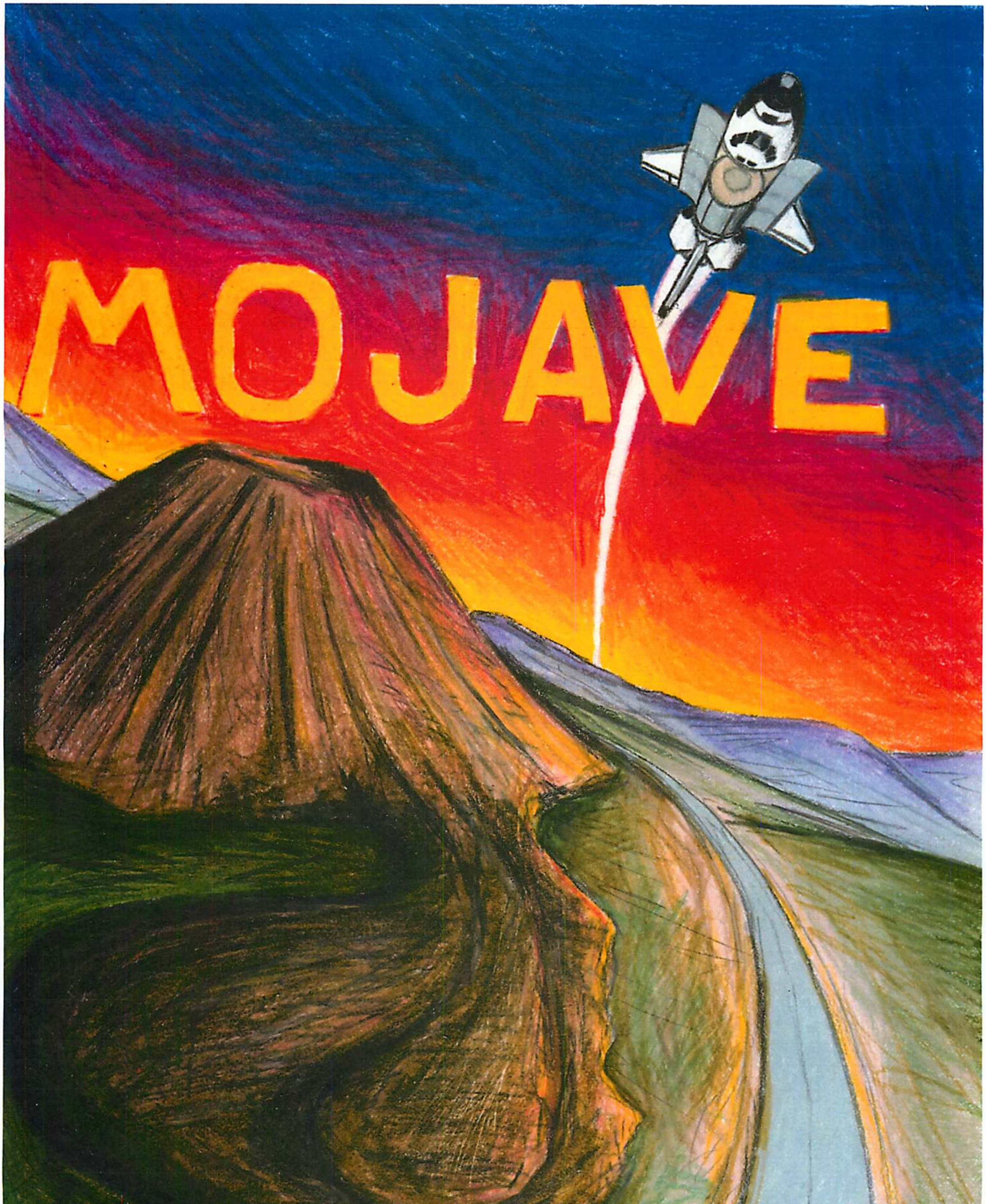

PTYS594: Planetary Geology Field Studies – Spring 2013

Because the remote is worth sensing. Have fun! - Melissa

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THURSDAY MORNING LEAVE LPL – 8AM

Kelso:

James & Kelly	Radar and Sand Dunes on Earth and Titan

THURSDAY NIGHT CAMP AT KELSO – SUNSET 7PM

Kelbaker Road:

James & Michelle	Composition and spectra of stuff near Kelso
Corey	Overall Geologic history of the Mojave

Cima:

Erin	Cima Volcanic Field
Cecilia & Davin	Alteration of cinder cones and tephra rings
Donna & Youngmin	Astrobiology & lava tubes (mostly Lava tubes)
Ali & Tiffany	Roughness and RADAR

Soda Lake:

Catherine	Radar and Playas on Earth and Titan
Sky	Flora and Fauna of the Mojave

FRIDAY NIGHT CAMP AT CIMA – SUNSET 7PM

Agricultural Fields:

Christa	Spectral behavior of vegetation

Pisgah:

Ali & Tiffany	Roughness and RADAR
Donna & Youngmin	Astrobiology & lava tubes (mostly Astrobiology)

Amboy:

Cecilia & Gabriel & Melissa	The Amboy Streak
Ali & Tiffany	Roughness and RADAR

SATURDAY NIGHT CAMP AT AMBOY – SUNSET 7PM

Broadwell Lake:

Catherine	Radar and Playas on Earth and Titan

SUNDAY EVENING AT LPL – SUNSET 7PM

Road log for PTYS 594 – All times are AZ times

Thursday 3/28/2013

7 AM Arrive at LPL loading dock with all our gear including breakfast, coffee, ice etc...

8 AM Depart LPL

Drive north on Cherry -> west on Speedway -> enter I10 westbound and drive 124 miles. Take exit 133B to merge onto AZ-101 Loop N. Drive 10 miles and then take exit 11 for US-60/Grand Ave. After 38 miles take a slight right onto US-93. After 58 miles, turn left onto Burro Creek Campground Rd.

12 PM Arrive Burro Creek Campground – Lunch here.

12.45PM Go back to US-93 and go 49 miles north. Transition to I40 west and go 147 miles to Kelbaker Road (probably stopping for gas near Kingman).

5.30PM Take exit 78 for Kelbaker Rd. Drive north on Kelbaker Road for 14.5 miles. Turn left at Kelso Dunes Road and drive 4-5 miles.

We'll hear from **Kelly and James** about how dunes behave in Radar data.

6PM Camp: Kelso Dunes. Hike to the top if there's time...
Elevation 2600'. Sunset 7PM AZ time.

Road log for PTYS 594 – All times are AZ times

FRIDAY 3/29/2012

8 AM Leave Camp. Sunrise 6.30AM
Backtrack to Kelbaker Road (4-5 miles) via restrooms. Drive north toward Baker for 11 miles.

8.45 AM Stop at a spectrally interesting outcrop of rock just west of the road. **James and Michelle** will tell us what they gleaned from the MASTER data here. **Corey** can also talk about the overall geologic history of the Mojave here before we get into the thick of the volcanic fields.
Travel another 12.5 miles north on Kelbaker Road. Take a right turn onto Aiken Mine Road. Head northeast for 2.5 miles. There's a small road to the left that leads about 500m up to a cinder cone.

10AM We're in the Cima Volcanic field, which **Erin** will describe. The summit material of this crater shows a compositional difference in the hyperspectral imagery, **Cecilia and Davin** will expound on why and we can hopefully scramble up the slope to check for ourselves.
Back to Aiken Mine Road and travel another 1.5 miles east. There's a fork in the road and we should bear left. There's a place to park ~400m past the fork, if possible we'll drive a little further (~200m) up this cinder cone. Pay attention to the roughness of the flow here, we'll compare it to a different Cima flow later today.

11.30AM Arrive at a lava tube cave where **Youngmin** will talk about cave detection on other planets. It's a short cave and easy to explore.

12PM Eat **Lunch** here.

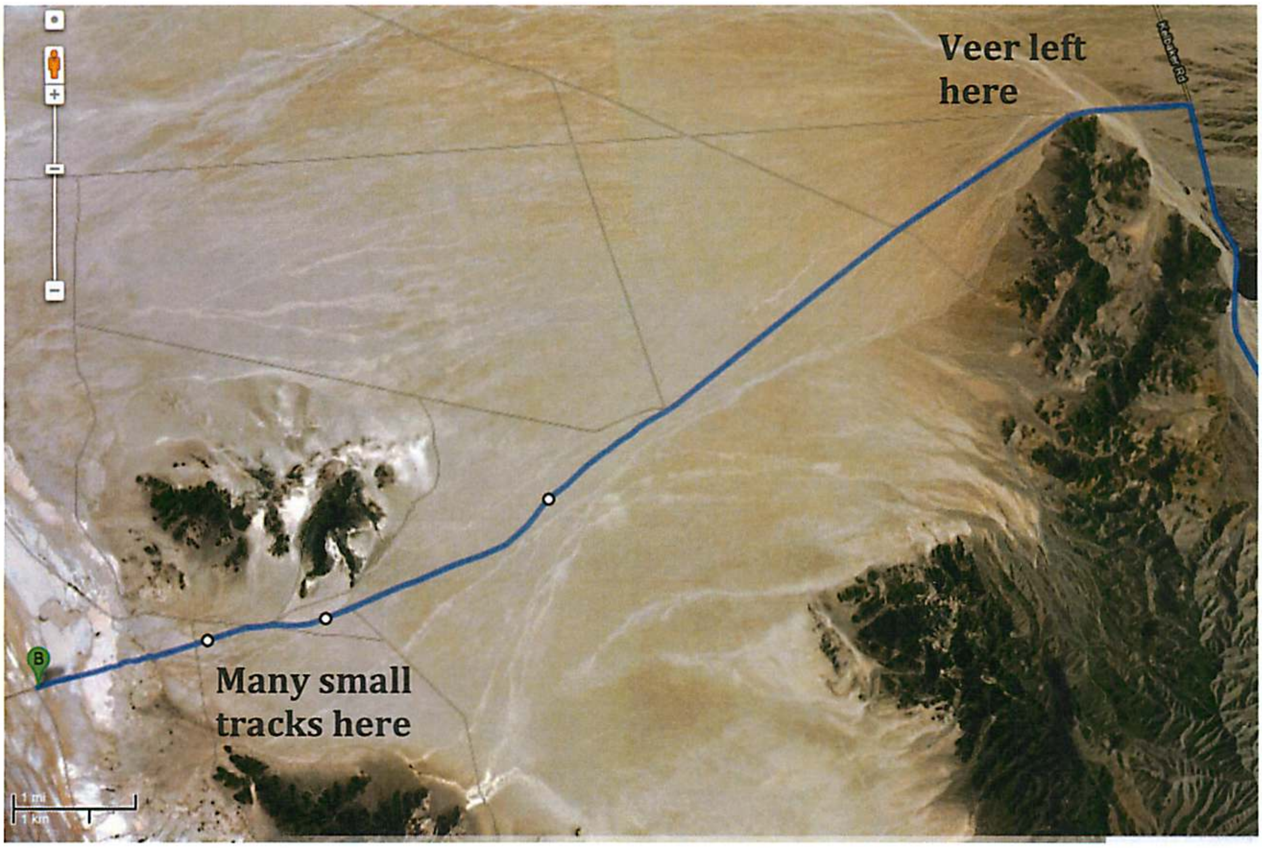
Head southwest on Aiken Mine Road for 5 miles and then north on Kelbaker road for 7.5 miles. Take a left turn onto Old Government Road and travel 11 miles The road is vaguely defined in places, but trends mostly WSW (see overleaf).

2.15PM We're in the middle of Soda Playa, the first of two playas we'll visit. **Catherine** will give us some info on its radar appearance, which is somewhat unusual.

Back along Old Government Road to Kelbaker Road. Turn right and travel 3 miles to Indian Springs trail, take a left turn and travel ~1 mile to the campsite.

4.30PM We're right beside an extremely rough lava flow. **Ali and Tiffany** will perform an amazing duet on roughness and radar. This is also a good place for **Sky** to wax lyrical about the flora and fauna of the Mojave too.

5.00PM Camp: Cima Volcanic Field.
Elevation 2600'. Sunset 7PM AZ time.



Kelbaker Road to the Soda Lake stop via Old Government Road.

Road log for PTYS 594 – All times are AZ times

SATURDAY 3/30/2012

8 AM — Leave Camp at Cima. Sunrise 6.30AM.
Backtrack to Kelbaker Road. Drive North to toward Baker for 16 miles. Here's a chance to gas up and hit restrooms.

Head 40 miles west on I15 South until exit 206 for Harvard Road. Travel 4 miles south before turning right onto Riverside road. After 1 mile take a left onto Newberry Road. There's a large agricultural field on the right after about 1.5 miles.

10AM — Arrive at the Mojave Agricultural fields and hear about the spectral behavior of vegetation from **Christa**. There's an interesting RADAR puzzle for us to solve here too...

10.45AM — Leave the fields and continue south on Newberry Road for 4.5 miles, turn left onto National Trails Highway (Rt 66) and travel 3.1 miles. Merge onto I40 east and 9 miles later take exit 33 and continue east, parallel to the freeway, for 4.5 miles. Turn right onto Pisgah Crater Road and travel 2 miles south.

11.15AM — Arrive at Pisgah Cone. This part is played somewhat by ear but we should try and drive just southeast of the cone to the start of the lava field. **Lunch** is here either before or after the talks below depending on the time.

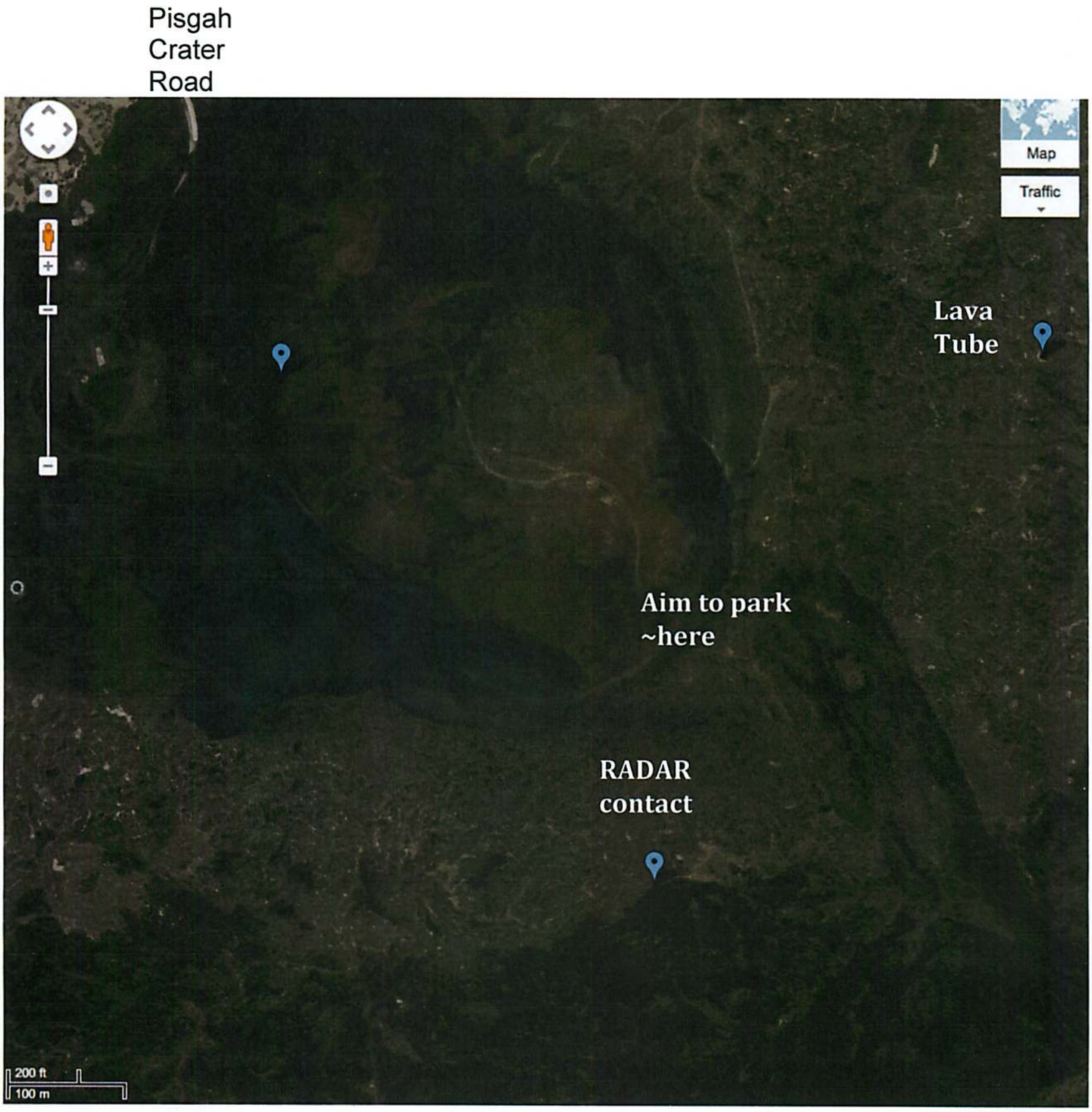
We'll walk about 150m south/southeast to a prominent contact in the p-band radar data. **Ali and Tiffany** can reprise their double act and talk about what the radar data say here and how it corresponds to reality...
There are some lava tubes we'll try and find about 200m east of the base of the cone (they're visible in google maps, see overleaf for location). We should have time to explore the cave and hear from **Donna** on cave astrobiological research, some of which happened here. This is a long cave and not that easy to explore, but we'll use what time we have to look around.

1PM — Leave Pisgah via Pisgah Crater Road and after 2 miles turn right on Route 66 (National Trails Highway). This runs about 40 miles toward Amboy, we'll turn off just before Amboy onto crater road and travel 0.5 miles south.

2.15PM — Arrive at the Amboy lava field. We'll walk out onto the flow towards the cone (about a mile, but the trail is smooth) where **Ali and Tiffany** will give us an encore performance on the Amboy flow's roughness. Rick and Melissa should appear soon – in the meantime some combination of **Cecilia, Gabriel and Melissa (via CB)** will tell us about the streak and their theories. The goal now is to find the streak! With help from our air-support team we'll locate some streak edges and see if we can figure out what's going on.

6PM — Camp: Amboy Volcanic Field.
Elevation 800'. Sunset 7PM AZ time.

Road log for PTYS 594 – All times are AZ times



Road log for PTYS 594 – All times are AZ times

SUNDAY 3/31/2012

8 AM Break Camp. Sunrise 6.30AM.
Drive west on Rt 66 for 26 miles. Take a right turn onto Crucero road and cross I40 at Ludlow. Continue North for ~7 miles.

9AM **Catherine** will tell us more about Playas and Radar and perhaps speculate wildly about Titan while waving her arms in wide circles.

9.30am Leave for home. It's ~7 hours driving from Broadwell Playa to LPL.
Stops and lunch along the way means this is probably 8.5 hours minimum.

6 PM Return to LPL. Sunset in Tucson 6:45PM

Participants

1. Atticus, Atticus
2. Atwood-Stone, Corey
3. Beard, Sky
4. Bramson, Ali
5. Byrne, Shane
6. Chung, Youngmin
7. Cox, Erin
8. *Dykhuis, Melissa
9. Elder, Catherine
10. Flateau, Davin
11. *Greenberg, Rick
12. Kataria, Tiffany
13. Keane, James
14. Leung, Cecilia
15. Miller, Kelly
16. Muro, Gabriel
17. Showman, Adam
18. Thompson, Michelle
19. Van Laerhoven, Christa
20. Viola, Donna

*Air Support

Radar and Dunes: Kelso Dunes and Titan

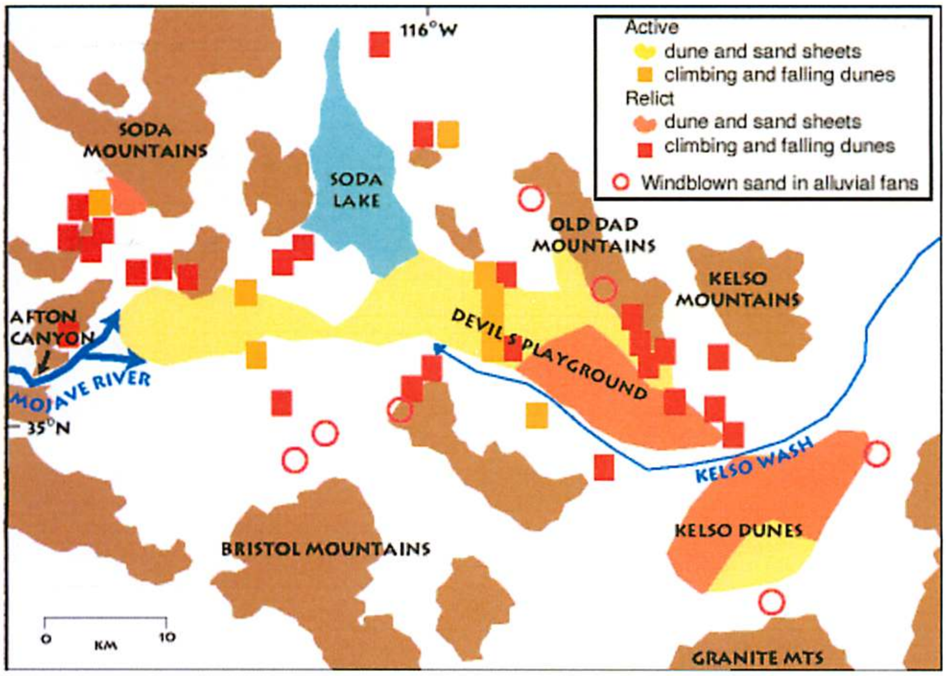


Figure 1: The Kelso Dunes sand system; image from nps.gov

Kelso Dunes

- Mostly quartz and feldspar, probably from San Bernadino Mountains
- Magnetite and amphibole tend to stay on the dune surface
- Composed of five different layers of dunes
  - Dry climates cause new accumulation of sand
  - Layers have built over a time period of ~25,000 years
- Currently contains active and inactive components

Figure 2: A USGS researcher discovers the source of sand in Kelso Dunes; image from Herbert 1965

Radar Basics

- Pulsed source at variable bands of wavelengths
  - C-band: ~5.6 cm
  - L-band: ~24 cm
  - P-band: ~68 cm
- Signal scatters off of surface
  - rough surfaces tend to have more faces oriented towards the detector, and will therefore return more signal
- Received signal is interpreted in terms of its Doppler shift in the direction of flight, and its delay time in the look direction.

- Reflection of signal also depends somewhat on composition – materials with high dielectric constant return signal strongly
- Dunes can be imaged with radar if they are more than 4-10 image resolutions elements apart, and are oriented more than 30 degrees from the radar look direction.

Radar of Kelso Dunes

- Part of the Mojave Field Experiment
    - Ground-truthing remote sensing data in preparation for the Magellan Mars Observer, CRAF, and Galileo missions
    - Late 1980's, early 1990's
- AIRSAR data look direction is roughly perpendicular to dunes (resolution ~10-25m)
- Generally radar dark – low dielectric constant
- P-band HH and VV have best topography of dunes
- C-band VH discriminates between active and inactive dunes
    - change in polarization not fully understood; probably related to subsurface

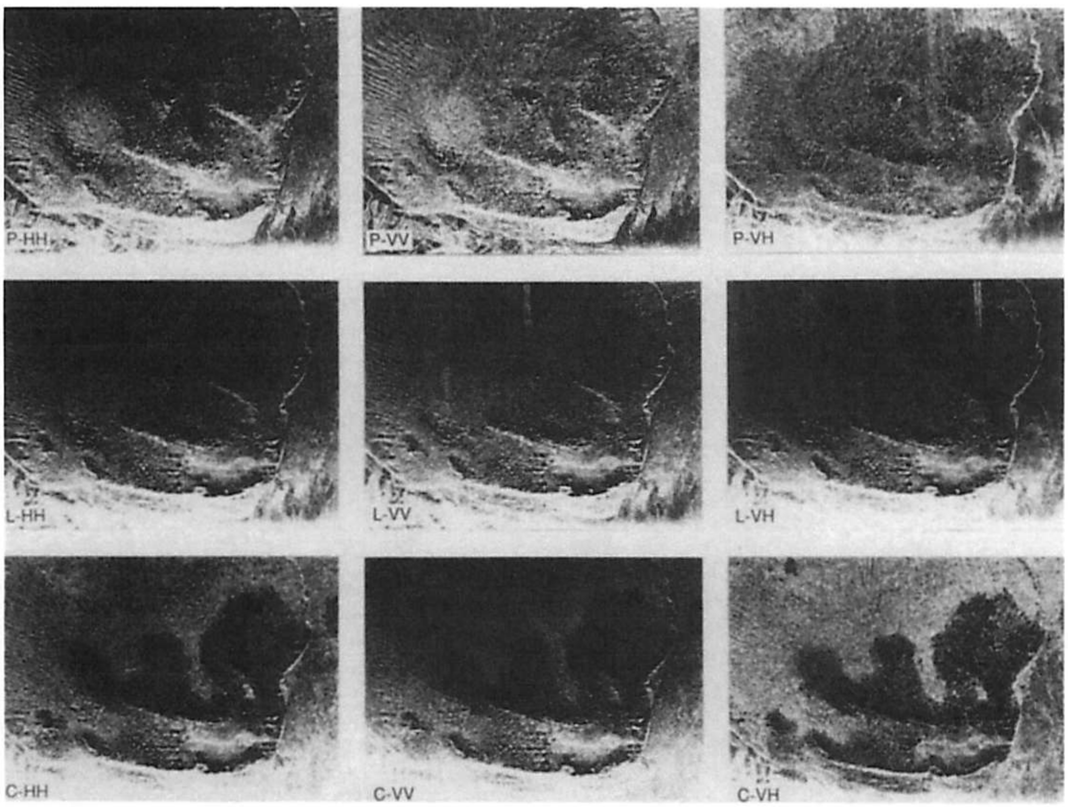
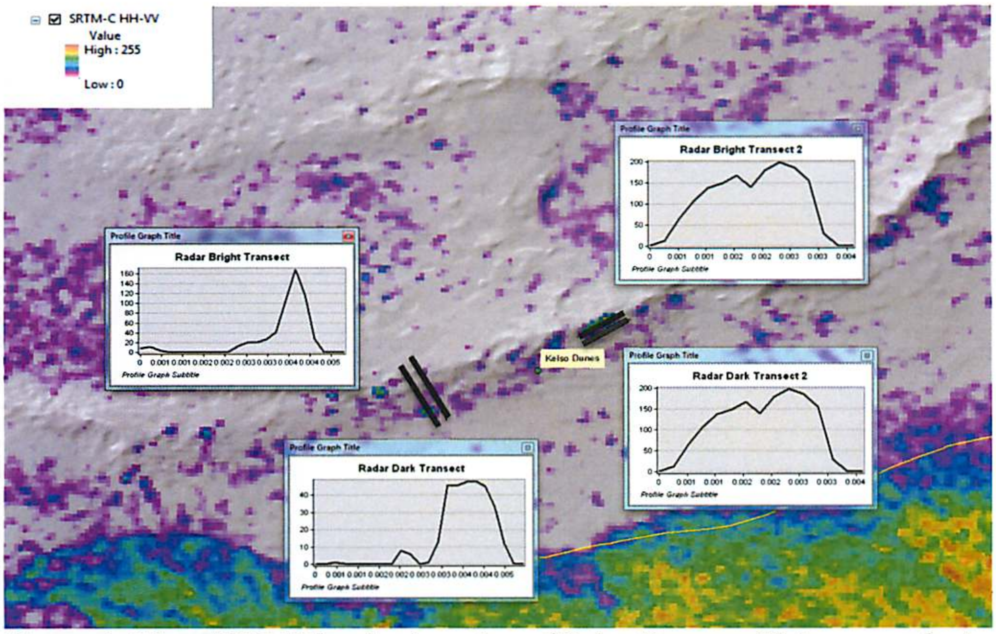


Figure 3: AIRSAR data from Kelso dunes; image from Lancaster et al., 1992

- Bright spots in HH and VV caused by concave avalanche faces directed towards detector



o **Figure 4: C-band HH-VV radar imaging of Kelso Dunes with topography transects; these transects indicate that radar-bright spots do not appear to correlate with topographical highs or lows**

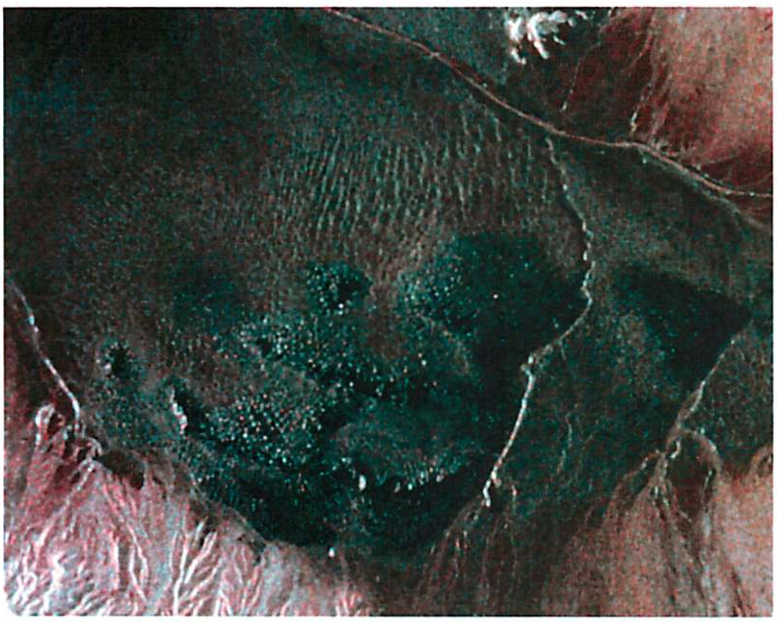


Figure 5: SIR-C RGB image of Kelso Dunes; in red is total power in the C band, and in green and blue are total power for the L band

Sand Dunes on Titan

- Up to 20% of Titan's surface covered in equatorial linear dunes
- IR data indicates water content of dunes is low; sand is thought to be organic; microwave radiometry suggests low dielectric constant
- Cassini images with resolution ~300 m found linear features with 1-2 km spacing
- Radar-dark indicates dunes are smooth at

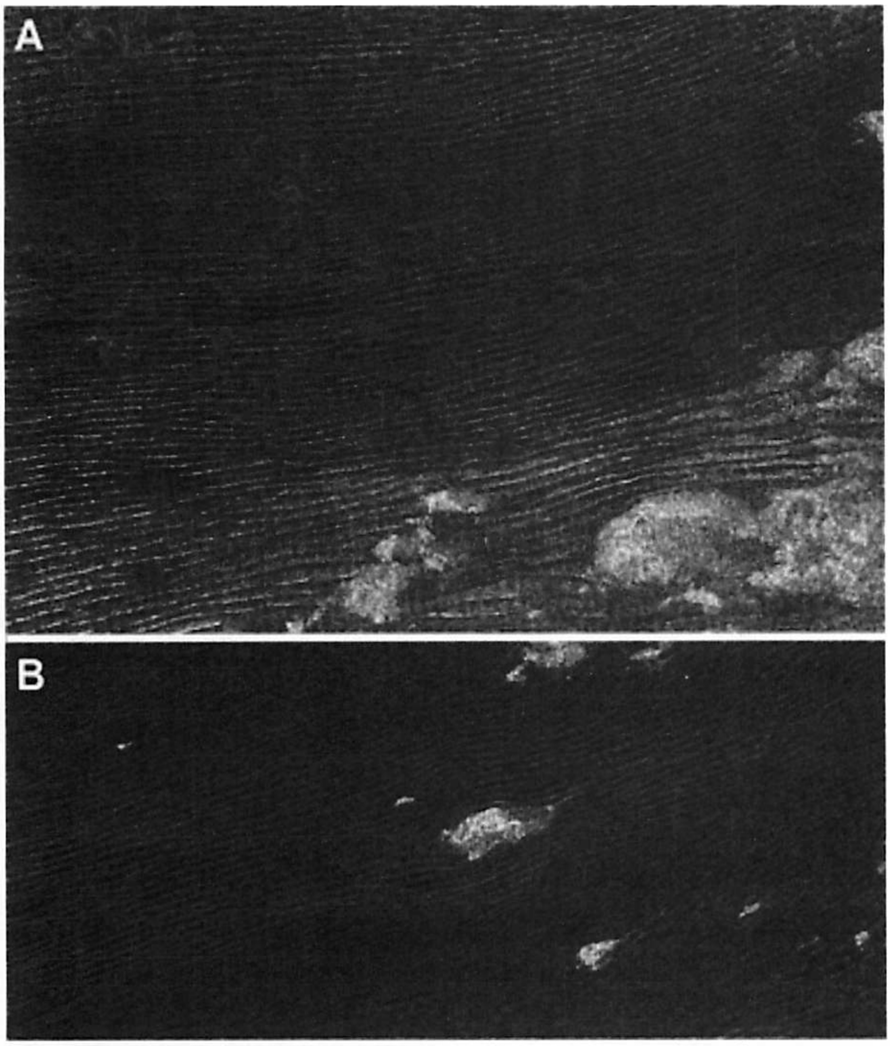


Figure 6: Cassini radar image of Titan; band wavelength is 2 cm, and polarization is HH; image from Lorenz et al., 2006

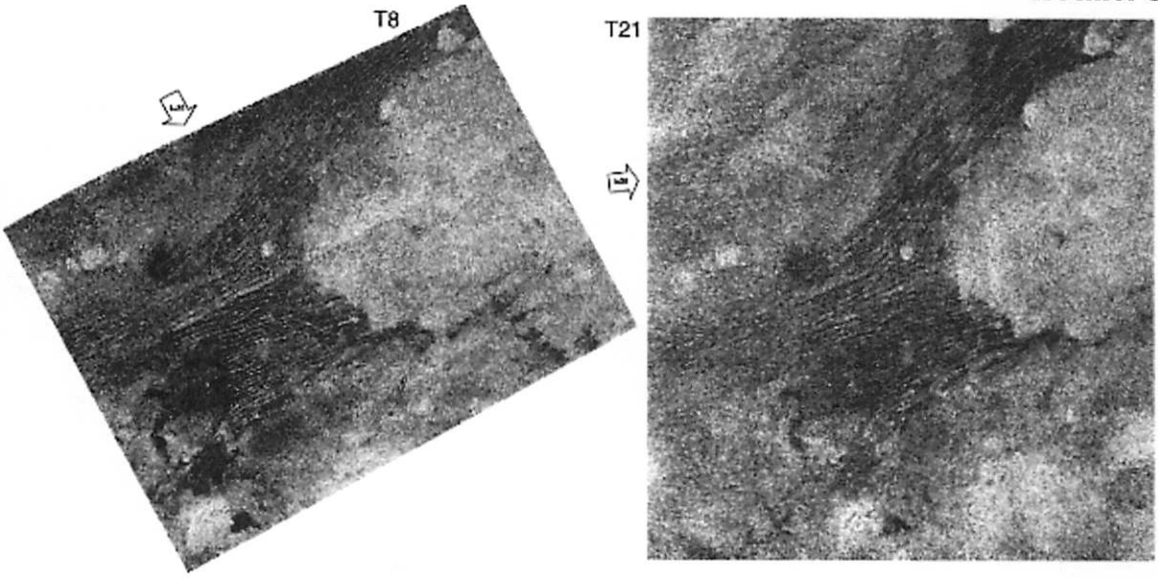


Figure 7: Titan's dunes appear to be relatively independent of radar look direction, as shown by these two images taken of the same area with look directions that differ by 70 degrees; image from Radebaugh et al., 2008

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MASTER Analysis for Spectrally Diverse Material at Kelbaker Road, Kelso, Mojave: That Shit be Cray-Cray

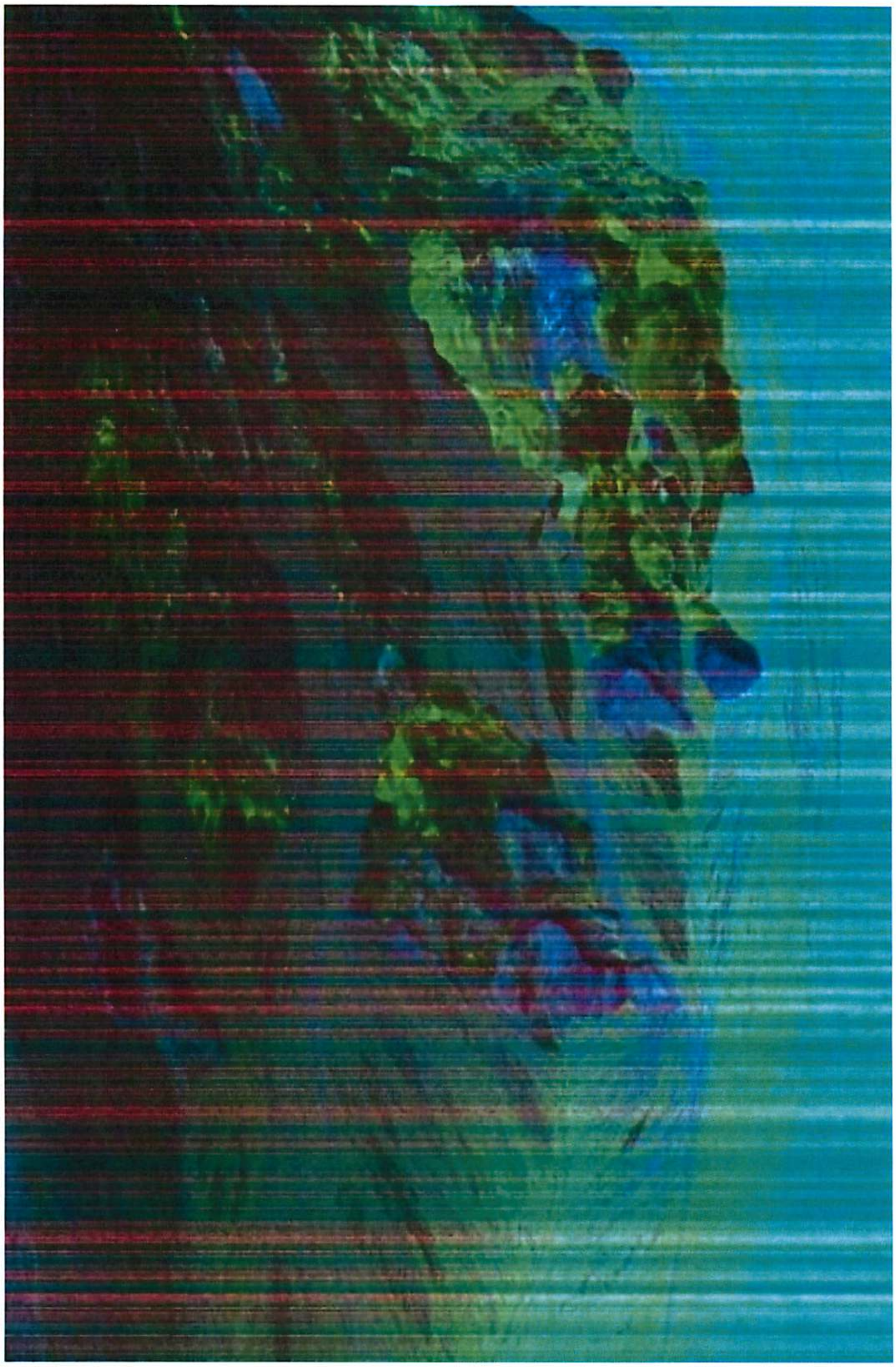
Michelle Thompson + James Keane

Figure 1: Location of the Compositionally Distinct Material inside red annotation, north of Kelso Dunes

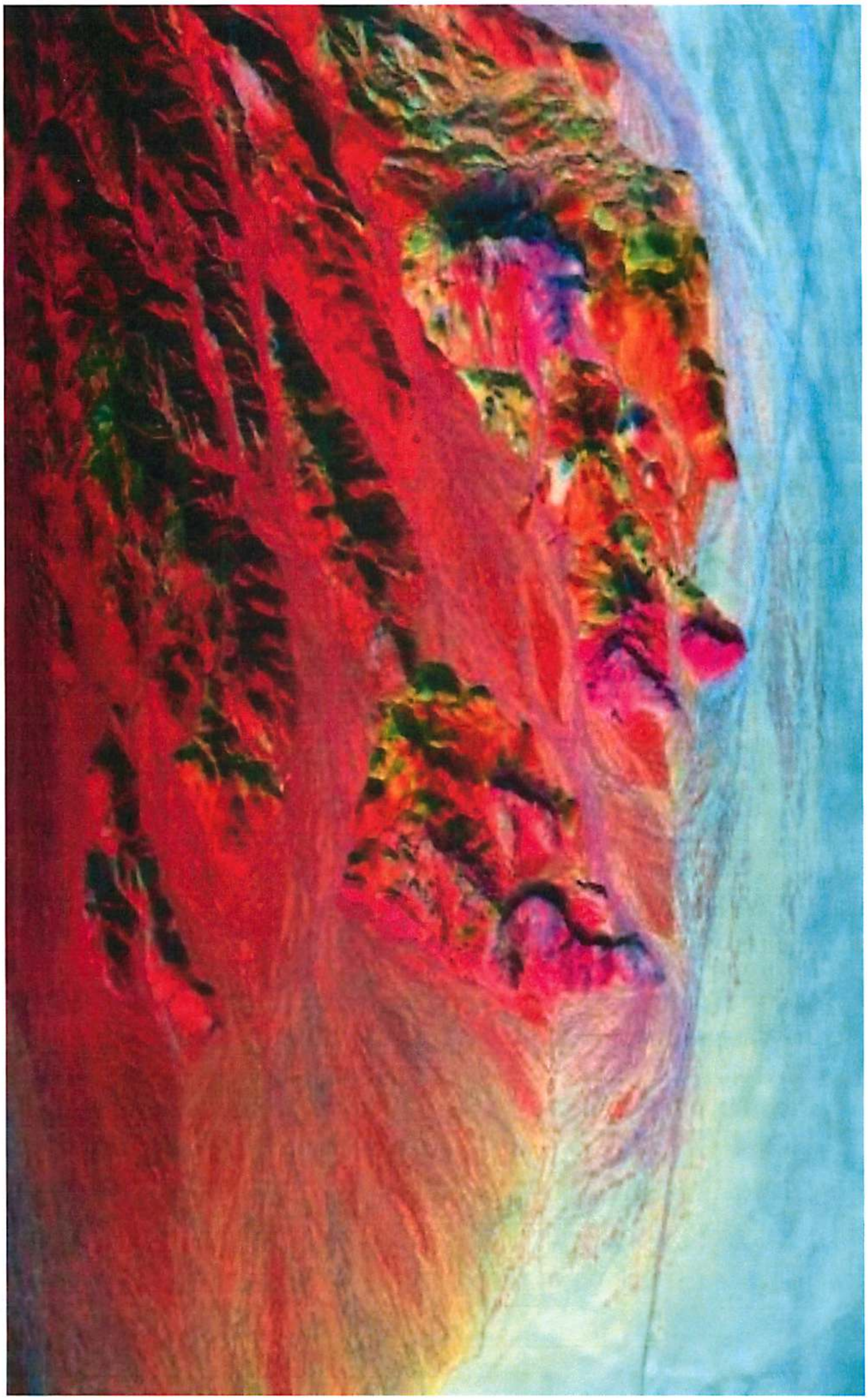
Figure 2: MASTER Analysis

2A: Red = 1.82 um, Green = 0.92 um, Blue = 0.54 um

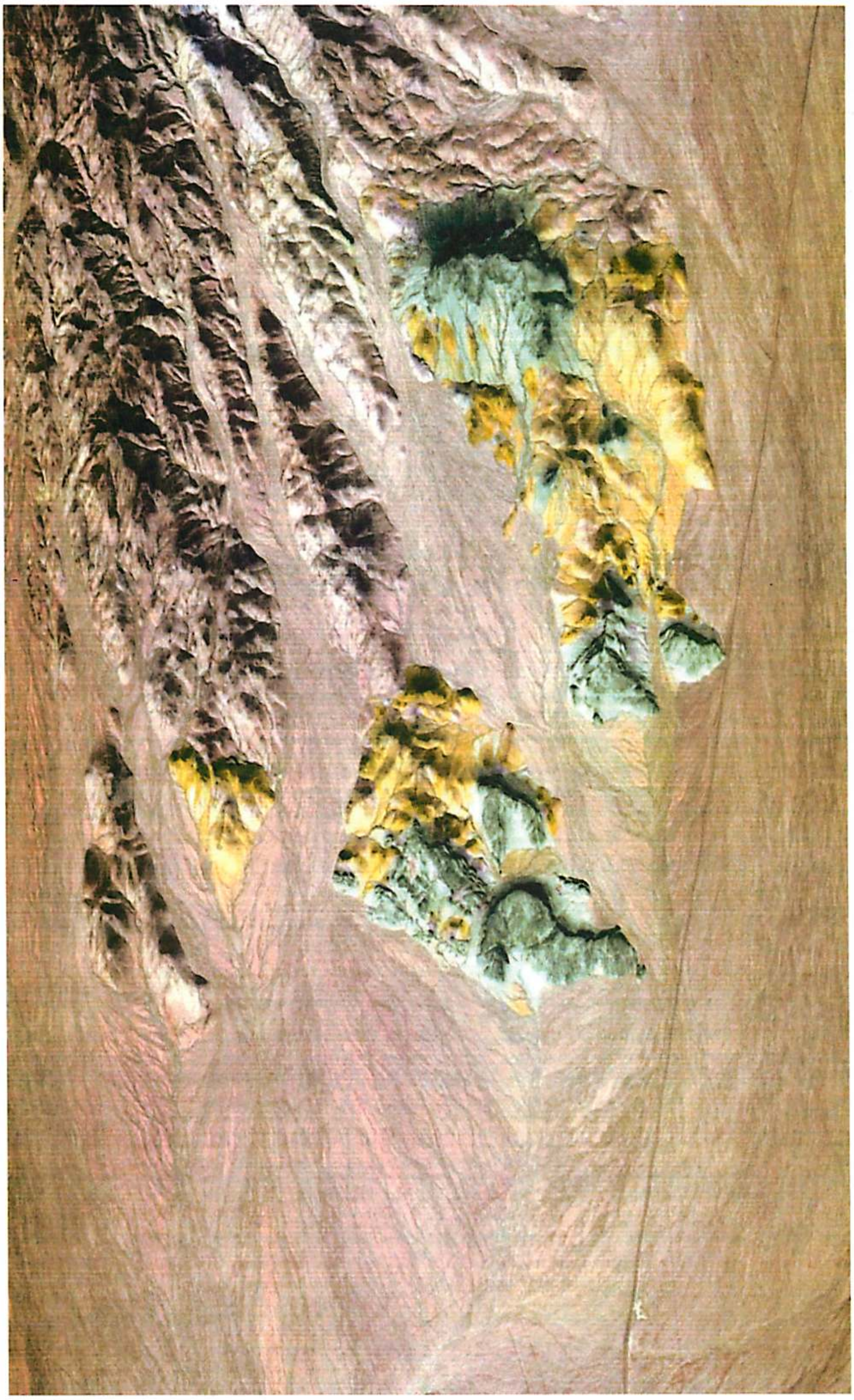
2B: Red = 2.25 um, Green = 1.77 um, Blue = 0.96 um



2C: Red = 3.15 um, Green = 1.66 um, Blue = 0.50 um



2D: Red = 9.75 um, Green = 2.15 um, Blue = 0.50 um



2E: Red = 12.22 um, Green = 10.17 um, Blue = 8.23 um

Figure 3: Spectra taken for 5 'units' as identified in Figure 2A, compared to standard spectra of calcite, dolomite and quartz (major constituent minerals of these rocks).

