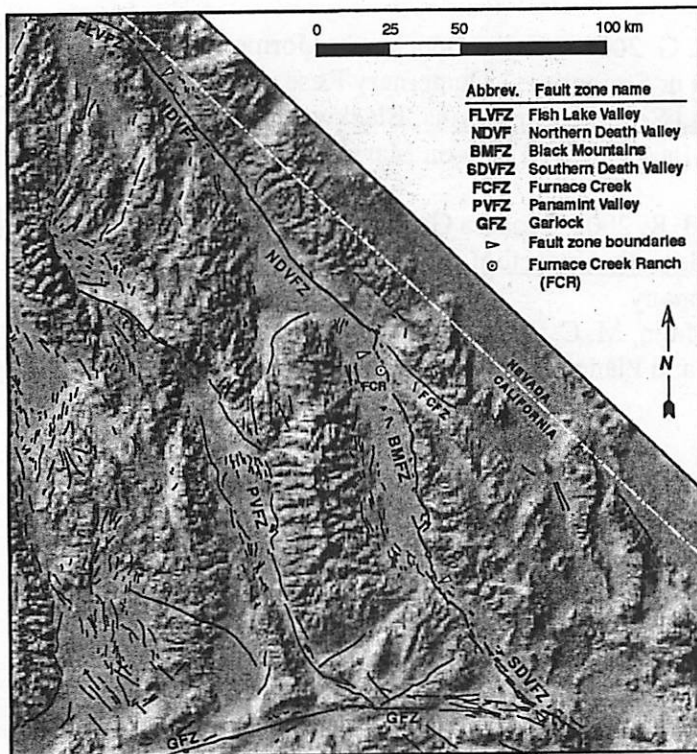
Figure 2. The Black Mountain fault zone and southern Death Valley occur within an extensional stepover between the Northern and Southern Death Valley Fault Zones. Figure from Machette et al., 2001.

Figure 1. Structural map of faults within the Death Valley region. Southern Death Valley is bounded on the east by the Black Mountain Fault Zone (BMFZ). Figure from Machette et al., 2001.

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Regional context

Death Valley is a part of the Basin and Range. This physiographic province stretches across the southwestern United States and northern Mexico. Formation of the Basin and Range province is thought to be driven by the movement of the Pacific plate below the North American plate. This movement causes extension of the overlying crust and the subsequent normal faulting responsible for typical Basin and Range Topography. Up to 3 km of vertical displacement has been proposed for some of these Basin and Range normal faults. As a result, the lithosphere below the Basin and Range is amongst the thinnest in the world (~30 km compared to 150-250 km average thickness of the continental lithosphere). The Basin and Range province is thought to have accommodated up to 100% extension over the past c. 20 million years.

Death Valley originated as a typical basin and range, but has since been modified by slip along the Northern and Southern Death Valley Fault Zones and Black Mountain Fault Zone. These fault zones now form the longest and most active fault systems in the Basin and Range province. These fault zones are part of the Eastern California Shear Zone, which parallels San Andreas Fault Zone. The Eastern California Shear Zone is an example of distributed deformation, whereas the San Andreas Fault Zone represents localized deformation. Slip along both the Eastern California Shear Zone and the San Andreas Fault Zone is driven by the relative motion between the Pacific and North American plates.

Recent activity

The minimal evidence of erosion visible on many faults in the Death Valley region suggests recent slip events have occurred along these faults. There are a few reports of historic activity along the faults of the Death Valley and Black Mountain Fault Zones. Slip along the normal faults of the Black Mountain Fault Zone was reported in 1908 and may be related to a M 6.5 earthquake that occurred in the region (Clements, 1954). Unfortunately these reports are difficult to verify and a causal relationship between fresh-looking fault scarps in the Black Mountain Fault Zone and the 1908 earthquake have not been established. Other reports have also been reported in the literature, however the credibility of these reports has not been established.

Trenching across faults of the Black Mountain Fault Zone has revealed an average recurrence rate of 1 event every 6700 years, where each event has an average of 0.3 m of normal fault displacement, or an average slip rate of 0.1 to 0.5 mm/yr over the past 100,000 years (Machette et al., 1999).

Fault-controlled fluid flow

There are a multitude of springs in Death Valley. Many of these springs occur along faults of the Death Valley and Black Mountain Fault Zones. These are excellent examples of fault-controlled fluid flow; groundwater utilizes these faults as highly-permeable (low-resistance) conduits to the surface. Examples of these fault-controlled springs are Salt spring, Sand spring, Triangle spring, and Travertine spring.

Faults on Mars are expected to serve as analogous conduits to the subsurface movement of volatiles. Faults on Mars are therefore excellent places to explore for evidence of past geochemical, and potential biogeochemical, processes.

Paleo-shorelines or faults?

Death Valley is largely a fault-controlled terrain; faults significantly influence the topography and morphology that we see today. This means that fault traces commonly follow the topography (or more precisely, the topography follows the faults; Figure 3). The tendency for faults to follow topography has significant implications for mapping the locations of paleo-shorelines in the Death Valley basin. Since both the fault traces and shorelines follow topography, detailed field studies are required to discern between terraces due to shoreline processes and morphologically similar fault scarps (Figure 4). How would you discern between paleo-shorelines and fault scarps on Mars?
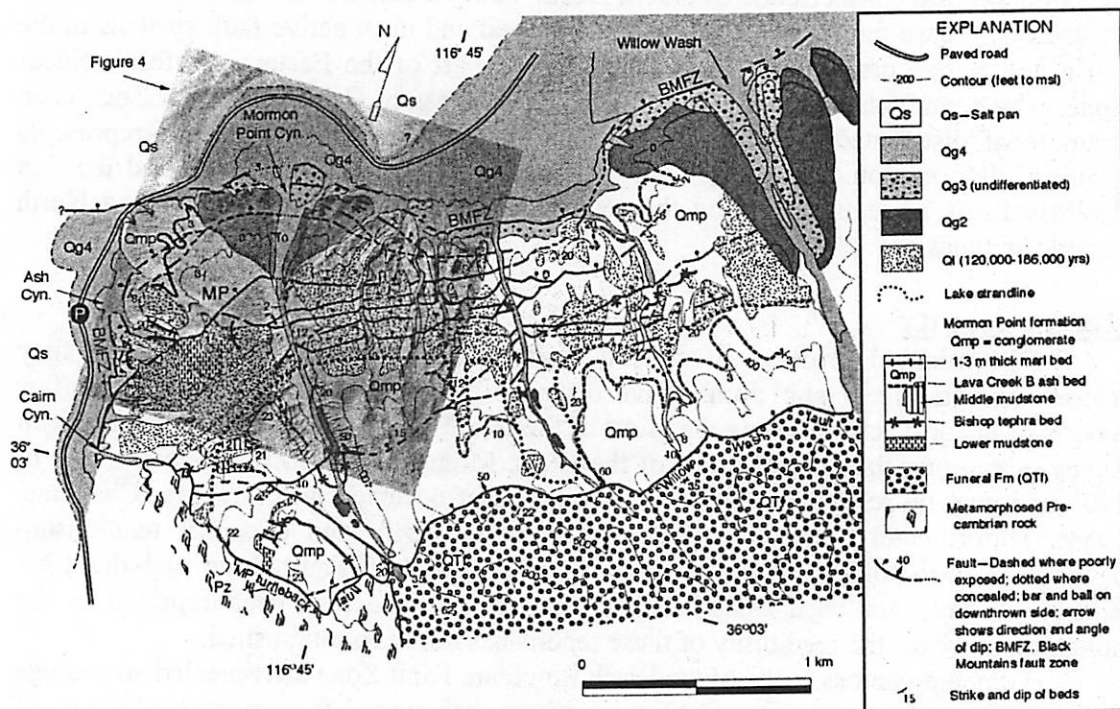
Figure 3. Structural map of faults in the Mormon Point area. Normal faults are part of the Black Mountain Fault Zone (BMFZ). The surface traces of these normal faults follow topography, making it difficult to distinguish them from paleo-shorelines in aerial photographs. Figure from Machette et al., 2001.
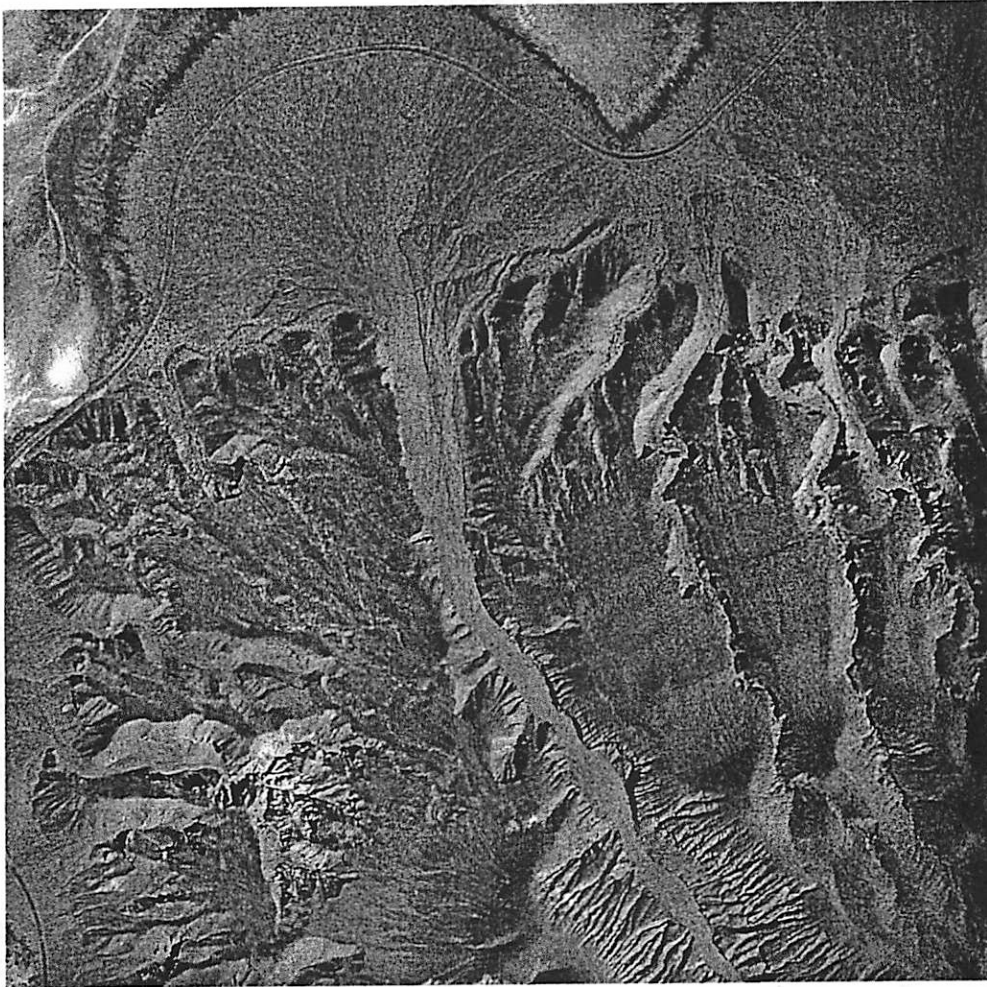
Figure 4. Aerial photograph of the Mormon Point area. Location and scale shown in figure 3. In this photograph, the surface ruptures (scarps) of normal faults in the Black Mountain Fault Zone appear very similar to the paleo-shorelines. In fact, there is only one true paleo-shoreline and one present-day shoreline in this photograph. Can you find the real paleo-shoreline? See Figure 3 for the answer.

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Desert Pavement
A primer by Robin Van Auken

Desert pavement is an interlocking mosaic of closely packed stones and pebbles, one to two clasts (particles) thick above a soil or other fine grained deposit. It serves as an armor that protects the underlying sediments from further wind erosion, effectively sealing the surface of a desert region. Some other common names for a desert pavement are reg, gibber plain, stony mantle, hammada, serir, or gobi.

There is an active debate over how desert pavements are formed.
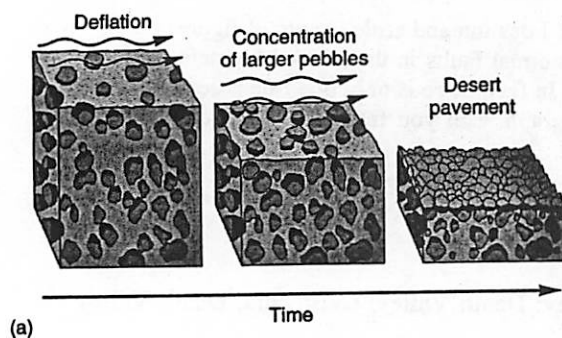
Erosion/Deflation: This first widely accepted theory attributed the growth of desert pavement to erosion/deflation, suggesting that the desert pavement surface is a lag deposit, consisting of rocks that were left behind after wind or water blew away all the fine grained material. (Fig. 1)

Wet/Drying Cycles: This theory suggests that the alternating shrinking and swelling of soil horizons, by repeated wetting and drying is responsible for the formation of desert pavement. The effect has been successfully created in laboratory experiments by wetting and drying a container filled with soil, yet it is unclear whether these experiments relate directly to the comparatively unconfined space of a desert.

In the above theories one would expect to find gravel pieces of varying ages making up the desert pavement, because these pieces would have arrived at the surface in a time-trangressive manner (Fig. 1). Yet Stephen Wells and Les McFadden used the method of He3 dating, at Cima Dome in the Mojave Desert, to test how many years a stone has been exposed on the ground, and found that the lava stones in the Cima Dome pavement have all been at the surface the same

amount of time as the solid lava flows right next to them. (He3 dating is based on cosmogenic helium-3, which forms by cosmic ray bombardment and is retained inside grains of olivine and pyroxene in the lava flows.) This led to the following, and currently preferred theory.

"Born at the Surface": In this model, pavements are maintained at the surface as the cumulic soils develop below them, by the incorporation of eolian dust into cracks in the rock. It suggests that desert pavements are born and maintained at the surface. It should be noted that this theory is most applicable for flat bedrock surfaces (such as the lava flows in Cima Dome), and may not apply to areas such as alluvial fans, where desert pavements are also often found. In these areas it is useful to consider a combination of the other preferred theories previously described.
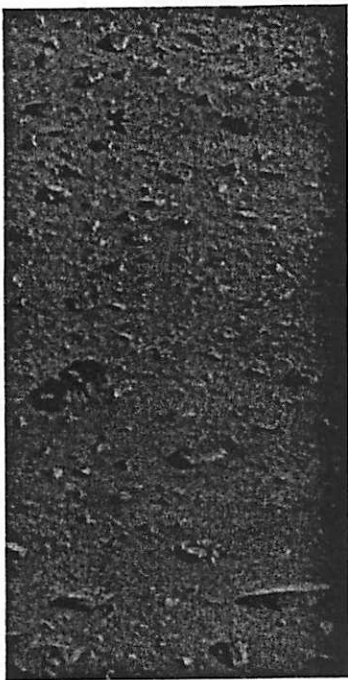
Planetary Connection: Gusev crater, traversed by Spirit was found to have terrain with many stones that are well sorted and evenly spaced, resembling a desert pavement.
Gusev crater itself appears to have formed over basalt flows. Because of this, there is a good possibility that it's geology has similarities to the Cima Dome, which is dominated basaltic lava flow rock.

Citations:

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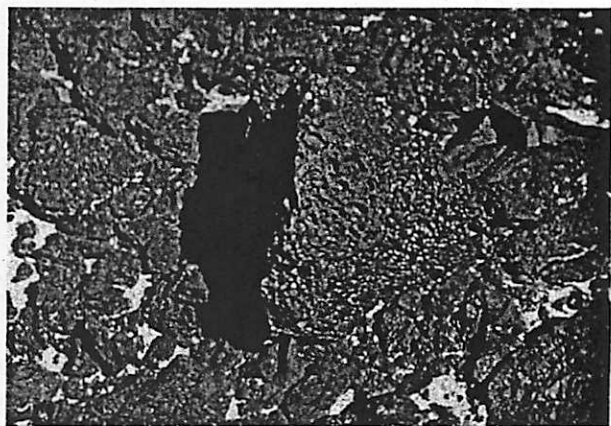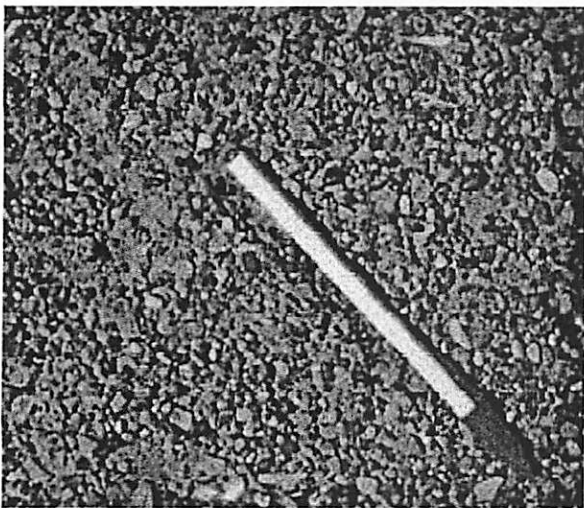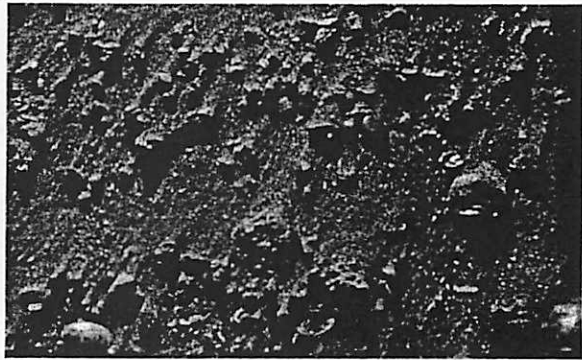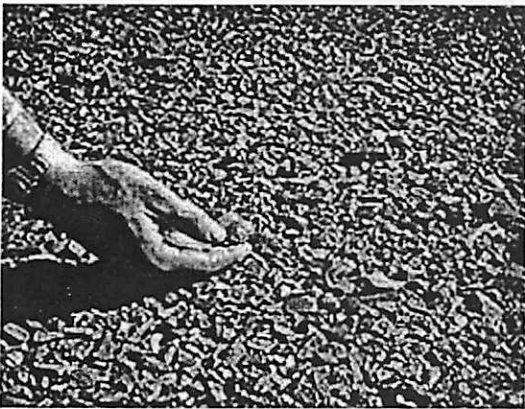
Lava flow rock on desert pavement (Mojave Desert)

Desert Varnish
Maki Hattori

Desert varnish is the dark coating found on exposed rocks in many arid environments. The color generally varies from black to brown. The varnish is composed of clay high in Fe-Mn oxyhydroxides (FeOOH, MnOOH)with trace Rare Earth Elements. It forms only on physically stable rocks in low precipitation areas. The contact between the rock and the varnish is sudden and there is no transition. Varnish occurs on nearly all types of rocks including quartzites which contain little Fe and Mn, however does not often occur on limestones which are not water soluble.

Geologists are not yet certain as to the exact formation mechanisms of desert varnish. Some theories are:
1) Clay deposited on the rock acts as a substrate to catch other elements. The high daytime temperatures cause the minerals to chemically react to create the varnish, cemented by hydroxides. Manganese might come from inside the rock dissolved by water.
2) Bacteria deposit a layer of manganese-rich material on the rock surface. Bacteria intake manganese and iron from the surrounding area, then oxidize it and deposit it on the rock.

The enrichment of manganese in the varnish is difficult to explain. While manganese makes up .12% of the earth's crust and iron makes up 5%, manganese can be ~50 times more abundant than iron in the varnish. Different layers of the varnish can contain different ratios of iron and manganese which may indicate climate changes in the desert (manganese rich varnish is more abundant in more humid regions). Varnish also contains records of human activity such as the introduction of lead into gasoline.
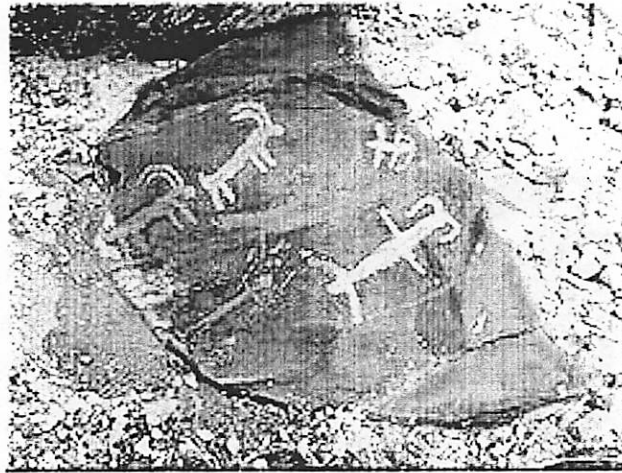
Death Valley Petroglyph – Bighorn sheep

One of the terrestrial uses for desert varnish is archaeological. Many Native American cultures carved pictures into the varnish such as that seen above, and newspaper rock on the a previous trip.

Planetary connection:

A shiny coating that appears to be desert varnish has been observed by the Mars missions - Viking, Pathfinder, Spirit and Opportunity. If the formation of desert varnish is shown to be dependant on microbacteria, these would be good places to search for past/present life.

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Ubehebe Crater

Diana E. Smith

Ubehebe is a volcanic phreatic explosion crater approximately 1 km wide and 150-250 m deep. It formed from the contact of hot magma with groundwater that then suddenly flashes to steam and causes the explosion.

The photo to the right shows the Ubehebe volcanic field. Photo by Peter Sanchez, NPS [5]
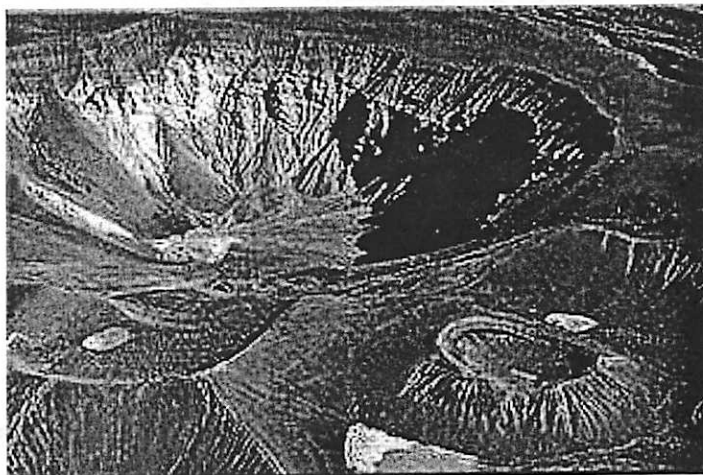
The Phreatic (Hydrovolcanic) Eruption

A "phreatic" eruption (also referred to as "hydrovolcanic") is an explosion or eruption caused by the sudden expansion of water when mixed with magma. The tremendous temperature of the magma causes the water to suddenly flash to steam and expand very quickly, creating an explosion of steam, water, and pyroclastic materials. If the juvenile material is involved, then the term "phreatomagmatic" is sometimes used. A "maar" is the wide, low relief crater results from such a phreatic. Sometimes it fills with water to form a crater lake.
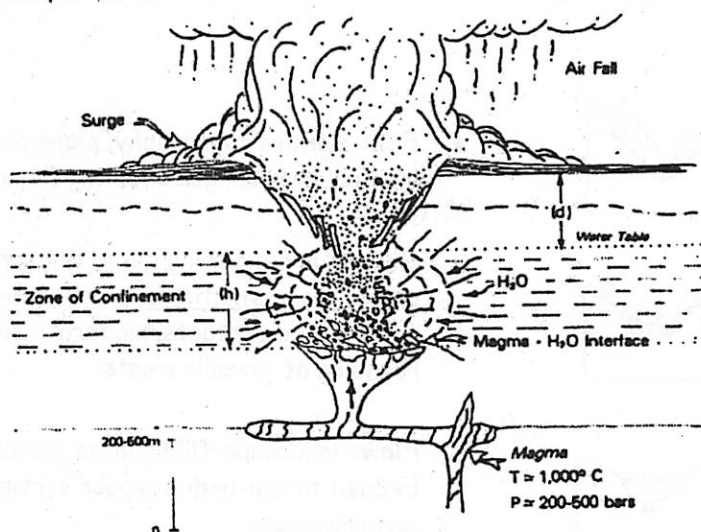
Heiken et al., 1996, Fig. W11

The Hydromagmatic Explosion System

The explosion is focused at the site where ascending magma contacts external water. Pyroclastic surge and fall deposits including ballistic clasts build low tuff ring around the deepening maar crater.
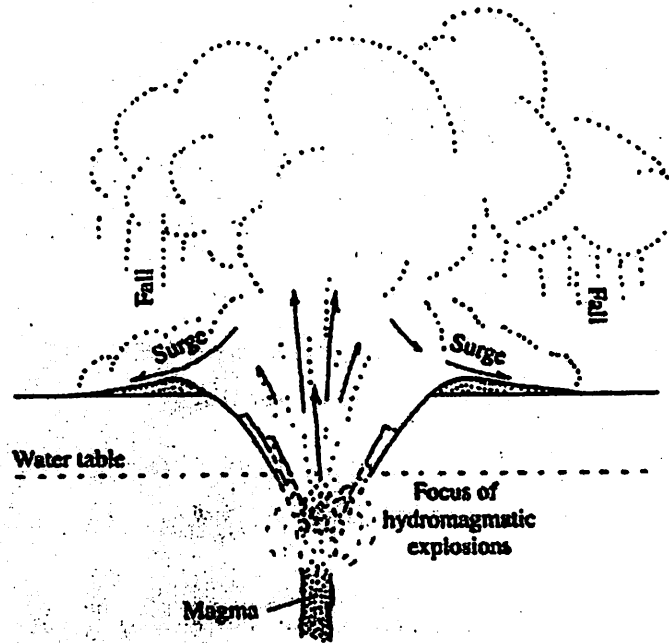
Best and Christiansen, 2001, Fig. 10.23

Pyroclastic Deposits
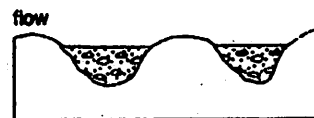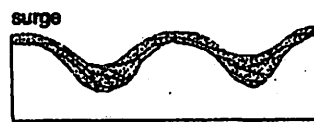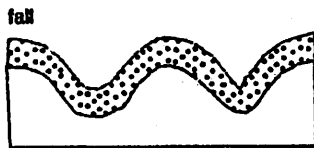
- **Fall:** mantles topography, plane parallel beds, no internal erosion, good sorting (if no water)

- **Surge:** non-mantling beds, thickening in low-lying areas, <u>cross-stratified</u>, pinch-and-swell bedding and scoured contacts, moderate sorting, some rounding of juvenile clasts

- **Flow:** landscape-filling units, generally poorly bedded to non-bedded, poor sorting, rounded juvenile clasts

Wilson and Houghton, Fig. 5

Anatomy of a Maar Volcano

A: Groundwater aquifer

C: Funnel-shaped conduit formed by explosive interaction of magma with groundwater (diatreme)

L: Crater filling: consisting of fallback tephra, reworked tephra from rim beds, and lake sediments

I: Inward-dipping rim bed

O: Outward-dipping rim bed
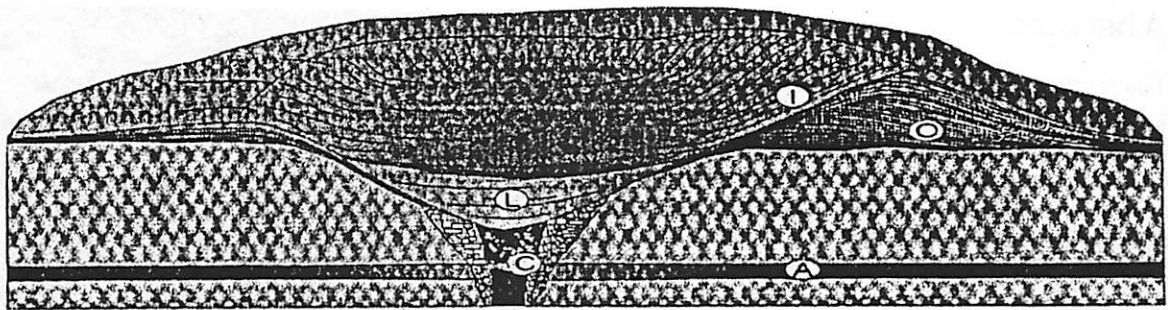
Vespermann and Schmincke, 2000, Fig. 6; from Fisher and Schmincke, 1984

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Don't Hate the Playa – Hate the Game.

Brian Jackson

March 24, 2006

Abstract

The motion of the rocks in Racetrack Playa has been a mystery since the first observations of the divergent tracks in the playa clay. Although the motive force of the rocks has long been attributed to winds, the necessary conditions for motion remain mysterious. Studies since the 1950s have yet to reach a concensus about what is required to move angular rocks of several hundred kilograms across hundreds of meters of ragged playa terrain. Although unusual, the mysterious motion of Racetrack Playa's rocks is not unique: similar observations have been made at several nearby playas, such as Little Bonnie Claire, Nelson Dry Lake and Rogers Playa. This suggests that wind-swept motion of rocks may be a relatively common occurence, given the right conditions, on Earth and other planets.

1 Geophysical Conditions of Racetrack Playa

The geophysical conditions in Racetrack Playa are of paramount import for understanding the motions of its rocks. Adjacent to the playa on the east and west are two prongs of the Panamint Range of roughly 1.8 km elevation. The north end of the playa opens up onto Racetrack Valley. Racetrack playa itself is an elliptical lake bed, 4.5 km north-south and 2.1 km east-west (Sharp and Carey, 1976). Alluvial fans line the sides of the playa, while a dolemite ridge, the posited origin of the wind-blown rocks, lies at the southeastern boundary of the playa. Topographic relief in the playa is very mild with the northern end of the playa only a few centimeters higher than the
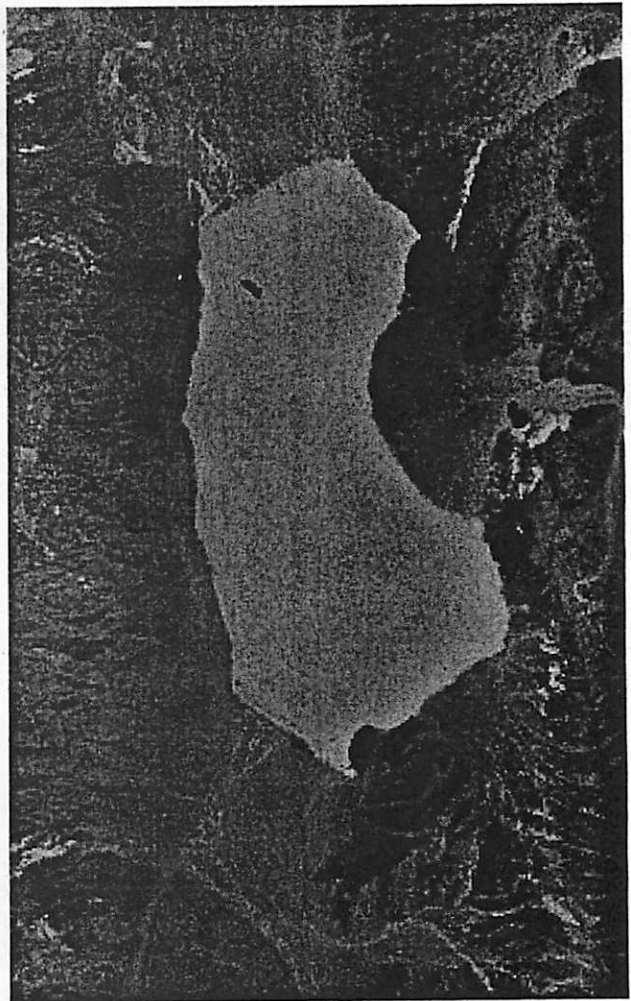

Figure 1: Satellite photo of Racetrack Playa $(36°41'N, 117°34'W)$ from Messina (2003)

southern end (Messina, 2003).

The annual precipitation in this region is 7 to 10 cm, but snow cover has been observed on the playa floor as thick as 30 cm (Sharp and Carey, 1976). Below freezing temperatures are frequently recorded during the winter, and thin sheets of ice have been observed lining the floor of the playa (Sharp and Carey, 1976). The prevailing wind is south to north (which correlates with the observed rock motion) and can be as high as 40 m/s (Bacon and Tombrello, 1996). Due to the extreme topology of the surrounding ridges, winds can be channelled and are strong and frequent.

According to Sharp and Carey (1976), Racetrack Playa, though occasionally completely flooded, when wetted, is usually only covered by a layer of water a few cm deep. This infrequent wetting and subsequent drying of fine clay silt leads to a rugged, crumbly surface (see John Keller's talk). However, when wet, the surface can be slick, according to Sharp and Carey (1976), possibly faciliating the motion of the playa rocks.

2   Evidence of Motion

No one has ever observed the Racetrack Playa rocks in motion. Owing to its isolation, Racetrack Playa has retained the mystery of its moving rocks. However, careful observation and monitoring of the playa rocks has been conducted. Sharp and Carey (1976) conducted a personally funded survey of the playa rock tracks over the course of several winters. In their study, they followed the motion of a few tens of rocks from 1964 to 1974 by tracing the clay furrows made by the rocks.