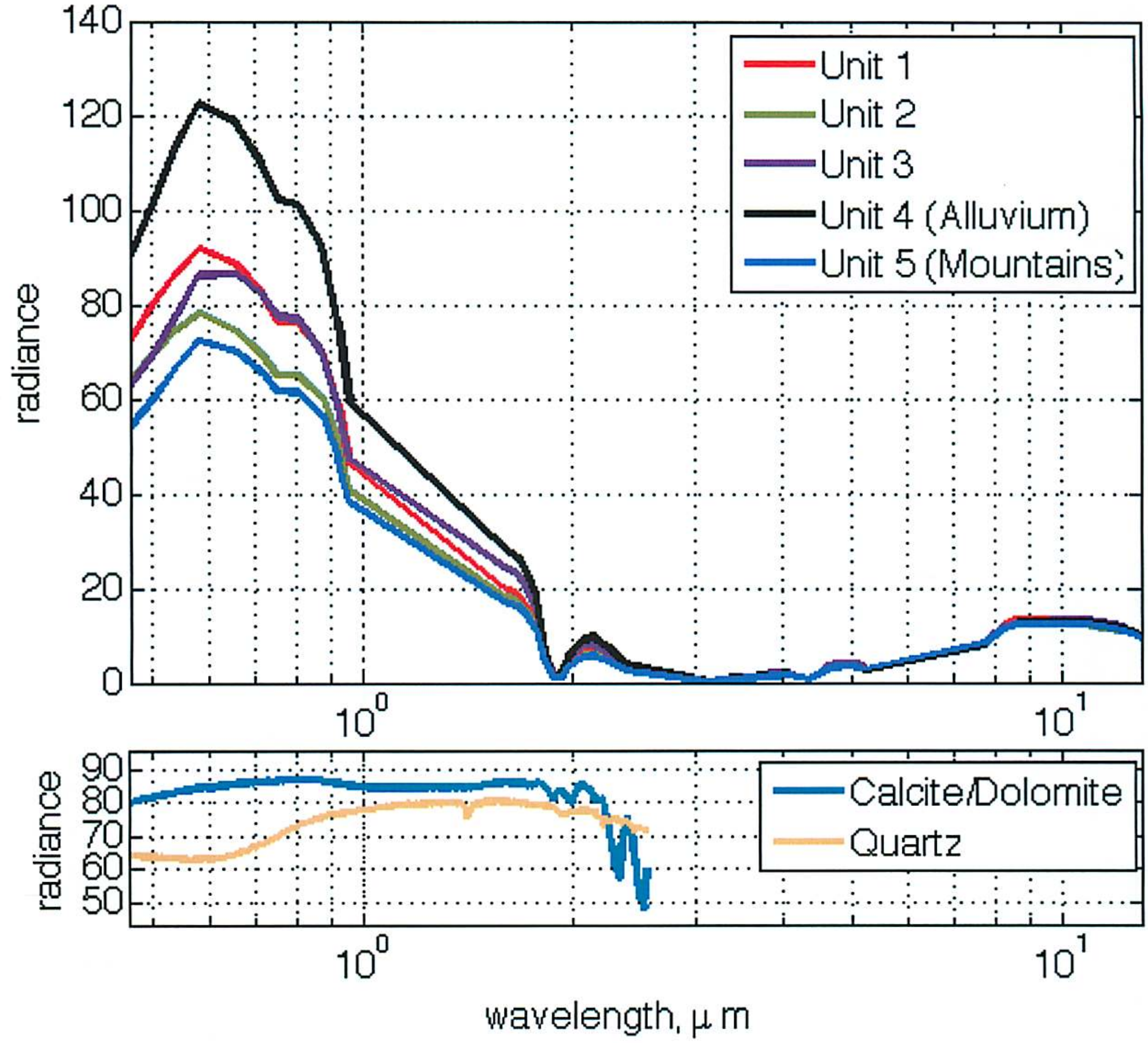
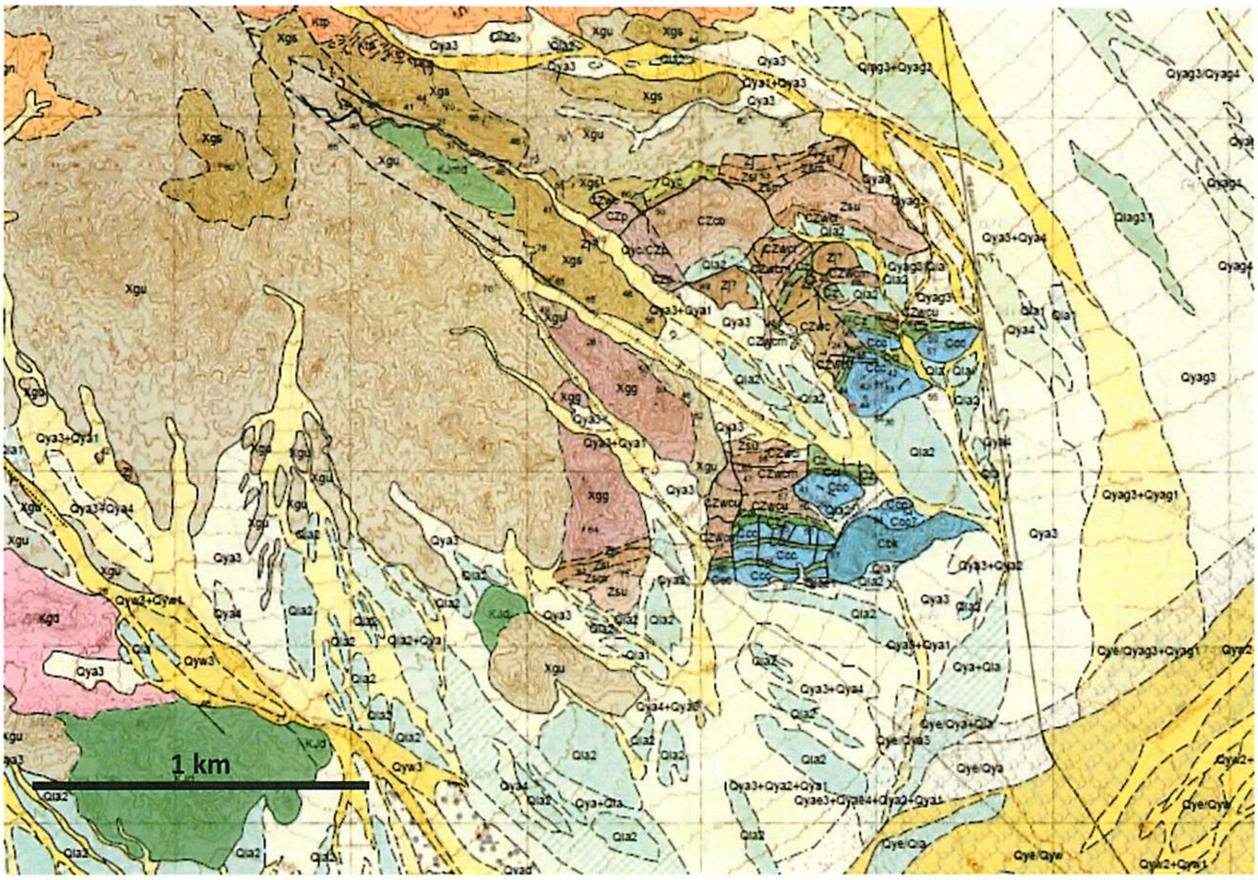


Figure 4: Geologic Map and Legend (Bedford, 2003).



Paleozoic and Late Proterozoic sedimentary rocks

Cbk — **Bonanza King Formation (Late and Middle Cambrian)** – Dark-blue to smoky-gray fine-to medium-grained mottled limestone and dolomite. Brown silty mottling generally less than 1 cm thick, indistinct bedding approximately 10 cm to 2 m. Heavily fractured with white recrystallized calcite in fractures. Rocks closely resemble lower "Member No. 1" of the Bonanza King Formation (Stone and others, 1983), but correlation is difficult based on structural complexity. Thickness indeterminate due to faulting

Carrara Formation (Middle and Early Cambrian) – Divided into:

Ccc — **Chambless Limestone (Early Cambrian)** – Light-gray fine-grained limestone containing 10 to 30 percent 2 to 3 cm dark blue gray concentric algal nodules (*Girvanella*). Bedding 1 to 2 meters thick. Heavily fractured with white recrystallized calcite in fractures, typically more fractured in lower sections. Thickness indeterminate due to faulting

Ccl — **Latham Shale (Early Cambrian)** – Dark-green to locally brown and red shale, containing sporadic 1 to 3 cm beds of buff fine-grained quartzite. Marker bed at approximately 2 to 3 m below top of unit consists of buff sandy limestone, 0.7 to 1.5 m thick, locally contains shell fragments. Thickness of unit approximately 8 to 15 m

Cz — **Zabriskie Quartzite (Early Cambrian)** – Light pink, yellow and white medium- to coarse-grained massive to faintly planar cross-bedded quartzite. Contains vertical 1cm diameter trace fossil burrows (Scolithus), white in color, commonly with a black hematite ring around the outside edge. Bedding 0.4 to 1 m thick. Thickness of unit approximately 18 to 20 m. Contacts with Latham Shale and Wood Canyon Formation are sharp at 1 m scale

CZwc — **Wood Canyon Formation, undivided (Early Cambrian and Late Proterozoic)** – Interbedded fine- to medium-grained dark-colored quartzite and fine-grained green shale. Locally divided into:

CZwcu — **Upper member (Early Cambrian)** – Fine-grained green shale and silty shale rhythmically interbedded with 0.10 to 0.4 m thick beds of fine-grained quartzite

CZwcm — **Middle member (Early Cambrian)** – Fine- to coarse-grained dark-colored quartzite with occasional beds of dark green to black shale. Basal 1 to 3 m consists of distinctive quartz and jasper pebble conglomerate. Above pebble conglomerate is medium to coarse-grained massive quartzite overlain by red-brown trough cross-bedded quartzite

CZwcl — **Lower member (Early Cambrian to Late Proterozoic)** – Fine-grained medium- to thick-bedded dark green shale with occasional interbeds of fine-grained quartzite

Zs — **Sterling Quartzite (Late Proterozoic)** – Divided into:

Zsu — **Upper member** – Dark-gray to black medium-grained poorly sorted quartzite with rare discontinuous lenses of 1cm pebble conglomerate

Zsm — **Middle member** – Thin-bedded green-gray shale, poorly exposed in saddles. Approximately 20 m thick

Zsl — **Lower member** – Basal reddish to white basal pebble conglomerate grades up to well-sorted white fine-grained quartzite. Weathers to red-brown in color. Approximately 30 m thick

Zj — **Johnnie Formation (Late Proterozoic)** – Consists of predominately 3 to 5 m thick beds of fine-grained white, gray, and buff quartzite interbedded with minor 0.2 to 0.5 m thick beds of pebble conglomerate, 1 to 10 cm thick shale, and 0.5 to 0.75 m thick buff dolomite beds. Locations where init is queried consist of thick, heavily fractured massive buff dolomite similar to that in the Johnnie Formation. Outcrops that are stratigraphically displaced from all other units may also be part of the Cambrian Nopah Formation

CZp — **Phyllite and Phyllitic Schist (Late Proterozoic and Cambrian?)** – Black and dark-green fine-grained phyllite and phyllitic schist. Structural complexity and metamorphism makes correlations difficult, but may include portions of the Johnnie, Wood Canyon, Nopah, or Cadiz Formations. Thickness indeterminate

CZcb — **Carbonate Breccia (Late Proterozoic and Cambrian?)** – Blocks of tan and blue-gray limestone and dolomite, thoroughly brecciated and displaced from stratigraphic context. Thoroughly brecciated and cemented, forms ridge crests and prominent spurs. May include Johnnie Formation, Chambless Limestone, Bonanza King, and possibly portions of the Nopah Formation, Noonday Dolomite, or Pahrump Group

Qia **Intermediate Age Alluvial Fan Deposits (Pleistocene)** – Light to dark brown poorly- to moderately-sorted sand and gravel. Clasts mostly subangular to sub-rounded and coarsen toward mountain fronts. Moderate-to well-developed interlocking desert pavement containing moderate to strong varnish coating on clasts, with the exception of granitoid clasts, which rarely varnish. Moderately developed soil profile, with moderate- to well-developed A_V horizon that is as much as 6 cm thick, distinct argillic B horizons up to 50 cm thick and with weak to moderate stage II to III calcic horizons. Surfaces lie 1 to 3 meters above young alluvial fan surfaces (Qya). Surface remnants flat to slightly rounded between incised younger channels. Sparse and stunted vegetation, typically along shoulders of incised channels or isolated on the surface

Qia1 **Intermediate Age Alluvial Fan Deposits (Latest Pleistocene)** – Poorly- to moderately-sorted sandy gravel. Surfaces commonly compact with moderately developed desert pavement consisting of non-interlocking mosaics of mixed size clasts. Relic bar and swale microtopography remains in some areas. Surface is light brown to dark brown to black depending on source lithology and degree of varnish. Varnishing of clasts variable, with granitic clasts having little or no varnish, to quartzite and other sedimentary rocks being very well varnished. Moderately- to well-developed soil profiles consisting of 2 to 6 cm thick silt and fine sand vesicular A_V horizon above 25 to 30 cm reddish argillic Bt horizon, with stage II to III- calcic development. Surfaces lie 1 to 2 m above active stream channels and younger deposits, inset 30 to 100 cm into unit Qia2. Sparsely vegetated. Deposit uncommon or indistinguishable from unit Qia2 in remote sensing, mapped where visited in field

Qia2 **Intermediate Age Alluvial Fan Deposits (Late Pleistocene)** – Similar characteristics to unit Qia1, with more pronounced soil development especially in thickness and degree of A_V horizon development, which ranges from 2 to 8 cm. Argillic Bt horizon with stage II to III calcic development. Pavement surfaces often very flat with well varnished, compact interlocking clasts. Surface is light brown to black. Vegetation is very sparse and tends to be isolated perennials such as creosote or Mojave Yucca (*Yucca schidigera*), or concentrated along shoulders of incisions. Surfaces are the most common of those of intermediate age

General Geologic History of the Mojave Desert

Corwin Atwood-Stone Field Guide

-Oldest rocks are early Proterozoic (2.5 – 1.7 Billion years old) high grade metamorphic rocks, derived from earlier rocks of all types.

-Approximately 1.4 bya magmas intrude into these rocks during a long period of mountain building as small landmasses assemble modern continental cores.

-From 1.4 bya to ~260 mya area is structurally quiescent and underwater. During this time very thick sequences of sedimentary rocks form. The thick (10 km) fossil rich carbonate sequence shows North America drifted north across equatorial regions during this time.

-Late Permian and Early Triassic: Pangaea begins to rift apart, turning the west coast in to an active margin. Mostly west verging folds and thrust faults deform the sedimentary sequences. Additionally volcaniclastic sediments are found and plutons of this age are found cutting rocks. Additionally left-lateral strike-slip truncation along the continental margin is observed to juxtapose different sedimentary sequences.

-During most of the Triassic this region is tectonically quiescent and shallow marine and non-marine sedimentation is observed. Some magmatic plutons are also found of this age which are interpreted as the earliest activity of the Cordilleran arc.

-In the mid-late Jurassic this area is very volcanically active and lots of huge granitic intrusions form which eventually form the cores for most of the mountains in this region. Tectonically this time period is complex as some areas show up to 15% north-south extension while regionally eastward verging thrust faults, folds and shear zones show that there is significant shortening.

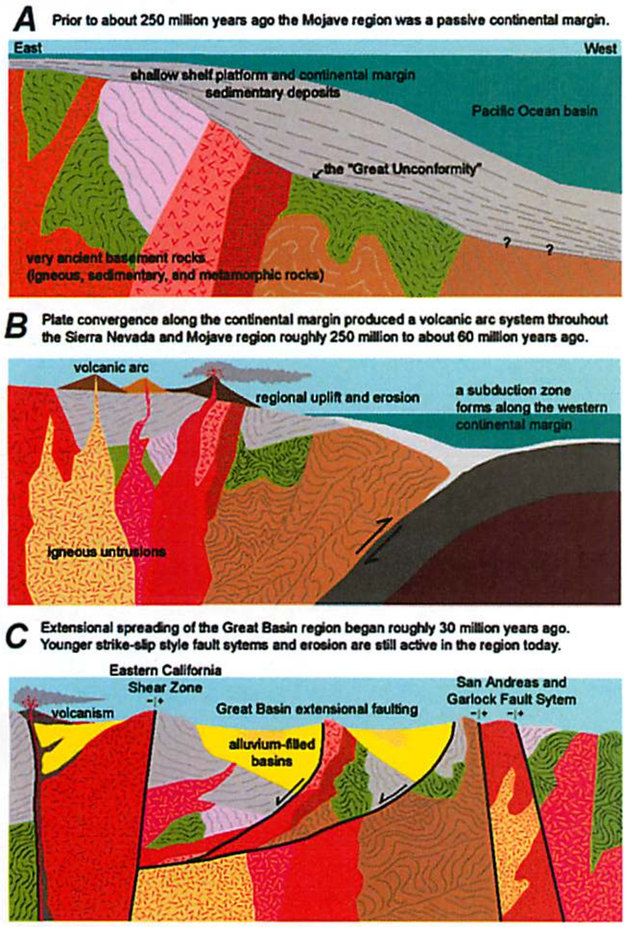
-The Cretaceous continues with mostly compressional deformation and significant continued intrusion of plutons, some of this deformation yielded significant metamorphism. In the late Cretaceous the Rand thrust emplaced the Rand Schist by underthrusting, pushing these high-grade metamorphic rocks under older sedimentary strata and replacing the lower crust.

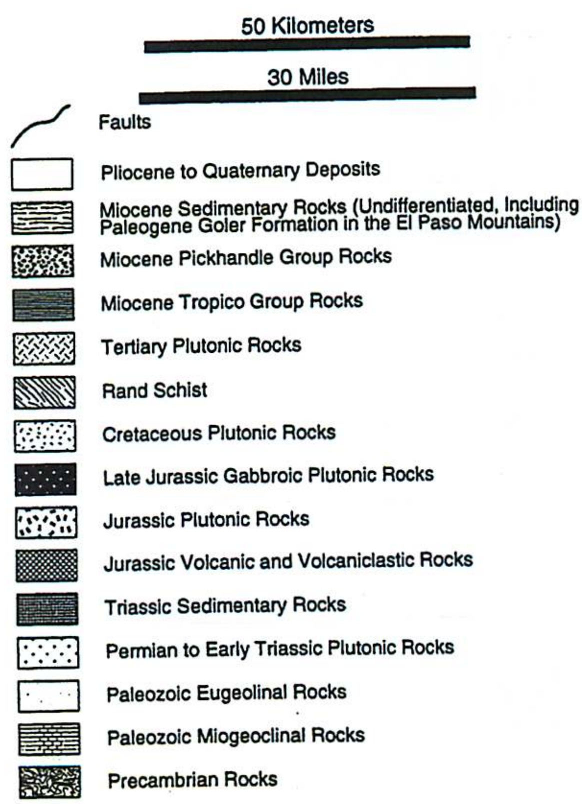
-There is no record of the Paleocene, Eocene and most of the Oligocene in this region, indicating the whole area was sufficiently uplifted (~4km) to be completely externally draining. Lack of volcanic activity is likely due to flat slab subduction which occurred during this period.

-In the late Oligocene to early Miocene magmatism and tectonism return to the Mojave as the Great Basin rift begins to open. Volcanism locally produces sequences several kms thick. Tectonism at this time was primarily extensional and was quite significant, in some places on the order of 10's of kms, often taking the form of large detachment faults. Also formed during this time was the Central Mojave Metamorphic Core Complex. Significant sedimentation is also associated with this time period. The end of this period is roughly coincident with the eruption of the Peach Springs Tuff.

-After this time volcanism quiets and basically shuts down until about 10 mya when basaltic cinder cones and lava flows begin to form. Tectonism also shifts character from extensional to strike-slip, as seen in the right-lateral shearing of the San Andreas fault, the Garlock Fault and the Eastern California Shear Zone, all of which have 100's of kms of displacement. Basins formed in this time are primarily strike-slip pull apart basins.

Geologic Map of the Mojave from Glazner et al. 1994, Reconstruction of the Mojave Block





Geologic History Idealized Cross-Sections from the USGS

Cima Volcano Field

Erin Cox

Volcano Field

- Most volcanic activity results in small volcanoes (<1km^3)
- Cinder cones, tuff cones/rings, lava domes, etc.
- Produced by individual volcanic events
- Usually basaltic (dark, fine grain; sometimes columnar structure) composition
- First mapped ~1766 in France
    - First geographically correct map
- Small and large fields
    - No correlation between size and lifetime

Important Characteristics

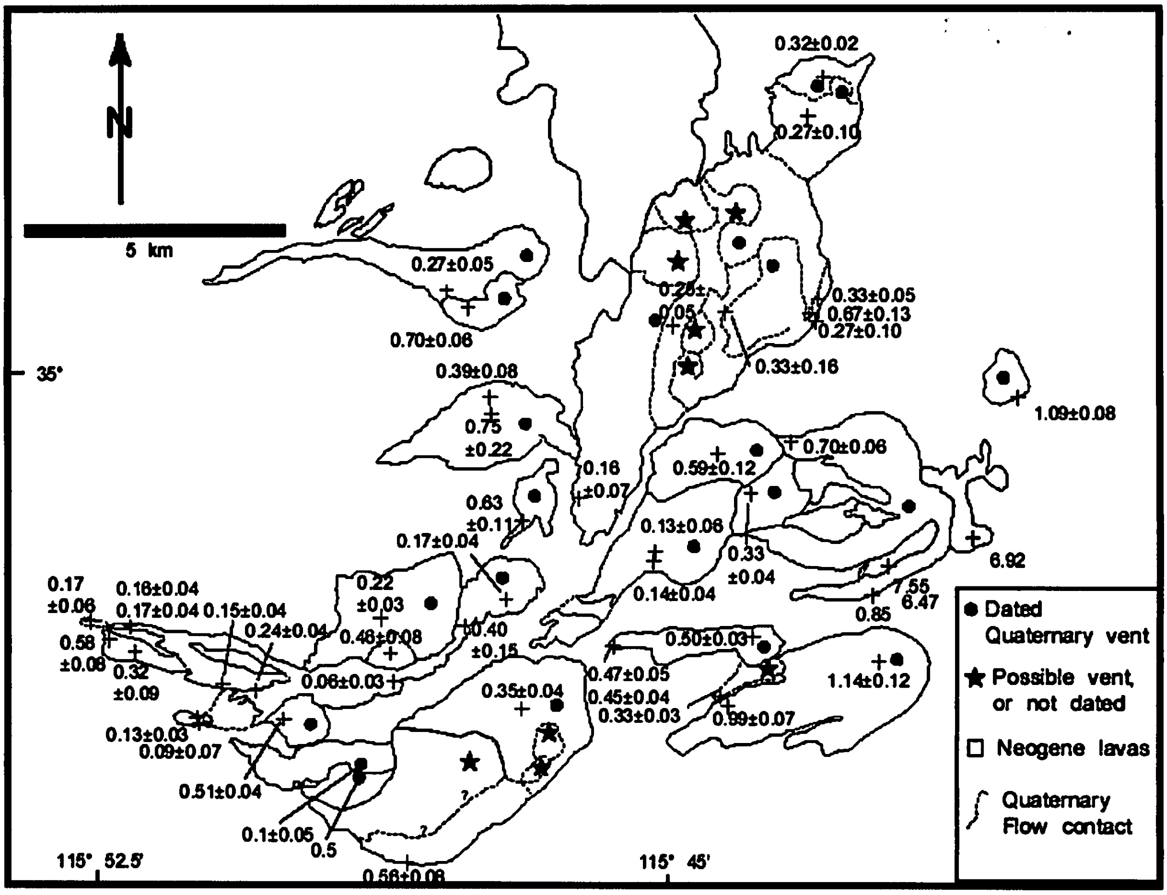
- Number and distribution of vents
- Occurrence of eruptions
    - Rates change over periods ≥ 1Myr
- Alignment with plates, fault lines, rift zones, etc.
- Roughness

Age

- Used for rate determination
    - Helpful for seeing how plate movement (and other geographical events) influences the rate of volcanic activity (not necessarily eruptions)
- Use lava flows, cinder cone morphology, radiometric age determination of vents.

Cima

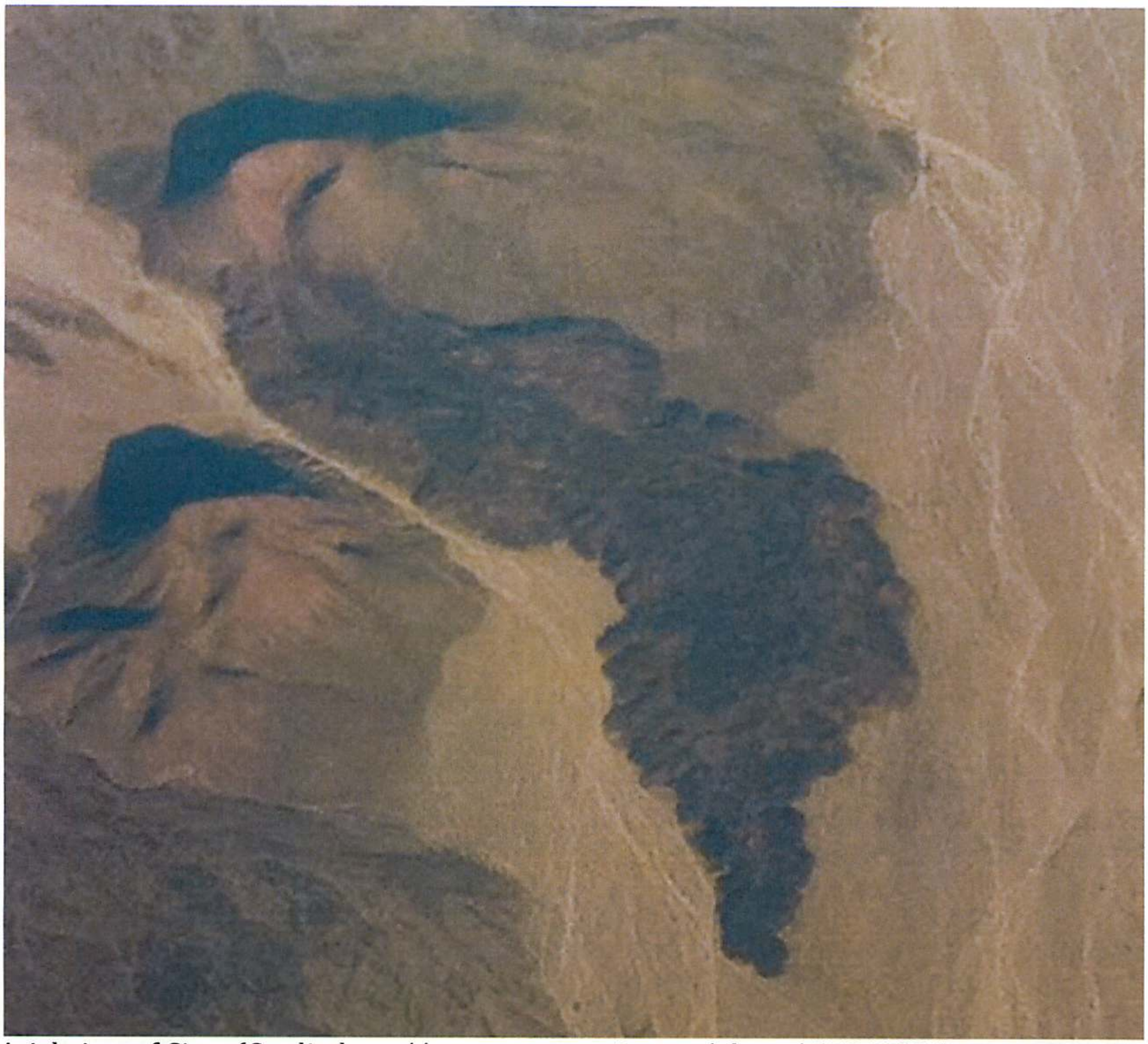
- Located in Mojave, CA
- ~40 cinder cone vents
    - 25 – 150 m in height and 200 – 900 m in diameter
- ~60 basaltic lava flows
    - 100 – 1700 m wide, 700 – 9100 m long
- Ages range from 8 Myr – 16,000 yr
- Importance for planetary science
    - Activity shows how volcanic surfaces change over time
    - Gives a look at how other planets with volcanism might evolve
    - Can study rock/ soil around flows to see what organisms/ animals can survive

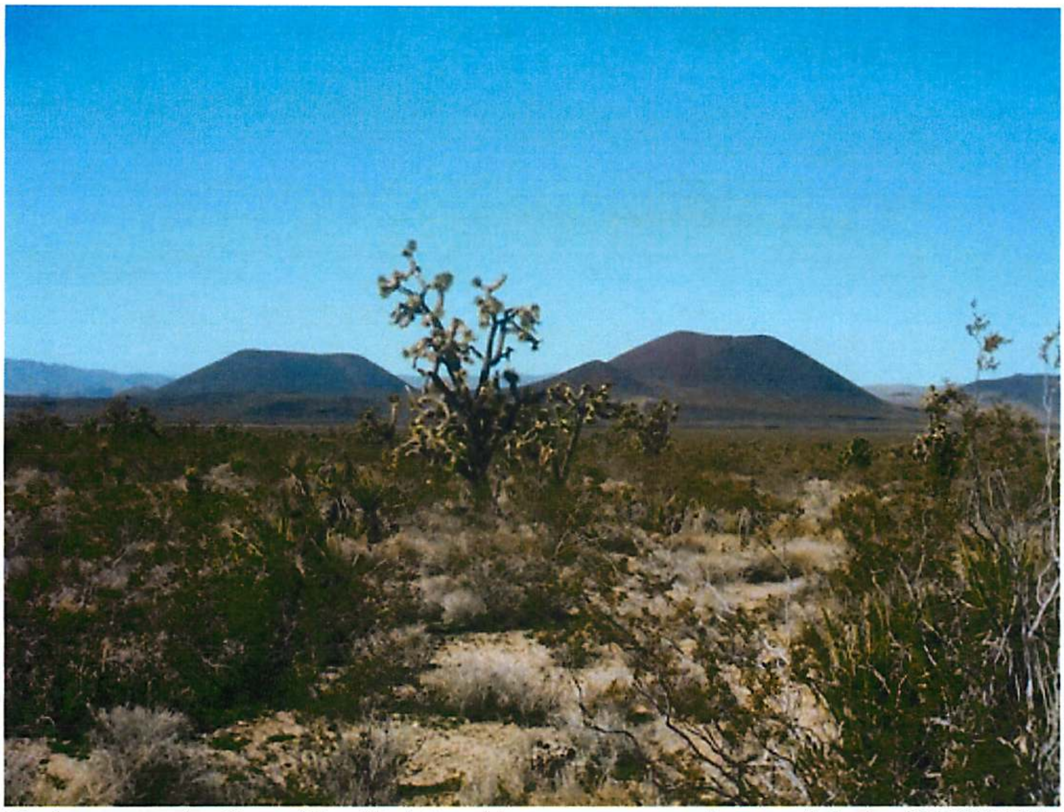


(Credit: http://www.cas.usf.edu/~cconnor/hazards/art4/figure3.html)

Southern map of Cima

- Approximately 30 vents
- Dated within last 0.7 Myr
- Activity of formation associated with large change in position of volcanic activity (older vents more north)


Ariel view of Cima (Credit: http://www.panoramio.com/photo/ 57348095)


Cinder cones in Cima (Credit: http://www.panoramio.com/photo/8152902)


Close up of cinder cone in Cima
(Credit: http://www.panoramio.com/photo/5034056)

References:

Farr, Tom. (1992) Microtopographic Evolution of Lava Flows at Cima Volcanic Field, Mojave Desert, California. *Journal of Geophysical Research*, 97, 15,171 - 15,179.

http://www.cas.usf.edu/~cconnor/hazards/art4/art4.html#Introduction

Tephra
Cecilia Leung & Jess Vriesema

Tephra is a general term for all pyroclastic materials ejected from a volcano regardless of composition, fragment size or emplacement mechanism. Airborne fragments are also referred to as ***pyroclasts***. In Greek, tephra means "ash", *Pyro* means "fire" and *klastos* means "broken"; thus pyroclasts carry the connotation of "broken by fire".

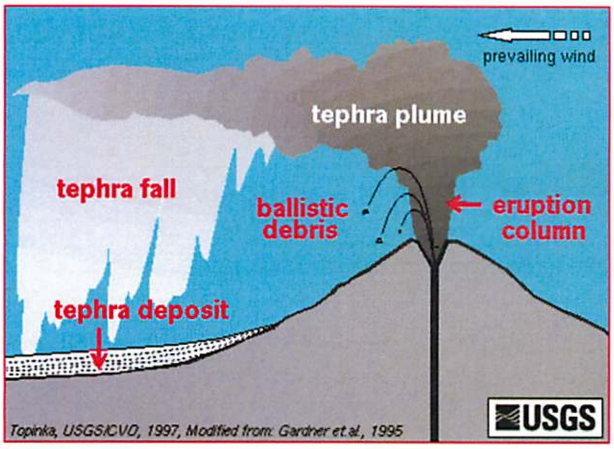


Fig 1: (left) Schematic drawing of erupting volcano showing tephra types. (right) Photograph of Cinder Cone by J.P. Lockwood

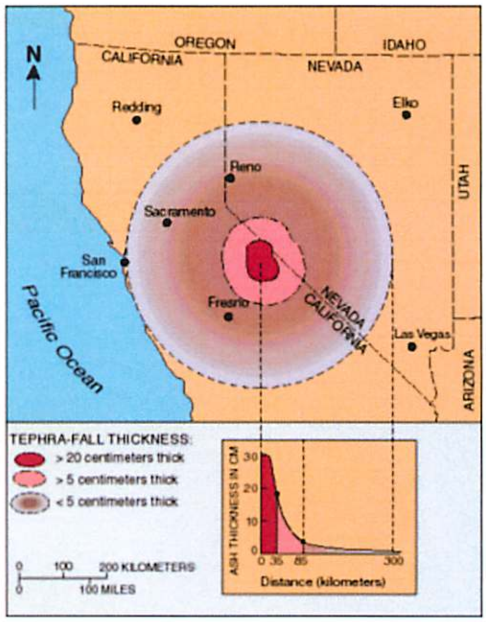
Classification: Tephra is classified based on pyroclast size:

Images: Courtesy of USGS.

Ash: Very fine-grained particles < 2 mm in diameter. Broken glass shards, broken crystal and lithic (rock) fragments
Lapilli: Cinders 2-64mm. (Latin for "little stones"). In water-rich eruptions, the accretion of wet ash may form rounded spheres known as *accretionary lapilli*
Blocks (solid) and **Bombs** (molton): Fragments > 64mm.

The basaltic flows in the Cima volcanic field were emplaced during 2 eposides of activity: 7-3Ma, and <1Ma. It has been suggested some of Cima's cinder cones are polygenetic in character, ie. having more than one source or origin. At least four of the Pleistocene cones have erupted discontinuously over 100s -1000s years. Tephrochonometry allows precise dating of widespread tephra layers, which bear their own unique chemistry and character, as temporal marker horizons.

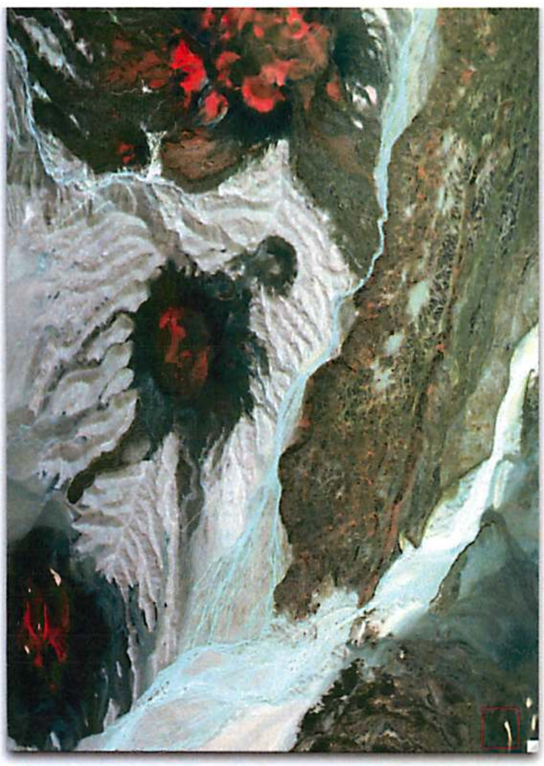
Tephra Fall Thickness:



Map from C.D. Miller (1989), modified by J. Johnson.

The distribution of tephra following an eruption usually involves the largest boulders falling to the ground quickest and therefore closest to the vent, while smaller fragments travel further. Ash can travel for thousands of miles, staying in the stratosphere for days to weeks following an eruption before being settled. Thickness of a tephra-fall deposit and distance from its source vent depends on regional wind patterns.

Map shows potential thickness of tephra fall from future eruptions in the Long Valley Mono Lake area.



Remote Sensing: MASTER & SAR

The washes in this image appear bluer than surrounding terrain because they are enriched in smaller-grained particles. This is because fluvial erosion breaks particles into smaller particles and carries them downstream and into washes.