They noted the greatest cumulative motion of any single rock was 262 m, while the single greatest episode of motion was 201 m for a rock weighing 250 g. Other stones weighing about 25 kg were observed to move as much as 219 m. They also concluded that the rocks seemed to move during the winter and their motion was always accompanied by a recent rain. The net average motion of the rocks was south/southwest to north/northwest. From observations of the rock furrows and apparent mud splash at the end of the rock tracks, Sharp and Carey (1976)
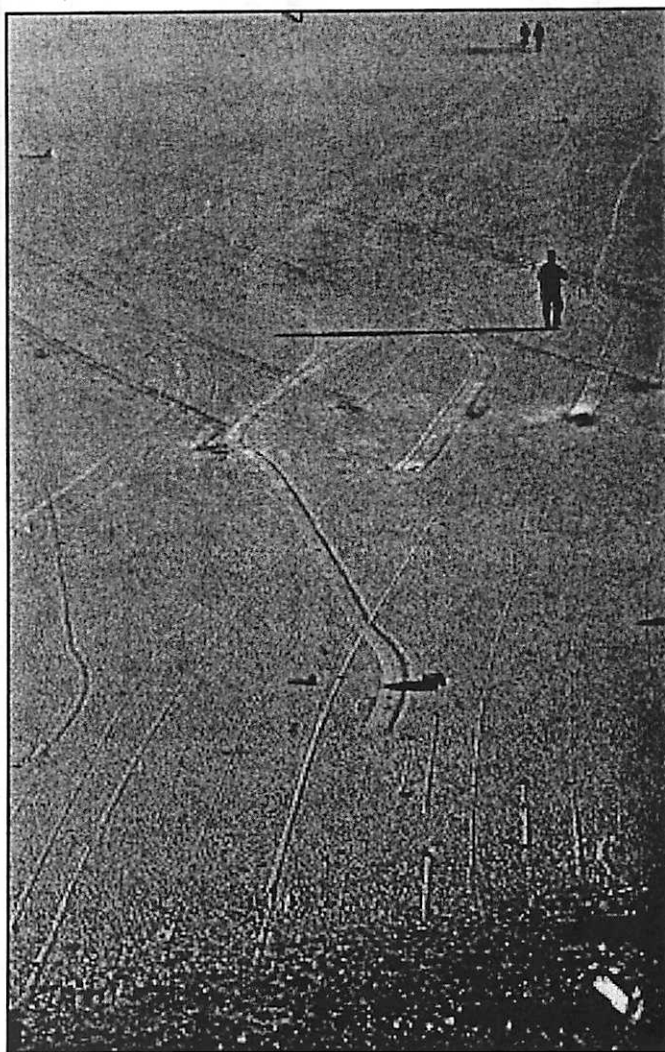

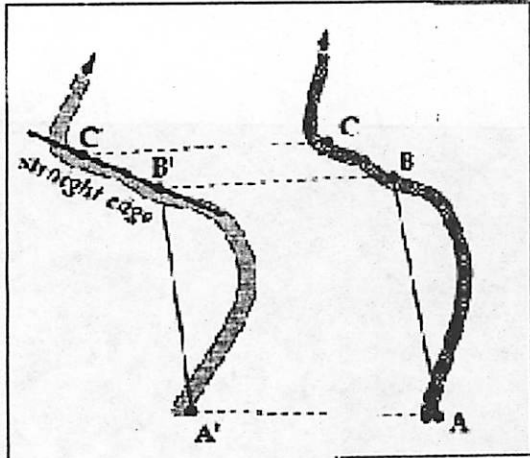Figure 2: Playa rock tracks, taken from Reid (1995)

43

Figure 3: Illustration of similar tracks followed by separated rocks, fig. 5 from Reid (1995)
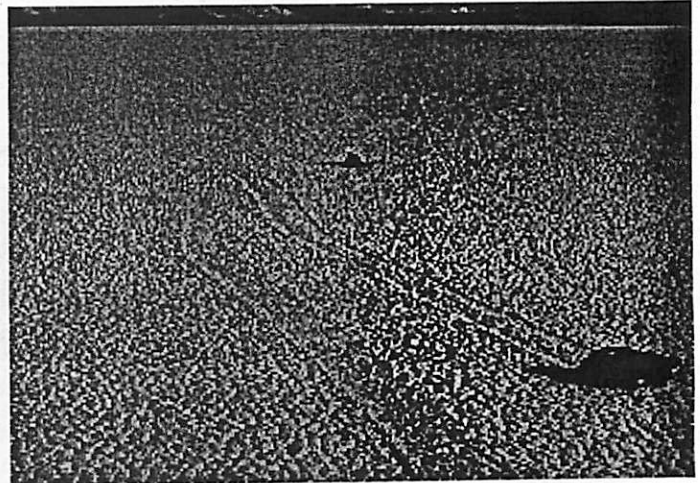

Figure 4: Divergent rock tracks, taken from Messina (2003)

estimated the rock velocities to be of the order 0.5 to 1.0 m/s. Distinctive lithologies allow more long term tracking of the net displacement of rocks from their origin and give a distance of about 3 km. Since rock furrows are ephemeral, they can only be used to track rocks for no more than about 7 years (Sharp and Carey, 1976).

Additionally mysterious is the apparent correlation and anti-correlation of rock furrows near one another and separated by great distances. Reid (1995) conducted a survey similar to Sharp and Carey's in which they observed a pair of rocks whose furrows matched to within a few centimeters but which were separated by 830 m, as illustrated schematically in 3. Other observations have shown rocks lying close to one another taking different paths. Also, variations in a single furrow's width suggest that the rocks rotate during the trek across the playa (Sharp and Carey, 1976). In general, the furrows consist of long either straight or gently curving sections separated by sharp curves, as illustrated in

3 Proposed Mechanisms

Although consensus holds that wind is the primary motive force behind the rocks' motion, the required conditions to allow wind-blown rocks to cross usually rough terrain have not yet been unequivocally established. Contrary to previous studies, Sharp and Carey (1976) proposed that the infrequent rains made the playa surface slick enough that wind gusts observed to occur on the playas would be able to move the rocks around. Key to their mechanism is the existence of a very clay sediment that they suggest settles out of the drying lake just as the water seeps down into the dessication cracks. This very fine sediment is the key to their theory, and they propose that previous experiments on wetted playa did not allow this lubricating sediment layer to settle out properly.

A more recent study by Reid (1995) proposed the formation of ice sheets in the winter after rain. Reid et al. claim that even if the playa were wet, the coefficient of static friction is still too high for a wind gust to drive rocks over the playa surface. They estimate coefficients of static friction for the playa rocks $\simeq 0.8$ and higher. They approximate the drag force,
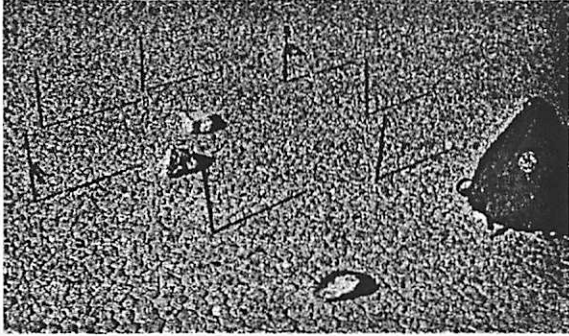
Figure 5: Sharp and Carey's rock corral

F, by the wind on a rock with

$$F = 1/2 \rho c_p A_{ver} v^2 \qquad (1)$$

where ρ is the air density, c_p the drag coefficient ($\sim 0.1 to 1.0$), A_{ver} the perpendicular area, and v the wind velocity. With this formulation and the frictional force relation to the rock's weight, they estimate the required winds to move a 20 kg rock to be $\sim$78 m/s at the surface. This surface wind corresponds to a wind at 10 m height of $\sim$125 m/s, much higher than any observed wind in the region of Racetrack Playa.

While Reid (1995) estimate more reasonable winds ($\sim$ 27 m/s) if the rocks were embedded in an ice sheet floating on a layer of water, their ice sheet theory also has problems. In particular, Sharp and Carey (1976) corralled several rocks in a circle of steel poles driven into the ground (see 5). In spite of this, one of the rocks moved out of the corral, while two stayed in. This would seem to argue against a floating ice sheet. Reid (1995) suggest that the ice sheet may experience local cracking which allows nearby rock paths to diverge. All in all, the conditions which allow playa rocks to move are unclear.

4 Planetary Connection

While the exact conditions sufficient for wind-blown playa rocks remain unknown, it is clear that this phenomenon is not unique to Racetrack Playa. Sharp and Carey (1976) cite several other authors who studied similar behavior in nearby playas. Obviously in order for wind to blow rocks across a planetary surface, the drag on the rocks by the boundary layer wind must be sufficient to overcome the static friction between the rock and the surface. To accomplish this, the wind must be strong or the friction must be small.

Wind-blown rocks are not terribly likely on Mars, for instance. Although the martian winds can reach 8000 cm/s, the air density at the surface is $\sim 10^{-5} g/cm^3$. This gives a drag force with a drag coefficient of 1.0 equivalent to a gravitational mass of 86 g under martian gravity. With a reasonable estimate for the static friction coefficient, say 0.8, the martian winds could blow a rock with a mass of roughly 100 g, about 3 cm on a side.

On Titan, however, static friction becomes much less owing to the different composition of the "rocks". On Titan, the bedrock is probably water ice (possibly with some organics mixed in) with the blown rocks made of ice as well. Recent estimates (Lorenz, 2006) of the surface winds give a value of 0.2 m/s or less. However, the surface density of the atmosphere on Titan is $\simeq 5 \times 10^{-1} g/cm^3$ (Yelle, 1997). Calculating the scaled mass transportable by Titan's surface winds gives about 60 g. Accounting for the reduced friction between ice surfaces (i.e. $\mu \simeq 0.1$), we find a mass for ice rock of about 600 g, equivalent to a block of ice about 8 cm to a side.

On Earth, the very level surface of a playa (corresponding to a roughness scale of about 0.1 mm (Bacon and Tombrello, 1996)) facilitates the development of a very small atmospheric boundary layer, i.e. very little surface drag. This allows relatively strong winds to persist very close to the surface. Do playas exist on Titan? The answer is not clear. The suggestive figure below was taken by the ISS instrument onboard the Cassini spacecraft while it was viewing the south pole of Titan.

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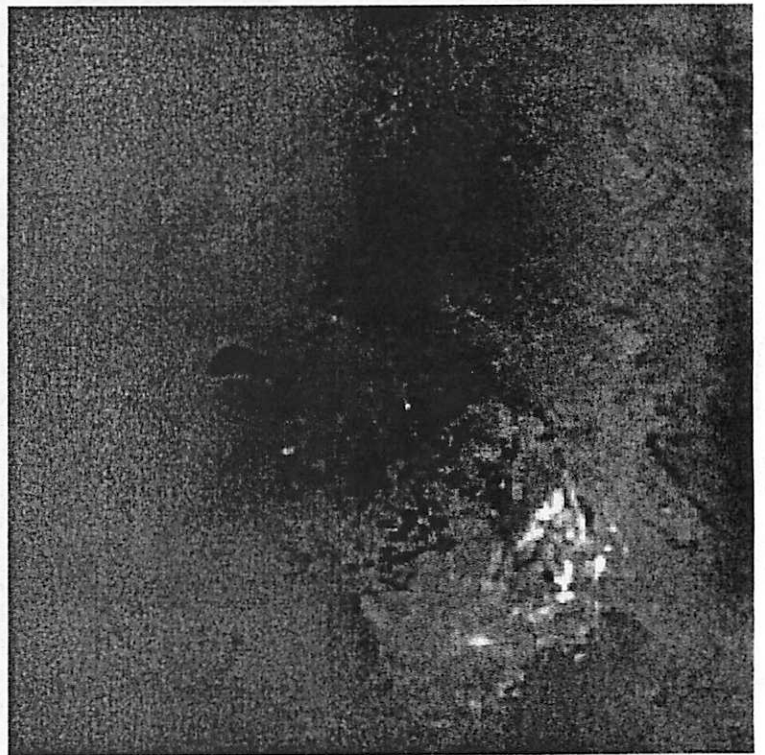Yelle, R., 1997. Engineering Models For Titan's Atmosphere. Huygens Engineering Report.

Figure 6: ISS image taken near Titan's south pole

The Tin Mountain Landslide

LANDSLIDE: A loose term that encompasses a wide range of gravity-dominated 'mass movement' processes that transport soil, rock and debris down slope.

Figure 1: Typical landslides

(Below) Block diagram of a typical landslide, illustrating landslide features and their spatial relationships [1]

(Left) Landslide in Kasei Valles (Mars) showing the typical curvate head scarp and 'pinched' toe. Image credit: NASA/JPL/MSSS.
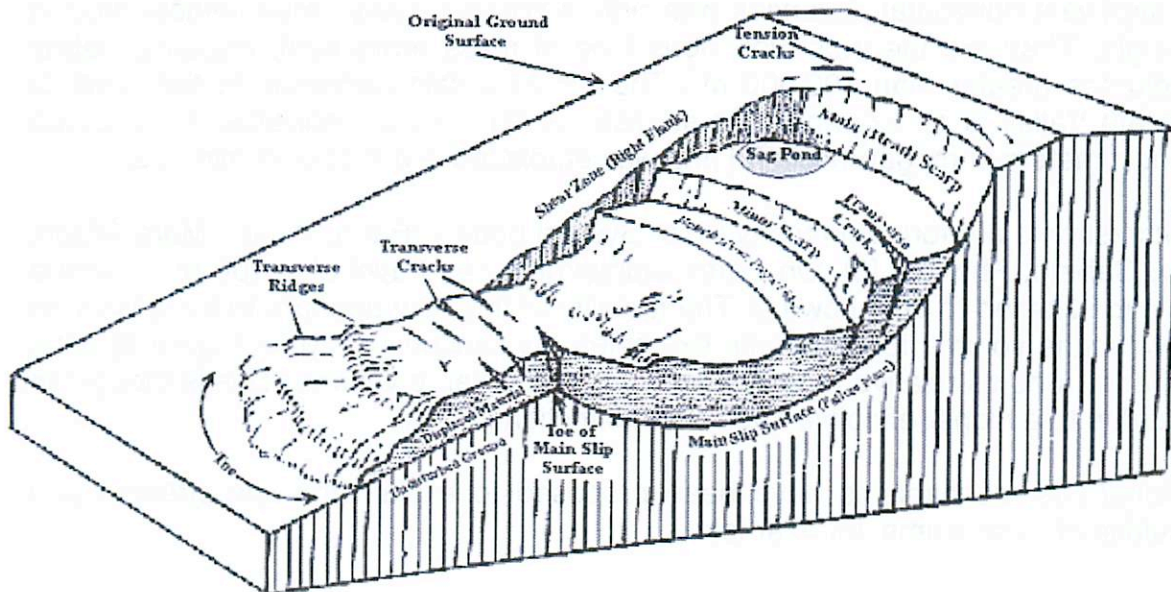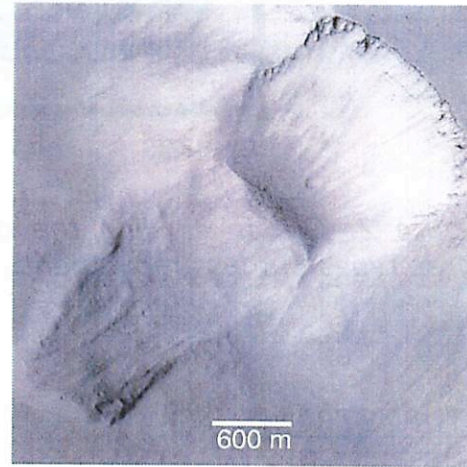
TYPES OF MASS MOVEMENT
The three main categories of mass movement include falls, flows and slides of rock, debris or soil. Depending on the local conditions and the failure 'trigger' (e.g. earthquake, heavy rain, etc), the mass movement will take place at different speeds and scales as outlined in figure 2.
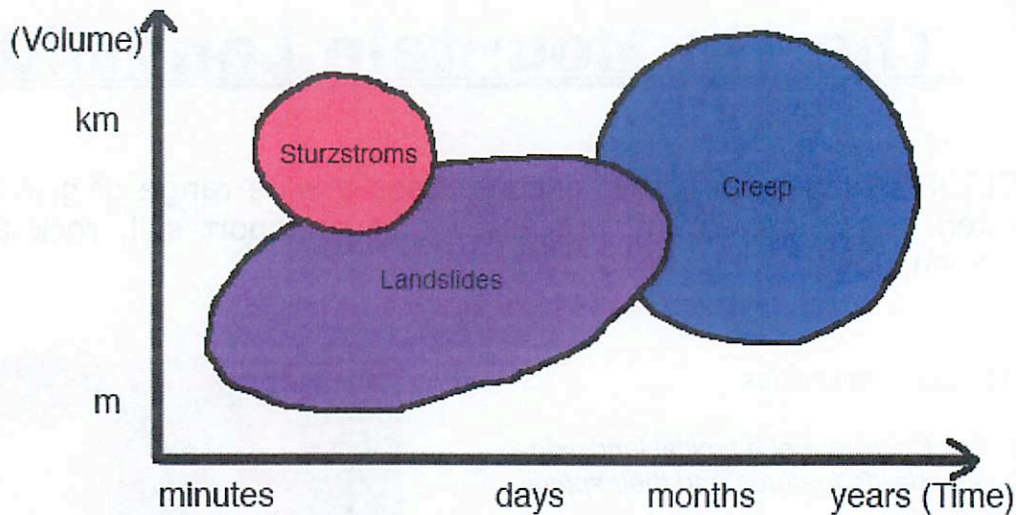
Figure 2: Graph showing the relative volumes and emplacement times of three types of mass movement.

STURZSTROMS

Sturzstroms are a rare category of unusually mobile dry rock avalanche that travel vast horizontal distances with only a comparatively small vertical drop in height. They are the most volumous type of mass movement, involving debris volumes greater than 100,000 m^3. The Tin Mountain Landslide to the West of Death Valley is an example of a sturzstrom. This deposit consists of ~ 2 billion cubic meters of megabreccia [2] and was emplaced in a matter of minutes.

Sturzstroms are found on many Solar System bodies (Earth, Venus, Mars, Moon, Io, Callisto, Phobos) [3]. On Earth, sturzstroms can travel at ~ 100 m s^{-1} with a motion likened to fluid flow [4]. The mobility of this flow appears to increase with avalanche volume for terrestrial examples. Avalanches on Mars (figure 3) have shorter runouts relative to terrestrial flows of the same volume. This is thought to be due to a higher effective coefficient of friction [5].