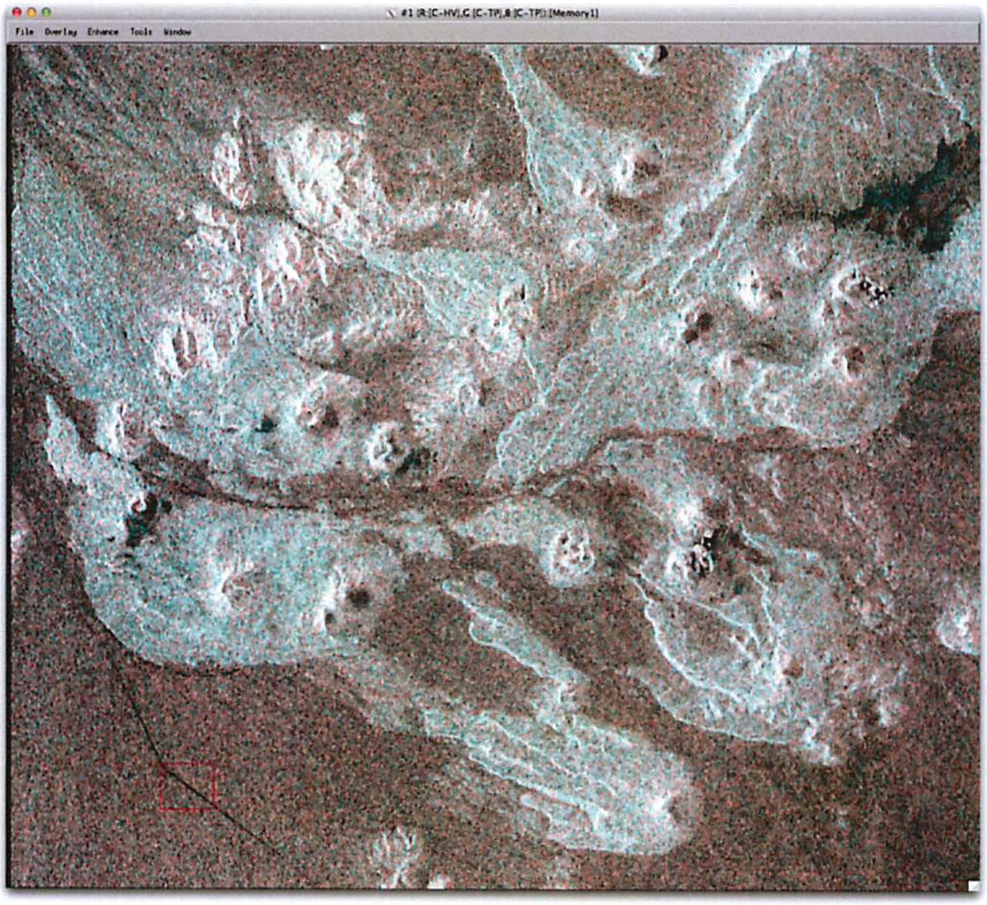
The tops of the cinder cones appear reddish because they have relatively more large-grained particles. This is because smaller particles fall between and beneath larger particles due to the large porosities of cinder cones.

At the northernmost flow in this image (see bottom-right close-up), there are numerous striations around the southern bank of the cone that are caused by strong erosion occurring along steep gradients.

The light-colored basin around the central cone (see bottom-left close-up) has numerous hills that have been cut out by erosion. To the west of this crater, the lava flow seems to be on the crests of the hills, indicating that this erosion happened after the eruption and likely cut away a significant amount of lava.

MASTER (R:1.662, G:0.872, B:0.66)

Cross Polarization C-Band Radar
(Red = cross HV. Green/Blue= Total Power)



References:
http://www.geology.sdsu.edu/how_volcanoes_work/Tephra.html
Joachim R. R. Ritter, Ulrich R. Christensen "Mantle Plumes: A Multidisciplinary Approach"
http://geology.csupomona.edu/drjessey/research/CimaGSA.pdf
https://137.227.239.76/lvo/hazards/TephraFall.php
http://geology.gsapubs.org/content/28/3/287.extract

Evolution of Cima Cinder Cones (pg. 1/2)

Davin Flateau

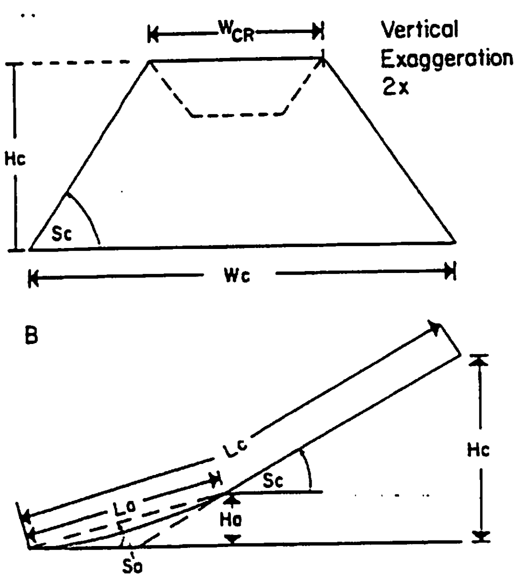


Fig. 1 (Dohrenwend et al. 1986)

W_{CR}: crater width
W_C: cone width
S_C: cone slope angle
H_C: cone height
H_a: apron height
S_a: mean apron slope angle
L_c: cone slope length
L_a: apron slope length

Cima field
~40 cinder cones
Ages: ~1.1 Mya-15,000 ya
Heights: 50-150m
Widths: 400-915m
Younger cones: H_C/W_C: 0.17

Cones show progressive degradation closely related to age:

W_{CR}/W_C=0.48 (young) to 0.21 (oldest with craters)

$\tan(S_C)$=0.57 (youngest) to 0.41 (oldest)

H_a/H_C increases from <0.1 (youngest) to avg 0.34 (oldest)

Cone drainage evolves from irregularly spaced gullies (youngest) to regularly spaced gullies to 110m wide X 10m deep on 0.59 Myr+ craters

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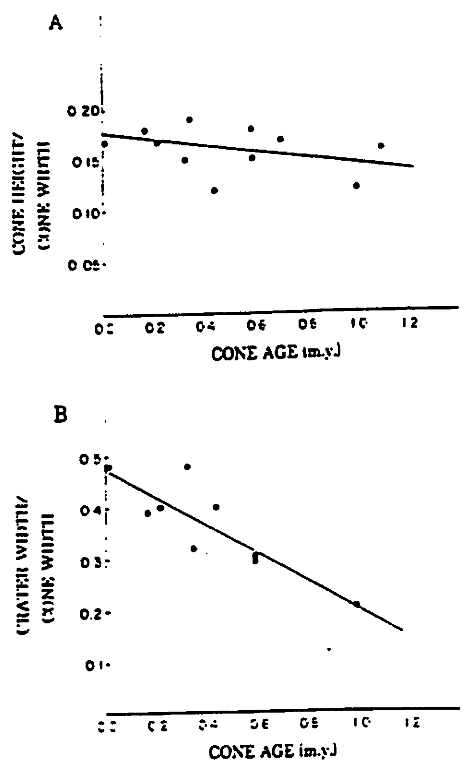

Fig. 2 (Dohrenwend et al. 1986)

Cinder Cone Degradation Model

1. **Erosional loss ~15% of cone volume during first million years**
2. **Progressive decline in cone slope (avg 0.006 deg/kyr) and cone height (avg 2.25 cm/kyr)**
3. **Rapid removal of loose cinder mantle from upper cone slopes that leads to rapid debris apron formation.**
4. **Gradual transition, between 0.25 and 0.6 Mya, from uniform stripping of upper slopes to local fluvial dissection of both cone slopes and aprons.**

Gully development strongly influenced by debris-flow processes, which are abundant on younger cones - important process in early stages of degradation.

Evolution of Cima Cinder Cones (pg. 2/2)

TABLE 1. CIMA VOLCANIC FIELD: CONE AGE DATA

Cone	Age (m.y.)	Age dating method	Magnetic polarity
A	0.015 ± 0.005	^{14}C; CRD*	Normal
U	0.16 ± 0.07	K-Ar	Normal
G	0.22 ± 0.03	K-Ar	Normal
BB	0.33 ± 0.16	K-Ar	Normal
E	0.35 ± 0.04	K-Ar	Normal
J	0.46 ± 0.05	K-Ar	Normal
F	0.59 ± 0.09	K-Ar	Normal
P	0.59 ± 0.12	K-Ar	Normal
R	0.70 ± 0.06	K-Ar	Normal
K	0.99 ± 0.07	K-Ar	Reversed
CC	1.09 ± 0.08	K-Ar	Reversed

*Cation-ratio dating of rock varnish.

Fig. 3 (Dohrenwend et al. 1986)

Fig. 4 (Crater BB, 0.33 Mya)

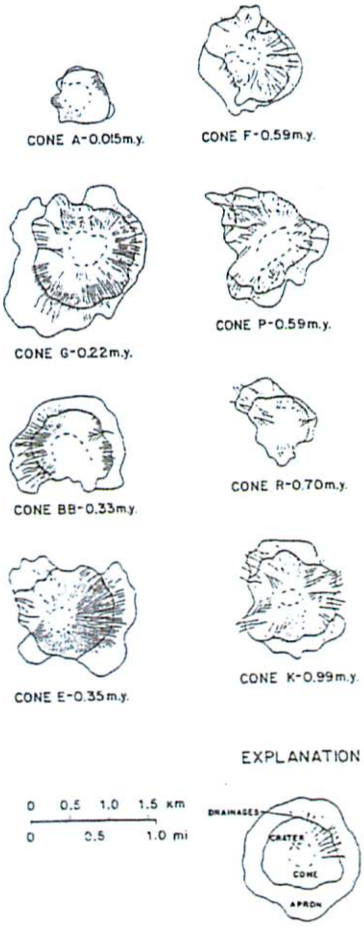

Fig. 5: Drainage network development on dated Cima cones (Dohrenwend et al. 1986)

Fig. 6 (Crater CC 1.1 Mya)

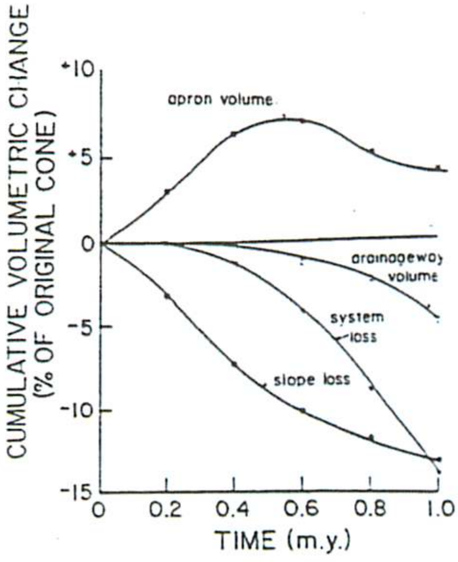

Fig. 7 (Dohrenwend et al. 1986)

References:

Dohrenwend, J.C. et al. 1986, Geological Society of America Bulletin, 97, 4, 421

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Wells, S.G. et al. 1984, Geological Society of America Bulletin, 96, 1518

Glove Cave and Astrobiological Studies at the Pisgah Volcanic Field

Donna Viola

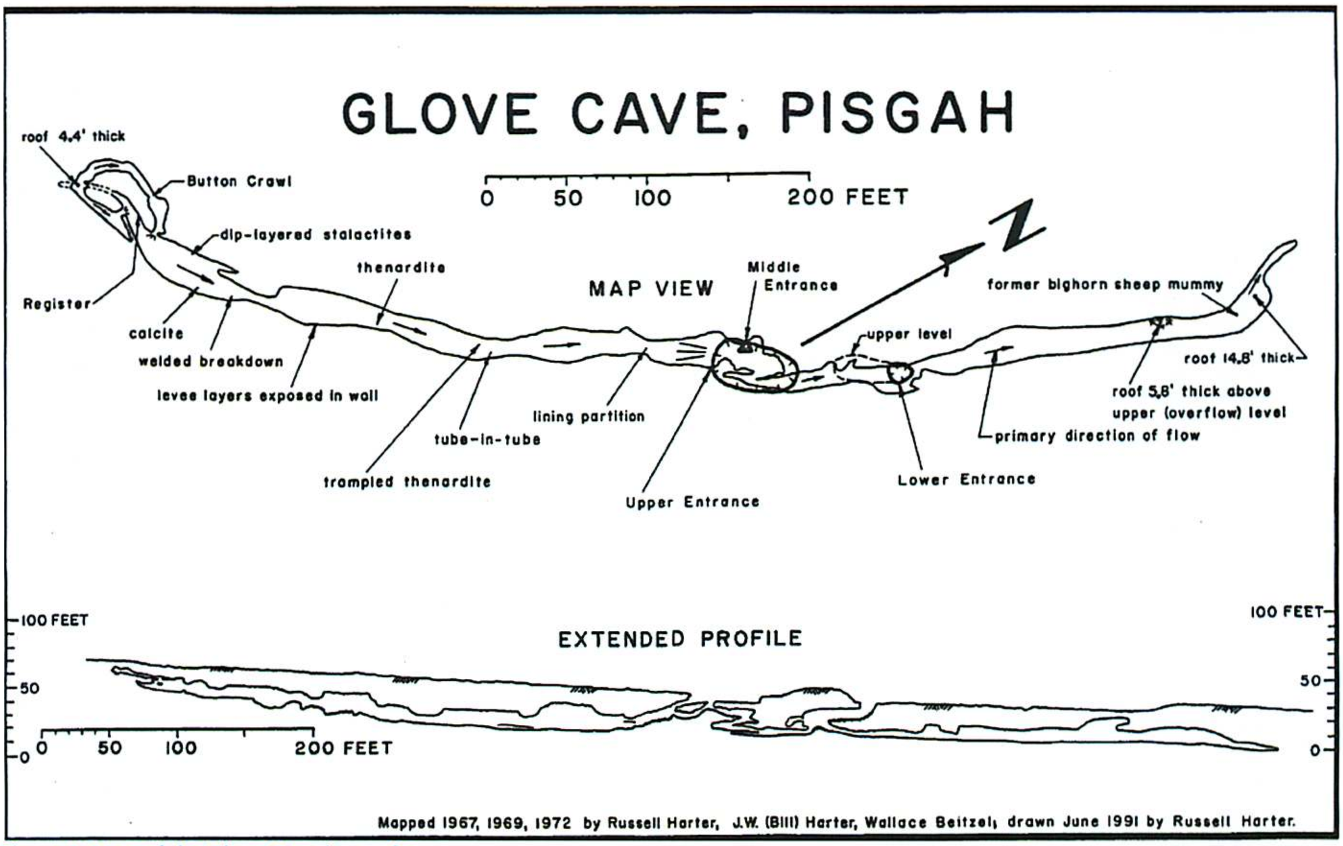


Figure 1: Map of the Glove Cave lava tube.

Glove Cave is one of the largest Pisgah lava tubes, 335 meters in length, and according to Caver Bob (of caverbob.com fame) it's the 35th-longest cave in California. It's one of the most popular lava tubes for visitors to the Pisgah flow, and has three entrances, all located near the middle (Figure 1). Features of note include remelt stalactites (from radiant heat remelting surface lava→dripping), dip-layered stalactites (from repeated rising/falling of lava streams), blowout pockets, whitish calcite crusts, and (in the past) a partially-mummified big horn sheep skeleton.

Astrobiology in the Pisgah Lava Field

In 2011, a paper by Stockton et al.[1] detailed a study of organic compounds in Pisgah's Yurtle Cave (located about 2 km south of Glove Cave, as per Figure 2), as well as hydrothermal outflow

[1] Stockton A.M., C.C. Tjin, T.N. Chiesl, R.A. Mathies (2011). Analysis of Carbonaceous Biomarkers with the Mars Organic Analyzer Microchip Capillary Electrophoresis System: Carboxylic Acids. Astrobiology 11:519-528.

Figure 2: Google Earth image showing the location of Glove Cave and, about 2 km south, Yurtle Cave.

channel in Lassen Volcanic National Park, using the Mars Organic Analyzer (MOA) technology[2], originally developed for highly sensitive amino acid detection.

The MOA uses fluorescence labeling and microchip capillary electrophoresis to measure low levels of organic compounds. Figure 3 shows the overall experimental layout of the MOA, including the sample fill stage (bottom right), the interior structure of the reaction chamber where samples are fluorescently labeled (with different reagents depending on the target organic molecule, left), and the microcapillary setup (top right) which quantifies the organic molecules in the sample. Previous studies using this instrument attained parts-per-trillion sensitivity for amino acids and parts-per-million to parts-per-billion sensitivity for polycyclic aromatic hydrocarbons.

Yurtle Cave's basaltic sediments were used as a terrestrial analog of Martian basalts in experiments to detect carboxylic acids using the MOA. Samples were collected near the mouth of the cave from a few centimeters below the surface, where the pH of 10 (slightly greater than the pH measured by Phoenix) demonstrated the technique's viability under conditions potentially similar to Mars. The carboxylic acids in the sample were solubilized using water, and the reaction shown in Figure 4 was used to activate and fluorescently-label the organic compounds of interest.

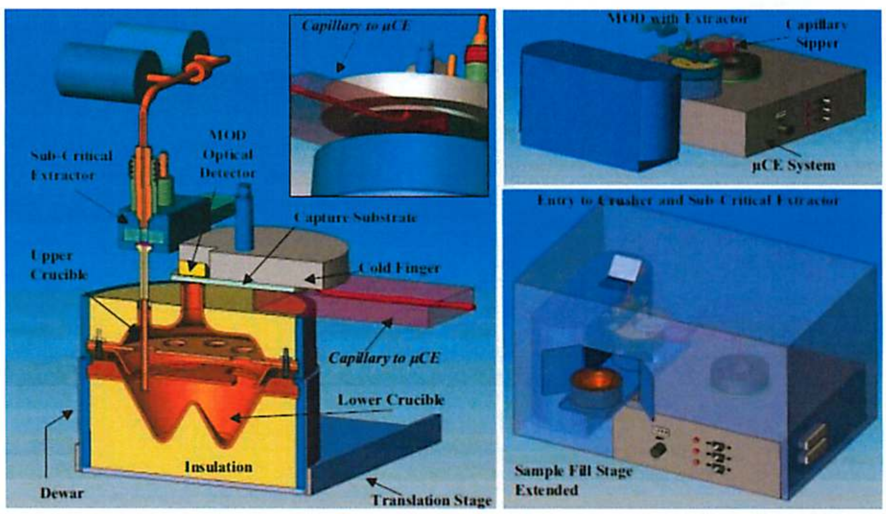


Figure 3: Design of the Mars Organic Analyzer (MOA).

[2] Skelley A.M., J.R. Scherer, A.D. Aubrey, W.H. Grover, R.H.C. Ivester. P. Ehrenfreund, F.J. Grunthaner, J.L. Bada, R.A. Mathies, H.B. Gray (2005). Development and Evaluation of a Microdevice for Amino Acid Biomarker Detection and Analysis on Mars. PNAS 102:1041-1046.

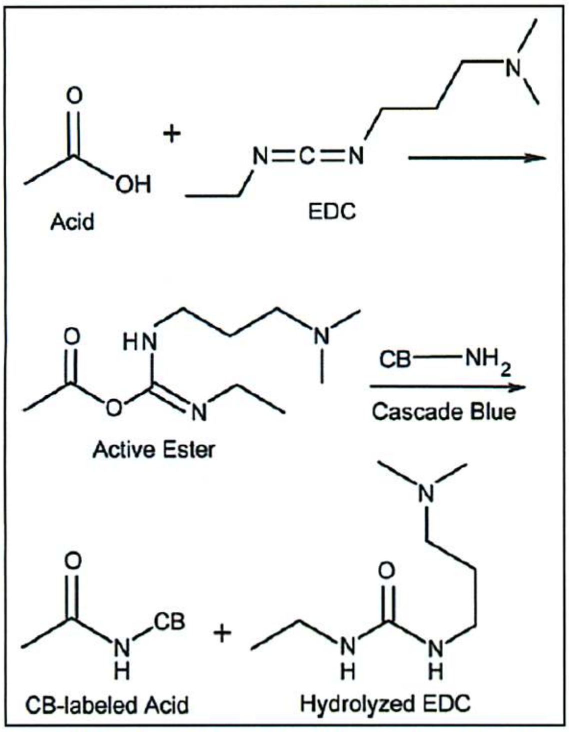


Figure 4: Reaction scheme for labeling carboxylic acids in Stockton et al. (2011).

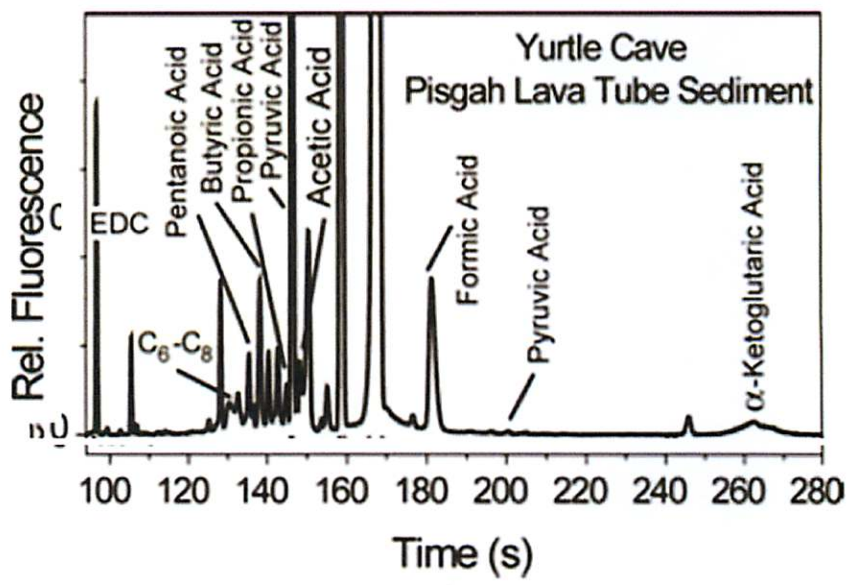


Figure 5: Results of the MOA analysis of the carboxylic acids present in the Pisgah sediments.

Results from the Pisgah sediment are shown in Figure 5. The estimated sensitivity of the carboxylic acid detection is 5 ppb, compared to the ~32 ppb that the SAM instrument on MSL would have for comparable compounds. Carboxylic acids are of interest especially in the search for Martian organics because they have been found in many places, including meteorites, interstellar space, and Earth's troposphere - and would be expected on the surface of Mars as well. In fact, due to the oxidizing conditions in the Martian soil, highly oxidized compounds such as carboxylic acids are a logical target molecule for planetary exploration.

Basalt from the Pisgah lava field was also used in a previous paper by the same group[3] to create a Mars simulant soil by adding ion concentrations similar to those measured by Phoenix, which was used to demonstrate that the MOA is able to detect aldehydes and ketones in soil samples. Since aldehydes and ketones are expected to have short lifetimes in Martian soil, their presence on Mars may be an indicator of recent biological activity.

The lava flows around Pisgah Crater have also been used for education/outreach purposes as a part of NASA's Spaceward Bound program[4], which give students and teachers the opportunity to conduct fieldwork alongside NASA scientists.

---

[3] Stockton A.M., C.C. Tjin, G.L. Huang, M. Benhabib, T.N. Chiesl, R.A. Mathies (2010). Analysis of carbonaceous biomarkers with the Mars Organic Analyzer microchip capillary electrophoresis system: Aldehydes and ketones. Electrophoresis 31:3642-3649.

[4] Allner M., C. McKay, L. Coe, J. Rask, J. Paradise, J.J. Wynne (2010). NASA's explorer school and spaceward bound programs: Insights into two education programs designed to heighten public support for space science initiatives. Acta Astronautica 66:1280-1284.

Lava tubes at Pisgah

Youngmin JeongAhn

Lava tubes are tunnels made lava flows erupted from volcanoes. Mostly **low viscous basaltic** or sometimes andesitic lavas are involved in the tube formation rather than rhyolitic lavas which have silica-rich compositions and show sticky flows. Fast moving **pāhoehoe** type lavas are ideal to make smooth tunnels while 'a'ā type flows leave rough inner surfaces.

While lava continuously flows in channelized way, outside part cools down and solidifies to make a crust. Then, the inner flow drains out and makes a hollow conduit. Some portion of roof collapses later on, which allows you to explore the cave!

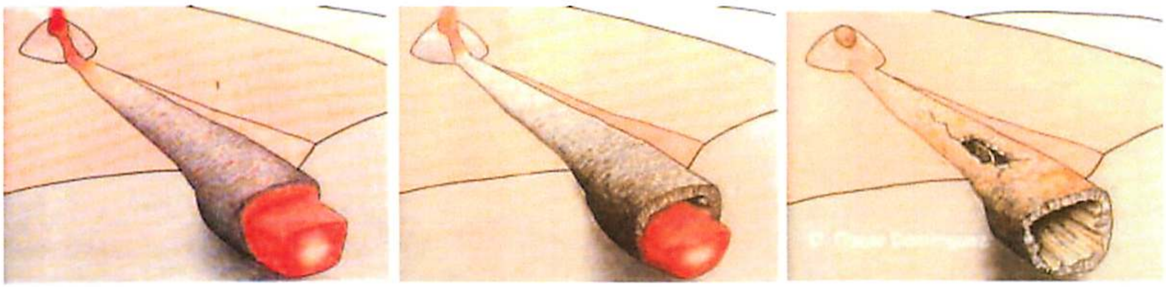


Figure 1 Formation of lava tube caves (image by Paulino Costa)

Figure 2 Lava tube opening with CSULB students

Pisgah crater and its surrounding Lavic Lake volcanic field are located in the middle of the Mojave Desert. This volcanic field (100 km^2) was made by pāhoehoe type lavas (hope we can see this ropy feature!) which are ideal for the lava tubes formation. Pisgah crater is one of the four cinder cones in the Lavic Lake volcanic field and has an elevation of 100m.

It was erupted about 25,000 years ago (pre-Holocene). During the period of eruption the environment here was desert climate, succeeded by cold and wet period which lasted for thousands of years. Calcite coatings on the walls and ceiling inside lava tubes were mainly developed by high precipitation during that time. Current desert environment with sparse vegetation helps to preserve its shape from erosion.

There are more than 300 lava tubes around Pisgah crater. The longest one is the SPJ Cave which stretches 1300 feet. Usually the tunnels are small and you should crawl inside but some part of C13 North Cave is large enough to allow you to walk. Most common morphology of lava tubes is surface tube in this region. (figure 4)

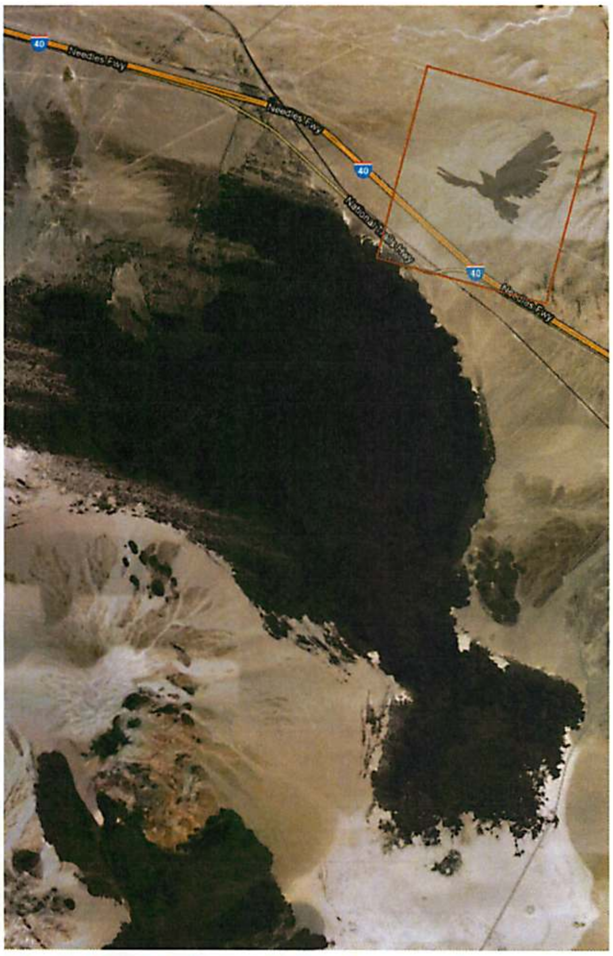


Figure 3 Aerial picture of Pisgah area. A giant raven?

Glove cave and Finis cave have stalactite made by remelting process. The fluffy, cotton-like masses on the bottom are composed of thenardite (Na_2SO_4).

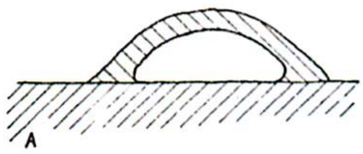


Figure 4 Shape of a surface tube

Did you know...

According to Deuteronomy, Moses climbed the Mount Nebo to the peak of **Pisgah** where he saw the view of the Promised Land, Canaan, and died.

References

Hartler III, J. W. 1972. Morphological Classification of Lava Tubes. *Proceedings of the International Symposium on Vulcanospeleology and its Extraterrestrial Applications*, 74-85.

Harter, R. 1991 Lava Tubes of Pisgah, Southern California. *International Symposium on Vulcanospeleology VI*, 63-64.

Harter, R. 2009 Pisgah! *Speleo-Ed seminar, Western Region, National Speleological Society*, 24-33.

Radar and Roughness: Cima and Pisgah Volcanic Fields

Ali 'Badger' Bramson and Tiffany 'The B*tch' Kataria

Introduction

Radar is a useful tool, as it does not require the sun's light to illuminate features and the microwave wavelengths typically used (1 cm-1 m) barely interact with the atmosphere. As such, they can be used night or day, in snow or shine, to map surface features.

To obtain radar images, the radar system directs pulses of a given wavelength to one side, looking perpendicular to the flight path. The waves interact with the surface and echoes that get bounced back in the direction of the radar antenna are recorded.

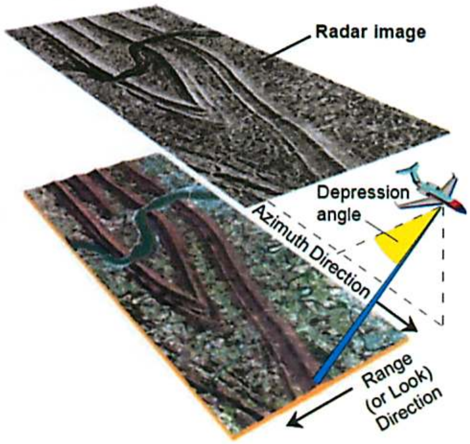


Figure 1: Radar imaging geometry (stolen from *Interpreting Digital RADAR Images*)

In radar images, bright regions indicate areas where more of the signal reflected back to the antenna, given a stronger return. This return is affected by many things, including the surface's roughness, orientation and electrical properties as well as the polarization of the wave.

Factors That Affect the Reflected Signal

A) SURFACE ROUGHNESS

Where the surface is flat, surface roughness plays a larger role. A smooth, horizontal surface will appear dark, because it will act like a mirror to direct the radar waves away from the antenna at an angle equal to the incidence angle (specular reflection). But, with a rougher surface, the radar waves can be scattered in many directions, including in the direction of the antenna, and that area will appear brighter on the radar image. Surface roughness for radar involves the amount of irregularity and vertical relief (in centimeter scales). As a general relation: brightness ∝ degree of surface roughness at that wavelength. A surface could be rough (appear bright) for a short wavelength while being smooth (dark) at longer wavelengths.

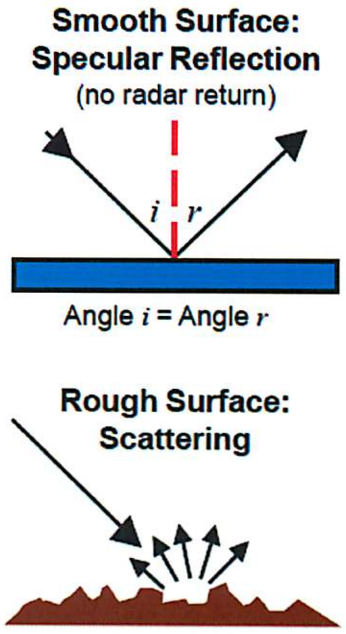
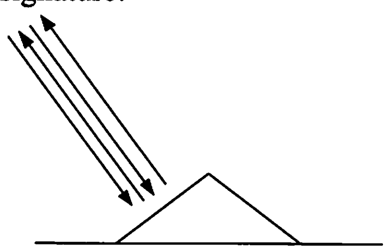


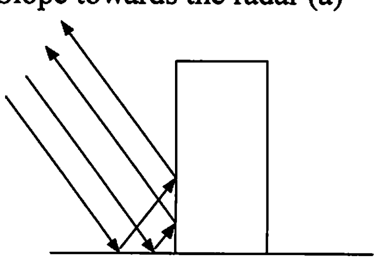
Figure 2: Cartoons depicting smooth and rough surfaces and the resulting radar return (stolen from *Interpreting Digital RADAR Images*)

B) TERRAIN ORIENTATION
Orientation of the surface relative to the direction of the radar wave also plays a role in the amount of signal that comes back to the antenna. Surfaces perpendicular to the wave's travel path produce stronger returns while slopes that face away produce weaker (darker) returns on the radar image, or no return if the slope is steeper enough where it causes a shadowing effect. An object or feature that is oriented at a right angle to the ground is called a corner reflector, and produces very bright radar returns to the radar wave reflecting back towards the antenna. Buildings, for example, act as corner reflectors and appear very bright in radar images. The following figures from *Geoscience and Remote Sensing* (pg. 432) show three types of reflections that return signal back towards the detector, leading to a bright signature:



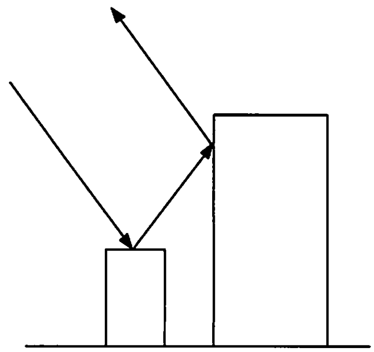
(a)

Slope towards the radar (a)



(b)

Corner reflector (double bounce reflection) (b)



(c)

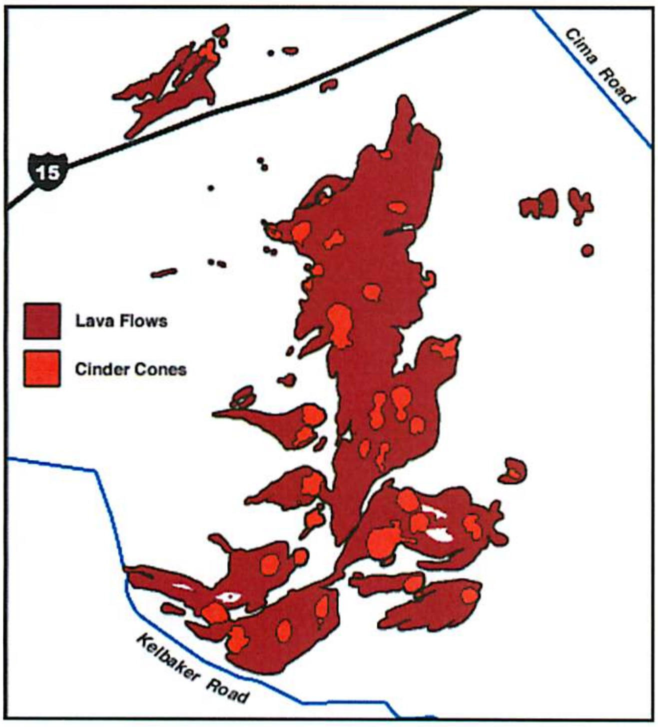
Multiple bounce reflections (c)

C) POLARIZATION

Radar systems generally transmit their pulse in a given polarization (horizontal H or vertical V). When the system transmit and receives in the same polarization (HH or VV) it is called like-polarization radar modes. When a system receives in the opposite polarization as what it transmits in (HV or VH) it is called cross-polarization. Typically when a polarized radar pulse goes through surface scattering (goes through the rough surface of soil/rock), it generally returns with the same polarization. In what is called volume scattering, where the pulse goes through many scattering events, with discontinuities in dielectric constant, such as in going through vegetation (hits leaves, twigs, branches, etc) or sea ice, the wave gets slightly depolarized and so the like-polarized signal gets slightly reduced (depending on the wavelength) and the cross-polarized signal appears very bright. A bright cross-polarized signal indicates the signal has gone through volume scattering, such as in vegetated areas. Mere surface scattering due to rock and soil will be dark in cross-polarized radar images.

Cima Volcanic Field

Cima is composed of 40 cinder codes and 60 basaltic flows ranging in age from 8 million to 16,000 years. The flows rest on gravels of the Cima pediment dome, which is down-wasting in a manner that is isolating the flows from each other. The flows fit into two categories: "elongate" with low gradients and low surface relief and "equant" with higher gradients and higher surface relief (Farr 1992).



We used SIR-C L- and C-band data to look at this region, as it had the best coverage. We see that both bands' radar returns come back brighter than the surroundings indicating the lava flows are rough at both L- and C-band wavelengths (~25 cm/pixel and ~5 cm/pixel, respectively). C-band does appear to have a brighter return than L-band, suggestion that the flow is roughest at the lower wavelength.

Figure 4: Geologic map of Cima volcanic field, indicating the cinder cones and lava flows in the area. (http://www.nature.nps.gov/grd/usgsnps/mojave/cinder1.html)

The SIR-C data clearly show the location of the cinder cones seen in Figure 4; the cinder cones correspond to radar bright sections on the edge along the flight path, while the opposite edge exhibits a radar dark signature. It is apparent, then, that radar signatures are largely dependent upon the orientation of the feature with respect to the flight path.

Cima has undergone much aeolian weathering over time, which has been divided into four stages (Fig. 6, left). Farr 1992 models the evolution of flow surfaces; Stage A involves rubbling (rock projections broken off and deposited in low spots for flows younger than 20,000 years) and fine-grained eolian deposits filling topographic lows between .06-.14 million years. Stage B was from 0.2 to 0.7 m.y. and was when eolian activity was decreasing. Stage C includes the development of drainages and bedrock exposure from plugging of soil by clays. Further drainage brings caliche (a hardened form of calcium carbonate) rubble to surface.

While in the field we can look for landscapes characteristic of these different stages (Fig. 6, right), which appear to be rough at different scales. Farr 1992's study suggests the youngest flow is roughest at all scales. From 0.016-0.14 m.y. is smoother and lost much of its centimeter-sized relief. This trend continues, with older flows (up to 0.56 m.y.) becoming smoother up to meter scales. The oldest flows, however, show increased roughness (especially at the meter length) suggesting processes worked to roughen them.

Red: C-HH Green: C-TP Blue: C-VV

Red: L-HH Green: L-TP Blue: L-VV

Figure 5a and 5b: SIR-C data of Cima volcanic field, with colors indicating the bands shown in each image.

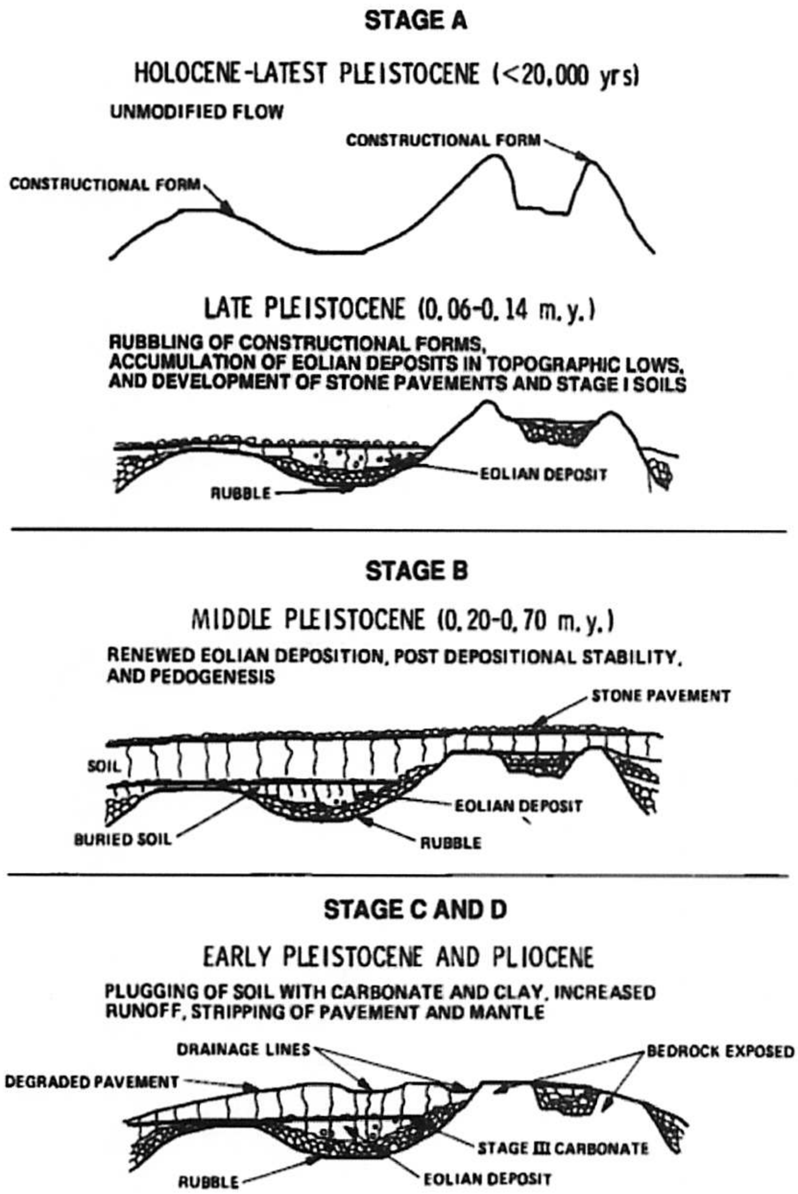


Fig. 3*a*

Fig. 3*b*

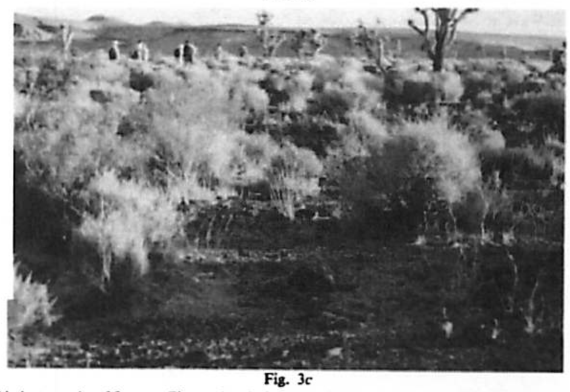


Fig. 3*c*

Fig. 3. Field photographs of flows at Cima volcanic field illustrating stages of landscape evolution. (*a*) a_1 flow (stage A), showing constructional features with some rubble in depressions. Hummock on flow in background is about 3 m high. (*b*) e_3 flow (stage B), showing stone pavement over accretionary mantle. (*c*) TV flow (stage D), showing stripping of stone pavement and exposure of accretionary mantle and fragments of white caliche.

Figure 6: (left) Diagrams from Farr 1992 illustrating the evolution of the Cima volcanic field over time, from Stage A to Stage D. (right) Field photographs illustrating three of the stages of evolution of the field.

Pisgah Crater/Volcanic Field

The Pisgah lava field is composed of three volcanic units, which correspond to three phases of flow. The first, **Phase I**, is the oldest of the flows, less than 1m in thickness, with a pahoehoe texture. **Phase II** primarily has a'a texture in the east and pahoehoe in the west, with a thickness less than 5 m. **Phase III** lavas have pahoehoe texture, with thicknesses ranging from 3-5 m, with hummocky surfaces containing pressure ridges and tumuli less than 3 m high (Gaddis 1994). Tumuli are dome-shaped pahoehoe features with axial fractures caused by buckling of crust from upwelling lava (geology.sdsu.edu).

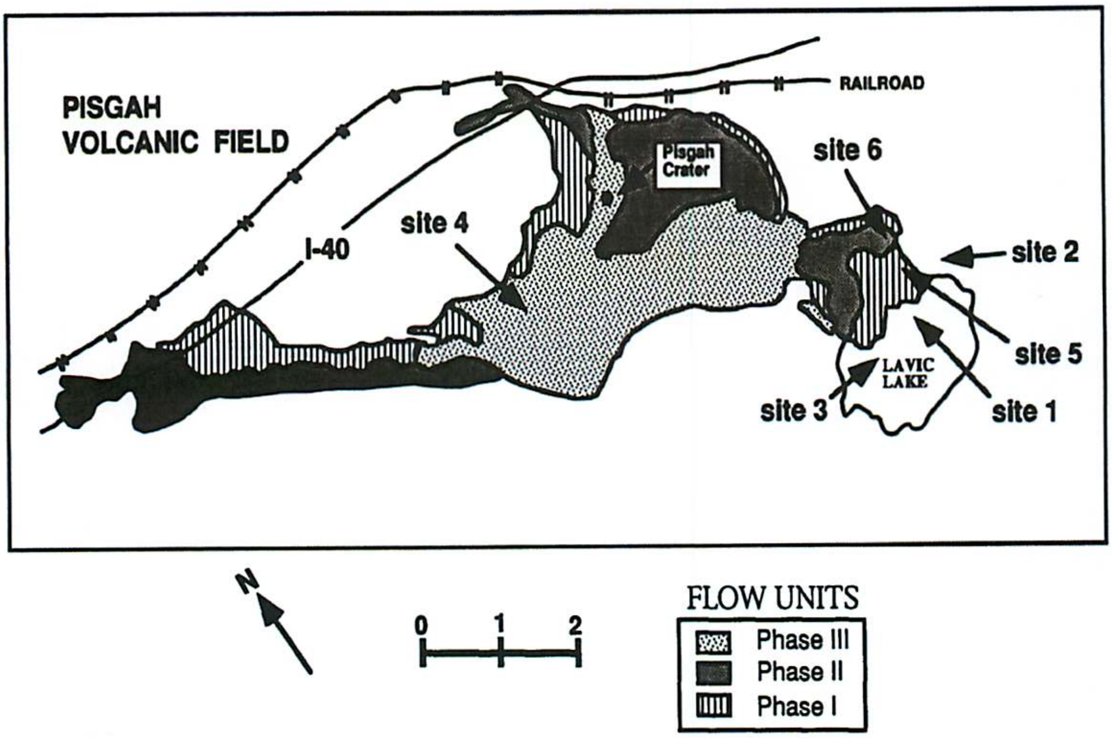


Figure 7: Geologic map of Pisgah volcanic field from Arvidson et al. 1993, indicating the different flow units (Gaddis 1994). Phase I lavas are oldest and pahoehoe. Phase II units are a'a in the east and pahoehoe in the west. Phase III units have pahoehoe textures.

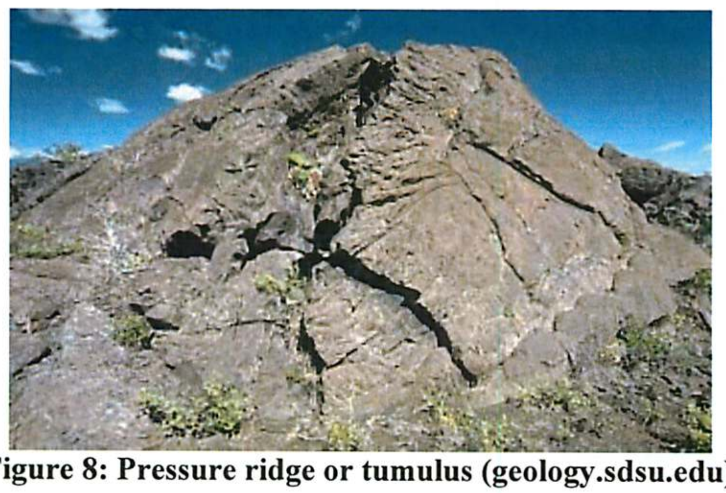


Figure 8: Pressure ridge or tumulus (geology.sdsu.edu)

The cinder/spatter cone is 100m high with a diameter of 500m. Pisgah erupted five times in its history, with each successive eruption containing more silica. Wise (1969) studied this eruption history, and found this compositional trend is the opposite of what occurs from a single alkali magma, which suggests the magma in these eruptions came from an area in the mantle still undergoing partial melting. The composition of the lava also suggests that the first melting was under high water pressure and later lavas were under dryer partial melting of garnet-orthopyroxene-clinopyroxene-olivine assemblages. The successive increase in silica while decrease in alkalis mean the partial melting zone moved shallower and shallower (Wise 1969). Today, desert varnish appears on most of the basalt surfaces. Compositional changes can lead to differences that could be seen today in the radar images by causing successive flows to be smoother or rougher. Any erosion that has happened since the lavas were formed could also contribute to differences in the radar signatures (such as what we see at Cima). However, we predict the main differences in radar data at Pisgah will be due to these different flows.

unit	s (cm)	ks (C)	ks (L)	ϵ_r
playa**	0.83	0.93	0.22	2.36+i0.2
pahoehoe (platform)**	2.9±1.2	3.36	0.78	4.5+i0.0
pahoehoe (hummocky)	6.0***	6.72	1.56	4(ave. 3-5)*
aa	20***	22.4	5.2	4(ave. 3-5)*

*Arvidson et al., 1993.
**van Zyl et al., 1991.
*** R. Greeley et al., unpublished data, 1994.

Table 1: List of units from Pisgah volcanic field, with characteristic values of the rms height of each unit, *s*, the roughness with respect the C and S wavelength bands, *ks* (where *k* is the wavenumber, 2π/λ), and the dielectric constants, ε_r (Gaddis 1994).

<u>UAVSAR data (L band)</u>

Entire field

From the UAVSAR data, we find that the Phase II a'a flow to the east is brightest. This is not surprising, as it has the roughest texture. Conversely, the Phase II pahoehoe flow to the west is indistinct from the other geologic units described above because of its smoothness.

Figure 9a: Satellite image of Pisgah Volcanic Field.

Figure 9b: UAVSAR image of Pisgah Volcanic Field.

Roughness comparison at Contact

Zooming in on the contact between the two flow units, Phase II and Phase III, it is clear that the radar signature of each is distinct. Like the radar data shown above, the a'a texture of the Phase II unit compared to the pahoehoe texture of the Phase III unit leads to a brighter radar return for Phase II than Phase III.

A part of the perimeter of the cinder cone also yields a bright radar return. This is due to the fact that the cinder cone acts as a corner reflector (see Figure 3) along the flight path, which leads to a radar bright signature along the perimeter of the left side of the cone.

Figure 10a: Satellite image of contact between Phase II and III flow units.

Figure 10b: UAVSAR image of contact between Phase II and III flow units.

Mine radar signatures
A mine is present to the west of the cinder cone, which exhibits interesting radar returns (Fig 11). The radar bright areas correspond to regions where excavated material may be collected, leading to a radar-rough texture. The dark areas probably correspond to roads, which are smooth and paved and hence radar-dark.

Figure 11a: Satellite image of mining area near Pisgah volcanic field.

Figure 11b: UAVSAR image of mining area near Pisgah volcanic field.

SIR-C

In the C-band, the Pisgah flows can be distinguished from the surroundings (Figure 12). Overall, the radar returns for the lava are brighter, almost white in some areas, indicating the region is extremely rough on the scale of ~5 cm. There are some differences in brightness corresponding to different flow units. Phase III is darker in the red color which corresponds to C-band HH in Figure 12, suggesting it is a bit smoother than Phase II. This means that the Phase II flow is rougher at ~5cm.

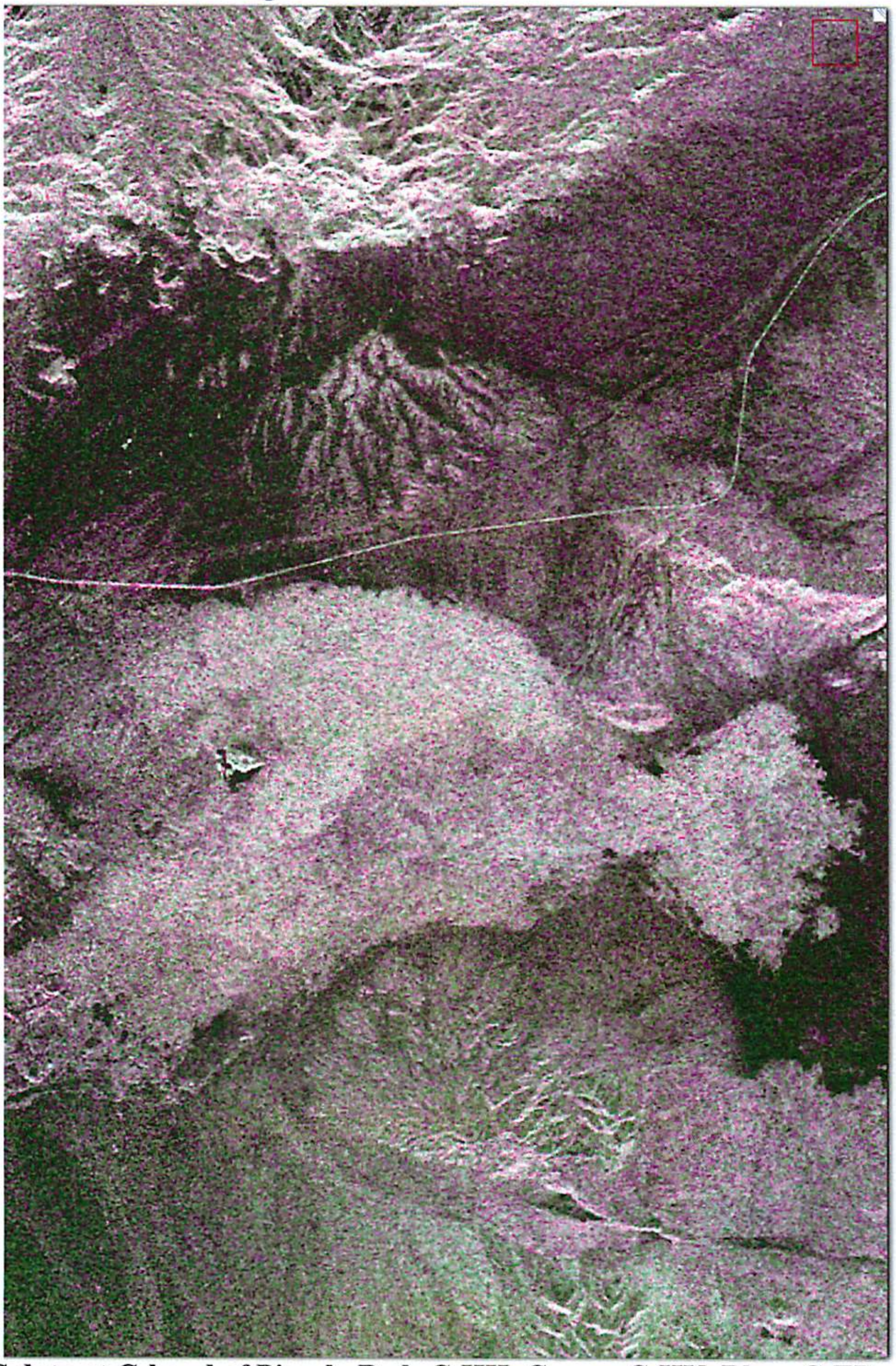


Figure 12: SIR-C data at C-band of Pisgah. Red: C-HH, Green: C-HV, Blue: C-TP

This difference between Phase II and Phase III flows is even more prominent when looking at the L-band (Figure 13). Both are still brighter than the surroundings, but Phase II is extremely bright. This means that the size of the features must be around both of these two length scales, especially Phase II, and especially L-band. Thus the Phase II unit is rougher at both those length scales (~5 cm and ~25 cm) than the Phase III unit, however Phase III is still rougher that the surrounding landscape.

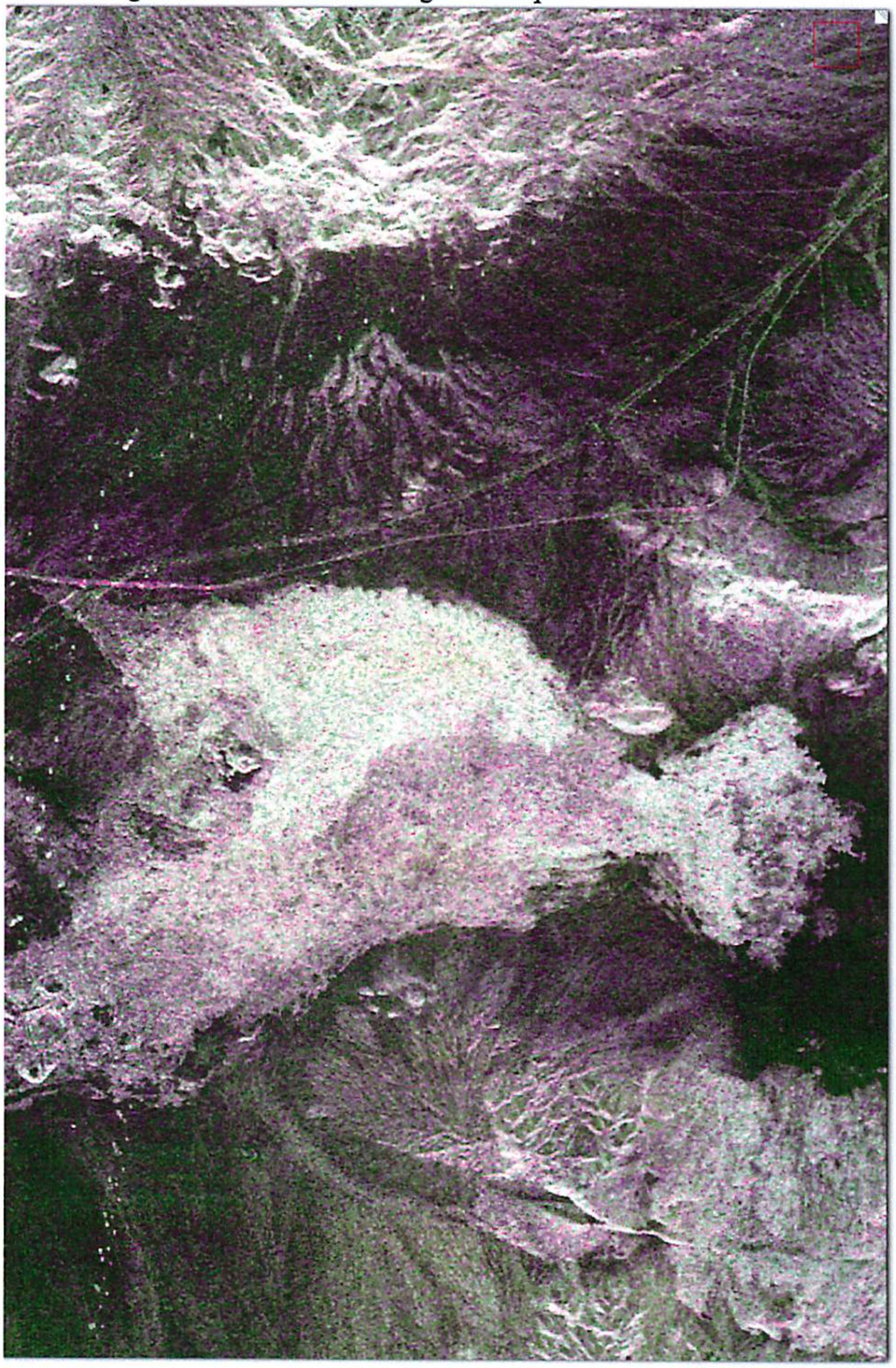


Figure 13: SIR-C data at L-band of Pisgah. Red: L-HH, Green: L-HV, Blue: L-TP

In some areas of the surroundings, the radar returns for the RGB images for both C-band and L-band appear very green suggesting the radar signal has gone through volume scattering (Figure 14). We should look for more vegetation in those areas, or perhaps something else exists in some of the surroundings that could cause the volume scattering necessary to get strong cross-polarization returns.

In an RGB image combining C and L band data (Figure 14), we see that the flow units are very distinct from the surrounding area. The surroundings appear much, much greener (C-band total power), suggesting the surroundings are smoother (less return) in the L-band (red) compared to the lava flows.

Also, we take note of the fact that the cinder cone has a very dark spot on one side compared to its surroundings. We hypothesize that this is due to the area being shadowed by the cinder come. If we do travel to this site, we should look for any distinct unit to the side of the cinder cone.

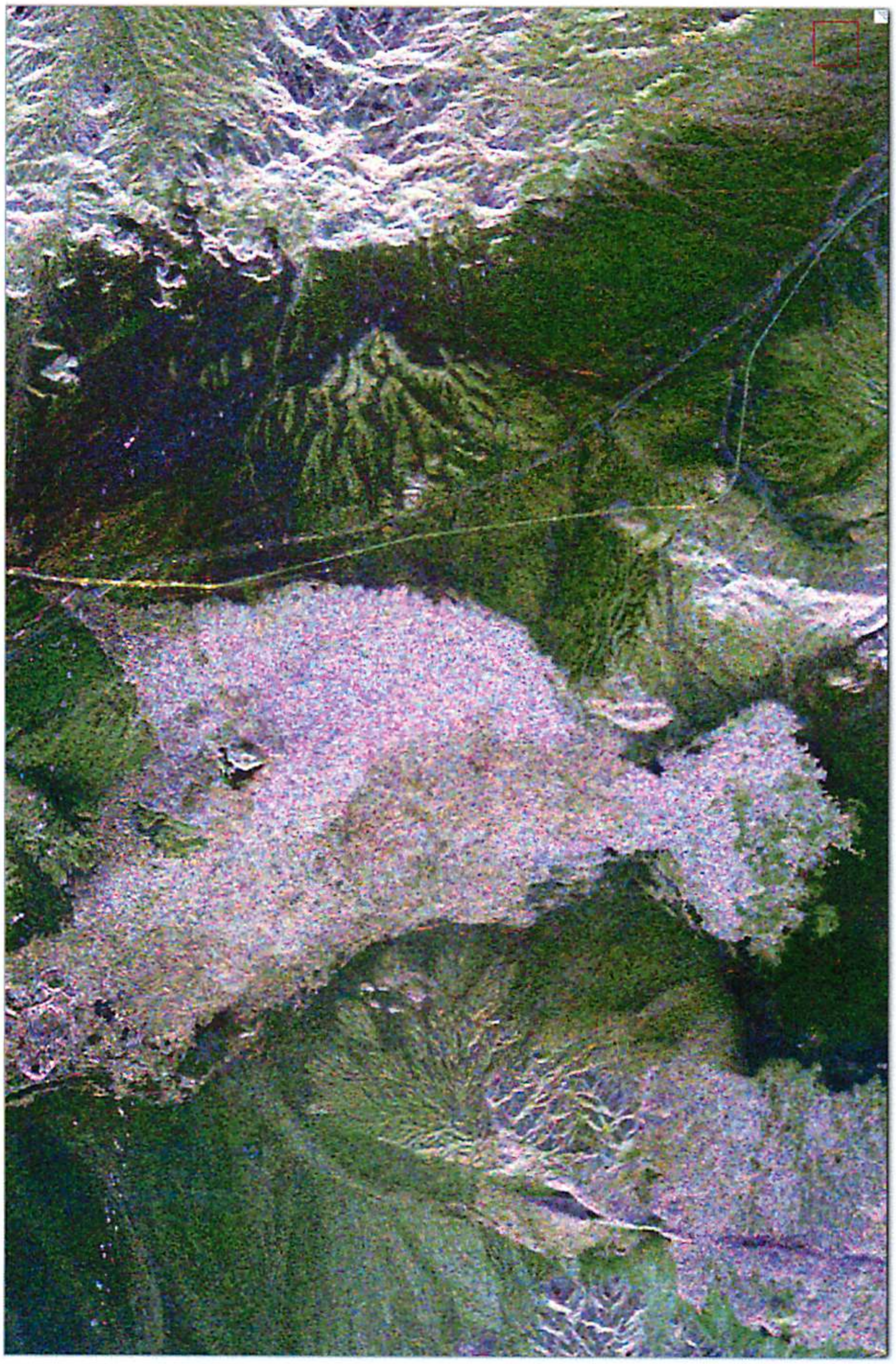


Figure 14: SIR-C data at L-band of Pisgah. Red: L-TP, Green: C-TP, Blue: L-HV

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"I like the desert for short periods of time, from inside a car, with the windows rolled up, and the doors locked. I prefer beach resorts with room service." –Anne Lamott

Radar and playas on Earth and Titan

Catherine Elder

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1 Broadwell Lake

Figure 1: The left figure shows a google maps satellite view of Broadwell Lake for context. The right figure shows radar reflection (SIR-C) where the L band (25 cm) is in the red channel and the C band (5 cm) is in both the green and blue channels. This shows that very little radar is reflected by the playa. What is reflected is primarily from the L band which implies the playa is rough at 25 cm length scales. Maybe this could be because of desiccation polygons?

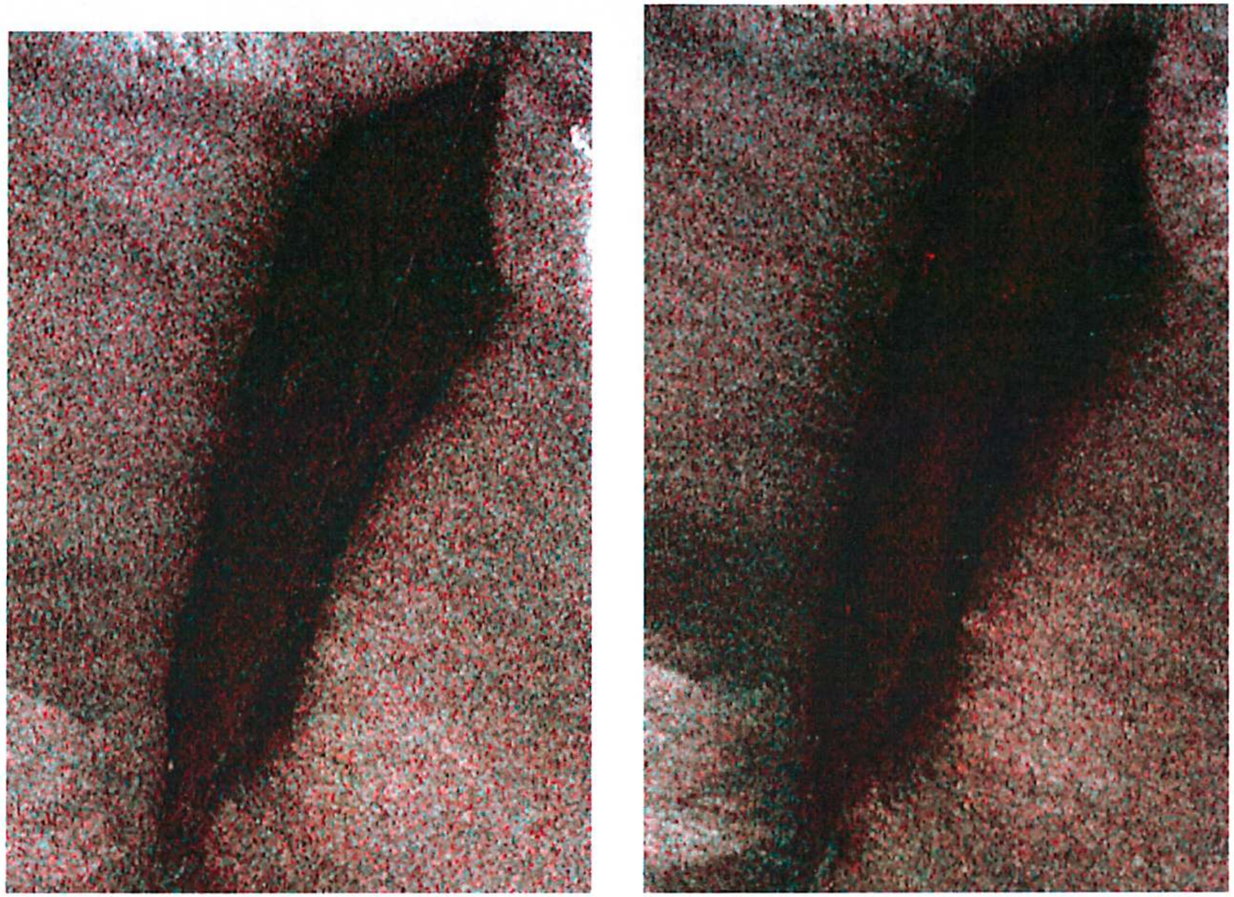

Figure 2: The left figure shows C band HH in the red channel and C band HV in the green and blue channels. The right figure shows L band HH in the red channel and L band HV in the green blue channels. Both of these figures show more reflection by HH which implies that this is surface scattering not volume (subsurface) scattering.

Broadwell lake is a typical playa that does not reflect much radar. The radar that it does reflect is primarily C band HH which implies surface reflection at 25 cm length scales. I would predict that this is caused by desiccation polygons on the surface of the playa.

2 Soda Lake

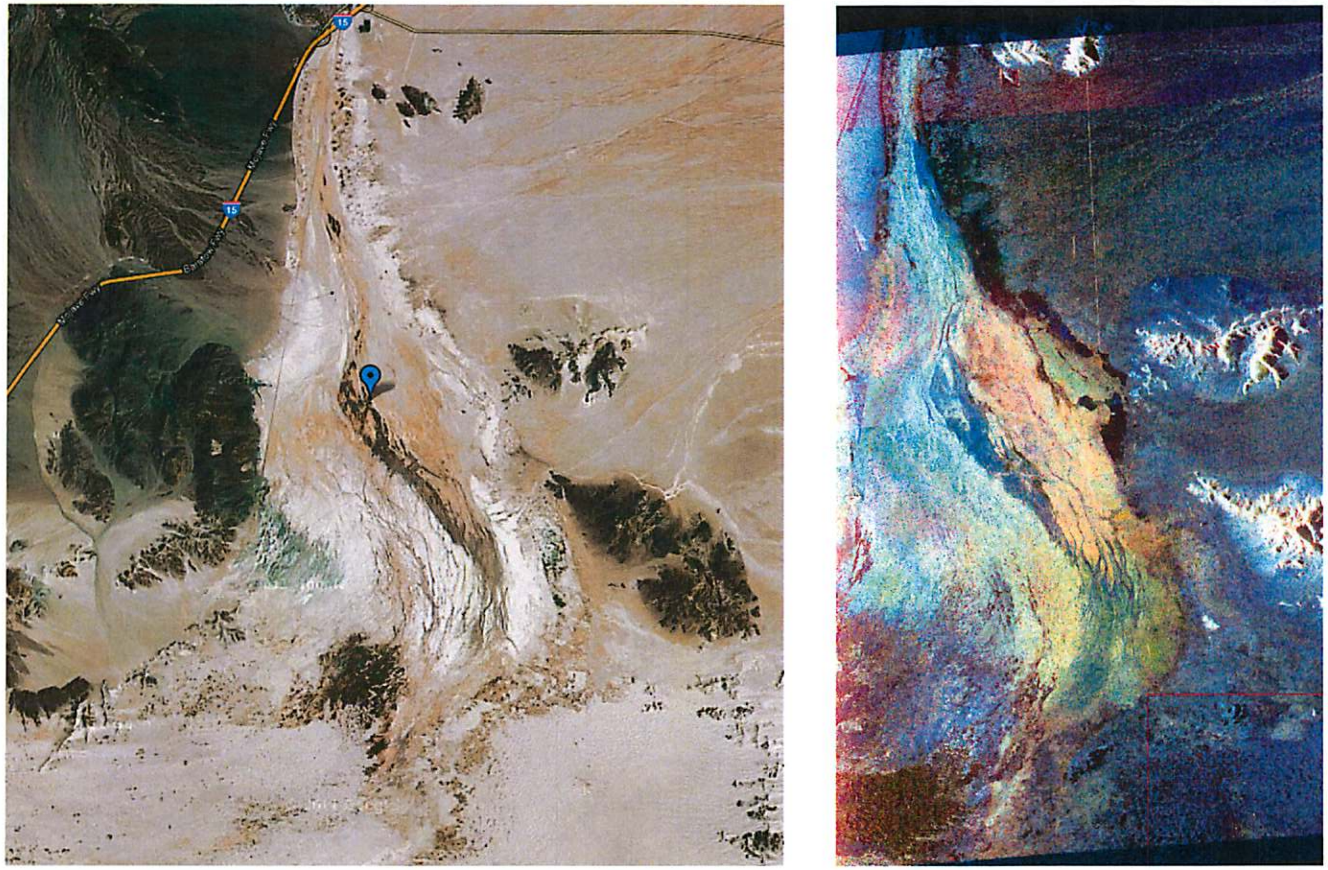

Figure 3: The left figure shows a google maps satellite view of Soda Lake for context. The right figure shows radar reflection (AirSAR) where the P band (80 cm) is in the red channel, the L band (25 cm) is in the green channel, and the C band (5 cm) is in the blue channels. The white deposits on the east side of the playa in the left figure are dark in the radar (right figure), so that area is probably similar to a typical playa. Other parts of the playa are less typical. The western part of the playa is scattering mainly at short wavelengths, and a portion of the eastern part of the playa scatters at longer wavelength.

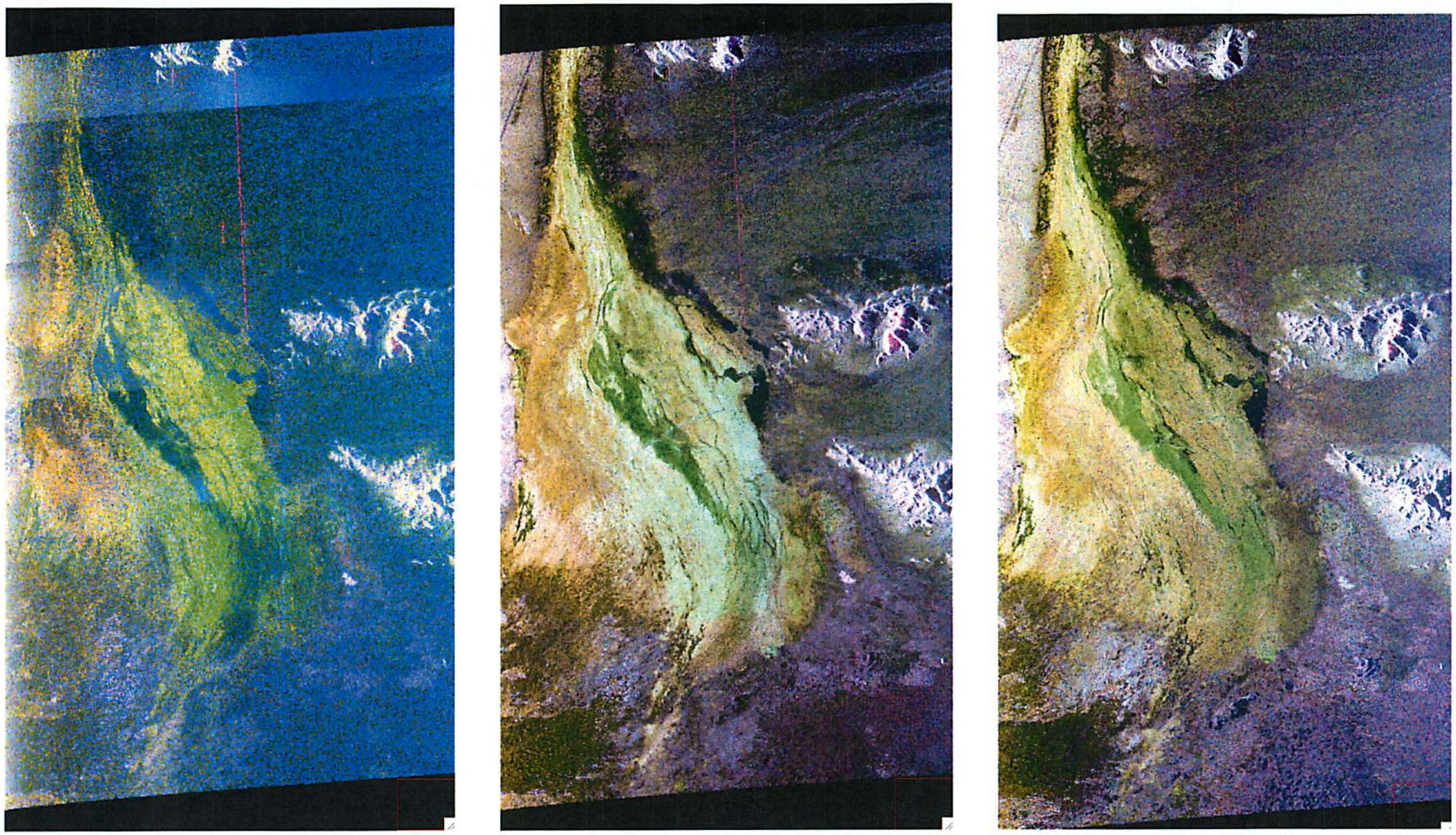

Figure 4: The left figure shows P (80 cm) band HH in the red channel, P band VV in the green channel, P band HV in the blue channel. The center figure shows L (25 cm) band HH in the red channel, L band VV in the green channel, L band HV in the blue channel. The right figure shows C (5 cm) band HH in the red channel, C band VV in the green channel, C band HV in the blue channel. In the L and C bands all the scattering from the playa is surface scattering. In the P band you have some volume scattering (blue).

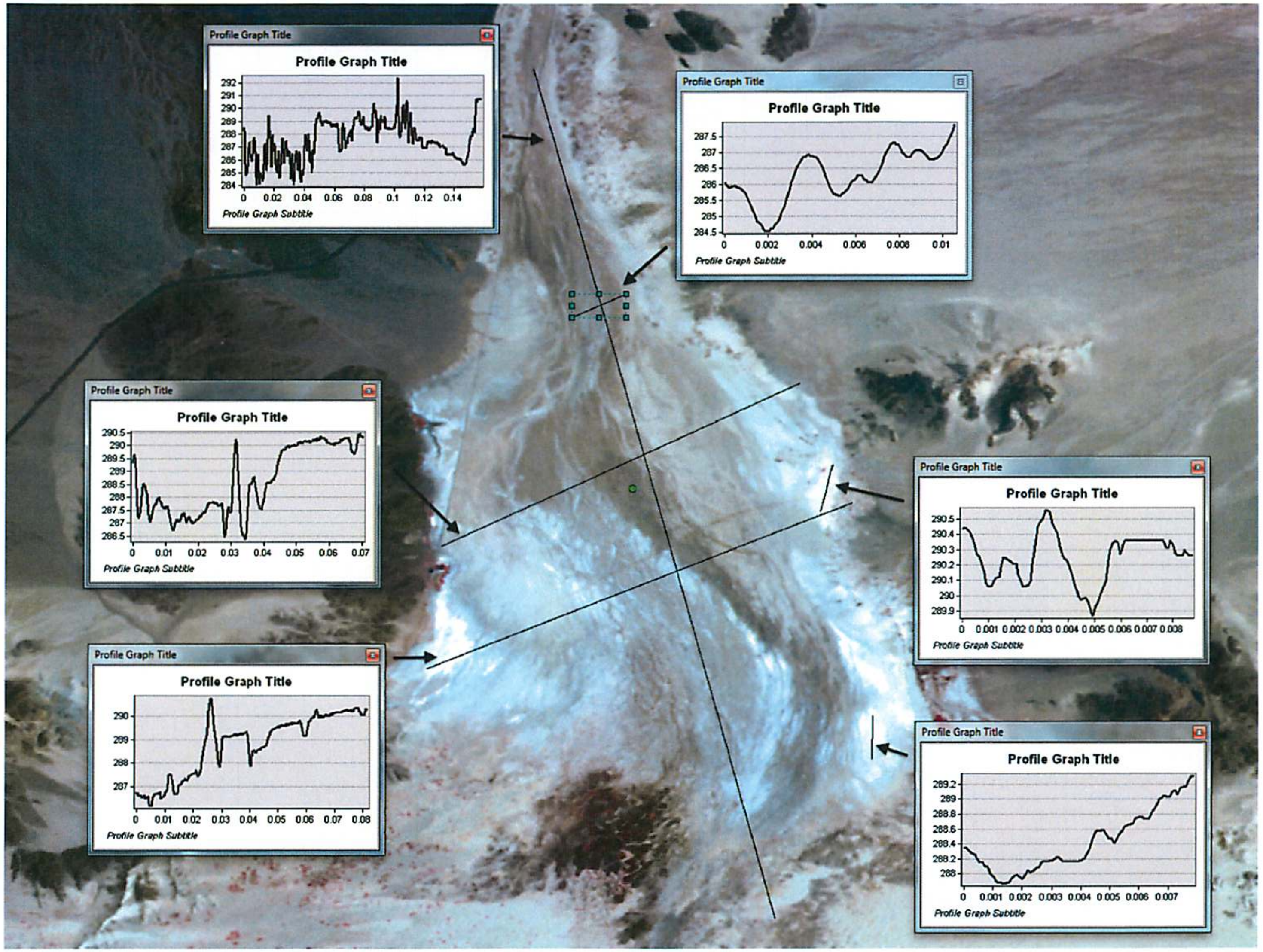

Figure 5: Topographic plots through Soda lake (elevation in meters; profiles run top to bottom or left to right). It is not very flat for a playa.

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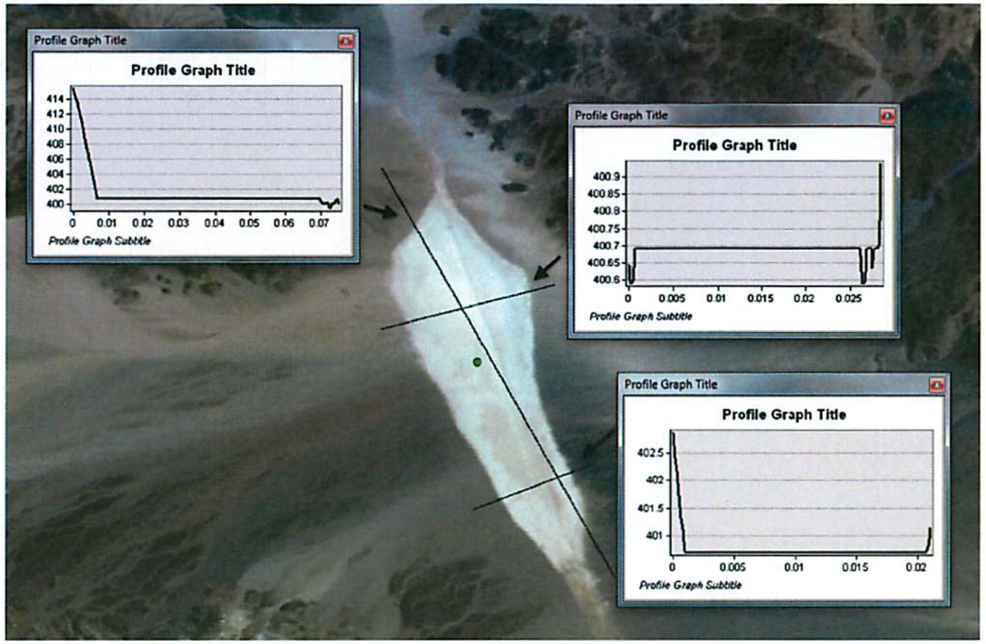

Figure 6: Topography of Broadwell lake (elevation in meters; profiles run top to bottom or left to right). It is remarkably flat compared to Soda Lake.

Some guesses about what might cause the strange appearance of Soda lake:

- Evaporite deposits (after all, it is called "Soda" lake...)? This would probably effect small length scales, C band, the most.

- Drainage channels? Soda lake is not nearly as flat as Broadwell lake. You could wave your hands and say it looks like a drainage system where the water flows from north to south and empties in the wider southern part of the lake/playa. In this case you could have small gullies running through it.

- Saturation of the subsurface at the time the data was taken? In the P band (80 cm), volume scattering occurs in the north-south streak that is dark in the visible. Maybe pore space below this streak was filled with water when this data was taken?

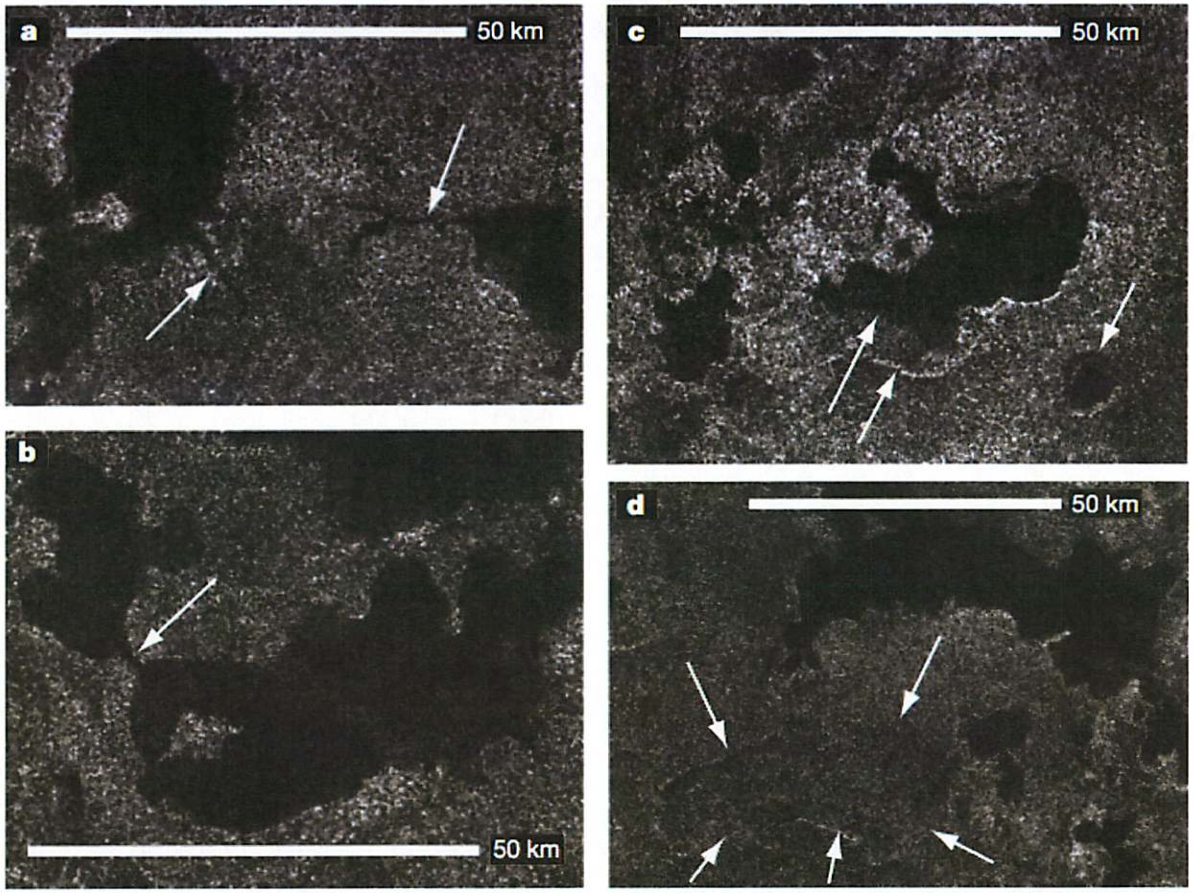

Figure 3 | Examples of lakes from the T_{16} swath. **a,** Sinuous radar-dark channels can be seen leading into two lakes. **b,** A pair of irregularly shaped lakes connected by a radar-dark channel. **c,** Radar-dark material in the lake to the left lies inside an apparent topographic edge (arrows), indicating that it might once have been at a higher level. The circular lake to the right seems to be a nested depression, with dark material filling the inner depression. **d,** A feature with a shape similar to lakes (arrows), but with backscatter similar to surrounding plains. On the basis of similarly shaped lakes and possibly partly filled features, we interpret this feature to be a dry lakebed.