Numerous mechanisms have been proposed to explain the low strength and fluidity of sturzstroms, for example:

- Water or air lubrication
- Local steam generation
- Melt generation
- Grain sorting
- Dispersive grain flow
- Granular temperature generation
- Acoustic fluidization

The discovery of sturzstroms on the moon, Mars, Venus, Io, Callisto, and Phobos, appears to rule out the involvement of significant volatiles or atmospheric gases in the flow mechanism. The preferential sorting of grains can also be ruled out due to the preservation of gross stratigraphy during motion. One of the remaining explanations of all the characteristics of sturzstroms is acoustic fluidization [6]
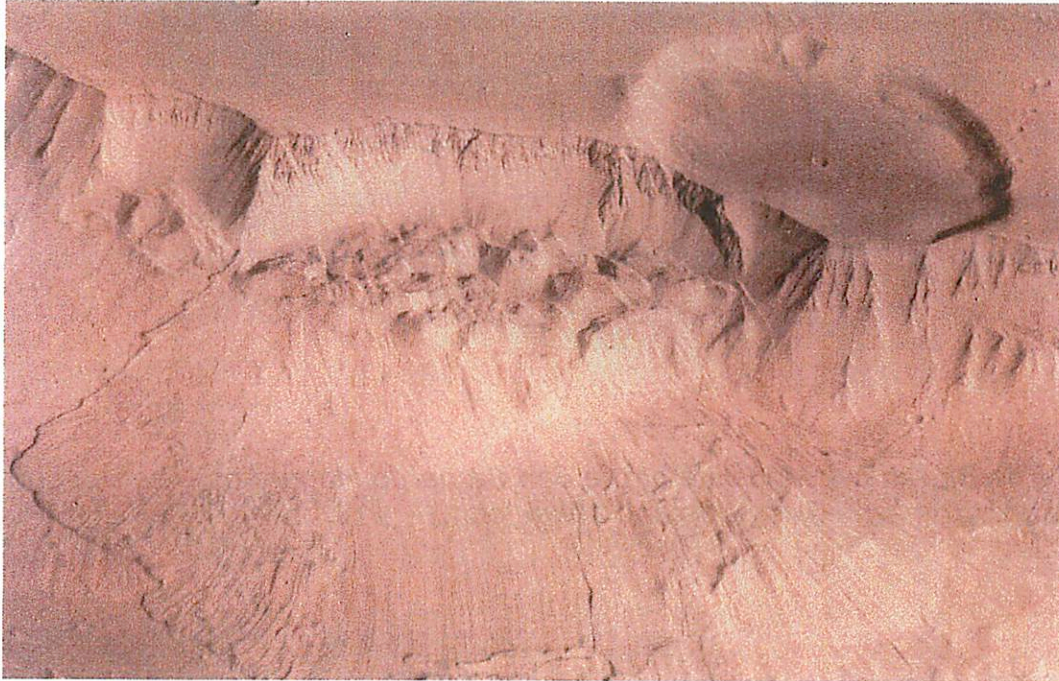

Figure 3: Landslide on the south wall of Valles Marineris, Mars. The image is 60 km across. Image credit: NASA/JPL/MSSS.

ACOUSTIC FLUIDIZATION

The idea of acoustic fluidization of rock debris during sturzstrom and impact crater formation was developed by Melosh [7] as an extension of existing models of earthquake induced landslides [8]. The basic concept involves rock debris flowing fluidly when subject to strong vibrations. These vibrations are transmitted as sound waves via rock to rock contacts. The effect of these pressure vibrations is to locally enhance or reduce the overburden pressure in the target. In areas where the strength of the rarefaction waves equals or exceeds the overburden pressure, blocks are able to move relative to one another. These sporadic localized slips allow the rock mass to move in a fluid-like manner on a macroscopic scale with a dynamic viscosity dictated by the frequency and violence of the vibrations. As the vibrations dissipate, slip events become more localized and less frequent leading to a larger dynamic viscosity and eventually halting the flow.

Figure 3: The Blackhawk landslide of the San Bernardo Mountains. The run out of this sturzstrom is ~ 3km wide and 10km long.

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A Descent into Chaos: Tales of Geologic Woe

Mike Bland

First coined to describe faulted structures in Death Valley, regions of chaos have been found in several localities in the southwestern US.

You might be a **Chaos** if:
1. Your arrangement of blocks is confused and disordered – Chaotic
2. Your blocks, although mostly too small to be individually mapped, are vastly larger than anything that could be called a breccia (50 m – .5 km) – You're a Super-Mega breccia!
3. Your blocks are tightly packed together rather than separated by finer grained material
4. Each of your blocks is bounded by surfaces of movement – in other words, each of your blocks is a fault block
5. Each of your blocks is minutely fractured throughout, but your original sedimentary bedding is still intact

The Tucki mountains are a nice example of fault chaos. The mountains consist of Precambrian sedimentary and metamorphic rocks in the west and Paleozoic marine rocks in the east. These rocks have been disrupted to the point where they form a "crazy-quilt pattern, bizarre and without explanation." (Sheehan 1988).

Left: Arial view of Tucki Mountains. Variations in shading suggested highly tilted and disrupted strata. **Right:** Chaos in the Amargosa fault zone, Death Valley.

Origin of Geologic Chaos in Death Valley:

Early (pre plate tectonics) work suggested that the chaos of Death Valley was due to regional thrust faulting during the Tertiary (~2-65 ma). However, a reinterpretation of fault displacement in the '70's and '80's found that the faults are more likely normal or strike-slip faults. These findings are more in-line with the regional extensional stresses found throughout the Death Valley area.

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Chaos in the Solar System
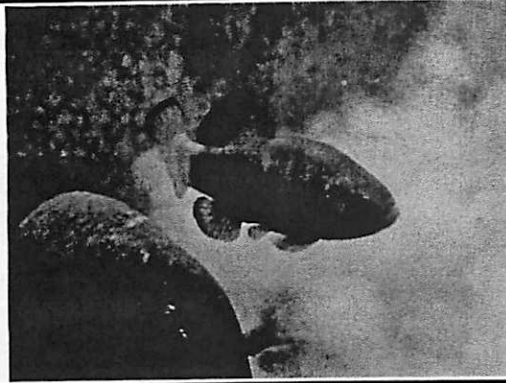
A distintive area of broken terrain

Colored Chaos, Mars
(Themis)
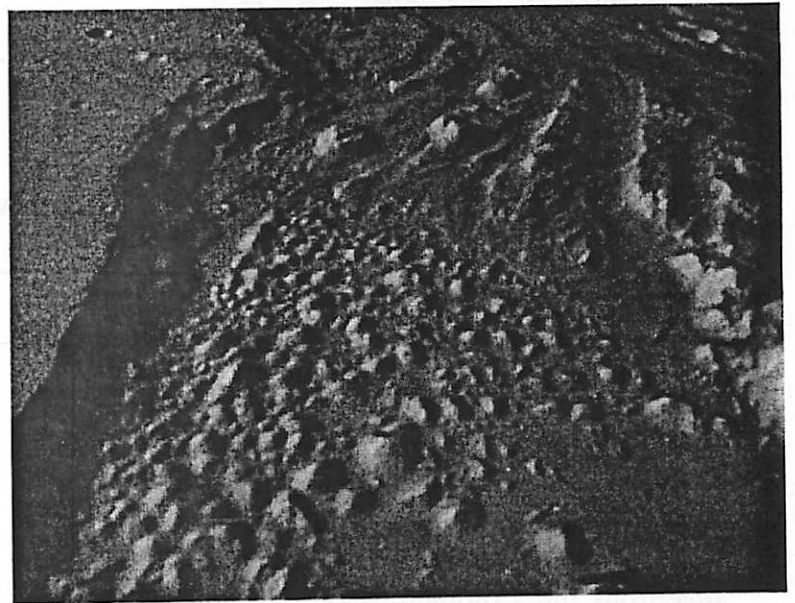
Ares Vallis, Mars
(HRSC oblique view)

Conamara Chaos, Europa
(Galileo SSI)

Life in Death Valley

The desert pupfish

Catherine Neish
Death Valley Field Trip (Spring 2006)

As unlikely as it seems, the desert of Death Valley is home to several species of fish. These desert pupfish live aquatic oases where the water table is near enough to the surface to produce springs, streams, and marshes. The ancestors of the desert pupfish first swam to the area from the Colorado River via an ancient system of rivers and lakes (Figure 1). Then, about 10,000 years ago, a drying trend began. Most waters shrank, leaving only isolated refuges for aquatic life.

The isolation imposed by the arid conditions creates a natural laboratory for studying how selection pressures influence the genetic make-up of populations (like the finches in the Galapagos islands). Today there are more than 20 populations of pupfish that have evolved into 10 distinct species or subspecies. Each species has taken on a distinct set of biological adaptations. The most divergent pupfishes are those that have been isolated for the longest period of time, like the Devil's Hole pupfish.

Figure 1: The Lake Manly lake system as it might have looked during its maximum extent 22,000 years ago.

Death Valley contains five native fish species:

saratoga pupfish *Cyprinodon nevadensis nevadensis*

Habitat: Saratoga Springs in Death Valley. Temperature constant at 28-29 C. Spring overflows to the north into a number of shallow lakes. Spawning occurs in lakes.

Shape: Small (less than 50mm), with a broad body. Has a greater than average number of scales. Scales are narrow and large. Pelvic fins are reduced and placed anteriorly.
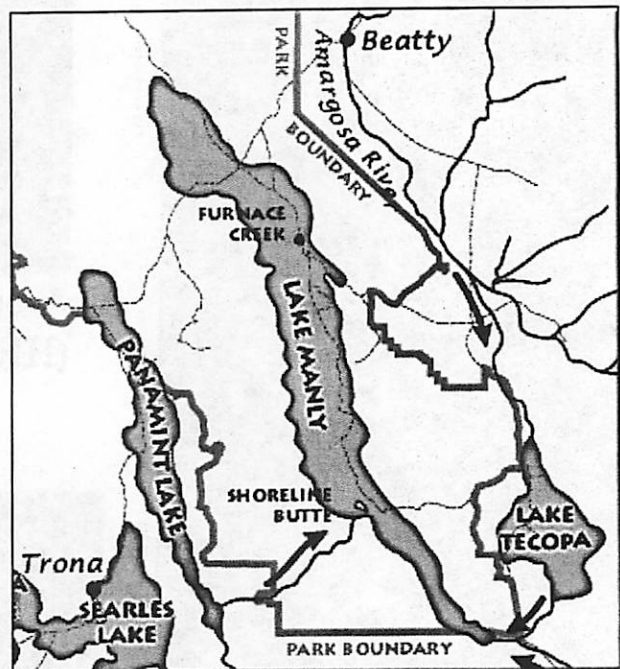
Colour: Bright blue with black band at edge of caudal fin (males); drab olive-brown with lateral vertical bars (females).

Reproduction: Become sexually mature in 4-6 weeks. Like other spring-dwelling fish, males establish territories. Peak breeding season occurs in summer, when temperatures are highest and food is abundant. Temperature tolerances lowest during reproduction.

Diet: Blue-green cyanobacteria, with some small invertebrates. Feed during the day.

Status: Stable, and occupying all available habitat. Pumping by the Las Vegas Valley Water District could cause groundwater depletion that would threaten its habitat.

amargosa pupfish *Cyprinodon nevadensis amargosa*

Habitat: Amargosa River. Includes an isolated downstream reach in Death Valley. Water temperature varies seasonably from 10-38 C. Water is clear and saline.

Shape: Similar to Saratoga pupfish, with more scales around the body.

Reproduction: Unlike the territorial Saratoga pupfish, Amargosa pupfish is a group spawner. Males direct receptive females to a group where spawning occurs.

Diet: Blue-green cyanobacteria, with some small invertebrates. Feed during the day.

Status: Most widespread of any Cyprinodon nevadenis subspecies. Fairly common in lower Amargosa River. Pumping by the Las Vegas Valley Water District could cause groundwater depletion that would threaten its habitat.

devil's hole pupfish *Cyprinodon diabolis*

Habitat: Devil's Hole, a geothermal (92°F), aquifer-fed pool within a limestone cavern in the Amargosa Desert of Nevada east of Death Valley. One of the oldest evolved forms of the Death Valley pupfishes (~22,000 years).

Shape: Smallest desert pupfish species, averaging 19 mm in length. Lacks pelvic fins and vertical barring common among other pupfish. Has a large head in proportion to body.
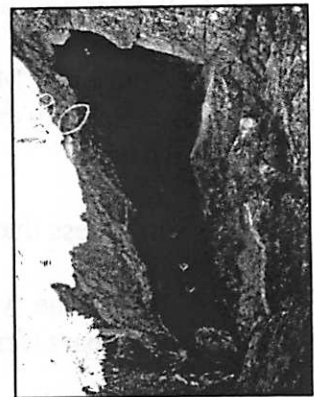
Colour: Blue and iridescent sides with brownish to silver back (males); Yellowish-brown along the back with dark edge on dorsal fin (females).

Reproduction: Use consort-pair breeding. In this system, one male follows closely behind an egg-bearing female, occasionally descending to an algae covered limestone shelf for spawning. Most reproduction in April and May, though possible year-round.

Diet: Algae and diatoms (eukaryotic algae) located on a small 2x4 meter limestone shelf.

Status: Endangered. In general, spring populations range from 150-200, increasing to 400-500 in the fall. However, half the population was destroyed during the summer of 2004 when a flash flood pushed debris and scientific equipment into Devil's Hole. In November 2005, divers counted just 84 individuals in Devil's Hole. Another major threat to its habitat has been groundwater depletion due to agricultural irrigation. The Supreme Court ruled to establish a minimum water level in Devil's Hole.

salt creek pupfish *Cyprinodon salinus salinus*

Habitat: Salt Creek in Death Valley. Water temperatures fluctuate between 0-40 C. Deeper waters in pools rarely exceed 28 C, providing refuge for the fish. Salinity approaches that of sea water. Colonization of areas beyond the permanent water also occurs. When waters recede, fish are trapped in side pools and perish.

Shape: Small (~6.5 cm long). Most slender bodies of all Death Valley pupfishes. Has small scales, reduced or absent pelvic fins, short head, and small eyes. Most closely related to *C. nevadenis*.

Colour: Deep blue on the sides, iridescent purple dorsally, with broad black bands on the sides (males); Brown with a silvery sheen and vertical lateral bars (females).

Reproduction: Live one year or less. Reproduce every 2-3 months. Large populations built up during favourable conditions of high water. Reproduction similar to Amargosa pupfish.

Status: Population varies widely on an annual basis. Most vulnerable when habitat has contracted due to seasonal evaporation of water in stream system.

cottonball marsh pupfish *Cyprinodon salinus milleri*

Habitat: Cottonball Marsh in Death Valley, into which Salt Creek overflows. Salinity between 14 – 160 ppt. Water temperature between 0-104 F.
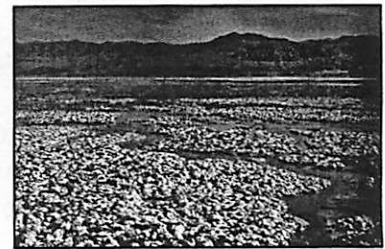
Shape: Small (less than 1.5 inches) and slender.

Colour: Deep blue with dark gray lateral bars and purple sheen (males); Silvery brown with lateral vertical bars (females).

Status: Threatened. Although isolated in a Wilderness Area, it is very vulnerable to disruption of groundwater sources, such as those proposed by the Las Vegas Valley Water District.

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http://www.death-valley.us/article105.html
http://www.nativefish.org/articles/desert.php

cottonball marsh pupfish
(*Cyprinodon salinus milleri*)

devil's hole pupfish
(*Cyprinodon diabolis*)

salt creek pupfish
(*Cyprinodon salinus salinus*)

amargosa pupfish
(*Cyprinodon nevadensis amargosa*)

saratoga pupfish
(*Cyprinodon nevadensis nevadensis*)

Salt Weathering in Death Valley

Yuan Lian
Death Valley Fieldtrip, Spring 2006

Salt weathering is a form of mechanical or physical weathering of rock, it will cause granular disintegration. Salt weathering breaks down the materials motionless processes; this is the major difference between erosion and weathering. No chemical alteration of rock constituents is involved in salt weathering. The salt derives from an external source. Salt weathering is favoured by dry conditions, such as are found in warm and cold (arctic) arid climates.

Where can we see salt weathering in Death Valley?

Most visible salts are distributed at Badwater and salt creek in Death Valley.
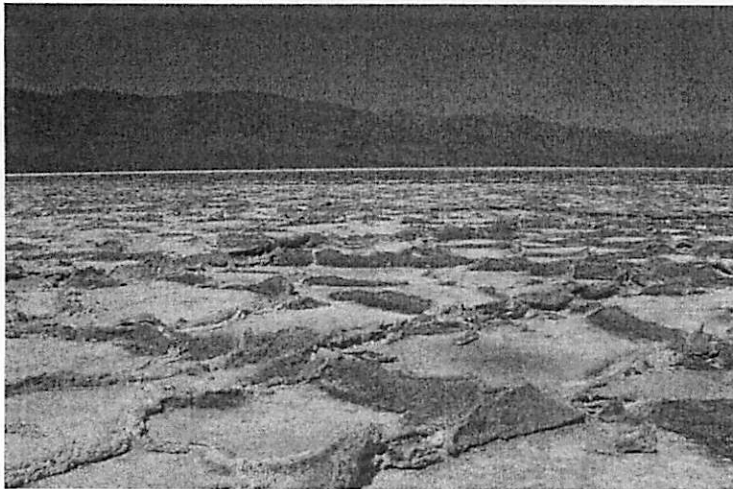

Figure 1: Saucer-shapped mud/salt formations on the Badwater in Death Valley.
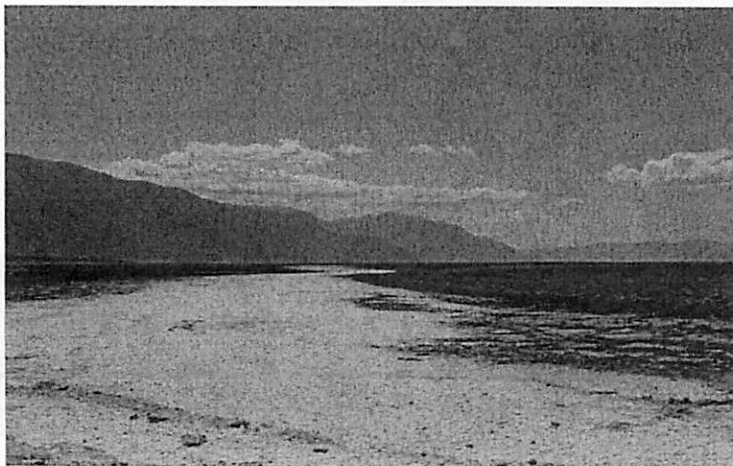The hexagon disks have about 2~3 meters in diameter.

Figure 2: Salt Creek within Devil's Golf Course

Figure 3: Salt weathering in Death Valley

What causes salt weathering and what are mechanisms of salt weathering?

Salt weathering requires both salts and sources of moisture. There are five types of cycles carrying salts according to FAO and Unesco (Szabolcs, 1979):

1. Continental cycles: the redistribution, movement and accumulation of carbonates, sulphates and chlorides derived from the weathering of different types of rocks in inland regions that have inward flowing drainage.
2. Marine cycles: the accumulation of marine salts (mainly sodium chlorides) on coastal plains of lowlands and along the shores of shallow bays.
3. Delta cycles: complex combination of movement processes and the accumulation of salts carried either from rivers and delta-valley ground systems, or from the sea.
4. Artesian cycles: evaporation of deep underground water forced towards the suface through tectonic fractures.
5. Anthropogenic cycles: economic human activities such as salinisation through a rise in water-table.

Sources of Moisture are:

Dew frequency: dewfall in desert areas.

Fog water: water precipitated from fog in coastal deserts

Rain: rainfall in desert or other region
Ground water

Mechanisms of salt weathering:

1. Crystallization of salts: salt crystals from solutions exert pressure on the walls of the rock pores.
2. Hydration: some salts hydrate is sensitive to changes of temperature and humidity. Absorption of water will result in increase of volume thus exert pressure on the walls of the rock pores.
3. Differential thermal expansion of salts: some salts have higher coefficients of thermal expansion than minerals of rocks.
4. Slaking: Salts cause accelerated slaking of clay-rich rocks such as shales and mudstones.

Salt weathering on Mars

Salt compounds are important component of the fine-grained regolith on Mars. Malin in 1974 proposed existence of salt weathering on Mars which gave the presence of salts and small amounts of water. He studied the Mariner 9 photographs of fretted terrain and interior of a major graben on Mars. By comparing these photographs to Wright dry valley in Antarctica, he suggested that salt weathering was acting to provide small-sized debris that could be transported easily, as seen from spectrum of slope morphologies that provides steep debris slopes growing at the expense of precipitous upper slopes until ridges are formed, and the island-like appearance of individual mesas of pyramidal configuration. Malin further suggested the bright areas of Mars may be due to the surficially oxidized iron accompanying salt weathering.
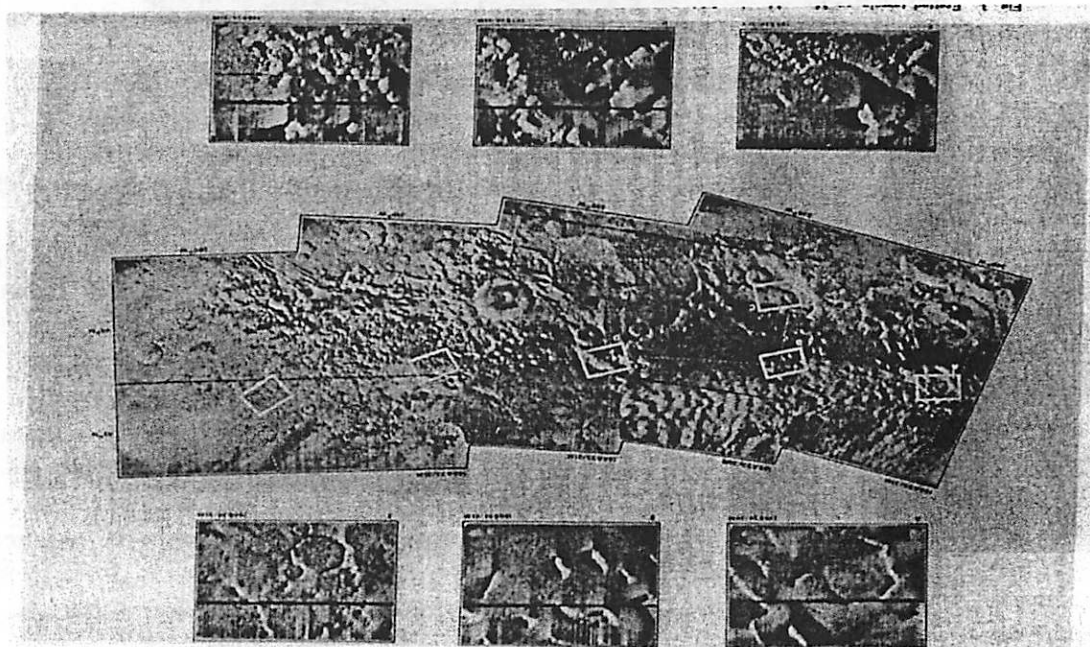

Figure 4: Fretted terrain on Mars. Mosaic Mariner 9 frames centered near 44° N and 318° W. Fretted terrain in general appears as formations of island-like mesas.
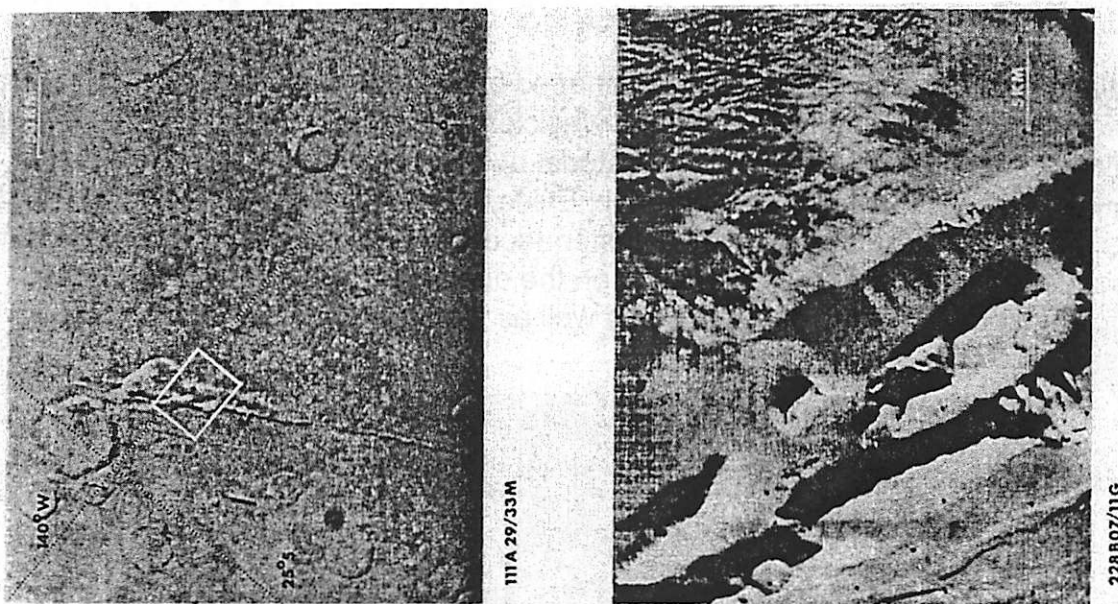
Figure 5: (Left) An "A" frame showing major graben radial from the Tharsis ridge volcanic province. (Right) Detail of graben showing erosion of Martian materials.

Clark and Van Hart in 1981 suggested that salts are present in fine grains at both Viking landing sites, take up to 25% of the bulk weight of the soil. They pointed out that five different processes by which the salts accomplish mechanical work were identified, but no names of these processes were given. They did give one example of identified salt weathering--hydration, which changes the volume as the environmental partial pressure of water vapor is cycled.

Wentworth *et al* in 2005 postulated that similar aqueous processes occurring in Antarctica are probably also occurring on Mars today, especially at the mid-latitudes or in the polar regions during their respective Martian summers. They said that if the analogy to Antarctica holds true, then local areas on the Martian surface will certainly have distinct weathering (i.e. salt weathering) histories.

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Q: Ventifacts? A: The answer my friend, is blowing in the wind, the answer is blowing in the wind...

Ventifacts are stones which have been shaped by sandblasting. In Death Valley, the ventifacts are basaltic and often riven by vesicles. Shaping is done by abrasion and deflation. Abrasion is the removal of material by frictional impact (saltation), and deflation is the removal of loose material. Evidence of these processes in Death Valley are exemplified by features including: luster, faceting. kanters, flutes, grooves and pits. These features also give us information on the direction and velocity of the wind, orientation and inclination of the rock, as well as the size, shape, and hardness of the abrasive material.
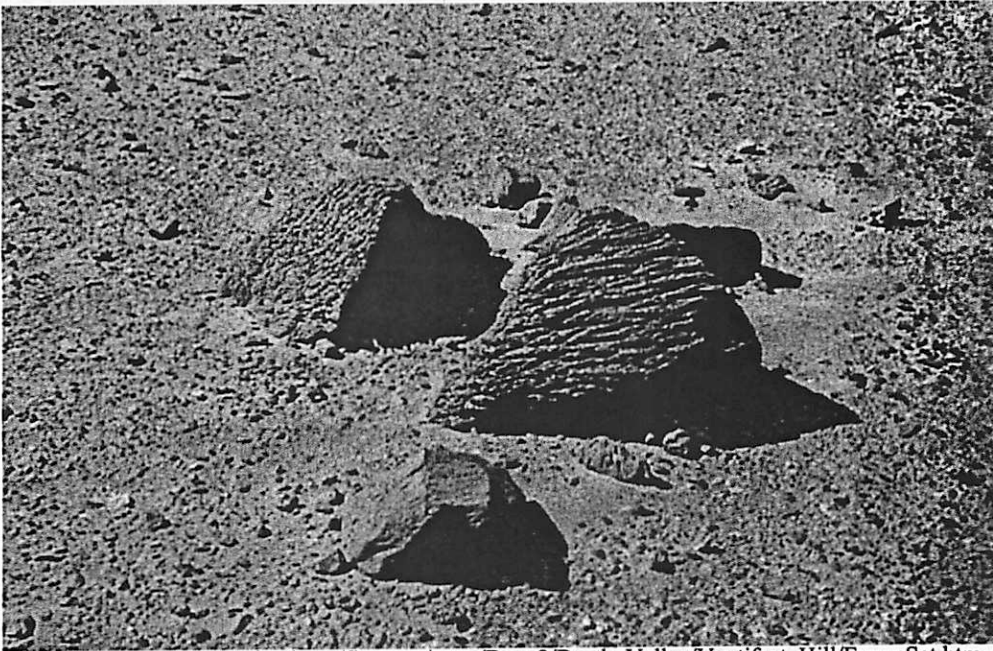
http://www.earth.monash.edu.au/firstyear/mars/Day_2/Death_Valley/Ventifact_Hill/FrameSet.htm

Evidence of Erosion:

•<u>Luster</u> is a cellophane-like polish, halfway between shiny and dull.

•<u>Facets</u> are sandblasted planar surfaces.

•<u>Kanters</u> are where 2 or more facets intersect in sharp edges.

•<u>Flutes</u> are small shallow depressions approximately 1 inch long by a fraction of an inch wide. They are U-shaped in cross-section. Typically, they are deeper at one end and resemble half of a hollowed out canoe.

•<u>Pits</u> are deeper, more irregular and larger than vesicles. They are found mainly on the steeper, larger stones.

•<u>Grooves</u> are similar to flutes, but on a much larger scale - up to several inches long and closed on the upwind side.

Directionality

•Tails of windblown sand form on the leeside of the larger stones.

•Lineation of the flutes.

•Pits tend to form on the sides of the rocks that face the wind.

Evidence supports wind directions of North and South at Ventifact Ridge.

Spring 2006, Eve L. Berger

Why Here?

- Local landforms are conducive to unidirectional (or bidirectional winds).

- Stones are unprotected and exposed to the winds…easy pickings for sandblasting.

- This is an arid climate, so sand and grit are readily available from the alluvial fans on both sides of Ventifact Ridge.

- There is a sparsity of vegetation to block winds.

Image of the rock "Chimp" taken by the Sojourner rover. Wind tails are visible from the lower right to upper left. http://mpfwww.jpl.nasa.gov/MPF/science/geology.html

Image of the rock "Moe" was taken by the Sojourner rover. Flute-like textures are clearly visible. http://mpfwww.jpl.nasa.gov/MPF/science/geology.html

Ventifacts on Mars?

A planet/body with rocks, sand, an arid climate, and wind, has the requisite ingredients for forming ventifacts.

The images on the left are from Sojourner at the Pathfinder landing site.

Morphologies including flutes, grooves, facets, and pits have been found on Martian rocks.

Note in the upper image that the lineation of the flutes is SE to NW, but the windblown sand tails are SW to NE. This indicates a change in the prevailing wind pattern over Mars' history. Geological evidence can provide much information about the climate in earlier stages of Mars' evolution.

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Evaporites

Kathryn Gardner

An **evaporite** is a sedimentary rock made of water-soluble mineral sediments that form from the precipitation of salts from natural brines during the evaporation of bodies of surficial water. These bodies may be salt pans, lagoons, supratidal flats or saline lakes.

Possible Depositional Environments

Grabens or half-grabens within continental rifts fed by rivers (Death Valley), or grabens in oceanic rifts fed by ocean water (Red Sea, Dead Sea)

Internal drainage basins fed by ephemeral drainage (Great Salt Lake, Simpson Desert)

Non-basin areas fed by groundwater (Victoria Desert)

Restricted coastal plans in regressive marine conditions (sabkha deposits in Iran and Saudi Arabia)

Drainage basins leading to extremely dry environments (Sahara and Chilean deserts)

Evaporite Mineralogy

Halides: halite ($NaCl$), sylvite (KCl), calcite ($CaCO_3$), and fluorite (CaF_2)

Sulfates: gypsum ($CaSO_4 \cdot 2H_2O$), barite ($BaSO_4$), anhydrite ($CaSO_4$), and thenardite (Na_2SO_4)

Nitrates: soda niter and niter ($NaNO_3$)

Borates: borax, ($Na_2[BO(OH)]_2[BO_2(OH)]_2 \cdot 8H_2O$), ulexite ($NaCaB_5O_9 \cdot 8H_2O$), and meyerhofferite ($CaB_6O_{11} \cdot 7H_2O$)

A case study in laminated evaporites: the Castile Formation

The Castile Formation is a succession of anhydrite and halite salts that filled the Delaware Basin (western Texas and southeastern New Mexico) in the Late Permian. During this time, a retreating ocean restricted the production of carbonate and caused the subsequent marine deposits to become less clastic-rich. The result was a laminated sequence of evaporites! The cyclic change from anhydrite (originally deposited as gypsum) to limestone and back to anhydrite reflects the seasonal changes in the climate during the Late Permian. In the spring, phytoplankton bloomed allowing calcite to form. Yet in the summer and through the autumn the temperatures rose enough for much of the water to evaporate. The evaporation of water caused the salinity in the remaining water to increase and precipitate gypsum. The Castile itself is actually subdivided into 4 cycles where the laminated anhydrite becomes halite with tiny anhydrite bands.
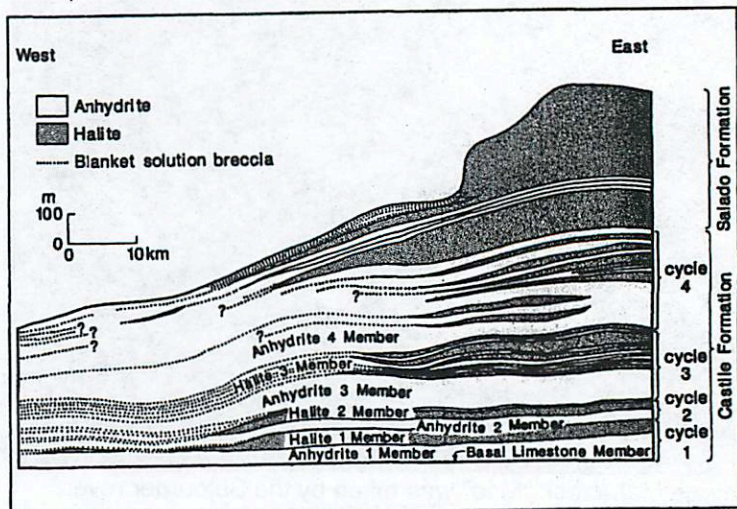