Figure 7: (Stofan *et al.* 2007)

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3 Playas and Lakes on Titan

Cassini Titan Radar Mapper:
- K_u band wavelength 2.17 cm (Stofan *et al.* 2007).
- Spatial resolution of 300-1,200 m (Stofan *et al.* 2007).

Lakes:

-Radar dark. Some might have zero reflection (detected level is within the noise). Some are a little brighter at the edge which is interpreted to be some of the radar reflecting from the bottom of the lake (Stofan *et al.* 2007).

- Some features have margins similar to other lakes but a surface backscatter similar to the surrounding terrain (figure 7). These are interpreted to be depressions devoid of liquid (Stofan *et al.* 2007).

- At Ontario Lacus on Titan, evaporation rates exceed precipitation rates which is the condition at playas on Earth as well (Lorenz *et al.* 2010). (But if they're supplied by 'methanifers', playas would only form if the methane table was somehow lowered, I think...)

- Radar reflection indicates that the lake level of Ontario Lacus does not vary by more than 3 mm, so there are no waves (wikipedia)

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Wild speculation:
- Many lakes on Titan are thought to be seasonal, so maybe they are playa-like during other seasons?
-Could ground penetrating radar detect the top of a subsurface methane table ('methanifer')?

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Flora and Fauna of the Mojave Desert
Sky Beard

The Mojave Desert is an environment of extreme heat, poor soil nutrients, limited soil water-holding capacity, and worst of all, little water. Even when rains come to the Mojave, often a great amount of water falls in a very short time onto ground so dry that the rain runs off quickly, washing away skimpy desert soil in the process

Desert animals are even more susceptible to temperature extremes than desert plants, receiving heat directly by radiation from the sun and indirectly by conduction from the rocks and soil. Animal tissue can function within a relatively narrow temperature range, so in the Mojave, many animals must employ strategies to obtain water and to avoid over- heating.

Many animals are nocturnal, when temperatures are the lowest. Other animals seek shelter in cool, moist burrows during the day or hide under rocks and bushes. Mule deer and jackrabbits have large ears that are densely lined with shallow blood vessels allowing air to cool their blood. These are just some brief examples of the strategies used to survive.

At first glance the desert may seem to have little in the way of wildlife, it actually contains large, diverse populations. The desert environment may seem an unlikely place for animals to thrive or even exist. However, desert animals have adapted to their environment, and each fills an important niche in the desert ecosystem.

Mammals

Badger:

Badgers can be found in northern Mexico and throughout the western United States and Canada, including the Mojave Desert. However, it is not common to see them in this area. They are characterized by a heavy body with thick fur, powerful jaws, a painted face, and are related to weasels, ferrets, skunks, and wolverines. They have extremely good senses and are capable of producing a strong, musky odor in a similar manner as its relative, the skunk. Their bodies are typically 1.5-2 feet in length with a 4-6 inch tail, and may weigh from 8-25 pounds.

Badgers can be very aggressive and are rarely attacked by other animals. They tend to live in solitary and hunt at night. They are excellent at digging and my dig a new burrow every morning in the summer time. There is also some suggestion of cooperation in hunting with coyotes. They favor rodents (squirrels, rats, mice, gophers, and prairie dogs), which it usually captures by digging directly into the other animals' burrows. They also prey on reptiles, birds, insects, and scorpions and is said to be immune to rattlesnake venom, (except for its nose?) which it actively hunts.

The badgers' main threat is from humans. Its numbers have fallen due to hunting, trapping, poisoning, traffic fatalities, and habitat destruction.


Jackrabbit:

Very common throughout the state, the Jackrabbit loves desert shrub areas. It is strictly herbivorous and prefers grasses, but will eat any vegetation within 20 in (50 cm) above the ground. They use shrubs for cover, build no special nest structures but just remain in ground burrows, and are very active at night. Jackrabbits are usually brown with some light black spotting and have distinctive long ears with black tips. Their long ears allow them to keep cool. They bread throughout the year, but most young are born in April and May. A year old female may produce 14 or more young per year, and depending on predation, can easily become a pest. Predators include coyotes, bobcats, eagles, owls, hawks, and some snakes. Jackrabbits are generally alert to their surroundings though may not run from vehicles until the vehicle is very close. They rely on their speed and agility to escape predators, and will flash the white underside of their tail to alert other rabbits in the area. During escape, jackrabbits will instinctively dart back and forth trying to confuse the predator giving chase, however, this can be fatal when trying to 'escape' vehicles.

Bobcat:

Bobcats get their name from their short, 'bobbed' tail, range from gray-brown to reddish in color and have distinctive ear tufts which enhance their hearing. The bobcat has keen senses and immense patience, which is key to its hunting habits. They tend to use shadows and darkness for cover as they wait to ambush and pounce on unsuspecting prey, which include birds, rodents, rabbits, insects, and occasionally mule deer. They live in dens in rock cavities or in dense brush. They compete with coyotes and when coyote populations decline, bobcat populations increase. Owls may kill the young, and domestic dogs and mountain lions have killed adults. Interestingly, the bobcat has been known to also feed on vegetation and even fruit.

Coyote:
The coyote is often considered the desert's most successful opportunistic animal, preferring open brush and shrub habitats. It is a skilled hunter and eats primarily mice, rats, ground squirrels, and gophers but will eat anything that can be swallowed, including insects, lizards, snakes, birds, rodents, rabbits, dead animals, fruit, nuts, grass, tortoises, and anything else it can find. They are mostly nocturnal but are sometimes active during the day. Many times they can be found in small family groups but it is also common for them to hunt in pairs or even be solitary hunters. They are very resilient and adapt well to human activities and efforts to control their numbers has been unsuccessful. Coyotes generally are not preyed upon, but are occasionally killed by golden eagles, horned owls, and mountain lions. They are famous for their howling and also bark when excited. Some reports indicate that they can reach speeds of up to 40 mph for short distances. They are about 25 inches tall at the shoulder and about 35 inches long, and weigh between 15-40 pounds.

Desert Cottontail:
Considered to be the most abundant desert mammal, desert cottontails love desert shrub habitats,

where they graze and browse on a wide variety of grasses, shrub leaves, twigs, fruit, and other vegetation. They commonly take cover among rock piles, fence rows, and patches of shrubs and brush. They build fur-lined nests on the ground or in burrows within dense shrubbery. Reproduction at a high rate is due to the fact that a wide range of carnivores preys them upon. They produce 1-5 young per liter, and can have up to 4-5 liters per year. They are smaller than jackrabbits, measuring about 14 inches tall and large examples may weigh up to 4 pounds. Bobcats, dogs, eagles, coyotes, weasels, cats, and many other predators hunt them, and snakes can kill their young.

Kangaroo Rat:
These rodents feed on grains and seeds and will opportunistically feed on leaves and arthropods. They live in burrows with 2-5 entrances located at the bases of shrubs. Kangaroo rats are aggressively solitary, nocturnal, and are fed on by foxes, badgers, snakes, owls, and coyotes.

Mule Deer:
Mule deer prefer forest, woodland, and brush habitats and tend to avoid deserts. Males are about 3.5 feet tall at the shoulder and can weigh up to 200 pounds, while females are about 3 feet tall and weigh about 125 pounds. Males are the only ones that grow antlers, which fall off and regrow annually. They graze on shrubs, tree leaves, grass, and even dig out subterranean mushrooms. Mule deers are preyed on regularly by mountain lions and sometimes by coyotes, domestic dogs, and bobcats. Human

activities have hurt populations over the years, especially due to water management factors.

Mountain Lion:

The mountain lion is a top level predator and largest wild cat in North America. Males weigh an average of 130-150 pounds and females average 65-90 pounds. They are a tan to grayish color and have dark brown on the end of their tail, ears and on the sides of their nose. Mountain lions are rarely seen and are only in parts of the Mojave that support mule deer populations; preferring to live in mountains and forests. This top predator is a true carnivore, and only feeds on other animals. They prefer mule deer and will feed on bighorn sheep, coyote, fox, rabbit, rodents, birds, porcupines, skunks and other animals. Hunting is done at night, while traveling is done in the day, though you will most likely never see one even if they pass by you. They locate and stalk prey by sent, and kill large prey by getting within a few meters and leaping onto it and biting at the base of the skull. Large hawks and eagles can kill their young and they are in competition with bobcats and coyotes. Spread of human development has fragmented their habitat and restricts their movements.

Reptiles:

Chuckwalla

The chuckwalla is the second largest lizard in the United States, following the gila monster. A male can measure as long as 18 inches. Though encounters can be intimidating, they are harmless and feed on flowers, fruits, and leaves. They prefer rocky outcrops to flat brush lands. Though there are no reports of predation, it is likely that they are potential prey for hawks, eagles, coyotes, and some snakes.

Horned Lizard:

The horned lizard is usually around 4 inches long and feeds on ants, beetles, and plant material. They prefer sandy soils in which they can burrow and lay 6-30 eggs per year. They are prey of some mammals, snakes and birds, however they have a anti-predation display that is often effective. Some subspecies can also shoot a jet of blood out of the eye (up to 4 feet) to distract and confuse a would-be predator, allowing them to flee to safety.

Mojave Rattlesnake:

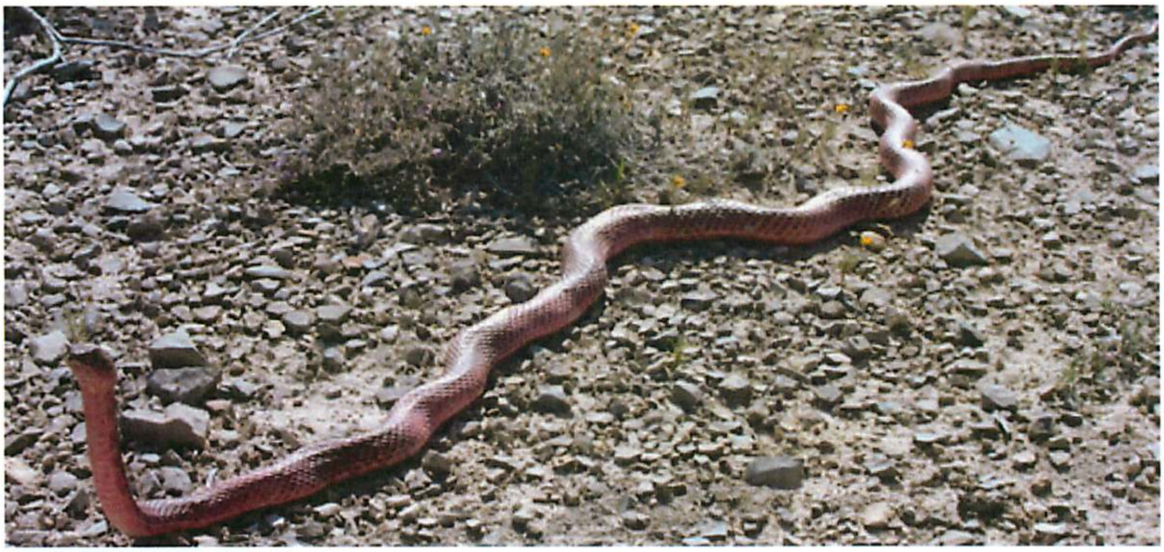
Sometimes called the "Mojave Green", this snake has the most potent venom of any rattlesnake in North America, 16 times more powerful than the Sidewinder's. Adults range from 2-4 feet in length, have a triangular shaped head, diamond shaped markings along their boy, and of course a rattle. They have a variety of colors, including tan, brown, yellow, and green. They give birth to 4 to 24 snakes, which are hatched inside and born live.

Its venom is used to immobilize its prey and defend itself. The venom attacks both the nervous system with neurotoxins and the bloodstream with hemotoxins. It feeds on rodents, lizards, snakes, birds, eggs, and some insects. The neurotoxins affect the heart, skeletal muscles and neuromuscular junctions. One bite is sufficient to kill a human: lethal dose is only 10-15 mg and one adult can yield 141 mg.

Despite its defenses, it is hunted by roadrunners, kingsnakes, and other avian and mammalian predators. This snake can be very aggressive and is responsible for several deaths each year, including a prominent snake toxin expert. This snake should be avoided. It won't come looking for trouble, but won't run from it either.

Red Racer:

This is the most commonly seen snake in the Mojave. It can be up to 6 feet long and is very slender. It is also the fastest moving snake in the desert, at around 7 mph. They vary in color from tan to pink, and become increasingly red as they get older. This snake should also not be handled, it is very aggressive and though not poisonous, it can tear away flesh.



Desert Tortoise:

The tortoise has remained unchanged for the last 37 million years. They don't reach sexual maturity until they are ~15-20 years old, and their lifetime often exceeds 80 years. They spend most (>90%) of this time in their burrow, which is sometimes shared with various birds, mammals, reptiles, and invertebrates. Tortoises are most susceptible to predation in the first 7 years, while their shell is still hardening. They mainly eat grasses, flowers, and cactus. They can live more than a year without water, and can hold up to 40% of their body weight worth of water inside.

Birds

Golden Eagle:

Named for the golden-colored feathers on the head and neck, this massive, 8-12 pound bird usually has a wingspan of 6-7 feet. They are sometimes found hunting in pairs, and feed mainly on ground squirrels, rabbits, birds, the occasional calf or lamb, and many other animals.

Turkey Vulture:
Another large bird, this scavenger has a wingspan of about 6 feet and has a redish/purple head and a curved ivory colored beak. The specialize in eating animal remains, rarely eating anything else, which they locate using their sense of smell. They can sometimes be found in roosts that number in the hundreds. Interestingly, they have been found to eat along side condors and ravens but act subordinate to both. Coyotes and Golden Eagles may also keep them away from a routing carcass.

Great Horned Owl:
This large nocturnal owl can sometimes be seen flying across the road at night. They have large ear tufts, a reddish face, a white patch on the throat, and yellow eyes. Another somewhat unique characteristic is that their legs and feet are covered with feathers up to their talons. Horned owls eat rats and mice, but can also eat other birds, rabbits and skunks. They can see remarkably well at night, and compared to humans, owls have a much sharper depth of perception to their hearing as well. This is possible because owl ears are not placed in the same position on either side of their head: the right ear is typically set higher in the skull and at a slightly different angle. By tilting or turning its head until the sound is the same in each ear, an owl can pinpoint both the direction and the distance to the source of a sound. Its only predators are thought to be golden eagles and humans.

Greater Roadrunner:

The greater roadrunner is a large black and white ground bird that prefers to run (up to 18 mph) rather than flying (with its short, rounded wings). It is a zygodactyl bird, having two toes facing forward, and two toes facing backwards. They are primarily carnivorous, eating lizards, snakes, scorpions, other birds, rodents and insects. Predators include house cats, hawks, eagles, skunks, and yes, even Wile E. Coyote.

Other:

Tarantula:
The largest desert spider is the tarantula, which is not poisonous to humans, but has a very painful bite. It feeds on insects, lizards, and small rodents such as mice. The body can be as much as 2-4 inches, with an additional 4 inch legs. Unlike most spiders, tarantulas don't use webbing to snare prey, but instead prefer to chase down their prey. Tarantulas mate in the fall and have litters of 500-1000. Females can live for 20 years or more, and may remain in a burrow for years before moving to another one.

Blister Beetle:
There are several thousand species of blister beetles worldwide and a few are in the Mojave. These beetles have a defensive secretion that causes burning and blistering, and are generally brightly colored. The secretion is of a poisonous chemical called cantharidin, which is used medically to remove warts. Consuming these beetles can be fatal; just a few are enough to kill a horse.

Tarantula Hawk

Tarantulas are parasitized by another arthropod, the tarantula hawk. Actually a wasp, the tarantula hawk stings a tarantula to paralyze it and then lays its egg on the body of the spider. When the wasp larvae hatches it feeds on the spider.

Scorpions

Scorpions have distinctively long tails tipped with a stinger. All scorpions are venomous, although only one species in the United States is potentially deadly to humans. Scorpions are nocturnal carnivores that use their stinger to kill prey or to defend themselves. Interestingly, scorpions glow green under ultraviolet (UV) light. The large hairy scorpion (pictured below) can grow to be about 5.5 inches (14 cm), and can feed on small snakes, lizards, spiders, and insects. They are a burrowing scorpion, but can be commonly found under rocks. They give birth to live young which remain on the mother's back for about a week. They are not harmful to humans, unless there is an allergic reaction.

Plants:

The Mojave Desert is dominated by low, widely spaced shrubs, including the creosote bush and Mojave sage. The Mojave flora includes few trees other than the signature Joshua tree, but features a number of cacti, several parasitic plants, and a vast variety of wildflowers. About 25 % of the plant species in the Mojave are endemics--found nowhere else in the world. The spiny-armed Joshua tree lives only within the Mojave Desert; in fact, the boundaries of the species' range define the areal limits of the ecosystem.

Joshua Tree

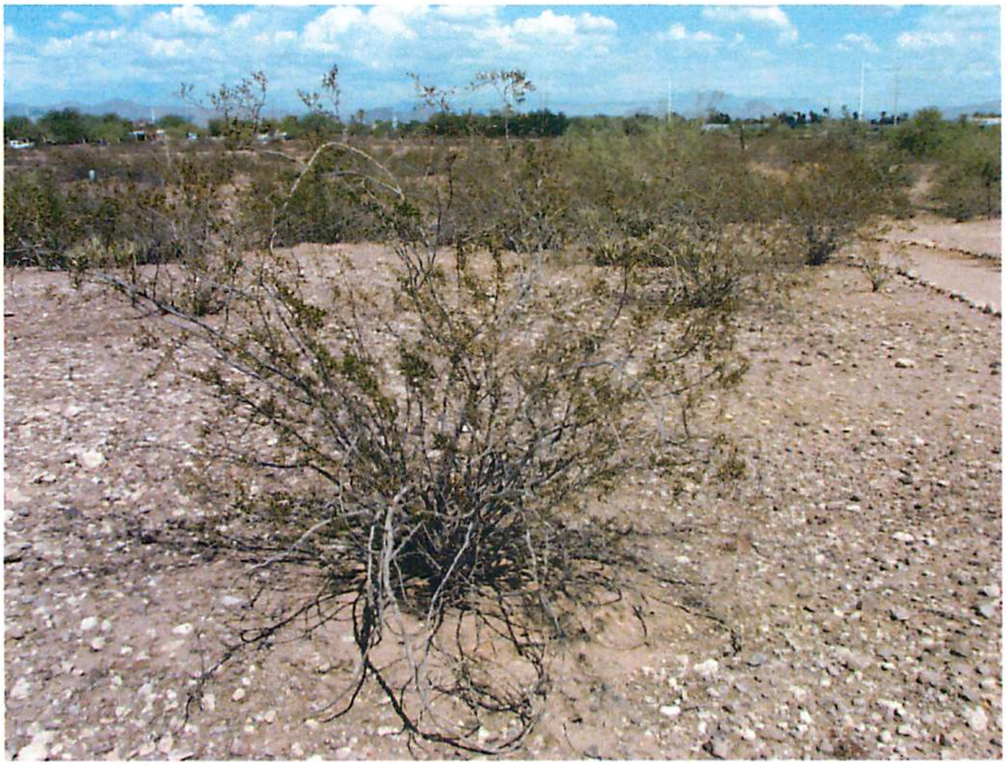
The most characteristic plant of the Mojave Desert is the Joshua Tree. It was named after the biblical leader, Joshua, because it reminded the Mormon pioneers of Joshua raising out stretched arms toward the heavens. This tree is one of the largest plants in the Mojave, reaching up to 49 feet in height with reddish-brown trunks that can grow to 4 feet in diameter. The erratic branching is caused by a boring weevil which destroys the growing tips.

California Juniper

Juniper is an important source of food and shelter for deer, wild horses, ground birds, and many other animals. At maturity, the juniper reaches 3-15 feet tall, and can occasionally reach 40 feet in height. It produces berries that are a reddish brown and contain two seeds, which are dispersed by birds and other mammals.

Creosote Bush:

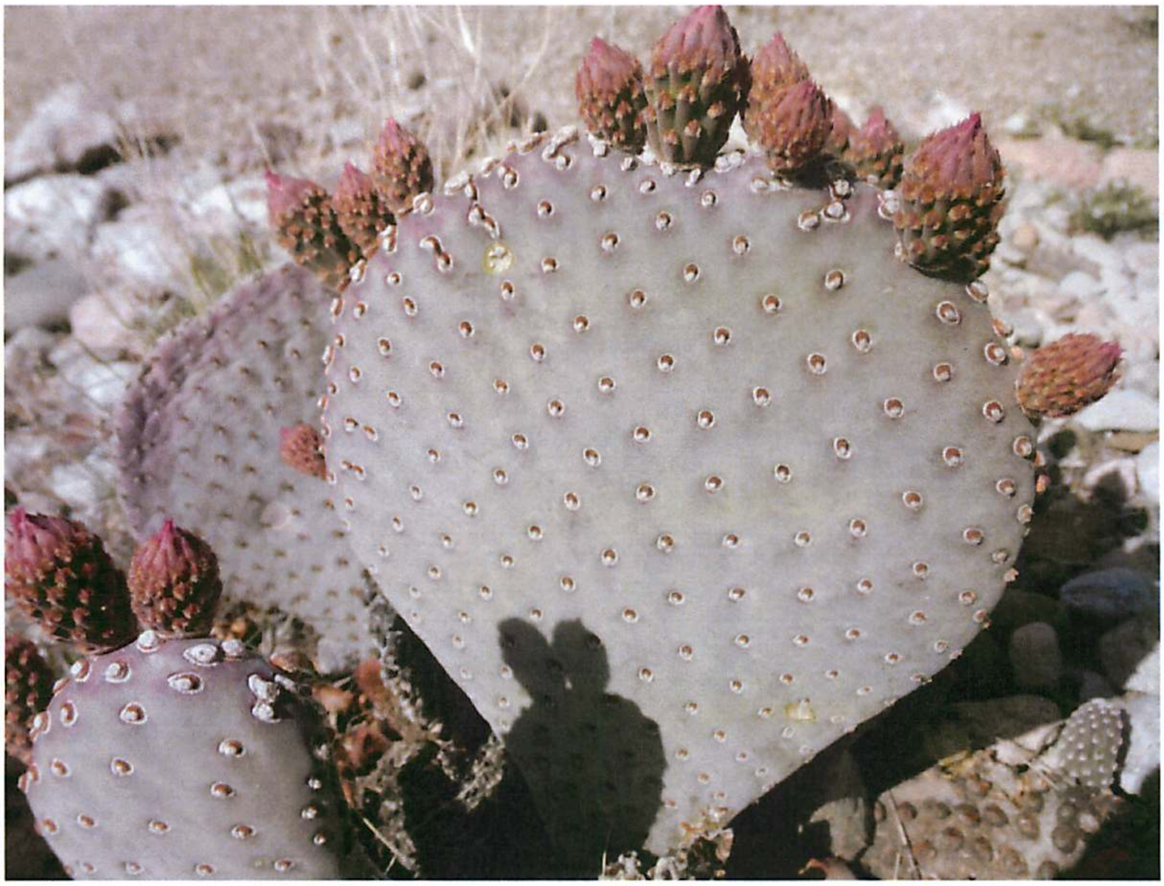
The creosote bush is found throughout the Mojave Desert and is known to attain ages of several thousand years. The oldest in Johnson Valley, California, is estimated at 9,400 years old. The leaves are thick and strongly scented, and the bush may have flowers and fruit. Many desert animals find a home in or under the creosote bush, including lizards, tortoise, kangaroo rats, fox, and others. This plant also has several medicinal purposes. The creosote bush is one of the most successful of all desert species because it uses a combination of several adaptations, including a deep tap root, a shallow root system, and wax-coated leaves that close their pores during the day to avoid loss of water. The creosote bush has the added advantage of being both bitter-smelling and -tasting; mos won't eat it, and other plants often won't even grow near it, reducing competition for water.



California Barrel Cactus:

Usually spherical and becomes more cylindrical with age. Older specimens can be up to 2 meters tall. It is covered in plentiful long spines which are strait and red when young, and turn gray and curve with age. They have flowers that blossom facing the sun, and are usually yellow.

Beavertail Prickly Pear:
This medium sized prickly pear is most commonly found here in the Mojave. It can be up to ~1 meter tall and contain around 100 flattened pads that are a blue-gray in color. They are generally spinless but have small barbed bristles that can easily penetrate the skin.



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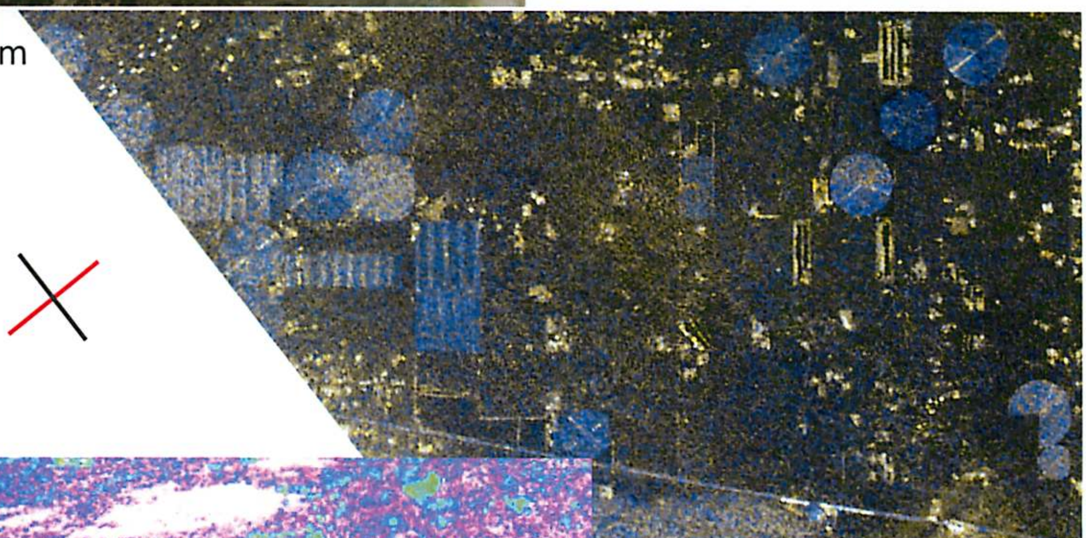
Spectral Behavior of Vegetation

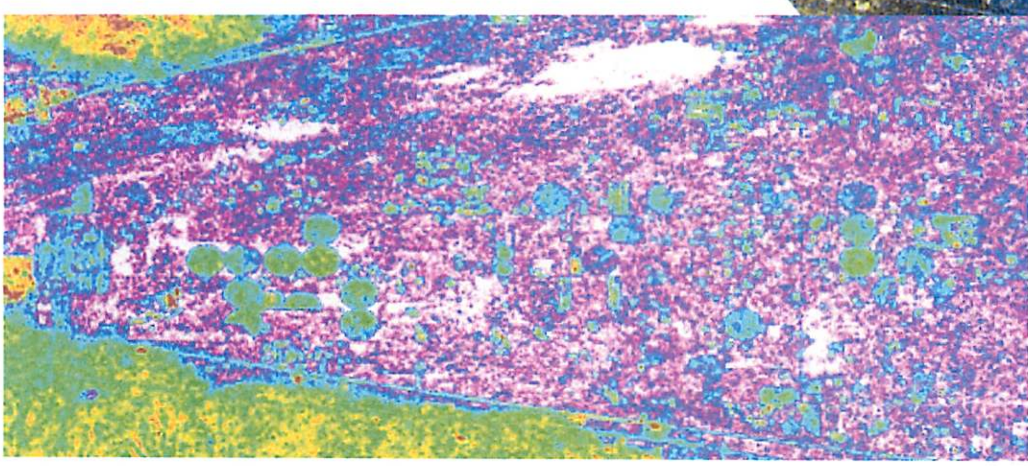
Christa Van Laerhoven

Satellite Image
Google Earth
2011-05-13



SIR-C (right)
PR13409_13410
1994-04-18

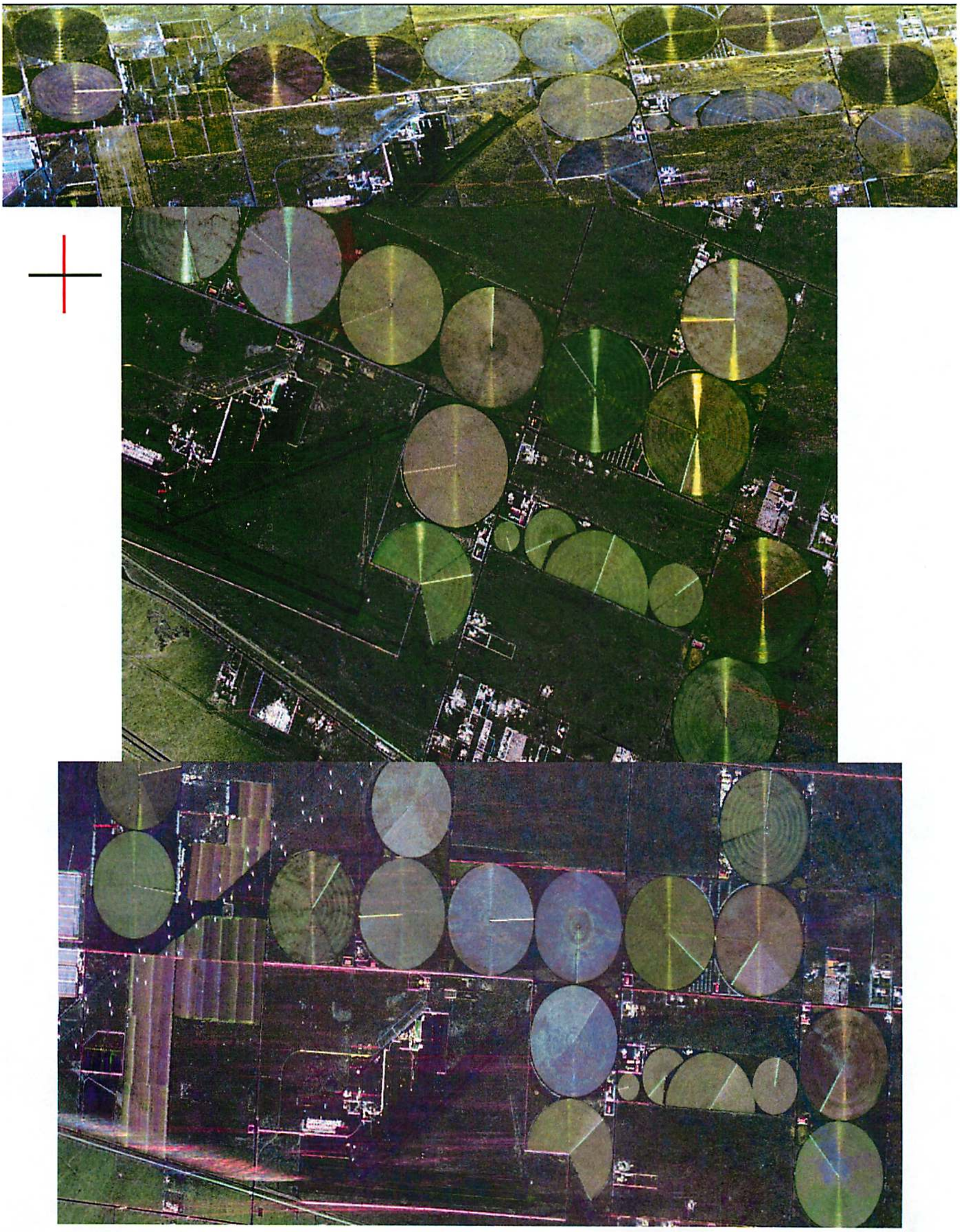
Red: L TP
Green: L TP
Blue: C TP



SRTM-C (left)
Red: high (255)
Blue: low (0)

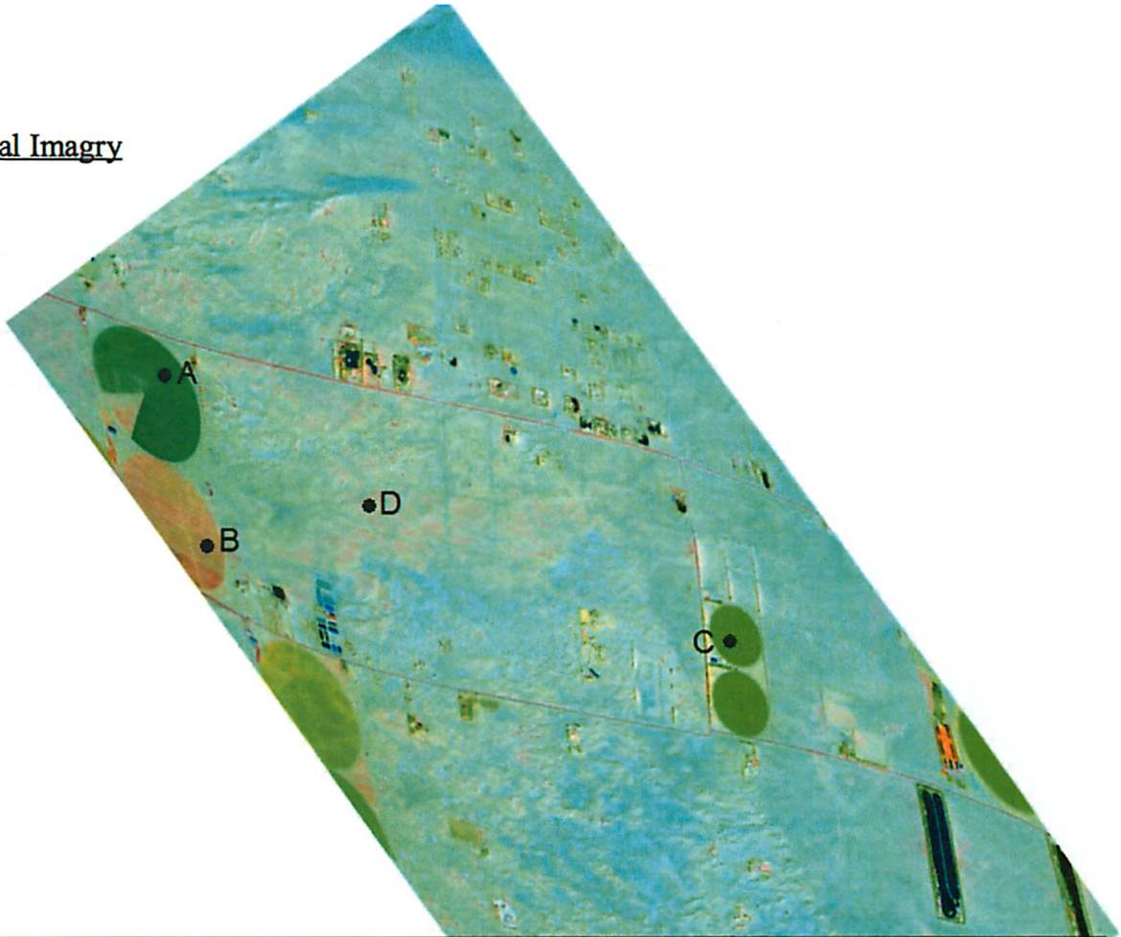
UAVSAR

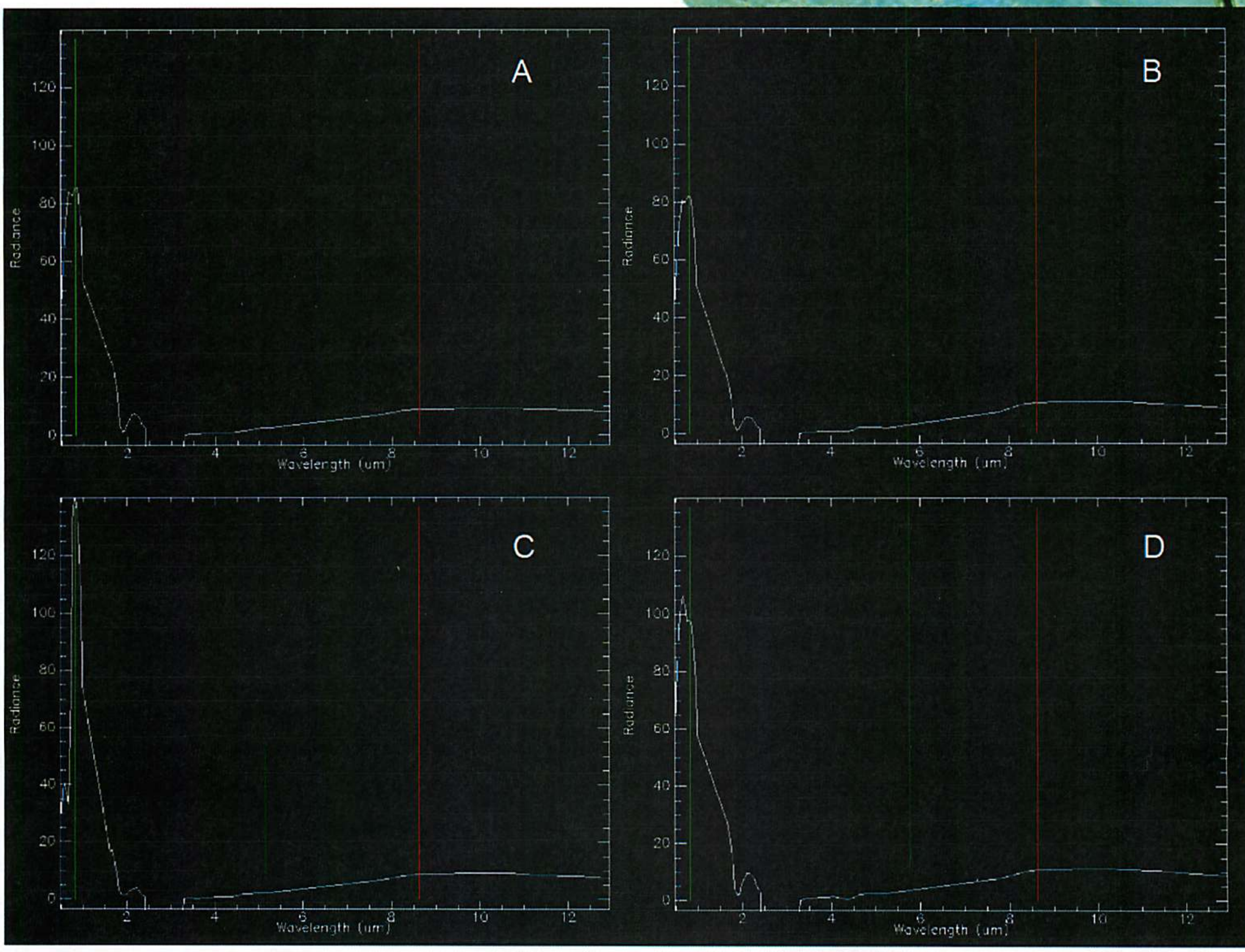
Red: L HH	top:	AmboyC_28002_11077_020_111202_L090_CX_01	2011-12-02
Green: L VV	middle:	SanAnd_25004_120116_004_120416_L090_CX_01	2012-04-16
Blue: L HV	bottom:	SanAnd_08531_12021_000_120427_L090_CX_02	2012-04-27



MASTER Hyperspectral Imagry

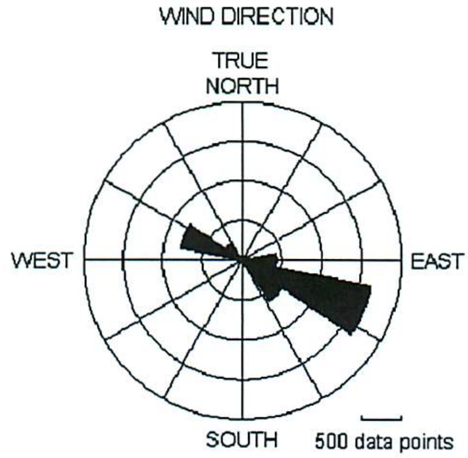
Red: 8.6210 µm
Green: 0.8010 µm
Blue: 0.5390 µm





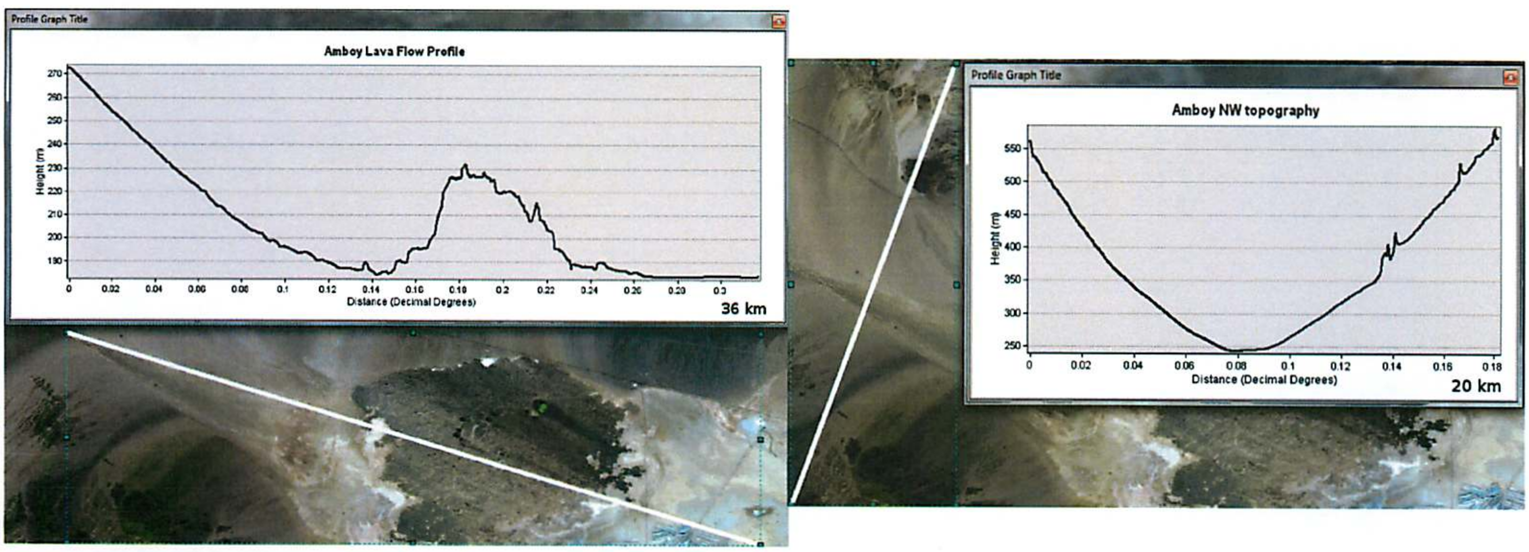
The Amboy Streak

Melissa Dykhuis, Cecilia Leung, Gabriel Muro



Amboy lava flow region rose diagram, Kienenberger 2011

The prevailing winds in the Amboy lava flow region follow a NW to SE trend (the rose diagram shown indicates *downwind* directions). The surrounding topography, in particular, the valley oriented NW of the region, help to funnel the winds past the lava flow. The dark streak SE of the crater is undoubtedly an **aeolian phenomenon**, the nature of which is explored in this report.