Figure 1: W-E Cross Section of Castile

*⁂*Death Valley's Evaporites*⁂*

Just as crystallization occurs in a predictable sequence, evaporation follows the same pattern, always precipitating the least soluble minerals first. Carbonates are less soluble than sulfates which are less soluble than chlorides. Thus the following precipitation sequence results:
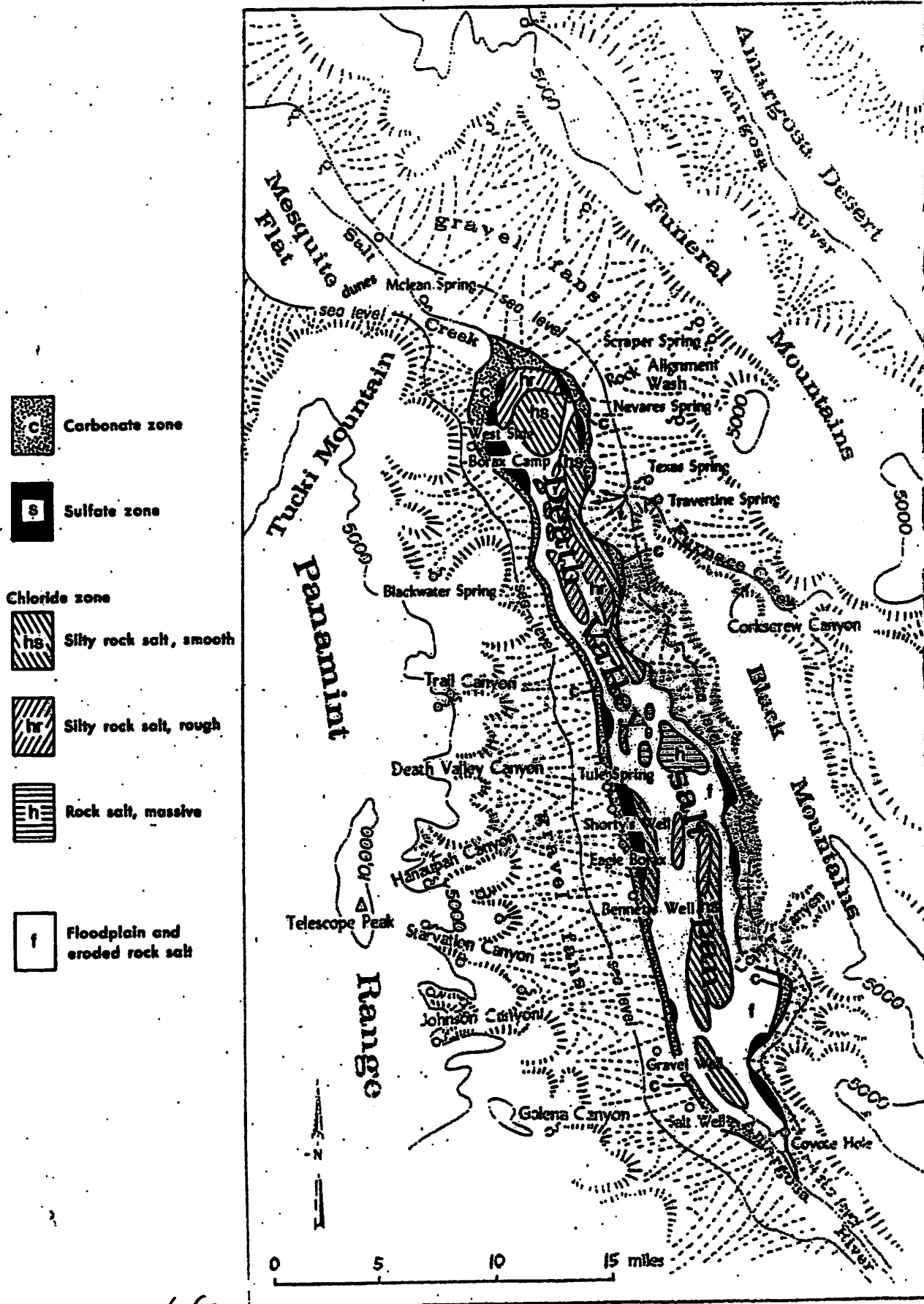
Calcite → Gypsum/Anhydrite → Halite/Sylvite

The evaporation of the 600-ft-deep Lake Manly in the Pleistocene and a 30-ft-deep lake during the Holocene made Death Valley a quintessential example of this evaporation sequence. We can see this sequence in the zonation of what is now called the Death Valley Salt Pan. Figure 2 represents a schematic of the three main zones of evaporites in Death Valley. Because carbonates precipitate first in the evaporation sequence, it is no surprise that carbonates rim most of the Salt Pan as the Carbonate Zone. Similarly, the intermediate sulfate composition lies along the inner edges of the carbonate as the Sulfate Zone. Last but not least, most of the Salt Pan is rock salt or halite, and this occurs in the middle of the Salt Pan as the chlorides are the last to precipitate. The salt rings seen here are not concentric due to an eastward tilt of the underlying rock beds as evaporation progressed (eastern side is 20 feet lower than western side).

The following is a detailed description of the three zones compiled from Charles Hunt's <u>Death Valley: Geology, Ecology, Archaeology</u> (University of California Press, 1975) and from Matt Tiscareno's handout for the 2000 LPL Death Valley fieldtrip. ☺

1. **Carbonate Zone:** Outer edges of the Salt Pan
   a. Sand or silt with crystals of calcite that formed *in situ*
   b. Some sulfate and chloride are present
   c. Groundwater forms hummocks of calcite-encrusted silt at the edges of the pan

2. **Sulfate Zone:** At the inner edges of the Carbonate Zone/outer edges of the Chloride Zone
   a. Sub-divided into zones:
      i. At north end, very little Ca is present so thenardite and other Na-sulfates were precipitated
      ii. At south end, abundant Ca is present so gypsum dominates
   b. Borates also appear with similar sub-divisions:
      i. At the north end, borax and ulexite
      ii. At the south end, meyerhofferite
      iii. Small pellets of borates called "cottonballs" at Cottonball Basin
   c. Gypsum also appears as 2-5 foot thick deposits, capped by 6 inches of anhydrite

3. **Chloride Zone:** The middle of the Salt Pan; covers 75% of the Salt Pan floor!
   a. Mostly halite with some sylvite
   b. Four main facies:
      i. <u>Massive Rock Salt</u>: 2 to 6 feet thick layers in the center of the Salt Pan covering 7 to 8 square miles! Almost pure rock salt (<0.5% insoluble residue)
      ii. <u>Rough Silty Rock Salt</u>: Devil's Golf Course; roughness from mud and silt that was incorporated into the salt during floods
      iii. <u>Smooth Silty Rock Salt</u>: smoother mud incorporation due to more frequent floods; salt layers contain ~15% insoluble residue, silt layers contain ~35% salt
      iv. <u>Eroded Rock Salt</u>: Areas where recent flooding has occurred

Figure 2: Map of Death Valley salt pan   (Hunt, 1975)

Legend:
- **C** Carbonate zone
- **S** Sulfate zone

Chloride zone
- **hs** Silty rock salt, smooth
- **hr** Silty rock salt, rough
- **h** Rock salt, massive
- **f** Floodplain and eroded rock salt

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Kevin Stube
594A
Spring 2006
Death Valley

Existence of Halophiles in Death Valley USA and the Analogs to Life Elsewhere in the Solar System.

Salt is used to kill bacteria in foods and animal skins. Because of this, for centuries, it was thought that where there were high salt concentrations, life could not exist. On Earth, life exists in many places once thought to be devoid of any life. Where there is water for at least part of the year, there is most likely life. In Death Valley, there is evidence of life in the past where water existed with very high saline content. If there was any surface water on Mars, it most likely had a high saline concentration. Even if there is no surface water on Mars today, there could be subterranean water or where there was in the past it could have had halophiles.[1]

What are Halophiles?
Extremophiles are usually unicellular organisms that thrive in what humans regard as extreme environments. These environments typically have high temperatures over 100°C, pH levels over 9 or below 3, high radiation levels, or high salt contents.

Halophiles are subgroup of extremophiles that crave salt (typically NaCl even though other salts exist). They are general found in areas where the salt content of the surrounding environment can be as much as 10 times higher than typical ocean water on Earth or roughly 30% NaCl. This environment is not necessarily liquid water, but can be salt crystals directly. Some of these locations include the Dead Sea, Great Salt Lake, Saltine Crackers, and Death Valley. To survive where other organisms cannot, halophiles use osmotic pressure (relationship of fluids on the inside and outside of the cell) along with sugars, alcohols, and amino acids to control the amount of salt inside them. If the membrane senses an excess of positively charged particles such as Na^+, then an osmotic pressure is created. At this point, water will diffuse across the membrane out of the cell and the Na^+ will move into the cell. If the organism is not adapted to a high salt concentration, it will dehydrate and die. Halophiles have developed a method to limit the Na^+ that reaches the interior of the cell. To relieve the osmotic pressure, Halophiles create K^+. While K^+ is toxic in high levels to cells, it is not as toxic as Na^+ to the cells, so the cell can still function.

The most important part of the salt balance system is the special protein coating they have that allows them to regulate the amount of salt inside. This protein layer is one of the main identifying characteristics of halophiles. One common halophile, *Halobacterium halobium,* is an Archaea that has adapted well to high salt concentrations. It will survive being dehydrated into a solid salt until water returns at a later time, some times for years. According to an article in *Nature,* living microbes have been cultured from salt deposits dated to 250 million years old[2] suggesting that even if they do not live on Mars now, they could have in the past and could come back if liquid water were reintroduced to the area. They can also travel more than a 1600 Km as a windblown dust allowing them to colonize in new areas despite to liquid water flow connection. The salt has a second benefit as well; it is opaque to short-wave UV light and protects the halophiles from damaging radiation.

The high salt concentration in the environment comes from the liquid water of the solution in which the salt is dissolved leaving the system normally by evaporation. As the water evaporates, the salt level increases leaving behind a layer of salt. If the water completely leaves the system, large deposits of

rock salt are left behind. If the water does not completely leave, or before it completely leaves, a liquid solution with salt contents much higher than ocean water will exist.

Why Death Valley?

Most of the water in Death Valley is in the form of saline rich ponds. Currently, most of the water is only in the form of perennial river flows on the surface and some underground flows. However, in the past, During the Wisconsin Glacial Period of the Pleistocene Epoch 50,000 years ago, Lake Manly filled most of Death Valley to a depth of nearly 200 meters. As recently as 2,000 years ago, a shallow lake occupied the valley floor. As this lake evaporated, it created what is now known as the salt pan, where the saline ponds and salt marshes are found.

Devil's Golf Course is an area in Death Valley of very rough and rocky terrain which was the bottom of the ancient lake bed. The area is full of complex and intricate salt crystals at different growth stages. The crystals were deposited by the ancient salt lakes and are re-deposited by the periodic floods that wash across the valley floor. As the ancient lakes and current floods subsided and evaporated, salts were deposited. The Devil's Golf Course is one of the largest salt pans in North America.

Analogs to the solar system
MARS

Quite frequently, it is thought that liquid water could not exist on Mars today as the atmospheric pressure is at or below the triple point of water; there however is large amounts of water in the formal of polar ice, permafrost, and water vapor in the atmosphere. In a few places on Mars, including the landing site of Viking 2, the pressure is above the 6.1mbar triple point of water. Viking 2 found pressures as higher than 10mbar suggesting that at this specific site, there is a 7°C. There are also many places on the surface where local temperatures do get above 273K during the day time[3]. Water could exist during the day even thought it might freeze at night. The addition of salts into the water can lower the melt temperature to as low as 210K[4]. It is not likely that there are large pools of water anywhere, but, hypothetically, there could be water from time to time. Mars is likely to have more preserved salt deposits as long as they are buried deep enough to avoid some cosmic ray damage. In some lab tests that are disputed, life has been recovered from samples that were as old as 650 my[5]. While the results are disputed, it does suggest the possibility that sample could be recovered from Mars and brought back to live on Earth or at least examined to show origin of life and the correlation or lack there of between ancient life on Mars and Earth.

EUROPA

Due to the location where Europa formed in the solar system, it most likely has a composition similar to that of carbonaceous chondrites which are high in organic carbons, alkanes, hydrocarbons, fatty acids, and amino acids. It is thought that when Europa formed, these materials were forced from the core into the ocean and ice crust. It is hypothesized that as the ocean formed and the surface of Europa froze, a thermal differential in the ocean would have formed a eutectic brine layer below the layer of more "pure" water.[6] The ice shell of Europa also draws pure water from the ocean below leaving behind a high salt concentration. The make of up this ocean is of wide debate with models showing temperatures between 216 K and 266 K with salt content being dependent on the temperature. If there are thermal vents, then the temperature could be warmer by 20 K or more than the equilibrium temperature of the ocean.[7]

FOR BOTH (and possibly other locations)

Microbes have been found in brine films as cold as -15C in Siberian permafrost and glaciers[8] as well as in high salt content areas of the Dead Seas, Death Valley, and many other places. The fact that life has been found in these places of extremely low temperatures and high salt content that are similar to how other locations in the solar system once may have been, or still could be gives hope that life of some form may be found off Earth.

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Death Valley and the Late Proterozoic Snowball Earth

David A. Minton

Introduction

Modern day Death Valley, CA is one of the hottest places on Earth, but evidence suggests that at least four times between ~750 million years (Ma) and the Cambrian period 543 Ma it was buried in ice [1, 4]. Paleomagnetic data also suggest that Death Valley and many other locations across the globe that also show evidence of glaciation at similar times were located at low latitudes, not near the poles. A late Proterozoic episode of planet–wide glaciation that eventually came to be called *Snowball Earth* was first proposed by Brian Harland in 1964, and later expanded by Joseph Kirschvink in 1992 in order to explain the low–latitude glacial deposits found across the globe [3, 9]. The Snowball Earth glacial deposits often conain carbonate debris, or are covered directly by carbonate that is normally found only in equatorial waters today [5]. Kirschvink also noted that an ice covered ocean could quickly become anoxic, and ferrous iron from mid–ocean ridges or from sedimentation would build up in solution and form banded iron formations [9]. Banded iron formations reappear in the geologic record in the late Proteroxoic after an absence of roughly 1 Gy [5, 12].

Field evidence for Snowball Earth

As an ice sheet grows the albedo of Earth increases, decreasing the solar insolation and creating a positive feedback effect that eventually leads to ice covering the entire Earth (with perhaps isolated equatorial seas or lakes) [6, 10]. Since the land is covered in ice, silicate weathering of rock is depressed and CO_2 builds up in the atmosphere until the greenhouse effect is strong enough to begin melting the ice. The melting ice sheets leave behind poorly sorted conglomerate deposits called *diamictite*. As the ice melts another positive feedback occurs as the albedo of the Earth increases and the Earth rapidly warms. The gas exchange between the ocean and the now high–CO_2 atmosphere can drive carbonate precipitation, leaving

Figure 1: Modern retreating glaciers leave behind poorly sorted rock debris that is similar to diamictite
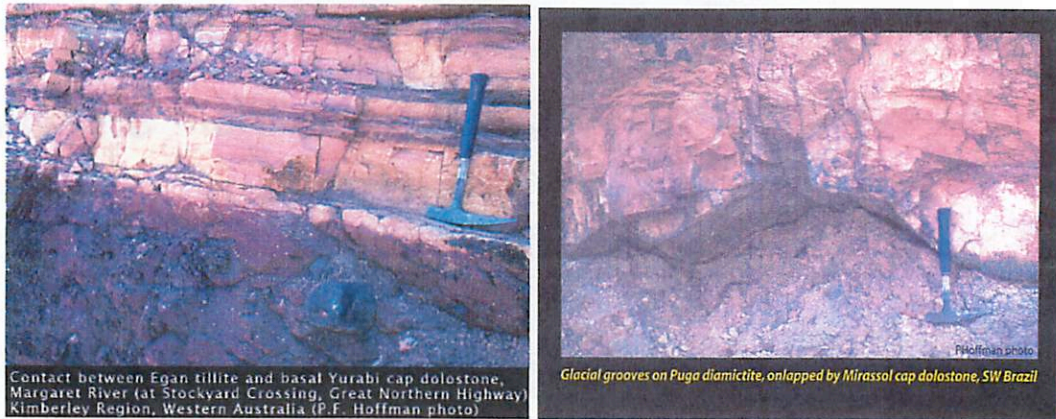
| (a) Cap carbonate | (b) Contact between dolostone and glacial diamictite |

Figure 2: Some field images of Snowball Earth deposits (Images from www.snowballearth.org)

behind carbonate deposits called *cap carbonates* [2, 5].

Snowball Earth Deposits in Death Valley

The Kingston Peak Formation in Death Valley, CA contains diamictite of Sturtian age ($\sim 750 - 700$ Ma) with microfossil evidence evidence of prokaryotic and eukaryotic microbial communities, including stromatolites [2]. Microfossils have been found in the cap carbonates in the Kingston Peak Formation, above both the banded iron formations and glacial deposits, with no significant loss of diversity compared to pre–glacial strata. This suggests that at least the Sturtian Snowball Earth was a "soft snowball," with open water in the tropics, rather than a "hard snowball" where the entire Earth was locked in solid ice [2, 6, 8, 11].