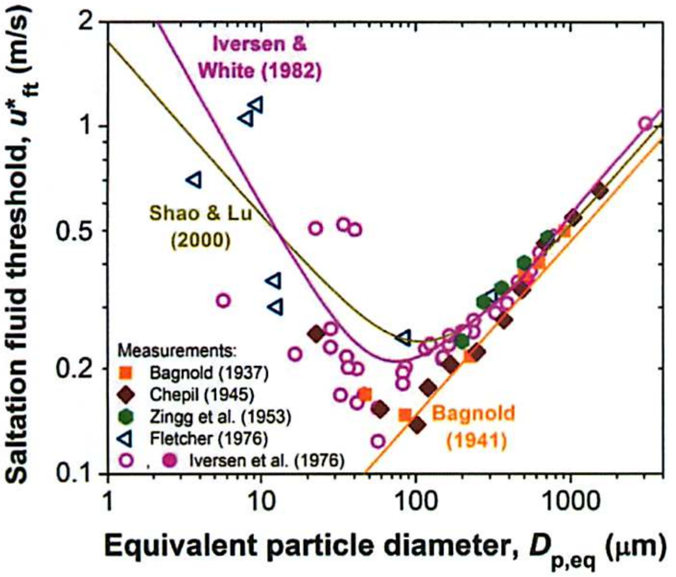


Topographic profiles of the Amboy lava flow region. The NW valley funnels the winds past the crater. All profiles move from left to right.

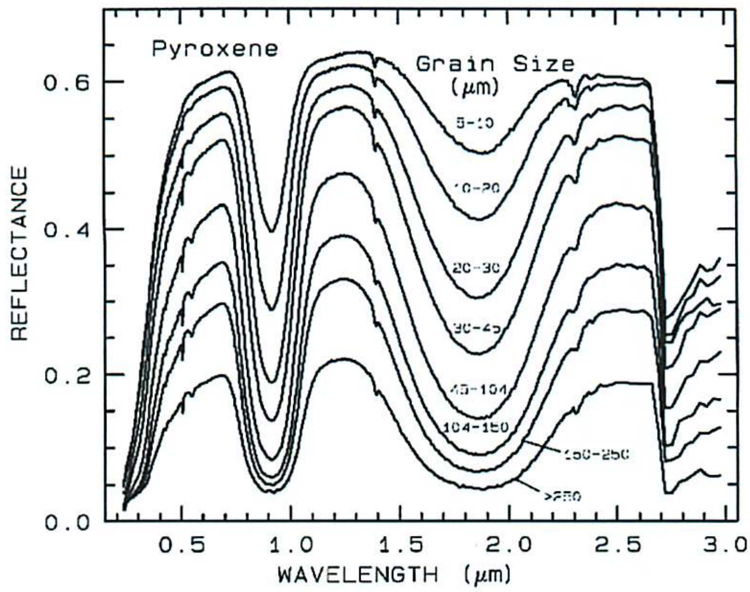
We initially developed **three possible formation mechanisms** to explain the existence of the streak:

1. Dark material from the crater is deposited downwind in the streak.
2. Turbulence downwind of the crater prevents higher-albedo material from being deposited on the darker bedrock under the streak.
3. The crater's wind shadow prevents removal of dark material along the streak.

One of the key factors that will help determine which of these mechanisms is the most plausible is how easily certain particle sizes and densities are carried along by the wind (see figure). We will also need to know information regarding the relationship between particle size and albedo (see figure).



Saltation of various grain sizes, Kok et al. 2012



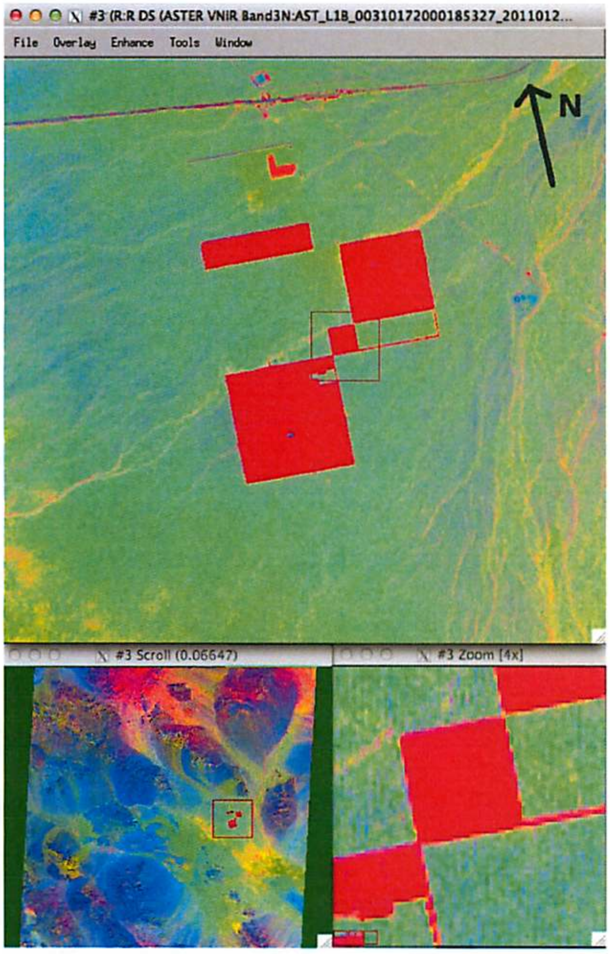
Reflectance spectrum of pyroxene, Clark 1999

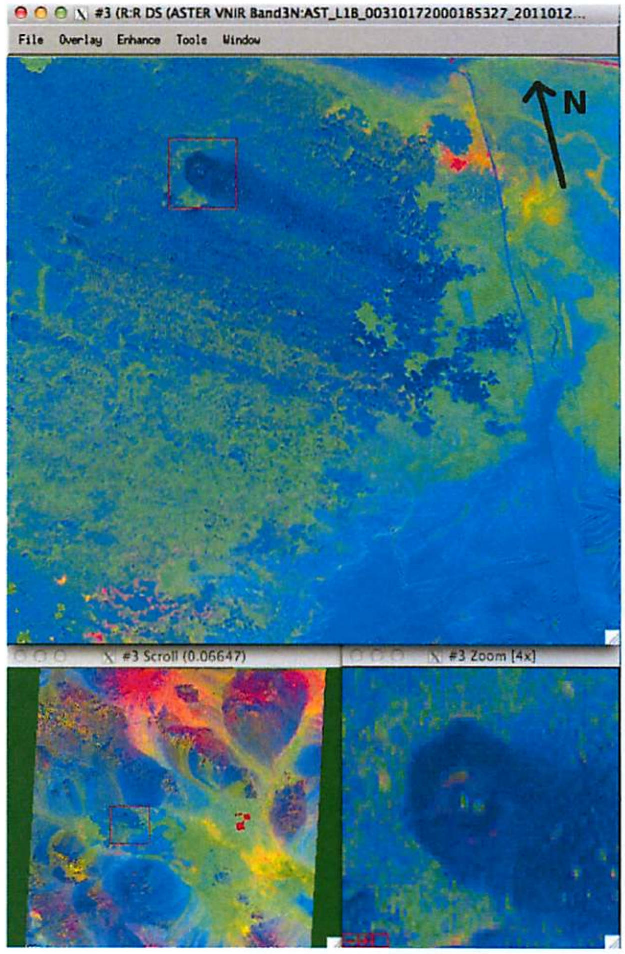
Putting all of these pieces together, the most likely particles to be saltating with the wind are **0.1 mm particles**, and they have lighter albedos than the bedrock particles underneath. The first hypothesis is thus improbable, as the large, dark, and heavy basalt grains from the crater would be unlikely to be carried far by the wind. In addition, the fact that **larger grains tend to have darker albedos than smaller grains** supports the second hypothesis over the third.

The compositional differences/similarities between the crater and the streak add another important piece to the puzzle. To determine compositional differences, we used the visible and near-IR data from ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) in three different bands: Band 1 (0.5560 µm), Band 2 (0.6610 µm), and Band 3N (0.8070 µm). The resolution in these bands is 15 m per pixel. To highlight compositional differences, we performed a decorrelation stretch on the data, which unhelpfully removes band information from the color scheme, but highlights composition differences.

The decorrelation stretch reveals a **halo of different material around the crater**. The crater, however, appears to be **compositionally similar** to the streak material, as well as the nearby features and their streaks.

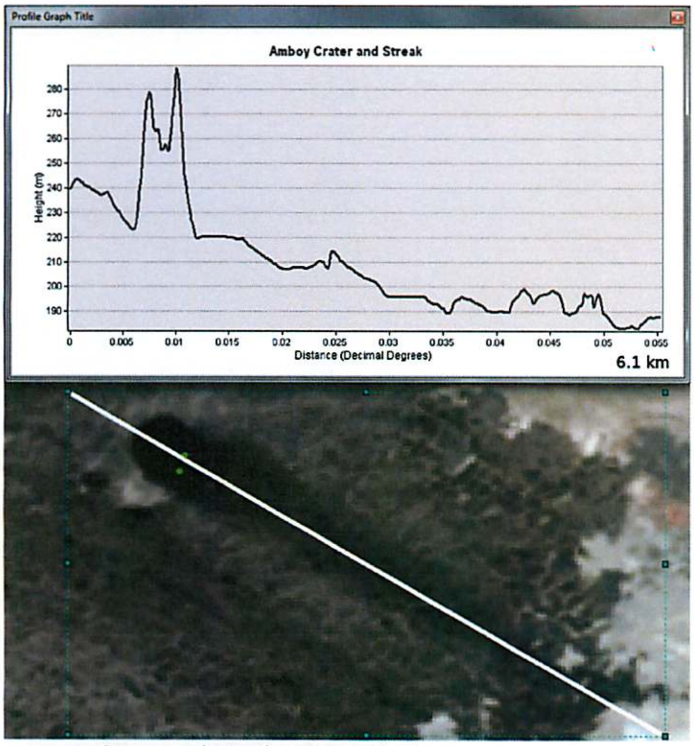
As a bit of a side note, while performing a decorrelation stretch on a larger region, we produced an image, which highlighted vegetation in red colors, and found a ring of red within Amboy Crater itself, suggesting the presence of vegetation within the crater.



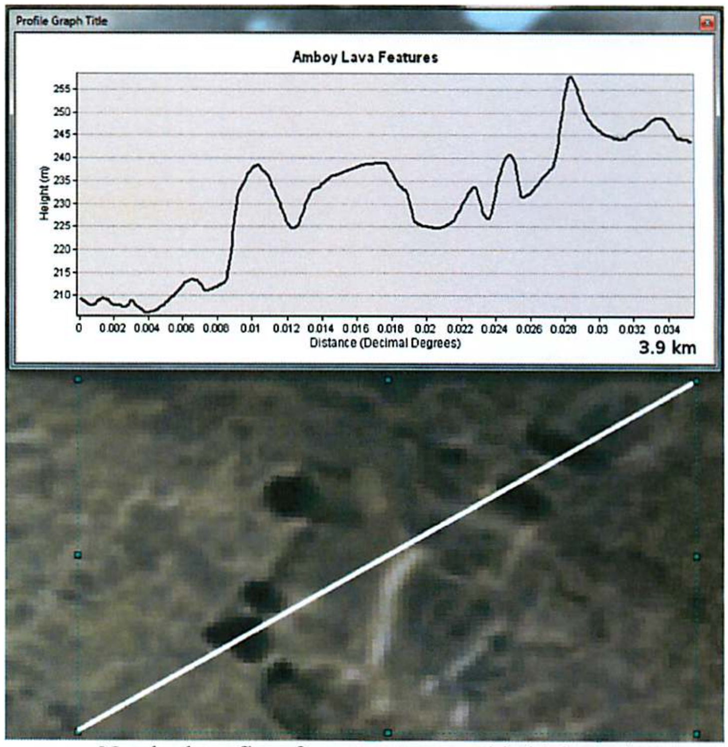


Visible wavelength map of the entire area (Google)

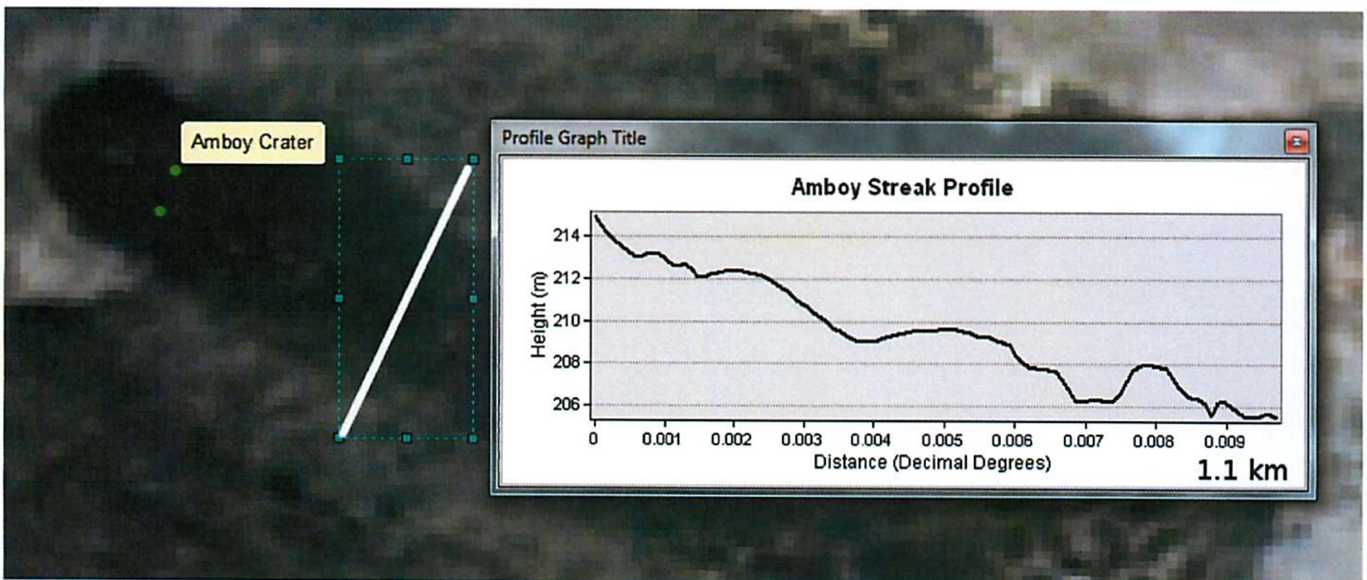
We looked at the topographical data of the crater and its streak, as well as nearby features and their streaks, to understand further the nature of the streak. The crater rises about 60 m above the surrounding lava flow, which itself is elevated about 40 m above the SE playa.



Crater and streak topography



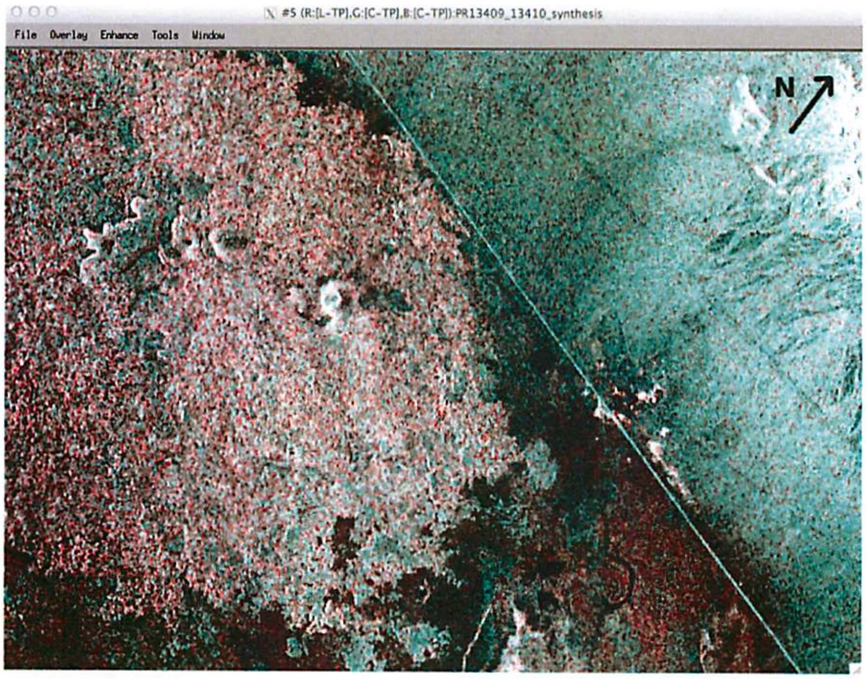
Nearby lava flow features, topographic highs



Profile across the streak, showing no significant topographical patterns.

The streaks show no significant topographical highs or lows relative to the surrounding lava flow. Curiously, the nearby features (which often have associated smaller streaks of their own, see Google satellite photo on first page) are topographic highs, which -- like the crater -- are darker than their surroundings. This could possibly be because the NW winds are not able to deposit lighter albedo grains on the surfaces of these features.

Lastly, in attempt to probe the roughness of the streak, we used the Spaceborne Imaging Radar-C (SIR-C) data in the C and L bands (~5 cm and ~25 cm wavelengths respectively). The top image contrasts the brightness in the C band (cyan) with the brightness in the L band (red). The northern playa is cyan, which indicates roughness in the 5 cm scale, while the lava flow is more rough in the 25 cm scales. The halo immediately around the crater is dark and more cyan, indicating less power in the 25 cm scales, possibly due to the presence of sub-5cm grains, which dissipate the radar power. The streak is slightly brighter than the lava flow, suggesting that it is reflecting more power in both the 5 and 25 cm scales, while the nearby lava flow is darker, possibly due to the presence of more small grains on the surface.



The bottom image contrasts C-band HH polarized radar (red) with C-band HV polarized radar (green). The lava flow is brighter in HH polarized radar, indicating surface polarization with less multiple scattering. The crater and surrounding halo are tinted green, indicating volume or deep polarization with multiple scattering present.

The data collected above most strongly support hypothesis 2 above, which describes the wind streak phenomenon as a result of turbulence behind the crater evacuating the downwind streak of finer, lighter-albedo particles, carried by the wind from the NW valley and playas across the lava flow. The existence of dark-albedo features to the SW of the main crater, which also have associated streaks, supports this idea also, as the saltating light-albedo grains are not deposited on the faces of those features.

Wind tunnel simulations have modeled the topography of the lava flow and reproduced the streak observed (below, from Greeley & Iversen 1985).

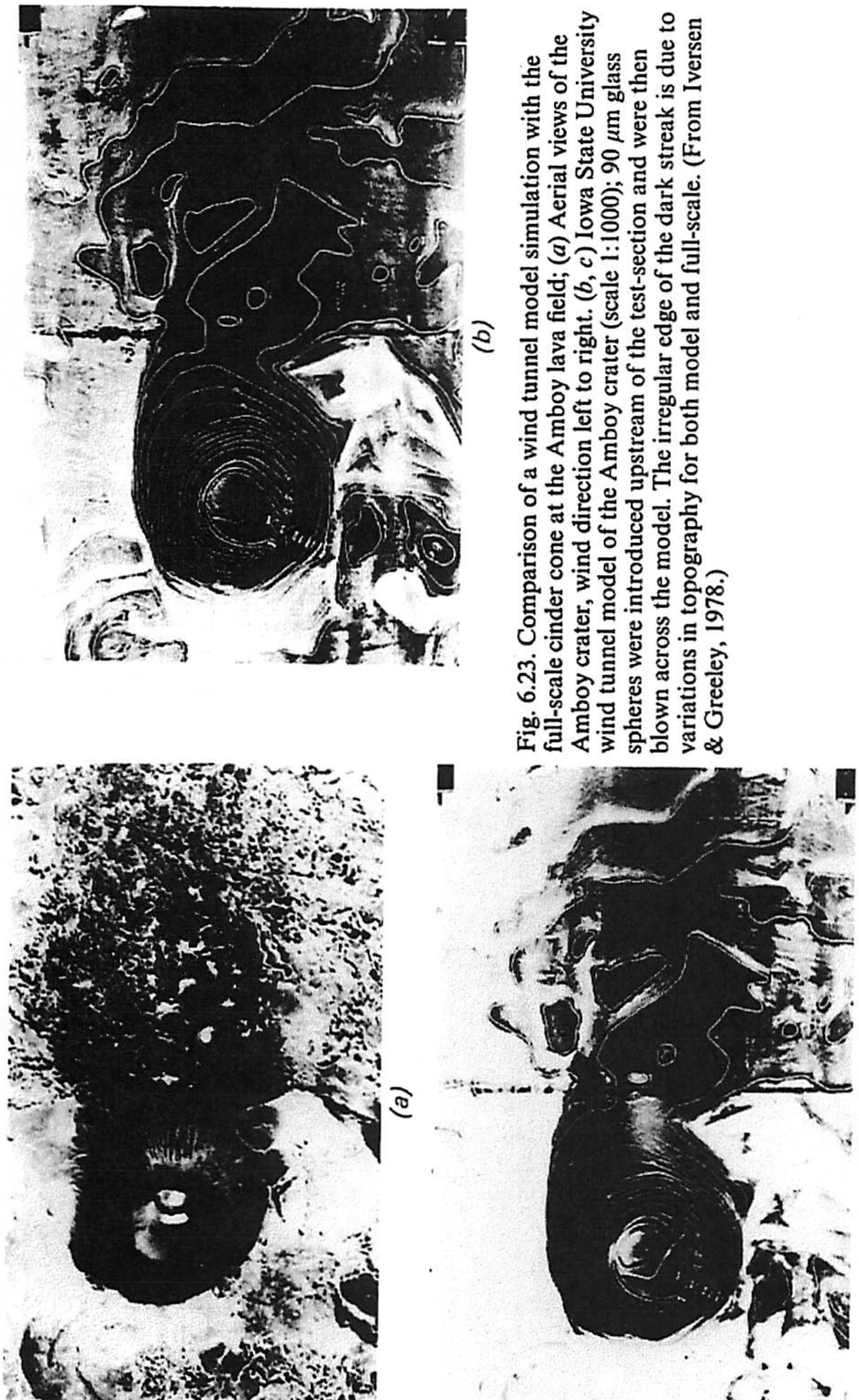
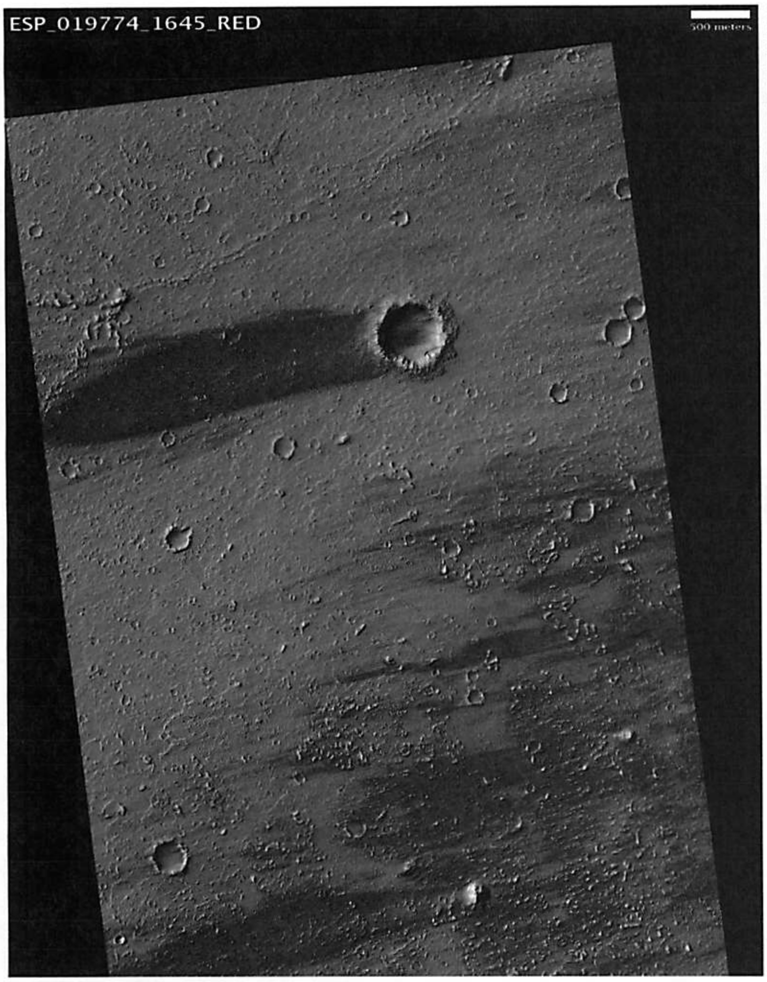
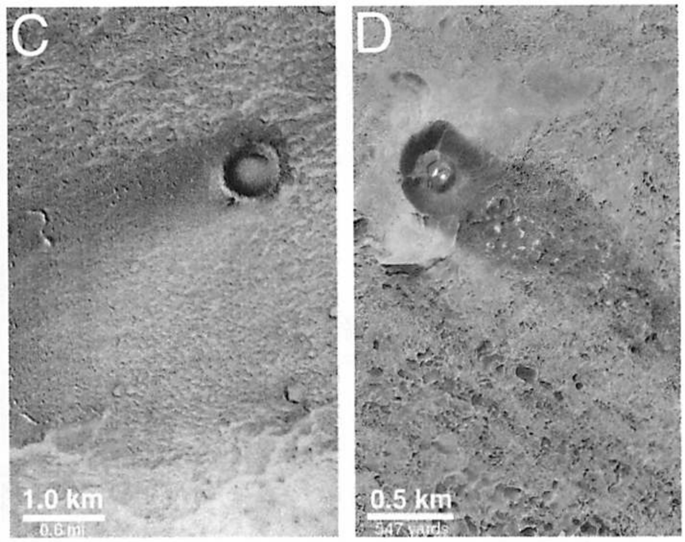


Fig. 6.23. Comparison of a wind tunnel model simulation with the full-scale cinder cone at the Amboy lava field; (*a*) Aerial views of the Amboy crater, wind direction left to right. (*b*, *c*) Iowa State University wind tunnel model of the Amboy crater (scale 1:1000); 90 μm glass spheres were introduced upstream of the test-section and were then blown across the model. The irregular edge of the dark streak is due to variations in topography for both model and full-scale. (From Iversen & Greeley, 1978.)

Planetary Connection: (below, left) Dark wind streaks are also found in several HiRISE images of Daedalia Planum on Mars, an area of dark lava flows west of Arsia Mons. Similar to the Amboy lava flow region, light colored particles are deposited on the surrounding area, but not directly behind the 500 m crater, leaving the original dark lava flow uncovered in its wind shadow.





(above) The Mars Global Surveyor's MOC also captured dark streak images behind Daedalia Planum craters and compared them to the Amboy Streak. Image C is illuminated from the left, while image D is illuminated from the right. The lengths of these dark streaks seem to follow a pattern of being several crater widths long. The above comparison appears to display a lack of saltating particles deposited on the upward slope of the windward facing side for both Mars and the Earth.

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Common Rock Forming Minerals

Dark-Colored minerals

Hardness	Cleavage	Physical Properties	Name
Hardness >5	Excellent or good	Dark gray, Blue-gray or black. May be iridescent. Cleavage in 2 planes at nearly right angles. Striations. Hardness-6	**Plagioclase Feldspar**
		Brown, gray, green or red. Cleavage in 2 planes at nearly right angles. Exsolution Lamellae. Hardness-6	**Potassium Feldspar**
		Opaque black. 2 cleavage planes at 60°and 120°. Hardness- 5.5	**Hornblende (Amphibole)**
	Poor or absent	Opaque red, gray, hexagonal prisms with striated flat ends. Hardness- 9	**Corrundum**
		Gray, brown or purple. Greasy luster. Massive or hexagonal prisms and pyramids. Transparent or translucent. Hardness- 7	**Quartz Black or brown- Smoky , Purple- Amethyst**
		Opaque red or brown. Waxy luster. Hardness- 7. Conchoidal Fracture	**Jasper**
		Opaque black. Waxy luster. Hardness- 7	**Flint**
		Transparent- translucent dark red to black. Hardness- 7	**Garnet**
Hardness < 5	Excellent or good	Colorless, purple, green, yellow, blue. Octahedral cleavage. Hardness- 4	**Flourite**
		Green. Splits along 1 excellent cleavage plane. Hardness- 2-3	**Chlorite**
		Black to dark brown. Splits along 1 excellent cleavage plane. Hardness- 2.5-3	**Biotite mica**
	Poor or absent	Opaque green, yellow or gray. Silky or greasy luster. Hardness- 2-5	**Serpentine**
		Opaque white, gray or green. Can be scratched with fingernail. Soapy feel. Hardness- 1	**Talc**
		Opaque earthy red to light brown. Hardness- 1.5-6	**Hematite**

Light-colored minerals

Hardness	Cleavage	Physical Properties	Name
Hardness >5	Excellent or good	White or gray. Cleavage in 2 planes at nearly right angles. Striations. Hardness-6	**Plagioclase Feldspar**
		Orange, brown, white, gray, green or pink. Cleavage in 2 planes at nearly right angles. Exsolution Lamellae. Hardness-6	**Potassium Feldspar**
		Pale brown, white or gray. Long slender prisms. Cleavage in 1 plane. Hardness- 6-7	**Sillimanite**
	Poor or absent	Opaque red, gray, white hexagonal prisms with striated flat ends. Hardness- 9	**Corrundum**
		Colorless, white, gray or other colors. Greasy luster. Massive or hexagonal prisms and pyramids. Transparent or translucent. Hardness- 7	**Quartz White-Milky, Yellow-Citrine, Pink- Rose**
		Opaque gray or white. Waxy luster. Hardness- 7. Conchoidal Fracture	**Chert**
		Colorless, white, yellow, light brown. Translucent opaque. Laminated or massive. Cryptocrystalline. Hardness- 7	**Chalcedony**
		Pale olive green. Conchoidal fracture. Transparent or translucent. Hardness- 7	**Olivine**
Hardness < 5	Excellent or good	Colorless, white, yellow, blue, green. Excellent cleavage in 3 planes. Breaks into rhombohedrons. Effervesces in HCl. Hardness- 3	**Calcite**
		Colorless, white, yellow, blue, green. Excellent cleavage in 3 planes. Breaks into rhombohedrons. Effervesces in HCl only if powdered. Hardness- 3.5-4	**Dolomite**
		White with tints of brown. Short tabular crystals or roses. Very heavy. Hardness- 3-3.5	**Barite**
		Colorless, white or gray. Massive or tabular crystals, blades or needles. Can be scratched by fingernail. Hardness- 2	**Gypsum**
		Colorless, white. Cubic crystals. Salty taste. Hardness- 2.5	**Halite**
		Colorless, purple, green, yellow, blue. Octahedral cleavage. Hardness- 4	**Flourite**
		Colorless, yellow, brown. Splits along 1 excellent cleavage plane. Hardness- 2-2.5	**Muscovite mica**
	Poor or absent	Yellow crystals or earthy masses. Hardness 1.5-2.5	**Sulfur**
		Opaque green, yellow or gray. Silky or greasy luster. Hardness- 2-5	**Sepentine**
		Opaque white, gray or green. Can be scratched with fingernail. Soapy feel. Hardness- 1	**Talc**
		Opaque earthy white to light brown. Hardness- 1-2	**Kaolinite**

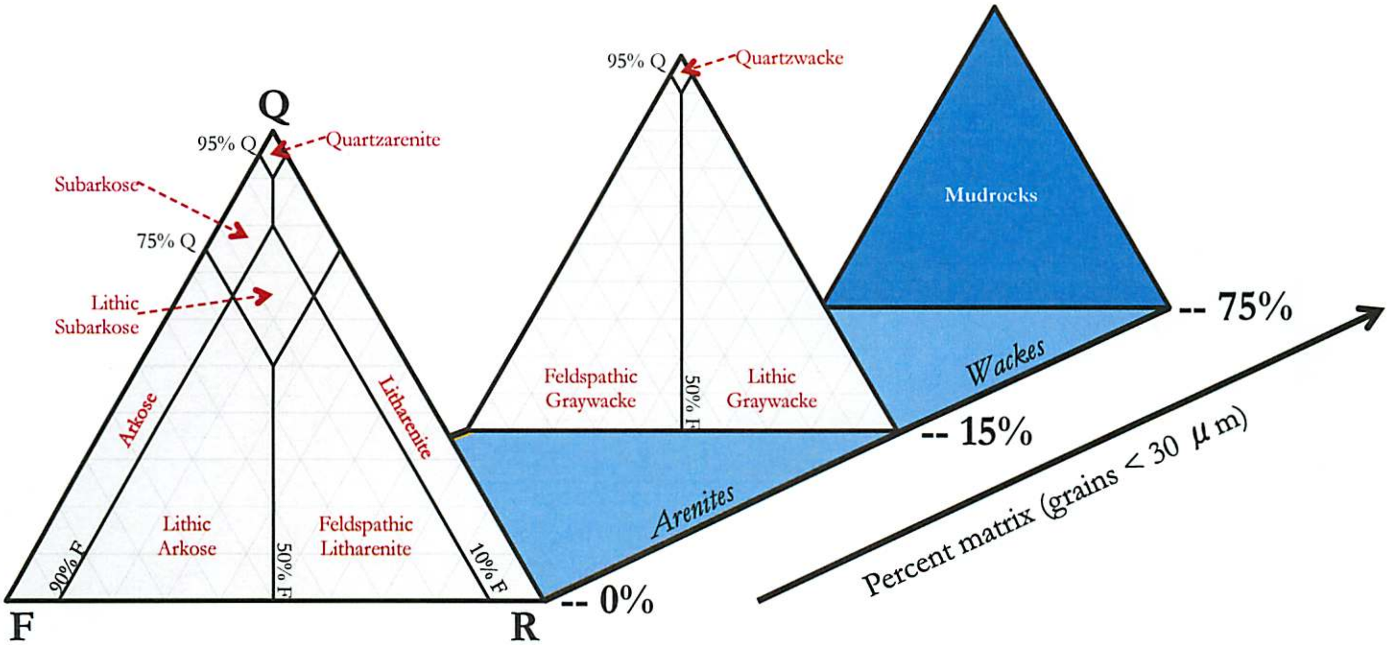
Metallic

	Streak	Physical Properties	Name
Hardness > 5	Dark Gray	Brass yellow	**Pyrite**
		Dark gray-black, attracted to magnet	**Magnetite**
	Brown	Silvery black to black tarnishes gray	**Chromite**
Harness < 5	Red-Red/Brown	Silvery gray, black, or brick red	**Hematite**
	Dark Gray	Brass yellow, tarnishes dark brown or purple	**Chalcopyrite**
		Iridescent blue, purple or copper red, tarnishes dark purple	**Bornite**
		Silvery gray, tarnishes dull gray Cleavage good to excellent	**Galena**
		Dark gray to black, can be scratched with fingernail	**Graphite**

Sedimentary Rocks

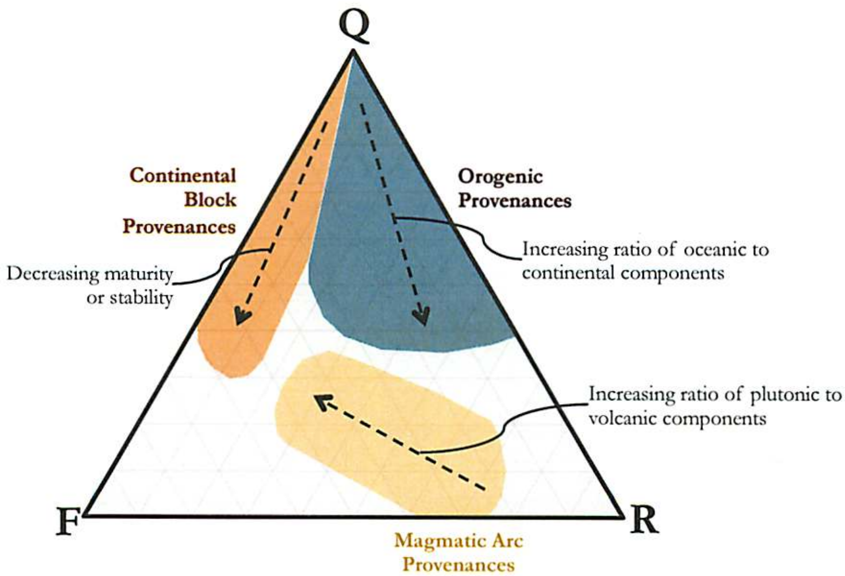
McBride, 1963 & Dott, 1964 Classification Scheme for Clastic Sedimentary Rocks

Scheme based on the normalized percentages of the visible grains: quartz and chert(Q), feldspar (F), and lithic rock fragments (R) – as well as the percent composed of matrix (mud & silt)



Tectonic Setting for Clastic Sedimentary Rocks

Scheme based on the normalized percentages of the visible grains: quartz and chert(Q), feldspar (F), and lithic rock fragments (R) – as well as the percent composed of matrix (mud & silt). Regions based upon field data.



Sedimentary Rocks

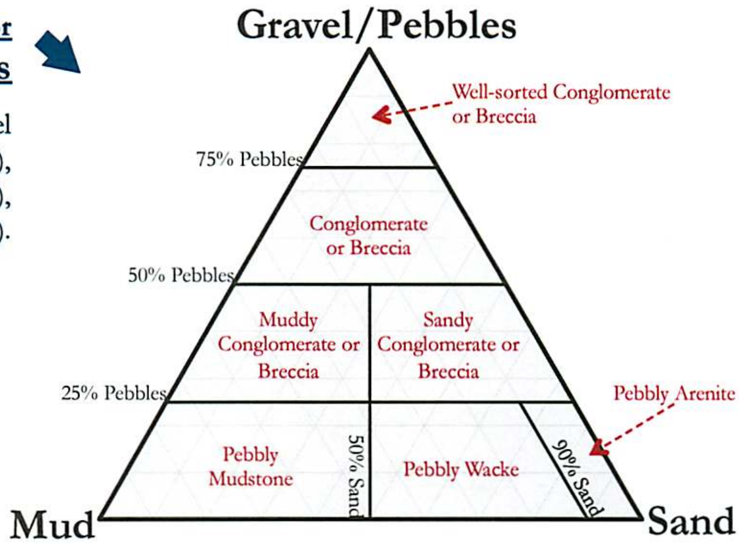
	Mudrocks (containing > 50% mud)			Rocks with <50%mud
	Silt dominant (> 2/3 of rock)	Clay and Silt	Clay dominant (> 2/3 of rock)	Sand-sized or larger grains dominant
Non-laminated	Siltstone	Mudstone	Claystone	Conglomerates, Breccias, Sandstones, etc.
Laminated	Laminated Siltstone	Mudshale	Clayshale	

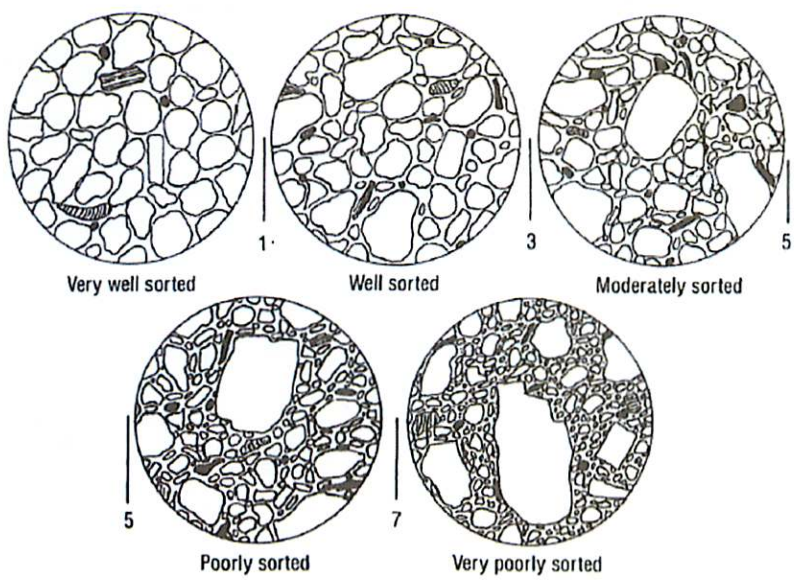
Classification Scheme for Mudrocks

Scheme based on clay/silt content, and whether the rock is laminated (layered) or not.

Classification Scheme for Sub-Conglomerates and Sub-Breccias

Scheme based on percent of a rock composed of: gravel or pebbles (size >2 mm), sand (2 mm > size > 1/16 mm), and mud (size < 1/16 mm).





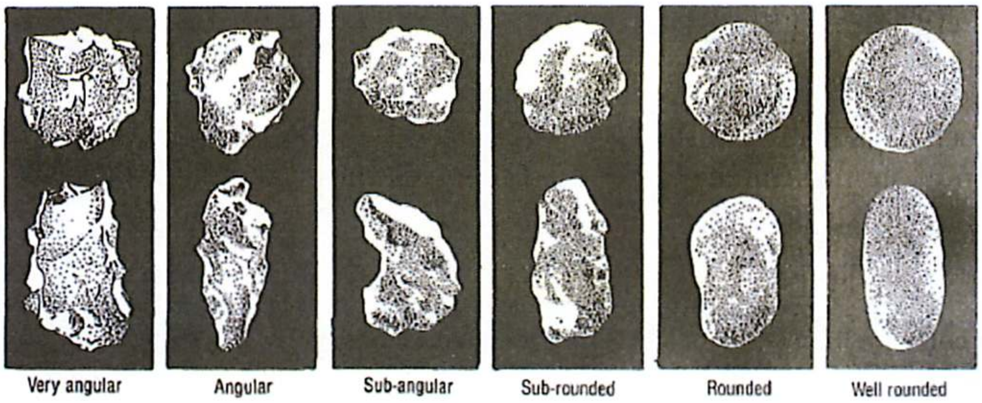
Estimating Sorting

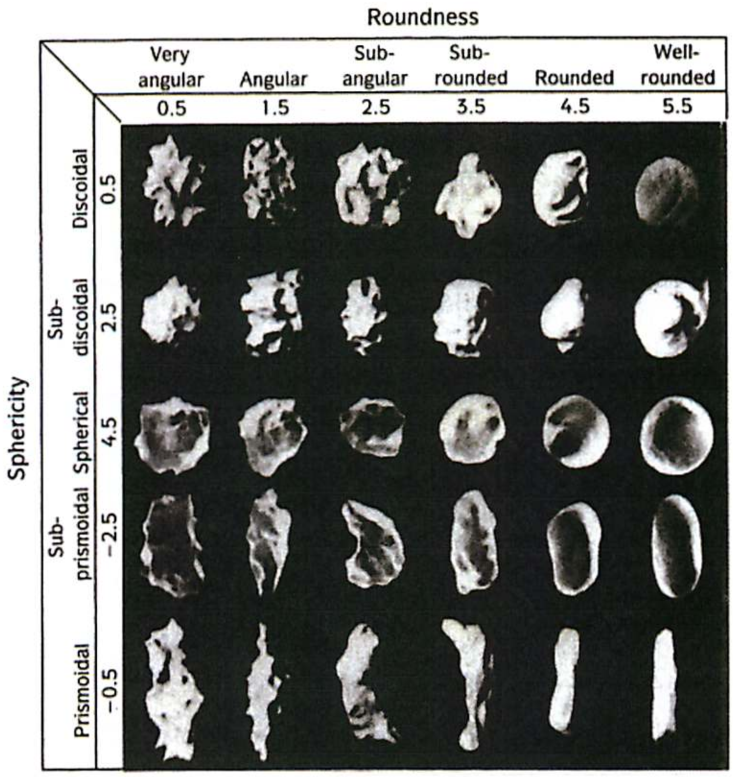
Example hand-lens view of detritus. From Compton, 1985

Sedimentary Rocks

Degrees of Rounding

Example hand-lens view of detritus of varying degrees of roundedness. The top row are equidimensional (spherical) grains, while the lower row are elongated grains. From Compton, 1985 and Davis & Reynolds, 1996, respectively.