Snowball Earth and Worlds Beyond

The Earth during the Proterozoic Eon was like an alien world. Studying it helps us to understand the limits and possibilites of habitation. Life at the time not only survived the most severe climate changes ever to occur in the history of our planet, it flourished in the aftermath leading to the great metazoan radiation of the Ediacaran and Cambrian [7]. Understanding the complex interactions between the solar irradiation, surface albedo, the atmosphere, and the biosphere helps to understand how exactly to define a "habitable zone" around other stars, and help constrain the search for life in the Universe. Studying the climate history of early Earth also helps to understand why the other terrestrial planets, namely Venus and Mars, have had such wildly different climatic histories.
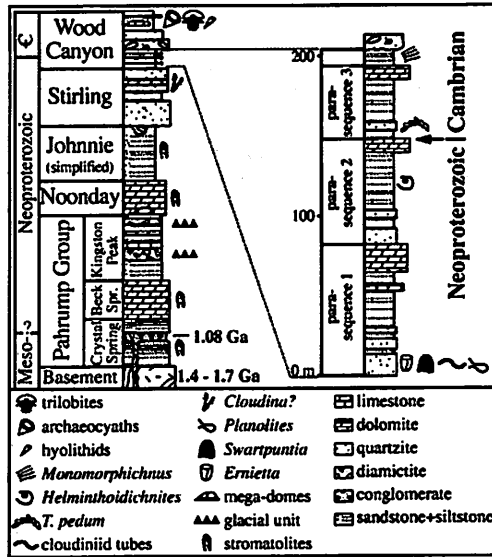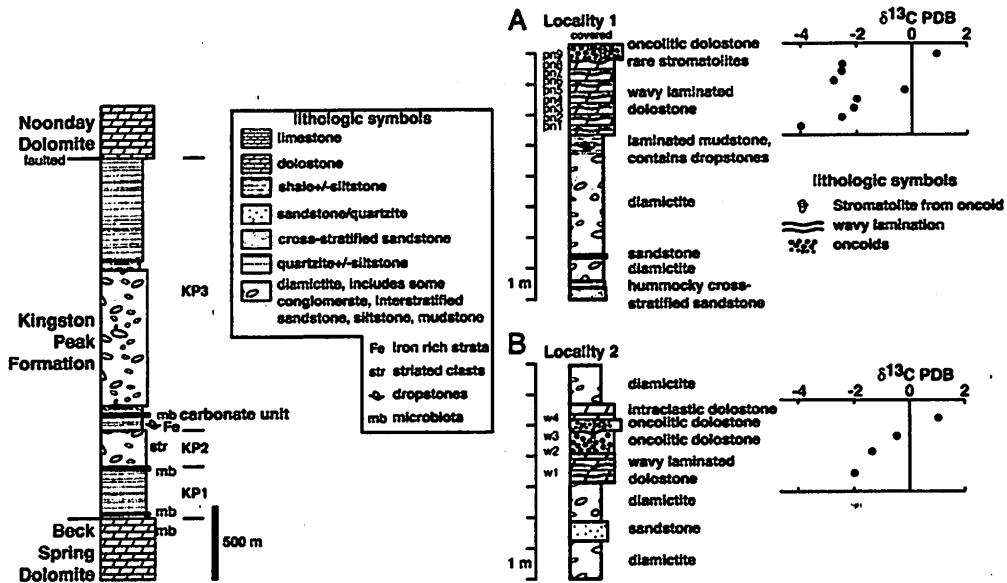
Figure 3: Generalized stratigraphic context for Death Valley region. Arrow indicates suggested position of Precambrian-Cambrian boundary in this region. Fossils depicted in inset reflect only first occurrences [1]

(a) Generalized stratigraphy of the Neoproterozoic Death Valley succession, Kingston Range, eastern California, at locality 1. Thicknesses are approximate [2]

(b) Detailed lithostratigraphy and chemostratigraphy of the carbonate unit at locality 1 (A) and locality 2 (B). Lithologic symbols are the same as in Fig. 1. PDB, Peedee belemnite standard. Numbers to the left of column correspond to isotopic analysis [2]

Figure 4: Stratigraphy of the Death Valley and the Kingston Peak Formation

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The Snowball Earth Hypothesis

by

Curtis S. Cooper

distribution of glacial deposits
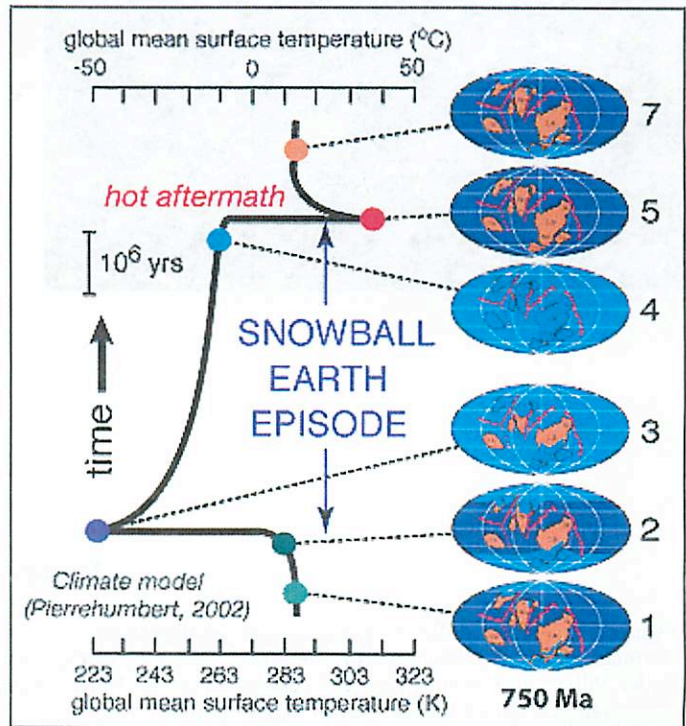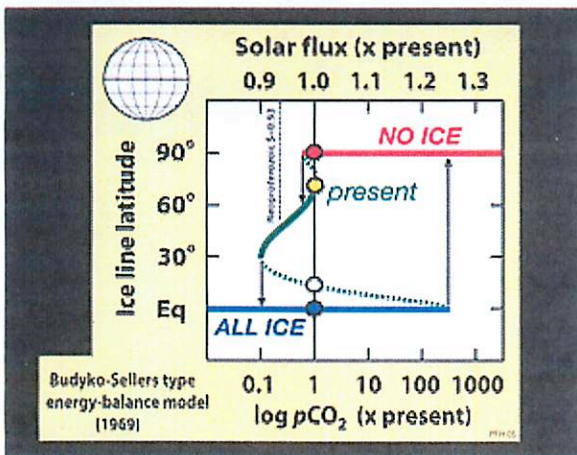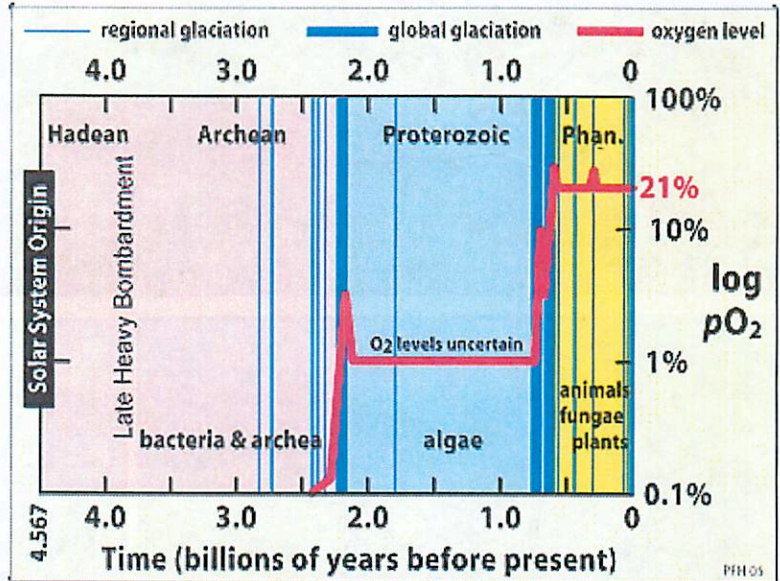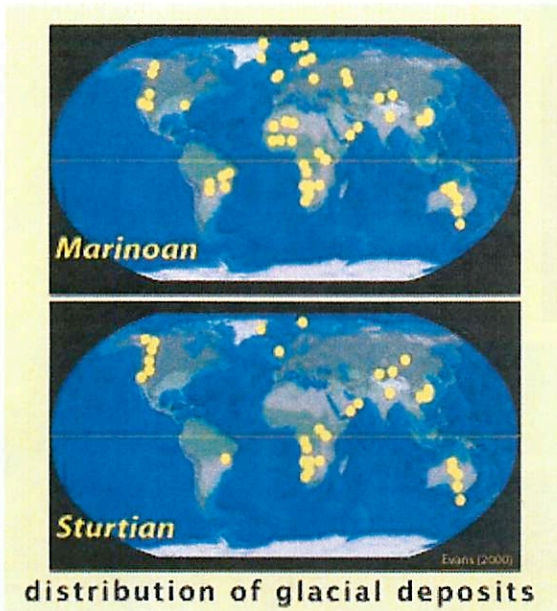
Contact between Egan tillite and basal Yurabi cap dolostone,
Margaret River (at Stockyard Crossing, Great Northern Highway)
Kimberley Region, Western Australia (P.F. Hoffman photo)

Cracks in dynamic sea-ice, a potential refugium for photo-trophs on snowball Earths.

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Vatnajökull

Magnus Tumi Guðmundsson

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The Dunes of Kelso
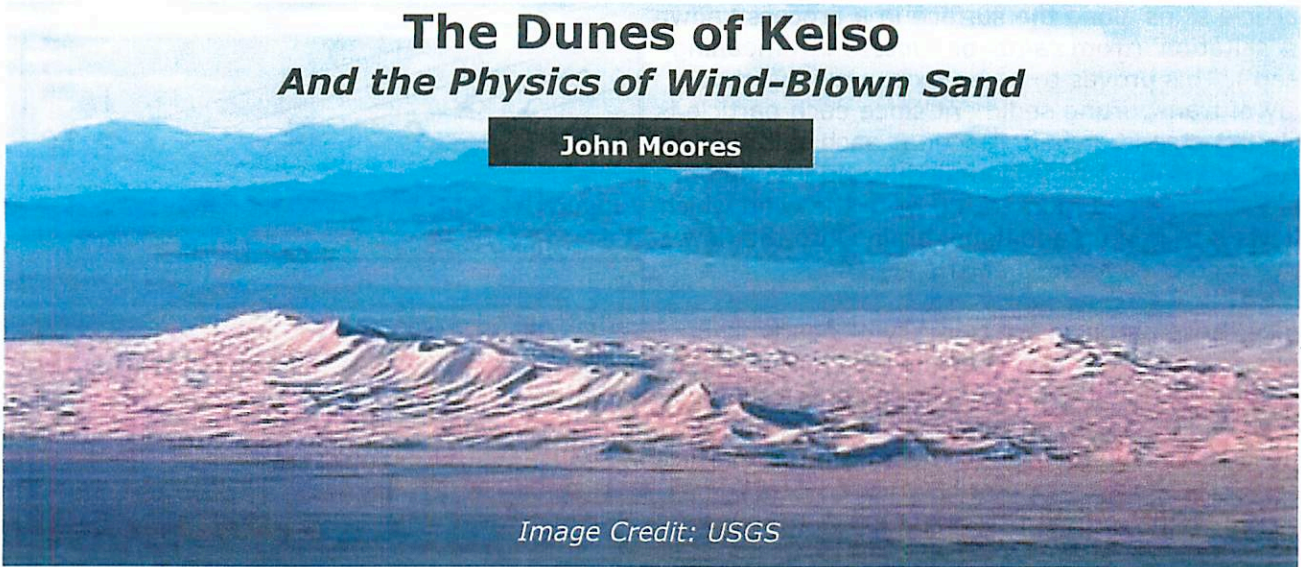## And the Physics of Wind-Blown Sand

John Moores

Image Credit: USGS

1. Introduction

Sand dunes are the manifestation of slow sediment transport by the wind (eolian transport). As such, usually it is fairly simple to trace a source region of eroding material which supplies the dunes and their destination. However, the material composing the kelso dunes in Mojave National Park, California has no clear source and is compositionally unlike any of the nearby erodable materials. The presence of these particular dunes in this location thus presented a mystery until recently. However, before describing the solution and the history of this particular formation it is first necessary to discuss some elementary facts about dunes. Specifically, we shall explore the ways in which dunes form, what materials compose them, how they move and their typical observed morphologies.

2. Saltation

One of the first things you notice when examining a sand dune is the uniformity of the size of each individual grain. This is not an accident, but rather is due to a size selection by winds blowing over a surface. In fact, the size of particle represented in dunes is exactly the particle size which is most effectively transported by winds. To begin to understand this selection process, we need to examine the interaction of wind with an eroding surface composed of grains of varying sizes.
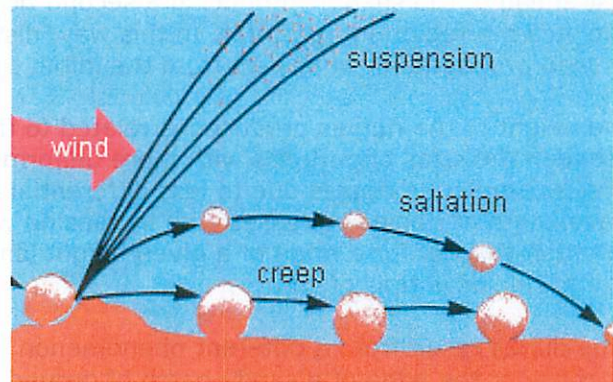

**Figure 1 - effect of changing grain size on eolian sediment transport menthod
[Credit: Science@NASA/NASAexplores]**

In any flowing viscous fluid, the velocity falls off towards a fixed surface due to friction. The velocity becomes so low, very close to the surface that the flow becomes smooth, a region called "laminar boundary layer." Small particles can hide within this layer where it is difficult for the wind to exert a drag force that would pluck them out. However, as the particle size increases it becomes more and more exposed to the winds.

Once the wind begins to move a particle, it's fate depends on its size. Very small grains are light enough to be suspended within the air itself. Larger grains are exposed above the boundary layer, but too heavy to be lofted by the winds and only roll along. However, there is an intermediate size of particle which is too big to suspended, but light enough to be lofted by the wind. This size of

particle skips along the surface in a process known as 'saltation' (from *saltus* or *sauter* both meaning 'leap'). This proves to be an extremely effective way of transporting sediment since each particle is the first step in a chain reaction: each saltating grain gains not only added distance in its hop but also an increased momentum from the wind which allows it to pop up additional grains into the flow once it crashes back to earth.

Figure 1.

Since these particles are typically of nearly uniform size and mass, they have a characteristic flight path. The sheet of moving sand (or snow) which can be observed "floating" above a dune (or road) on a windy day is actually composed of these saltating particles.

Figure 2.
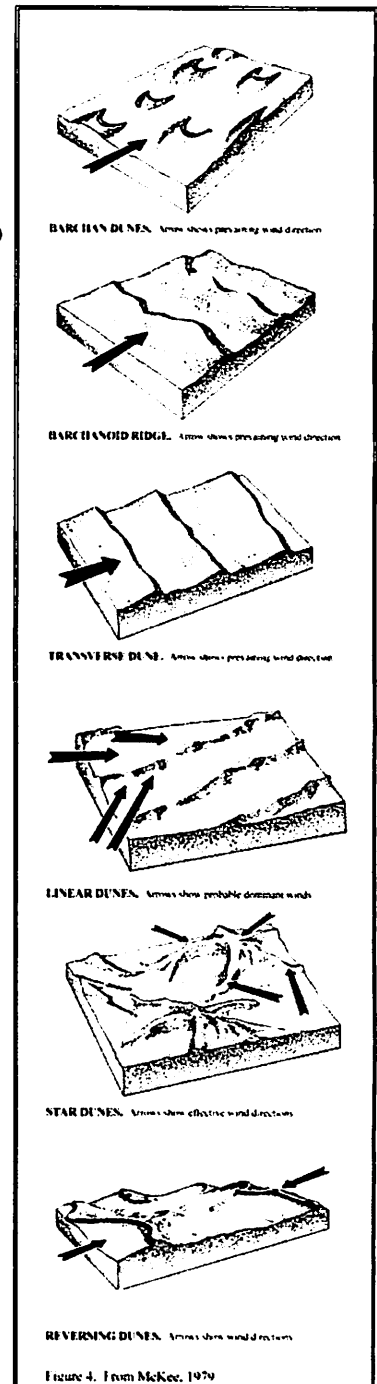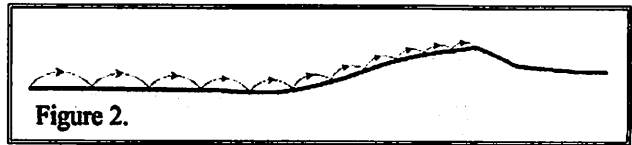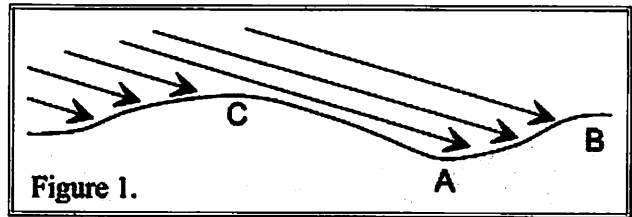
3. Dunes: from grain to erg

While the preceding section explains why sand moves it does not explain how it organizes itself into the large forms with which we are familiar. As the name of this section suggests we will work our way up from the level of grains to the great sand seas known as ergs.

The most fundamental question of why sand forms patterns at all comes down to the physics of saltation. Since there are slight variations in the sizes of individual particles the rates at which they saltate and creep will be different. The larger, slower grains can accumulate into jams which creates a single ripple. However, due to the low angle at which saltating sand strikes the ground the ripple tends to deplete the region just in front of it, creating a "saltation shadow" (Figure 2) The sand removed from this region end up piled just ahead of the shadow producing a second ridge which then depletes the region in front of it. In this way, disturbances in the flow of sand propagate downstream from the initial perturbation.

The height of the ripples produced is related to the differences between the sizes of particles with more uniform particles producing smaller amplitude ripples due to less differential saltation. The wavelength of ripples increases with increasing wind speed as the saltation shadow for a ridge of a given height lengthens. The typical size of ripples is tens of cm.

True dunes result from a different phenomenon – saltation drag. Let us consider the edge of a sandy patch of ground. As a parcel of wind travels over the ground it induces particles to begin to saltate. As the particles enter into the air stream they are accelerated, a process which slows the air parcel. As such, less momentum is transmitted to particles the further downrange which in turn saltate a shorter distance (Figure 3).

This differential rate of transport along the sand field causes the sand to pile up into large mounds. As the point of maximum sand deposition moves up the mound the downstream face becomes steeper until a slip-face is formed with sand at the angle of repose. At this point the mound has become a dune which propagates itself by transporting sand up over the surface and sliding down the slip-face. The typical size observed for dunes is measured in the tens of meters.

BARCHAN DUNES. Arrow shows prevailing wind direction

BARCHANOID RIDGE. Arrow shows prevailing wind direction

TRANSVERSE DUNE. Arrow shows prevailing wind direction

LINEAR DUNES. Arrows show probable dominant winds

STAR DUNES. Arrows show effective wind directions

REVERSING DUNES. Arrows show wind direction

Figure 4. From McKee, 1979

Depending upon the precise wind conditions, dunes can have many different morphologies. Examples of these are shown in figure 4.

One interesting part of the movement of sand morphologies is that the speed of propagation is inversely related to the size of the morphology. That is, dunes propagate more slowly then do ripples.

Are there any forms larger then classic dunes which would travel more slowly? It turns out that many sand seas (ergs) are divided into separate sandy areas which have morphologies similar to classic dunes but are much larger in size. These mega-dunes or "draas" typically are kilometers in size and will have dunes superimposed upon them which in turn are covered in ripples which brings us right back down to the scale of grains.
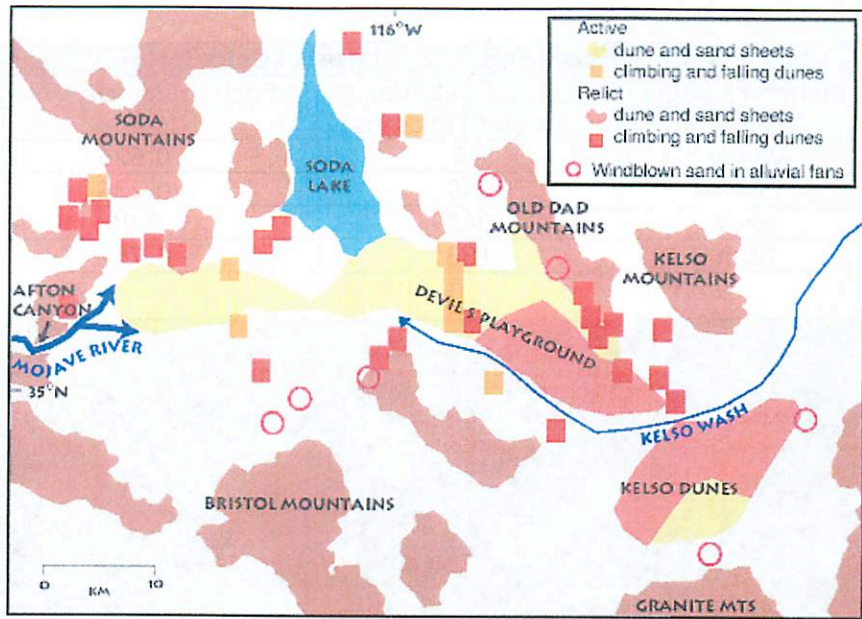
4. The mystery of the Kelso Dunes

Most dune fields have clearly defined source regions at which erosion is constantly producing sand sized particles. The wind then saltates these particles away where they form the dunes that we see. However, the sand which composes the Kelso dunes is not currently being resupplied and is compositionally different from the materials which make up the surrounding mountains. This begs the question: where did all this sand come from?

The answer has two parts. First, the answer to the source region for the Kelso Dunes turns out to be the Mojave River sink, in particular sediments deposited in Soda and Silver lakes. As can be seen in the figure, the Kelso Dunes are just a part of this large scale sand transport system.

So why is no sand accumulating now? The reason for this is simply that current conditions inhibit the movement of sand and thus the formation of large dunes. In dry periods the lakes in the source region dry up and the sediment supply is increased to the point when dune formation becomes possible. Thus the dunes were formed during short climactic pulses of which there have been five over the past 25,000 years.
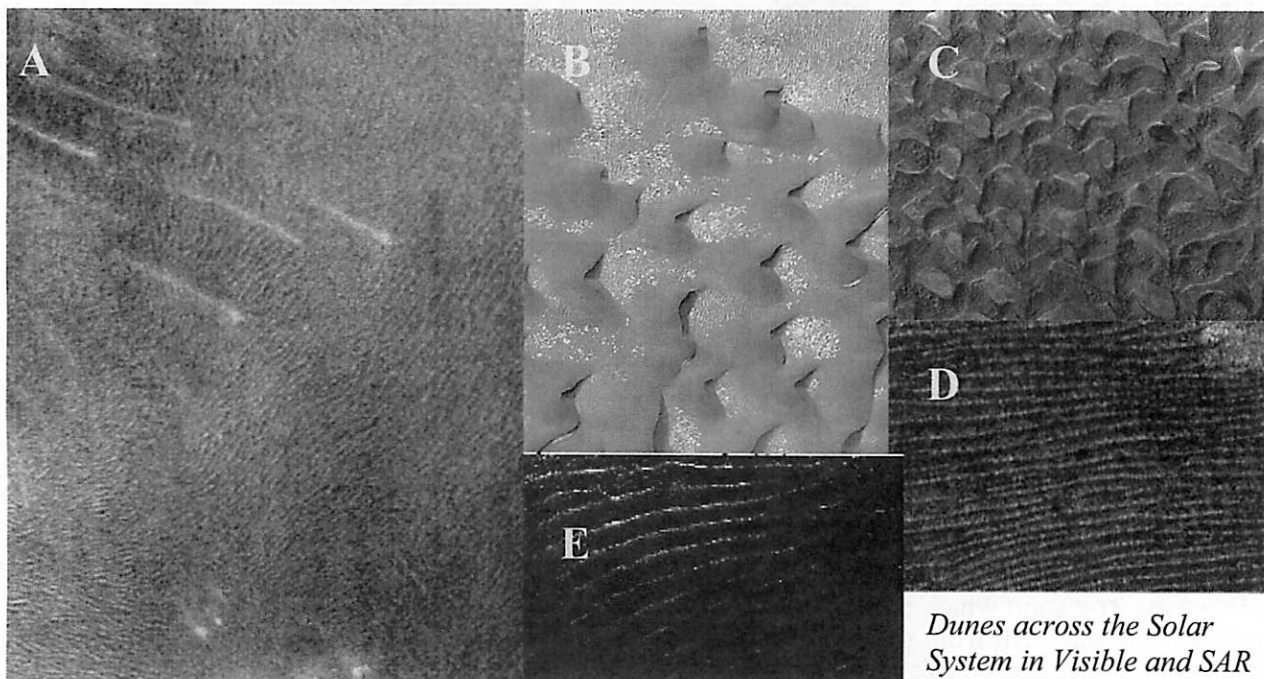
5. For Jason & Ralph: The Planetary Connection

The required ingredients for saltation are: a planet with enough atmosphere to impart momentum to lofted particles, enough gravity to bring them back down, and erosion capable of producing saltation sized grains. To our knowledge, there are four bodies in the solar system which meet these criteria – the Earth, Mars, Venus and Titan and all of these exhibit dunes some of which may be extensive in their areal extent. Even so, some of these situations are puzzling. Shown on the next page in tabular format are the saltation particle sizes and the wind speeds required:

Dunes are easy to identify in orbital imagery. One example from each planet is provided below. It is left as an exercise to the reader to determine which is which.

Finally, winds are not the only way of manufacturing dunes. Dunes are also observed to be produced by the action of water and in tuff deposits from maar volcanoes; any moving fluid will do.

Comparison Between Planets (Calculations based on Bagnold,1941)			
Planetary Body	Critical Saltation Diameter (microns)	Friction Velocity (m/s)	Meteorological Wind Speed (km/h @ 2m)
Venus	95	0.626	2.25
Earth	240	0.236	26.1
Mars	940	2.06	205.
Titan	188	0.702	2.53

Dunes across the Solar System in Visible and SAR [BT-MELT DELV]

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Cinder Cones and Amboy Crater

Cinder Cones (also called scoria cones): Mounds of basaltic scoria built from ejected lava fragments that solidify during flight

-simplest and most common type of volcano

-can occur alone but are often found in groups or fields of up to 100 comes

-align along fissures or form as parasitic cones on the flanks of composite or shield volcanoes

-usually form later in an eruption when activity has localized to one or more discrete vents

-eruptions can last less than a month to over 10 years

-can grow to be over 1000 feet tall

-Scoria fragments (cinders) range in size from fine ash to bombs (most are pea- to walnut size lapilli), can be rounded or irregular, are markedly vesicular, and are typically black to reddish-brown in color

-usually form from gas-rich basaltic magma

-occasionally can form from silica-rich magma producing a light-colored cone composed of ash and pumice

-have a simple, distinctive shape – roughly circular in plan view

-are typically symmetrical but may be higher in the downwind side

-have steep sides due to the high angle of repose of cinders – young cones may have slopes ranging from 30-40 degrees

-have large, deep, bowl-shaped craters at the summit

-are usually the product of a single eruptive episode – once the event ceases, magma in the pipe connecting the vent to the magma chamber solidifies and the volcano does not erupt again

-are sometimes mined for the cinders to be used in road construction, road sanding in winters, and decorative "lava rocks"

Formation of a Cinder Cone:

Vent Formation:

- a magma reservoir forms below the ground
- the reservoir grows in size until the pressure is large enough to form a vent in the crust

Cone Formation:

- expanding gas bubbles cause the lava to be violently thrown up into the air in a pyroclastic explosion
- due to the heights reached by the pyroclasts, they cool before reaching the ground and do not stick together
- solid lava fragments pile up in the shape of a cone around the vent

Lava Flows:

- if gas pressure drops in the final stage, a lava flow can break through the base of the cone forming a vent called a "boca."

Schematic representation of the internal structure of a typical cinder cone.
Source: USGS

82
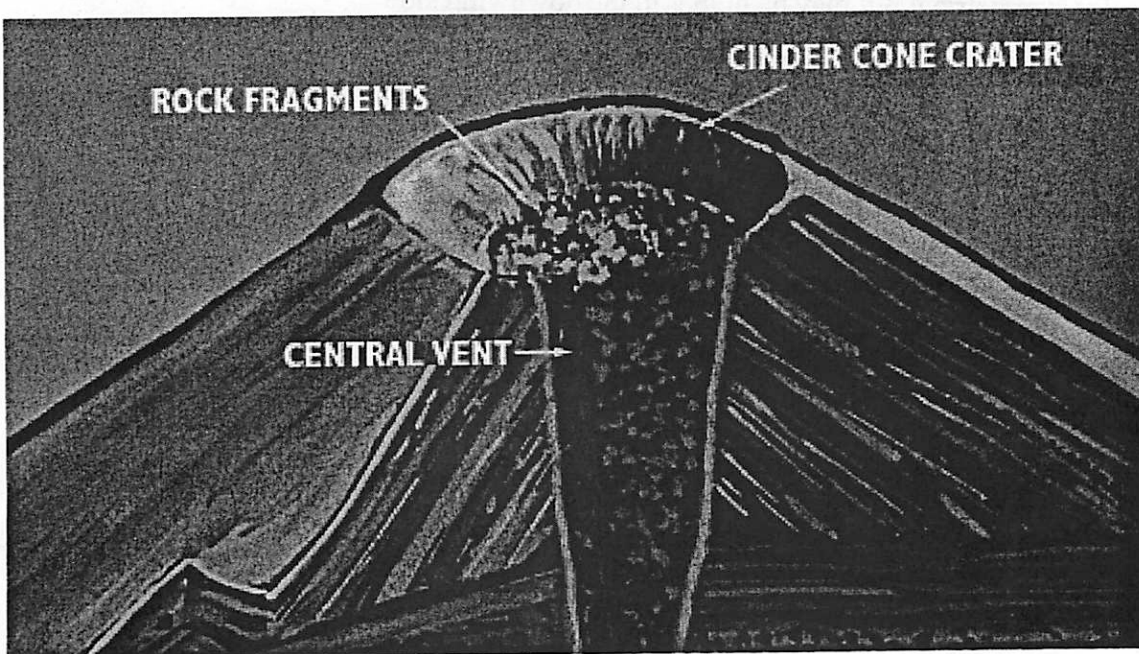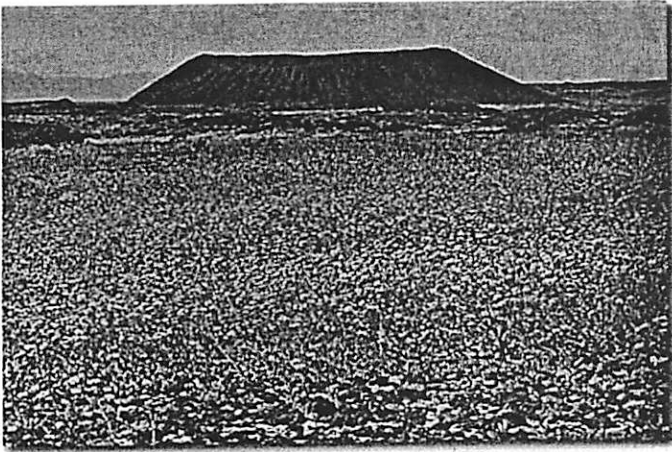
Amboy crater
Photo: DesertUSA.com

Amboy Crater: Location: 35.5N, 115.8W

Elevation: 984 ft (300 m)

-erupted along the northern border of Bristol Dry Lake and poured lava onto its surface dividing

it into the two present playas

-height is 288 meters, cone rises 75 meters above the surrounding lava flows and is ~460 meters

in basal diameter

-erupted ~10,000 years ago

-is not a single cone but is composed of at least four nearby coaxial nested cones

-within the main outer cone, there is a remnant of a second cone on the west side (both cones

breached to the west)

-two primarily undisturbed cone walls are within the main crater

Composition:

-loose accumulation of volcanic ejecta

-secondary amounts of agglutinated scoriaceous tephra

-ropy, ribbon- and almond-shaped bombs

-some lithic non-vesicular acessory basaltic ejecta

-innermost cones are composed mostly of angular scoriaceous cinders

Amboy Lava Field – an alluvial-filled valley between the Bullion Mountains (SW) and the Bristol Mountains (NE) lying between Bagdad Dry Lake (W) and Bristol Dry Lake (E) (playa lakes)

      -consists of several mafic lava flows and cinder cones from several vents during the past approximately 10,000 years
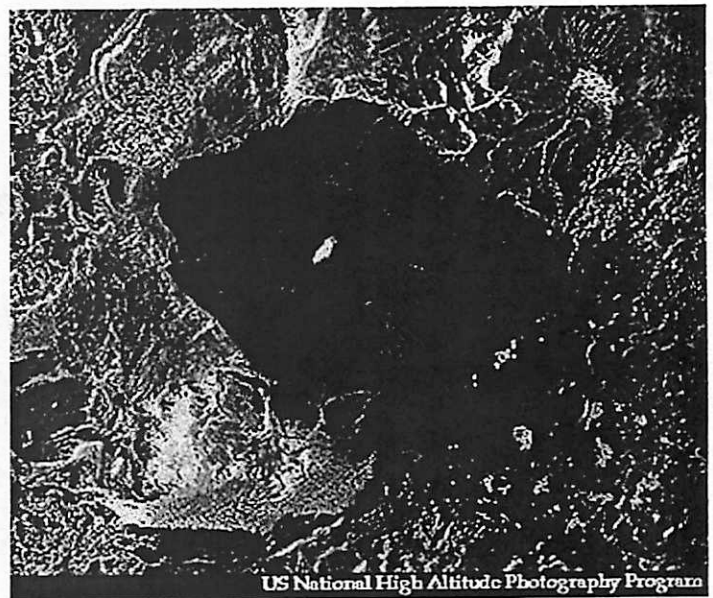
      -covers approximately 70 square kilometers

      -consists primarily of vesicular pahoehoe

      -characterized by abundant tumuli and pressure ridges

      -a few lava channels are present but does not contain lava tubes

Amboy Crater and surrounding Amboy lava field

US National High Altitude Photography Program

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