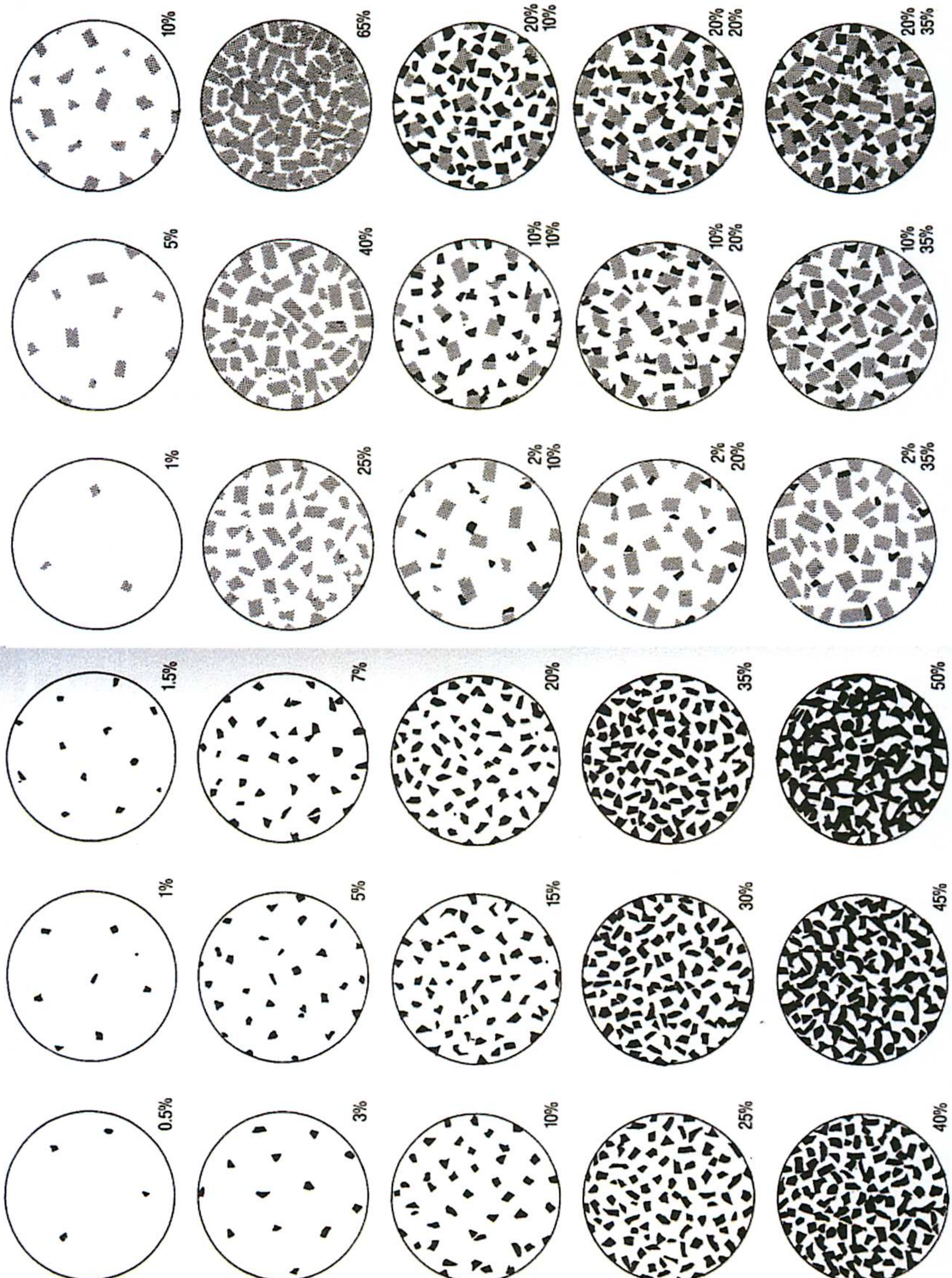




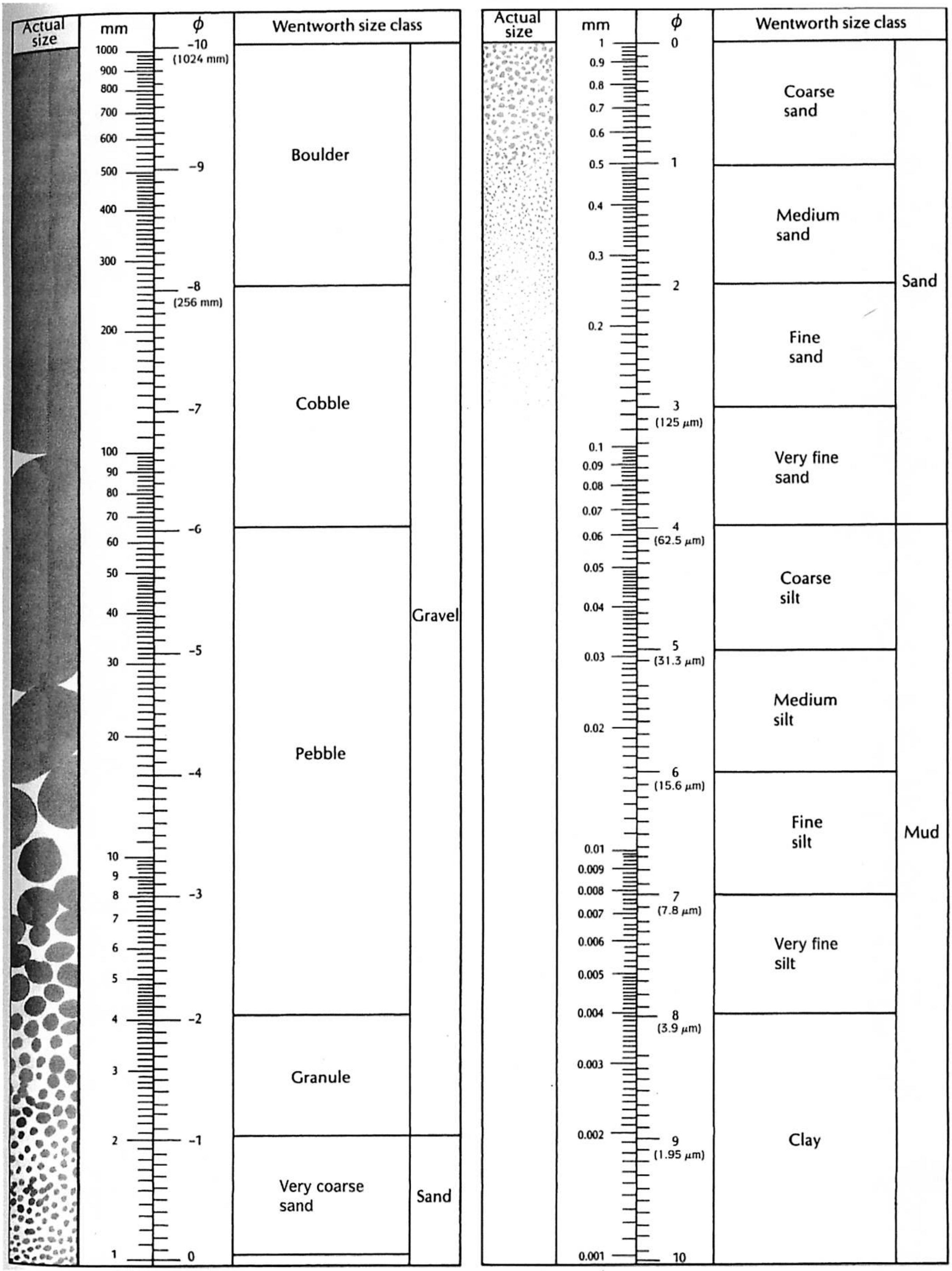
Sedimentary Rocks

Percentage Diagrams for Estimating Composition by Volume

Example hand-lens view of rocks with varying composition. To find weight percents, simply multiply each volume percent by the specific gravity of that mineral, and re-normalize. Compton, 1985



Sedimentary Rocks

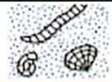
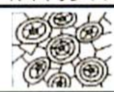
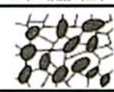
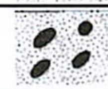
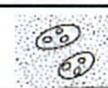


From Prothero and Schwab, 2004

Sedimentary Rocks: Carbonates

Folk Classification Scheme for Carbonate Rocks

Folk's classification scheme is based upon the composition (and type of allochems) within a limestone. Figures from Prothero and Schwab, 2004

Principle Allochems in Limestone	Limestone Type			
	Cemented by Sparite		Cemented by Micritic Matrix	
Skeletal Grains (Bioclasts)	Biosparite		Biomicrite	
Ooids	Oosparite		Oomicrite	
Peloids	Pelsparite		Pelmicrite	
Intraclasts	Intrasparite		Intramicrite	
Limestone formed in place	Biolithite		Terrestrial Limestone	

Dunham Classification Scheme for Carbonate Rocks

Dunham's classification scheme is based upon depositional textures within a limestone.

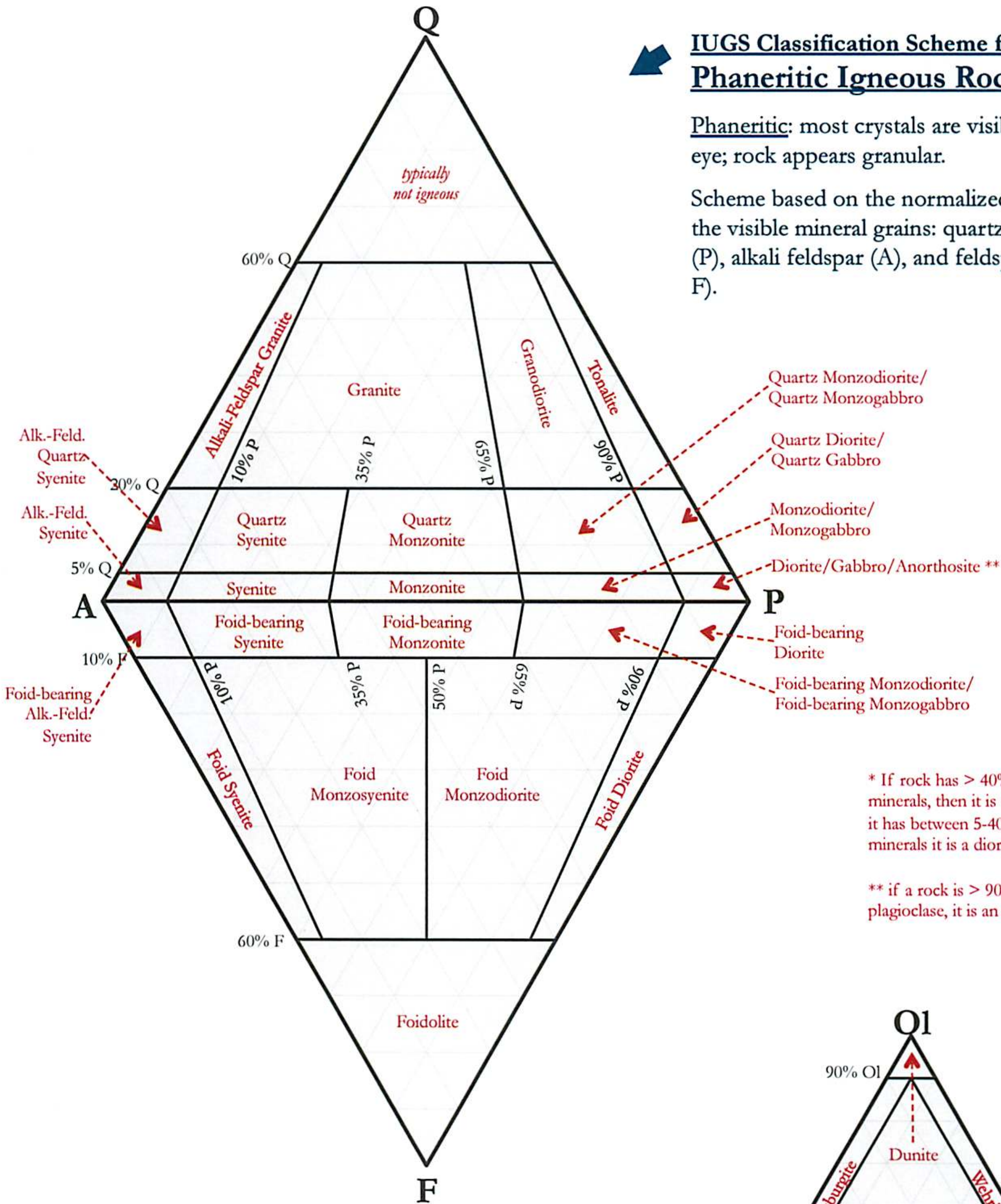
Allochthonous Limestone (original components not organically bound during deposition)						**Autochthonous Limestone** (original components organically bound during deposition; reef rocks)		
Of the allochems, less than 10% are larger than 2 mm				Of the allochems, greater than 10% are larger than 2 mm				
Contains carbonate mud			No mud	Matrix supported	Grain supported	Organisms acted as baffles	Organisms are encrusting and binding	Organisms building a rigid framework
Grain supported		Grain supported						
Less than 10% grains	More than 10% grains							
Mudstone	Wackestone	Packstone	Grainstone	Floatstone	Rudstone	Bafflestone	Bindstone	Framestone

Igneous Rocks

IUGS Classification Scheme for
Phaneritic Igneous Rocks

Phaneritic: most crystals are visible to the naked eye; rock appears granular.

Scheme based on the normalized percentages of the visible mineral grains: quartz (Q), plagioclase (P), alkali feldspar (A), and feldspathoids (foids, F).



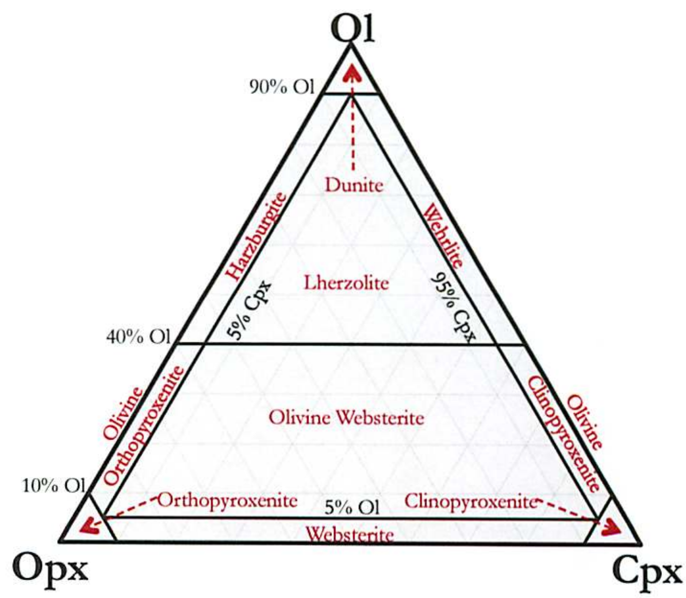
* If rock has > 40% mafic minerals, then it is a gabbo. If it has between 5-40% mafic minerals it is a diorite.

** if a rock is > 90% plagioclase, it is an anorthosite

IUGS Classification Scheme for
Phaneritic Ultramafic Igneous Rocks (1)

Ultramafic: more than 90% of the total minerals are mafic.

Scheme based on the normalized percentages of the visible minerals: olivine (Ol), orthopyroxene (Opx), and clinopyroxene (Cpx).

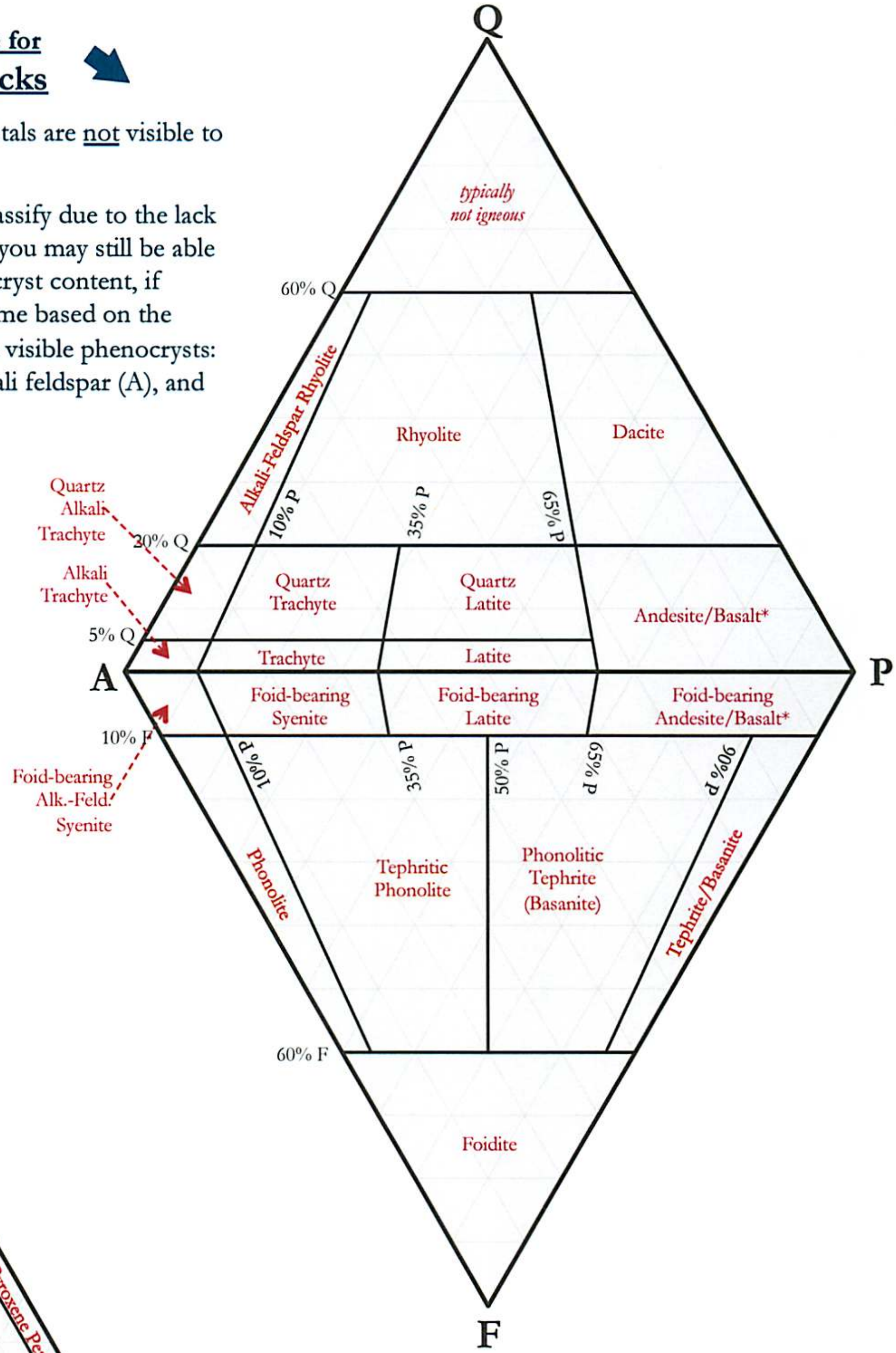


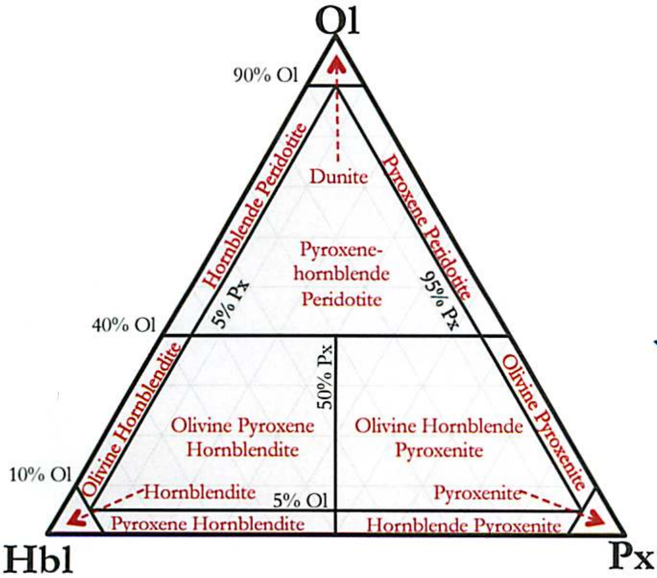
Igneous Rocks

IUGS Classification Scheme for
Aphanitic Igneous Rocks

Aphanitic: the majority of crystals are not visible to the naked eye.

Aphanetic rocks are hard to classify due to the lack of visible minerals. However, you may still be able identify them based on phenocryst content, if phenocrysts are present. Scheme based on the normalized percentages of the visible phenocrysts: quartz (Q), plagioclase (P), alkali feldspar (A), and feldspathoids (foids, F).





IUGS Classification Scheme for
Phaneritic Ultramafic Igneous Rocks (2)

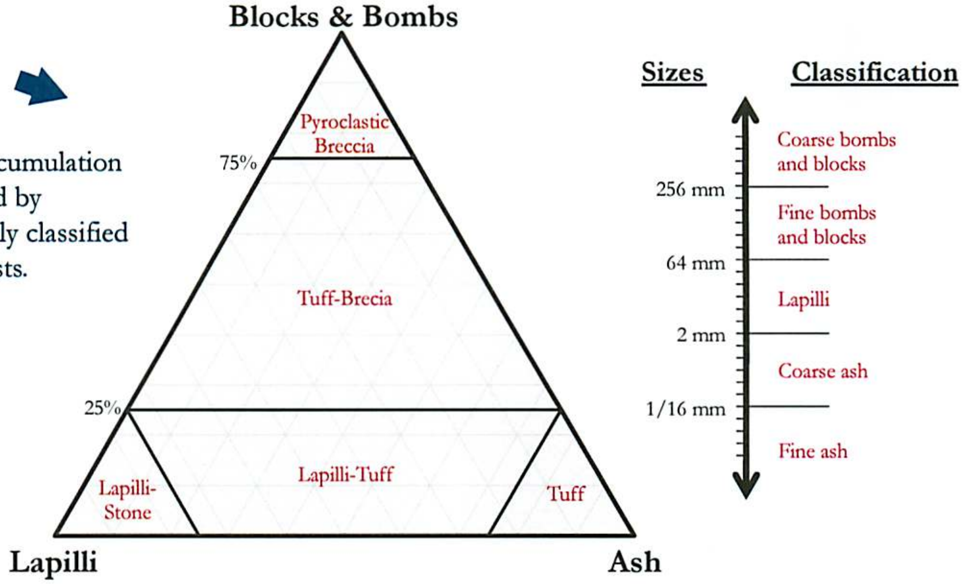
Ultramafic: more than 90% of the total minerals are mafic.

Scheme based on the normalized percentages of the visible minerals: olivine (Ol), hornblende (Hbl), and pyroxene (Px).

Igneous Rocks

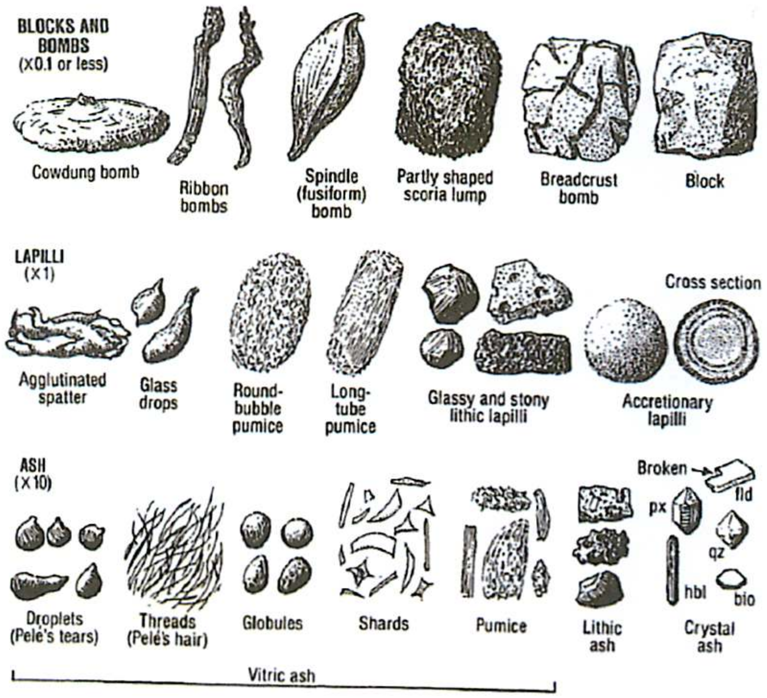
Classification Scheme for Pyroclastic Igneous Rocks

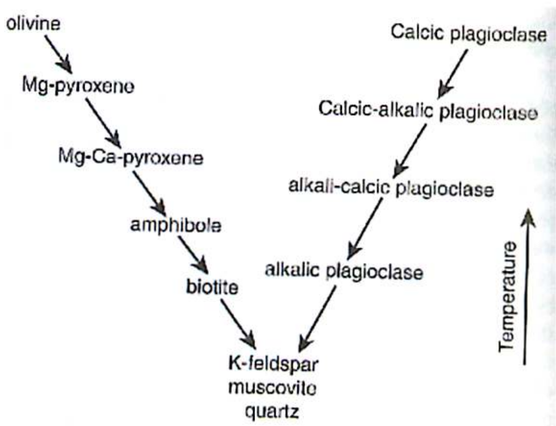
Pyroclastic rocks are formed via the accumulation of fragments of volcanic rock scattered by volcanic explosions. They are frequently classified based upon the size distribution of clasts.



Types of Tephra (Pyroclasts)

In each row, the viscosity of the lava increases to the right. From Compton, 1985.





Bowen's Reaction Series

From Winter, 2010.

Metamorphic Rocks

Classification Scheme for Metamorphic Rocks

Based upon texture and mineralogical composition.

Structure & Texture		Characteristic Properties	Characteristic Mineralogy	Rock Name
Foliate (layered)	Increasing grain size, and degree of metamorphism ↓	Dull luster; very flat fracture surface; grains are too small to readily see; more dense than shale	No visible minerals	Slate
		Silky sheen; Crenulated (wavy) fracture structure; A few grains visible, but most are not	Development of mica and/or hornblende possible	Phyllite
		Sub-parallel orientations of individual mineral grains; wavy-sheet like fracture; often contains porphyroblasts; thinly foliated	Abundant feldspar; Quartz and mica are common; hornblende possible	Schist
		Sub-parallel, alternating bands or layers of light and dark material; coarsely foliated; blocky fracture	Abundant feldspars; Quartz, mica, and hornblende are common	Gneiss
Foliate (layered)		Interlocking crystals; effervesces in dilute HCl; softer than glass	Calcite	Marble
		Nearly equigranular grains; fracture across grains (not around them); sub-vitreous appearance; smooth feel compared to sandstone	Quartz	Quartzite

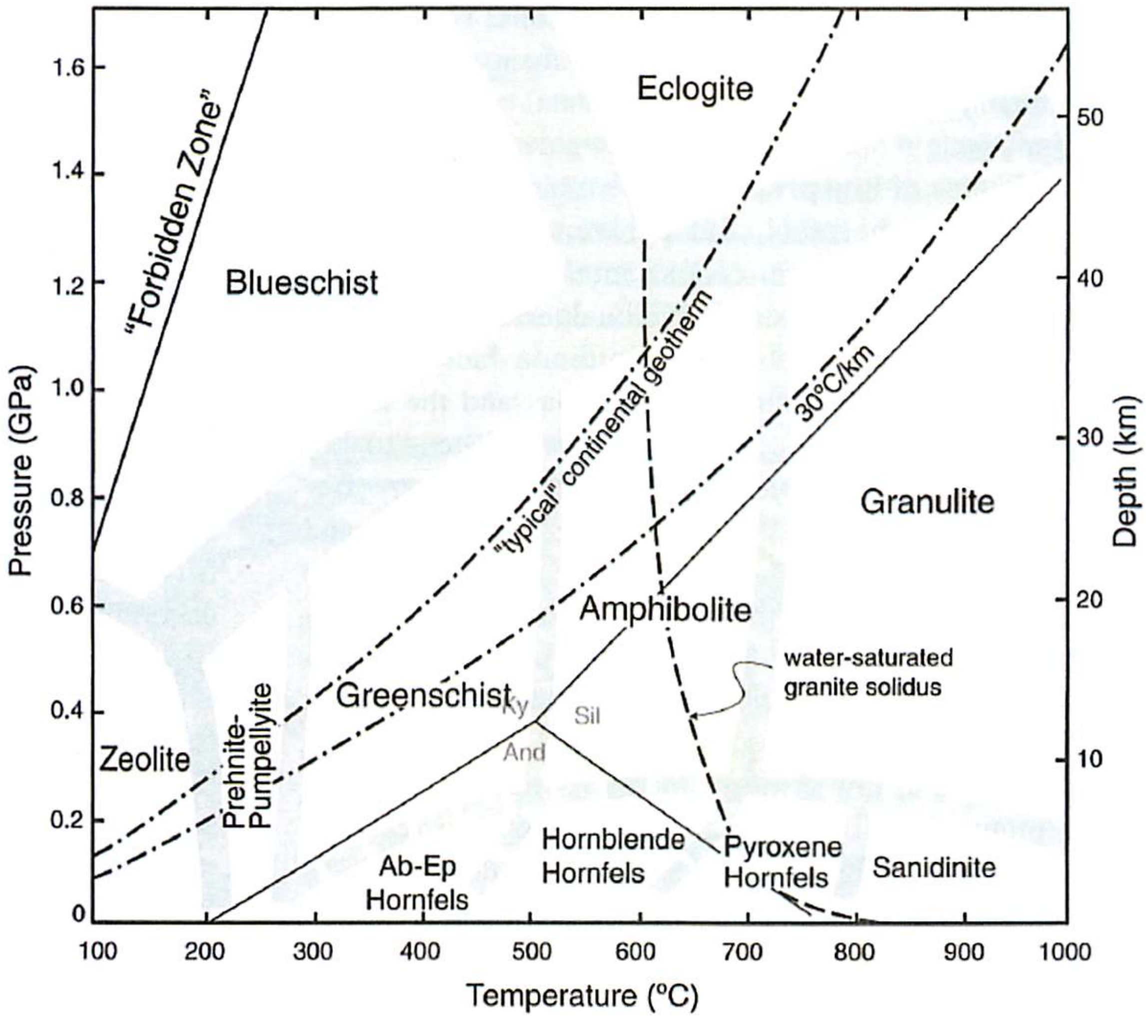
Mineralogy for Metamorphic Rock Facies

Facies	Definitive Mineral Assemblages in Mafic Rocks
Zeolite	zeolites: especially laumontite, wairakite, analcime (in place of other Ca-Al silicates such as prehnite, pumpellyite and epidote)
Prehnite-Pumpellyite	prehnite + pumpellyite (+ chlorite + albite)
Greenschist	chlorite + albite +epidote (or zoisite) + actinolite ± quartz
Amphibolite	hornblende + plagioclase (oligoclase, andesine) ± garnet
Granulite	orthopyroxene + clinopyroxene + plagioclase ± garnet
Blueschist	glaucophane + lawsonite or epidote/zoisite (± albite ± chlorite ± garnet)
Eclogite	pyralspite garnet + omphacitic pyroxene (± kyanite ± quartz), no plagioclase
Contact Facies	mineral assemblages in mafic rocks of the facies of contact metamorphism do not differ substantially from those of the corresponding regional facies at higher pressure

Metamorphic Rocks

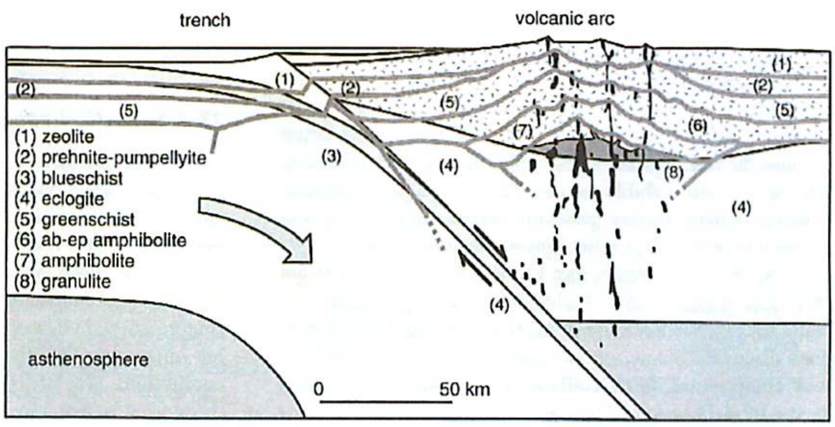
Metamorphic Rock Facies, P vs. T diagram

From Winter, 2010



Schematic of Island Arc, and the origins of Metamorphic Facies

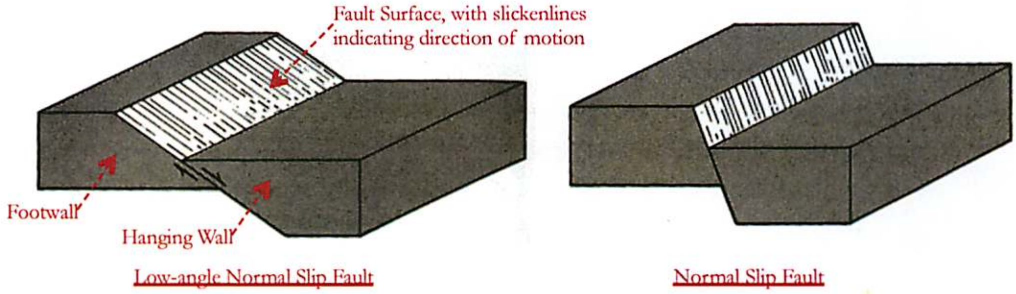
A schematic cross section of an island arc. Light gray lines are isotherms. From Winter, 2010



Structural Geology: Normal Faults

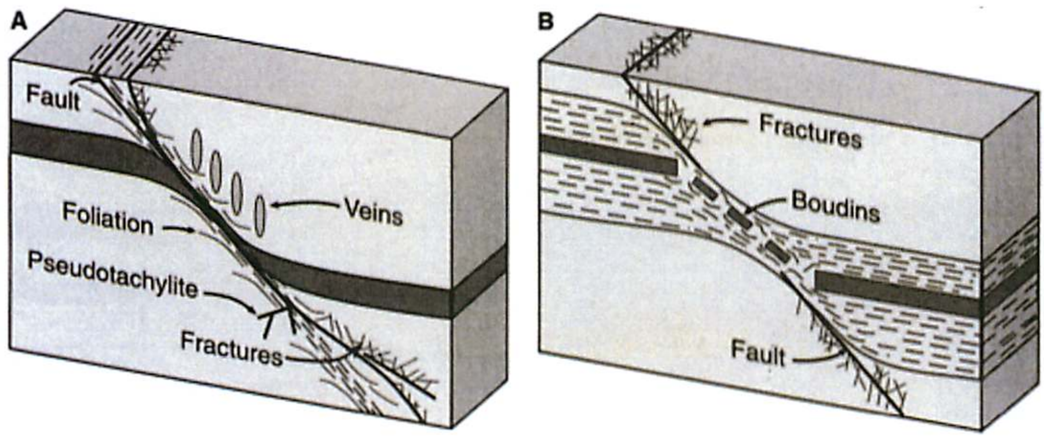
Normal Faults

In normal faults, the footwall goes up with respect to the hanging wall. Normal faults are indicative of extension. Figures from Davis & Reynolds, 1996.



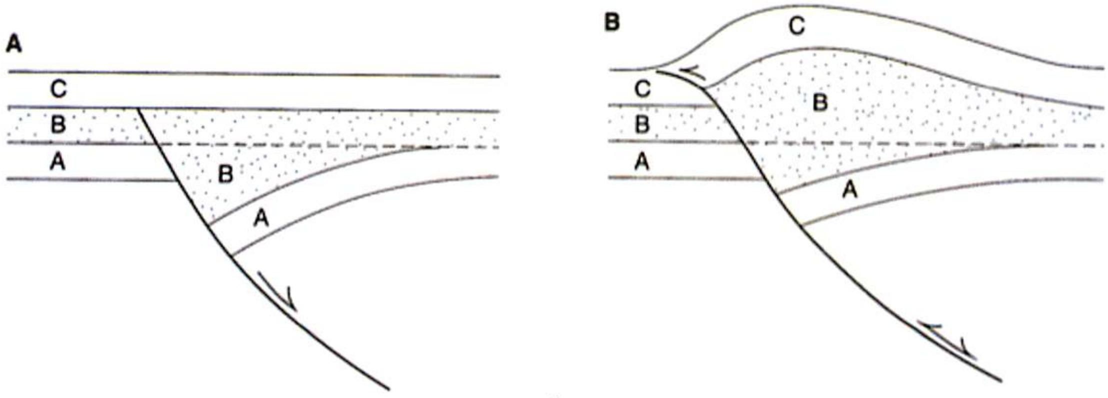
Effects of Brittle or Ductile Shear in Normal Faults

The block diagrams below illustrate the effects of changing the nature of deformation, between brittle deformation (which results in clear fault planes, fractures and fault rocks), ductile deformation (which causes deformation over a larger shear zone). Often, strata of different rheologies will behave differently, as is shown in the figure at right. The dashed layer was weak and deformed ductilely, while the middle grey layer was rigid and formed boudins. Figures from Davis & Reynolds, 1996.



Inversion Tectonics

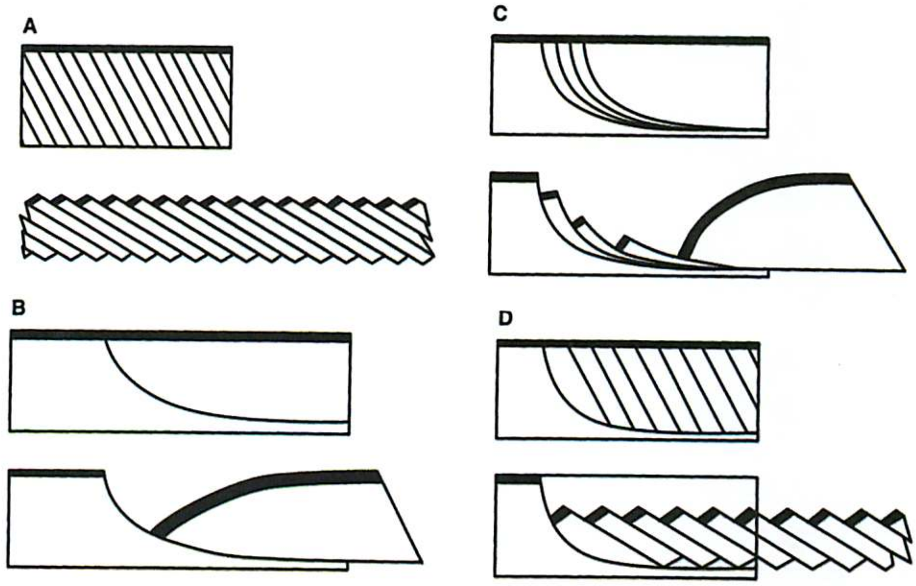
If the regional stresses change, previously inactive faults can reactivate, and change their sense of motion. In the figure at left, layer-A was formed prior to the formation of a normal fault. Layer-B and layer-C were deposited after the formation, and shut down of the fault. In the figure at the right, the fault has reactivated, though as a reverse fault. The resulting stratigraphic sequence is a combination of effects one would expect from both normal and reverse faults. Figures from Davis & Reynolds, 1996.

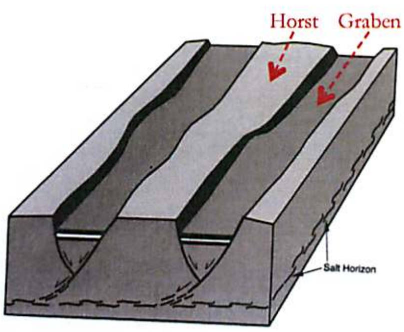


Structural Geology: Normal Faults

Normal Faults Geometries

Various normal fault geometries are possible. They all allow for lithospheric extension. (A) Domino style faulting. (B) Listric normal faulting with reverse drag. (C) Imbricate listric normal faulting. Note that listric faulting can cause extreme rotation of faulted blocks. (D) Listric normal faulting bounding a family of planar normal faults. Figures from Davis & Reynolds, 1996.



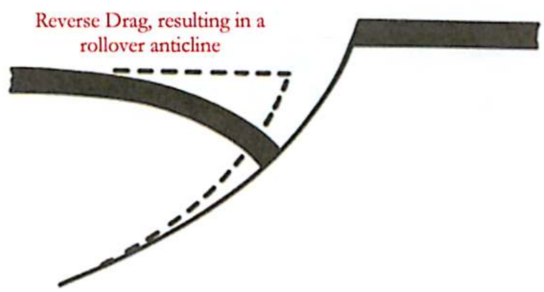


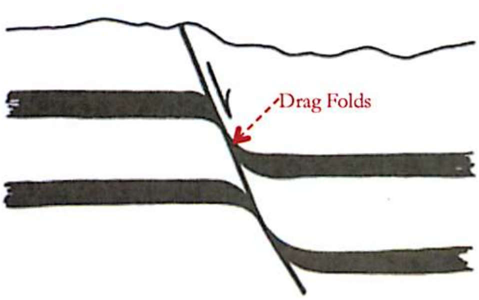
Horsts & Grabens

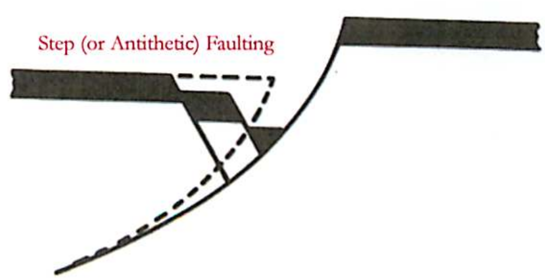
Classical formation describing fault-bounded uplifted (horsts) and down-dropped blocks (grabens). Figures from Davis & Reynolds, 1996.

Drag Folds, Reverse Drag, and Step Faulting

Faulting does not always produce clean displacement along the fault surface. Fault blocks are frequently folded or fractured, and the nature of these deformations are non-trivial. Figures from Davis & Reynolds, 1996.



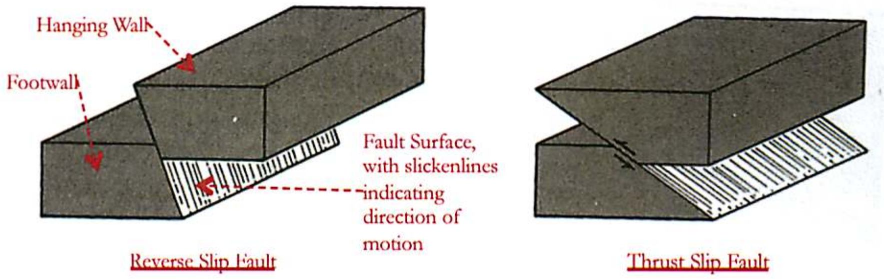




Structural Geology: Reverse & Thrust Faults

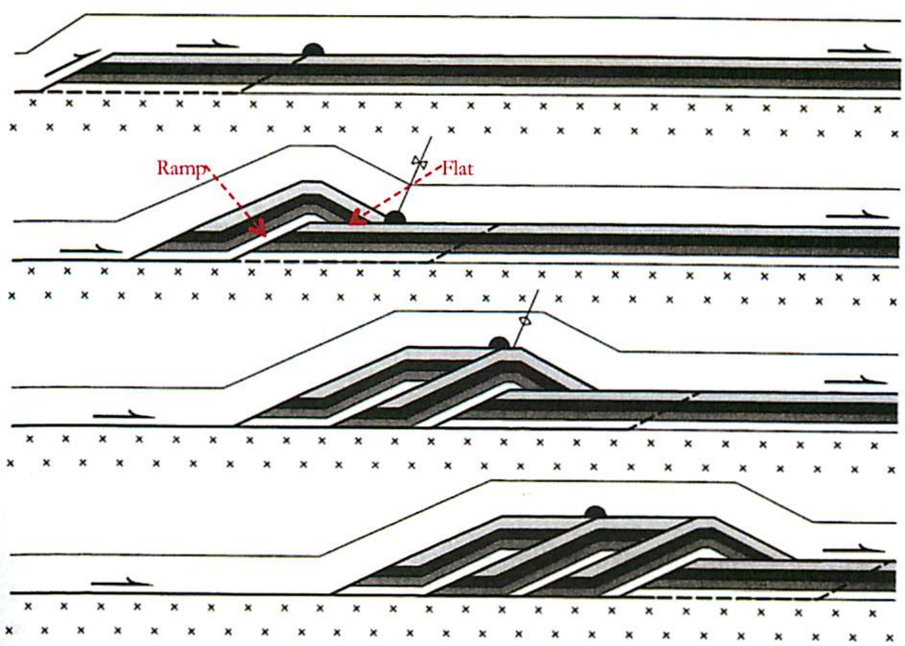
Reverse Faults

In reverse faults, the footwall goes down with respect to the hanging wall. Normal faults are indicative of compression. Thrust faults are reverse faults with fault dips <45 degrees. Figures from Davis & Reynolds, 1996.



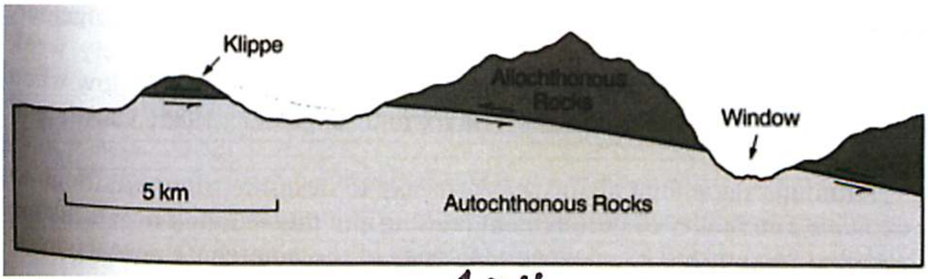
"Ramp-Flat" Geometry of Typical Thrust Fault Systems

In a regional thrust, faulted blocks are "thrust" on top of younger strata. The exact geometry of these thrust systems can vary significantly. Figures from Davis & Reynolds, 1996.

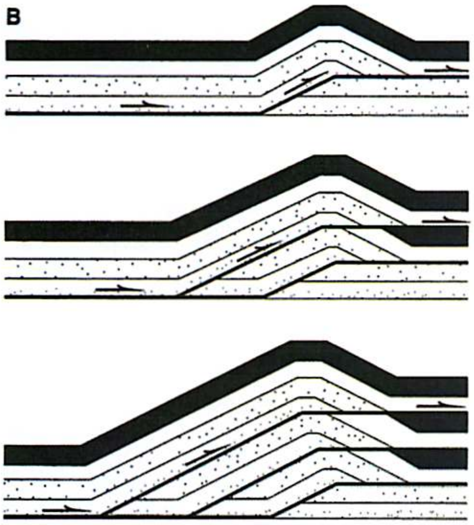


Klippe & Windows

Thrust faults move large blocks of non-indigenous rock (referred to as "allochthonous" rock) over emplaced rock (referred to as "autochthonous" rock). If the overlying allochthonous rock is eroded, it can create windows into the lower underlying autochthonous rock. Erosion can also create islands of isolated allochthonous rock, called klippe. Figures from Davis & Reynolds, 1996.



Structural Geology: Reverse & Thrust Faults

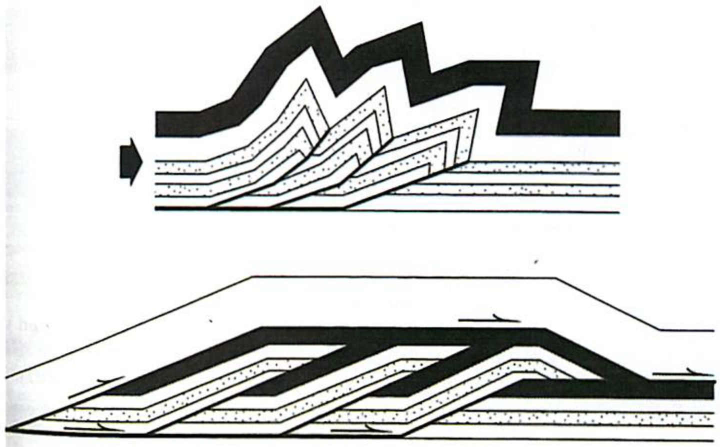


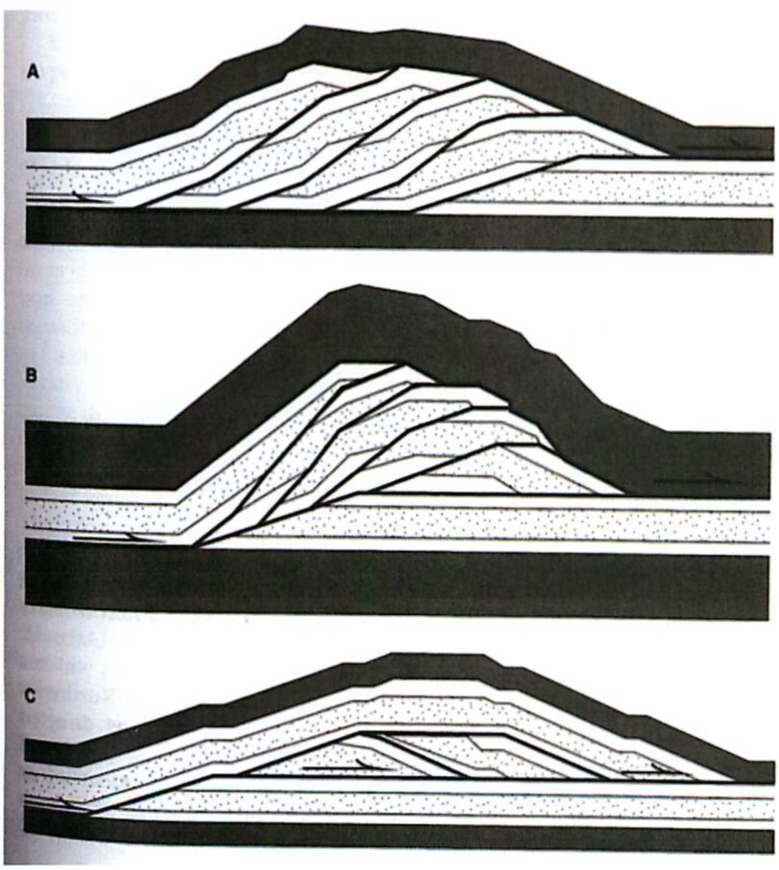
Out-of-Sequence Thrust Fault System

Unlike "in-sequence" thrust fault systems (as shown on the previous page, the "roof" of the thrust block in an out-of-sequence system becomes the "flat" for subsequent fault blocks. Figures from Davis & Reynolds, 1996.

Imbricate Fans vs. Duplexes

Two thrust fault geometries: imbricate fans (top) and duplexes (bottom). Figures from Davis & Reynolds, 1996.





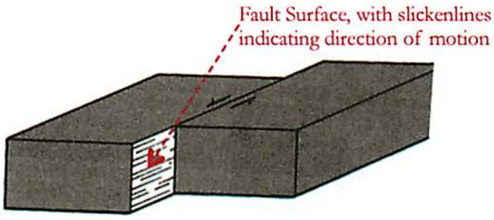
Forms of Duplexes

The exact form of a duplex or imbricate fan depends on the spacing of ramps and the amount of slip. (A) A normal duplex develops when slice length exceeds the fault slip. (B) An antiformal duplex develops when slice length and fault slip are effectively equal. (C) A forward-dipping duplex develops when the fault slip is greater than the slice length. Figures from Davis & Reynolds, 1996.

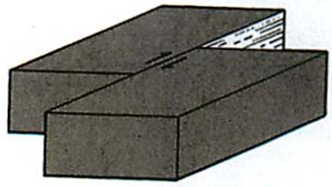
Structural Geology: Strike-Slip or Transform Faults

Strike-Slip Faults

In reverse faults, the footwall goes down with respect to the hanging wall. Normal faults are indicative of compression. Thrust faults are reverse faults with fault dips <45 degrees. Figures from Davis & Reynolds, 1996.

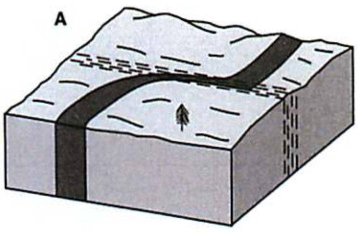


Left Lateral (Sinistral) Strike-Slip Fault

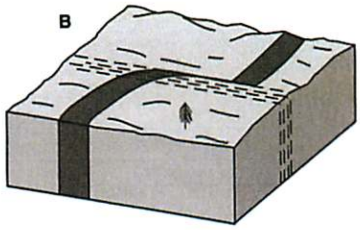

Right Lateral (Dextral) Strike-Slip Fault

Ductile Shear Zones

Shear in a strike-slip fault is not always located in a single plane. Sometimes, shear takes place over an extended region. Figures from Davis & Reynolds, 1996.



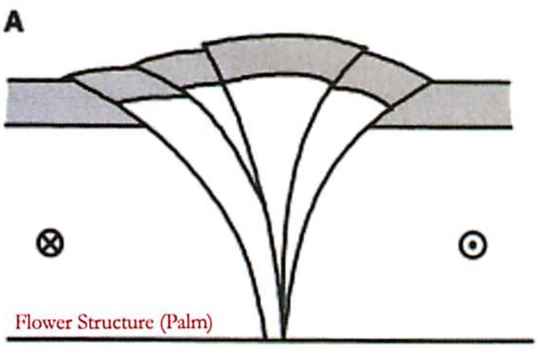
Continuous Shear Zone



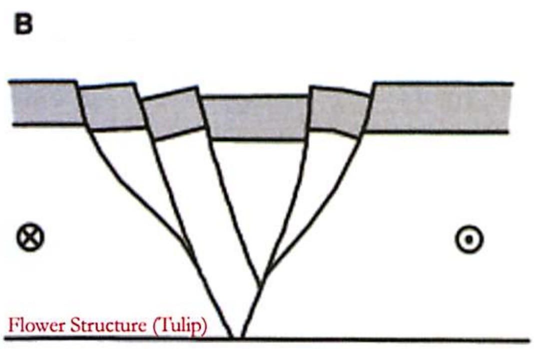
Discontinuous Shear Zone

Brittle Shear Zones

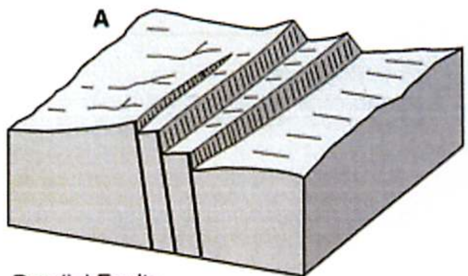
Figures from Davis & Reynolds, 1996.



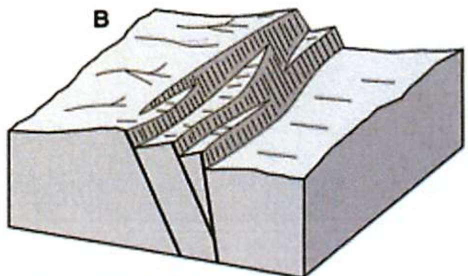
Flower Structure (Palm)



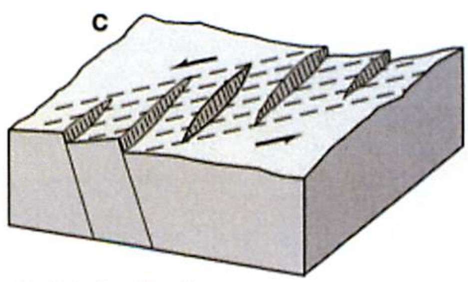
Flower Structure (Tulip)



Parallel Faults



Anastomosing Faults

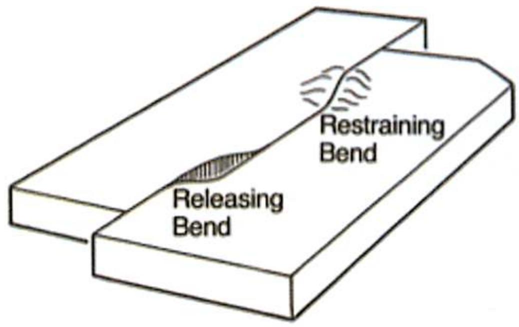


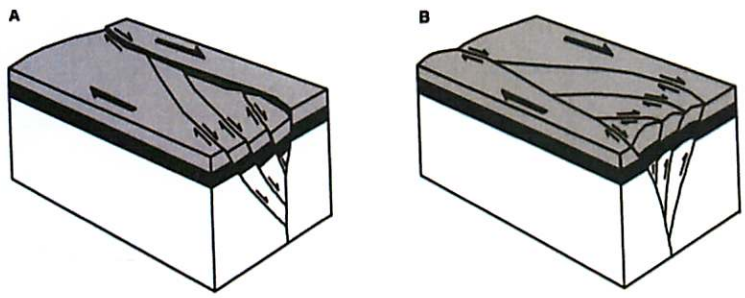
En Echelon Faults

Structural Geology: Strike-Slip or Transform Faults

Bends in Strike-Slip Faults

Strike-slip faults along irregularly curved faults creates localized regions of extension and compression. Figures from Davis & Reynolds, 1996.



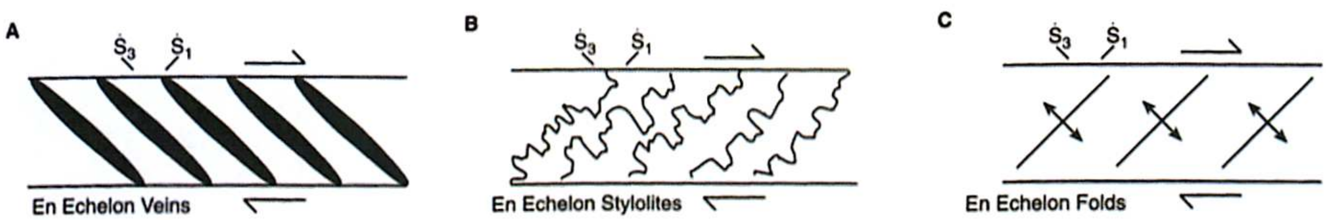


Strike-Slip Duplexes

(A) Extensional duplexes can form at releasing bends. (B) Compressional duplexes can form at restraining bends. Figures from Davis & Reynolds, 1996.

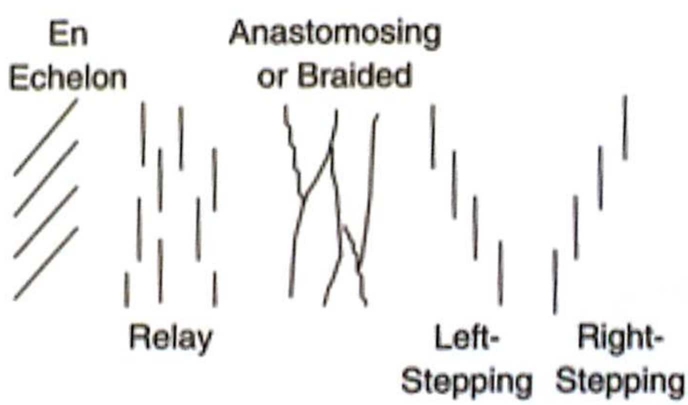
Slip Indicators in Strike-Slip Systems

In strike-slip systems, the maximum (S_1) and minimum compressional stresses (S_3) are at an angle with respect to the sense of shear. This can lead to the formation of both large scale folds and faults, or small scale fractures or veins, which are indicative to the sense of motion. Figures from Davis & Reynolds, 1996.



Even more Geometric Arrangements of Strike-Slip Faults

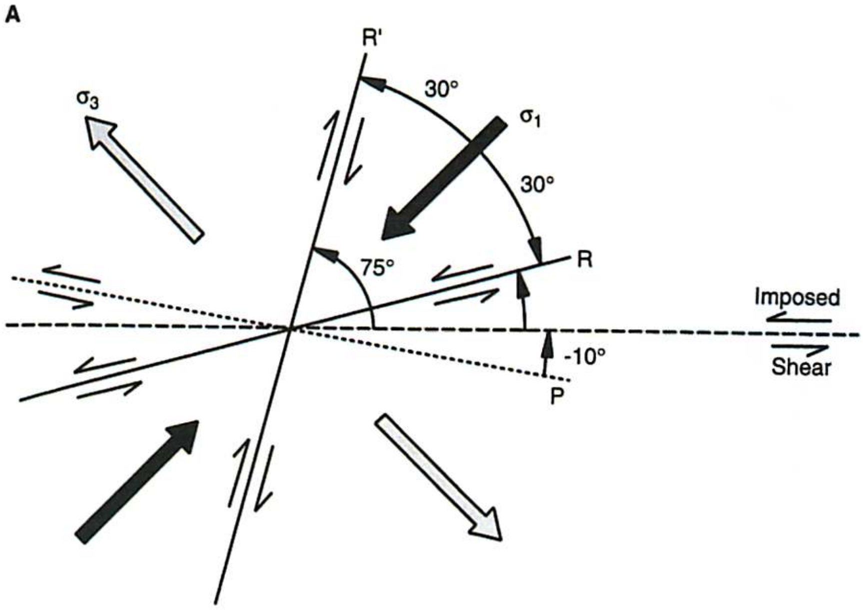
Figures from Davis & Reynolds, 1996.

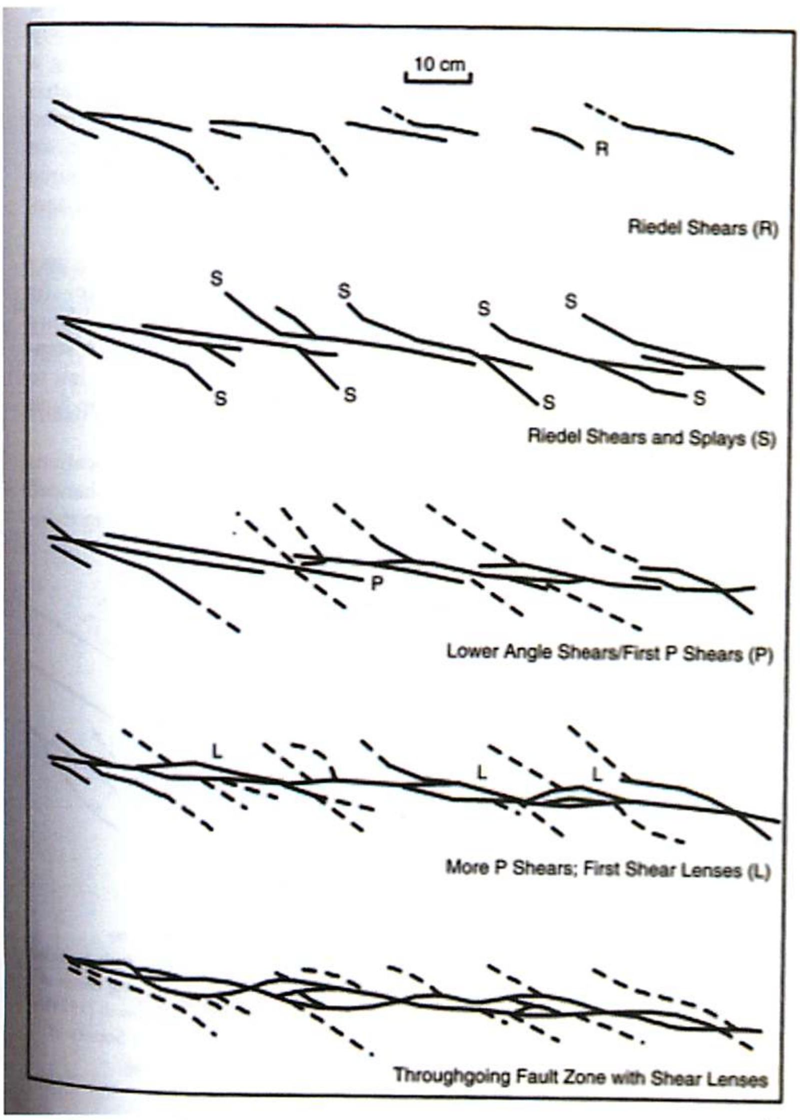


Structural Geology: Strike-Slip or Transform Faults

Riedel Shears

When under compression, rocks tend to form fail with faults forming 30° from the primary compressional stress. In a strike-slip fault, the primary compressional stress (σ_1) is 45° away from the plane of strike-slip shearing. The combination of these two facts results in fractures at interesting angles with respect to the motion of shear. These are called Riedel shears. The figure below shows a left-handed strike-slip zone. Figures from Davis & Reynolds, 1996.



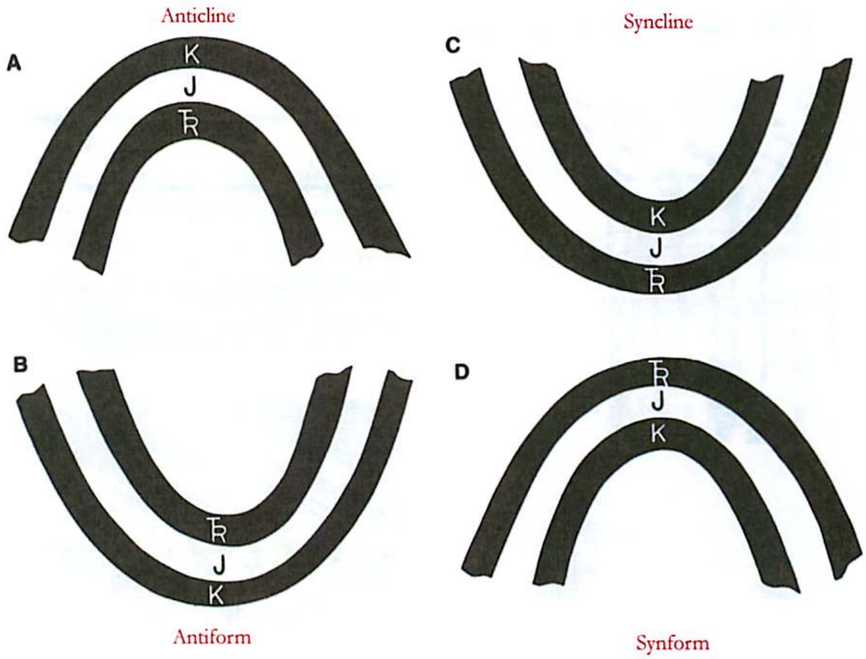


The figure at left illustrate the formation sequence of Riedel shears and other splays and shears in a right-handed strike-slip zone. Figures from Davis & Reynolds, 1996.

Structural Geology: Folds

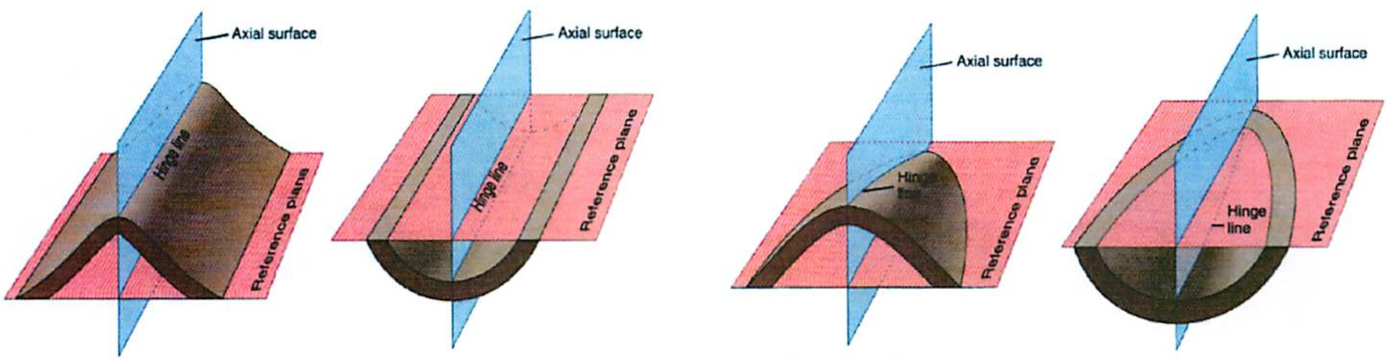
Anticlines & Antiforms, and Synclines & Synforms

Antiforms are concave-down folds, while Synforms are concave-up folds. Anticlines are antiforms were we <u>know</u> that the younger strata lie on top of older strata. Similarly, Synclines are antiforms where younger strata lie on top of older strata. Figures from Davis & Reynolds, 1996.



Plunging Folds

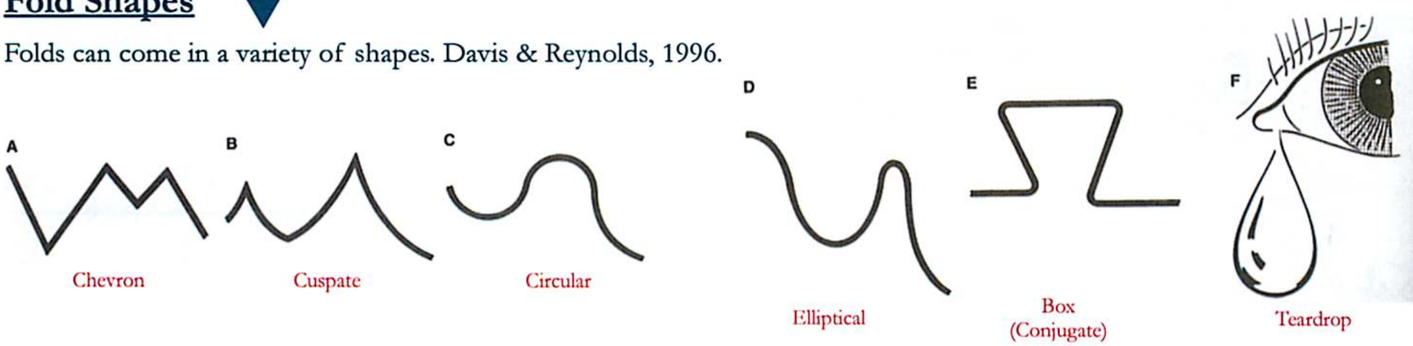
Folds (defined by hinge lines and axial surfaces) are not necessarily perpendicular to the Earth's surface. They can be dipping into or out of the surface. This can create interesting patterns of exposed surface rock, or even topography. Figures from Jones, 2001.



Non-plunging antiform   Non-plunging synform   Plunging antiform   Plunging synform

Fold Shapes

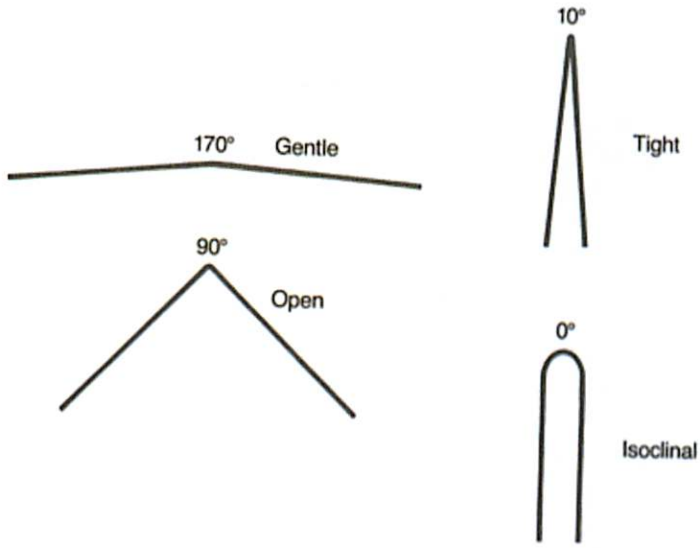
Folds can come in a variety of shapes. Davis & Reynolds, 1996.

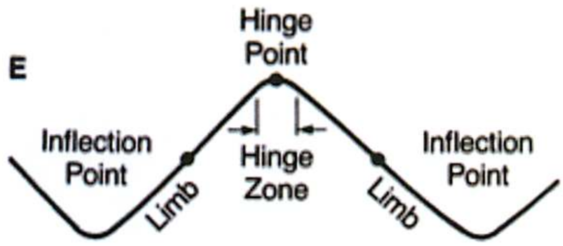


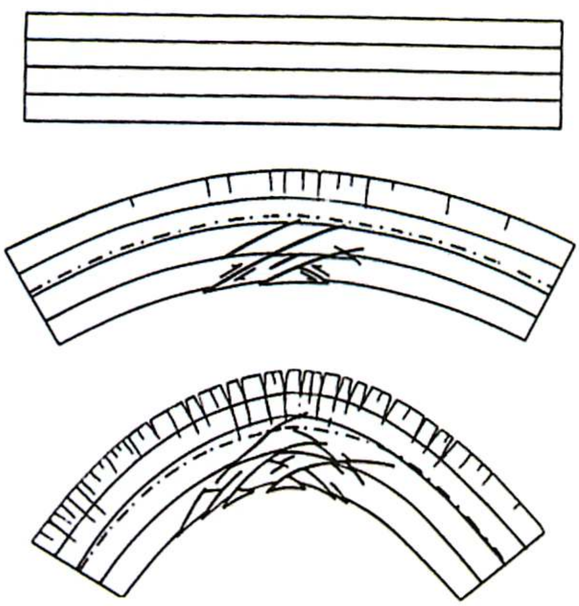
Structural Geology: Folds

Fold Tightness

Fold tightness is based upon the size of the inter-limb angle. Figures from Davis & Reynolds, 1996.





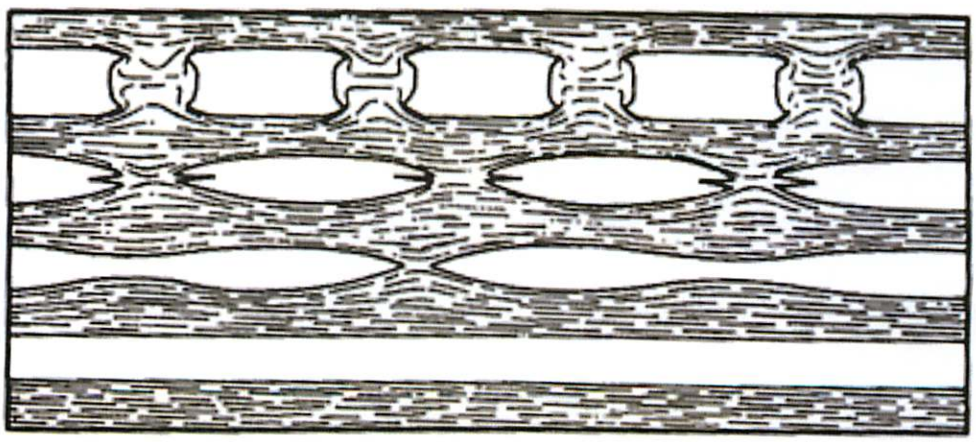


Minor Structures in Folds

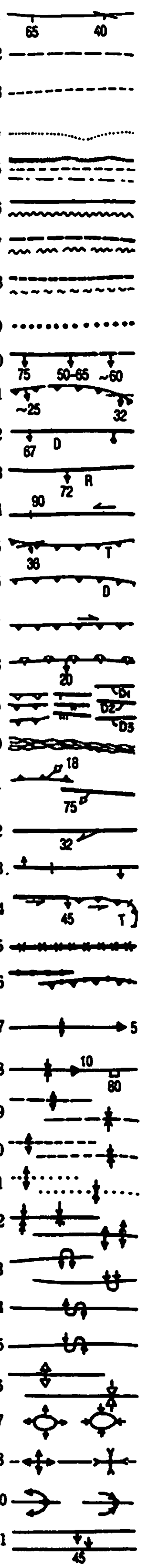
When folding layers of strata, layer-parallel stretching occurs in the outer arc of a folded layer, while layer-parallel shortening occurs in the inner arc. Figures from Davis & Reynolds, 1996.

Boudins

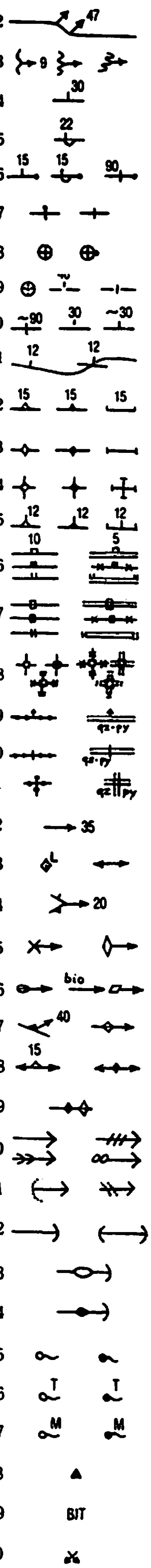
Layer-parallel stretching can pinch off layers of strata, depending on the ductility contrast between layers. This can result in pinch-and-swell structures or boudins (where the pinching completely pinches off portions of a given strata). Figures from Davis & Reynolds, 1996.



Geologic Map Symbols



1 Contact, showing dip where trace is horizontal, and strike and dip where trace is inclined
2 Contact, located approximately (give limits)
3 Contact, located very approximately, or conjectural
4 Contact, concealed beneath mapped units
5 Contact, gradational (optional symbols)
6 Fault, nonspecific, well located (optional symbols)
7 Fault, nonspecific, located approximately
8 Fault, nonspecific, assumed (existence uncertain)
9 Fault, concealed beneath mapped units
10 Fault, high-angle, showing dip (left) and approximate dips
11 Fault, low-angle, showing approximate dip and strike and dip
12 Fault, high-angle normal (D or ball and bar on downthrown side)
13 Fault, reverse (R on upthrown side)
14 Fault, high-angle strike-slip (example is left lateral)
15 Fault, thrust (T on overthrust side)
16 Fault, low-angle normal or detachment (D on downthrown side)
17 Fault, low-angle strike-slip (example is right lateral)
18 Fault, low-angle, overturned (teeth in direction of dip)
19 Optional sets of symbols for different age-groups of faults
20 Fault zone or shear zone, width to scale (dip and other accessory symbols may be added)
21 Faults with arrows showing plunge of rolls, grooves or slickensides
22 Fault showing bearing and plunge of net slip
23 Point of inflection (bar) on a high-angle fault
24 Points of inflection on a strike-slip fault passing into a thrust
25 Fault intruded by a dike
26 Faults associated with veins
27 Anticline, showing trace and plunge of hinge or crest line (specify)
28 Syncline (as above), showing dip of axial surface or trough surface
29 Folds (as above), located approximately
30 Folds, conjectural
31 Folds beneath mapped units
32 Asymmetric folds with steeper limbs dipping north (optional symbols)
33 Anticline (top) and syncline, overturned
34 Antiformal (inverted) syncline
35 Synformal (inverted) anticline
36 Antiform (top) and synform (stratigraphic sequence unknown)
37 Separate dome (left) and basin
38 Culmination (left) and depression
40 Vertically plunging anticline and syncline
41 Monocline, south-facing, showing traces of axial surfaces



42 Steeply plunging monocline or flexure, showing trace in horizontal section and plunge of hinges
43 Plunge of hinge lines of small folds, showing shapes in horizontal section
44 Strike and dip of beds or bedding
45 Strike and dip of overturned beds
46 Strike and dip of beds where stratigraphic tops are known from primary features
47 Strike and dip of vertical beds or bedding (dot is on side known to be stratigraphically the top)
48 Horizontal beds or bedding (as above)
49 Approximate (typically estimated) strike and dip of beds
50 Strike of beds exact but dip approximate
51 Trace of single bed, showing dip where trace is horizontal and where it is inclined
52 Strike and dip of foliation (optional symbols)
53 Strike of vertical foliation
54 Horizontal foliation
55 Strike and dip of bedding and parallel foliation
56 Strike and dip of joints (left) and dikes (optional symbols)
57 Vertical joints (left) and dikes
58 Horizontal joints (left) and dikes
59 Strike and dip of veins (optional symbols)
60 Vertical veins
61 Horizontal veins
62 Bearing (trend) and plunge of lineation
63 Vertical and horizontal lineations
64 Bearing and plunge of cleavage-bedding intersection
65 Bearing and plunge of cleavage-cleavage intersections
66 Bearings of pebble, mineral, etc. lineations
67 Bearing of lineations in plane of foliation
68 Horizontal lineation in plane of foliation
69 Vertical lineation in plane of vertical foliation
70 Bearing of current from primary features; from upper left: general; from cross-bedding; from flute casts; from imbrication
71 Bearing of wind direction from dune forms (left) and cross-bedding
72 Bearing of ice flow from striations (left) and orientation of striations
73 Bearing of ice flow from drumlins
74 Bearing of ice flow from crag and tail forms
75 Spring
76 Thermal spring
77 Mineral spring
78 Asphaltic deposit
79 Bituminous deposit
80 Sand, gravel, clay, or placer pit

From Compton, 1985

Geologic Map Symbols

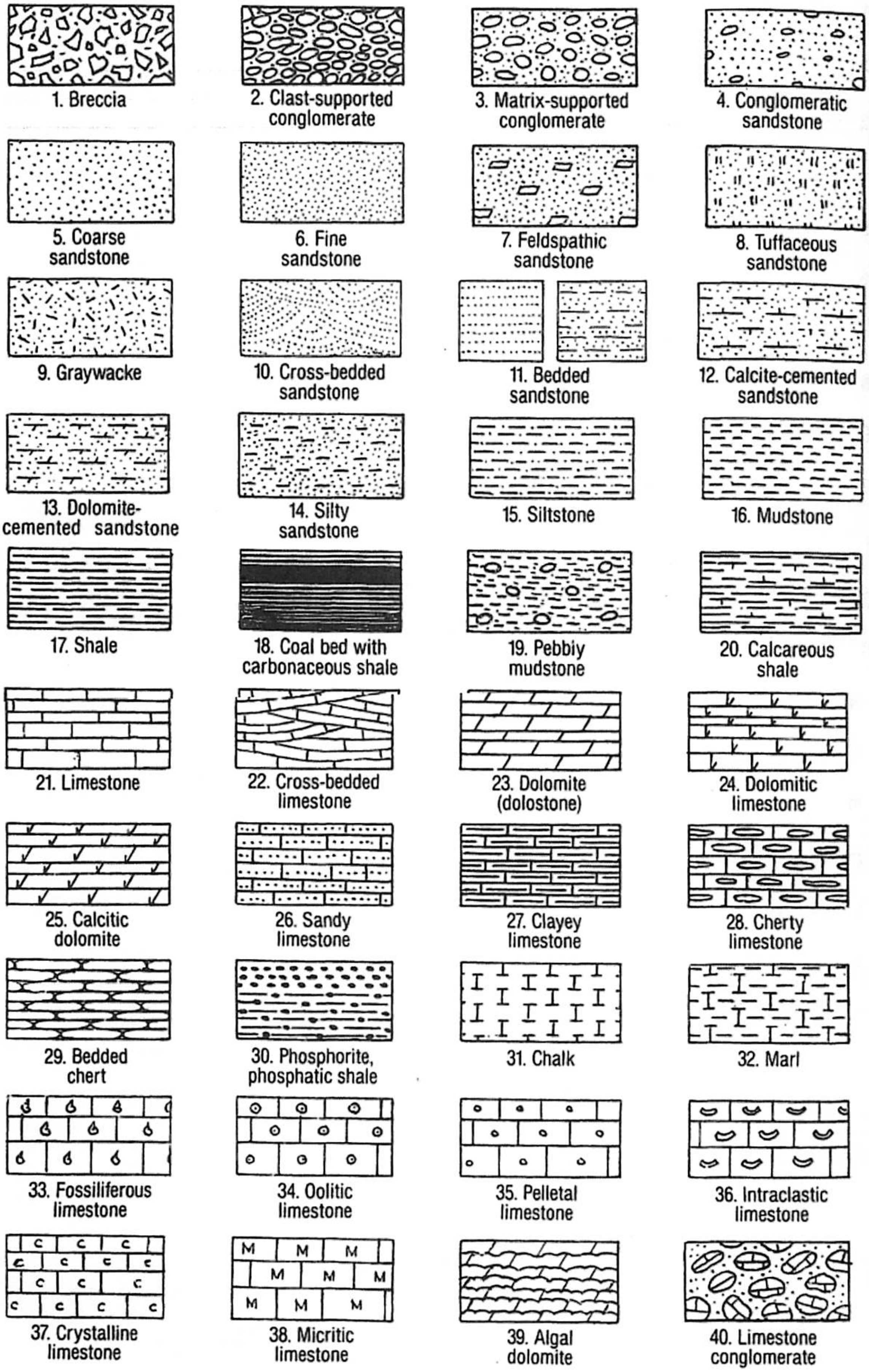
81		Mine, quarry, or open pit
82		Shafts: vertical, inclined, and abandoned
83		Adit, open (left) and inaccessible
84	x	Trench (left) and prospect
85		Water wells: flowing, nonflowing, and dry
86		Oil well (left) and gas well
87		Well drilled for oil or gas, dry
88		Wells with shows of oil (left) and gas
89		Oil or gas well, abandoned (left) and shut in
90		Drilling well or well location
91		Glory hole, open pit, or quarry, to scale
92		Dump or fill, to scale

Fossil and Structural Symbols for Stratigraphic Columns

- Algae
- Algal mats
- Ammonites
- Belemnites
- Brachiopods
- Bryozoans
- Corals, solitary
- Corals, colonial
- Crinoids
- Echinoderms
- Echinoids
- Fish bones
- Fish scales
- Tree trunk fallen
- Trilobites
- Vertebrates
- Wood
- Beds distinct
- Beds obscure
- Unbedded
- Graded beds
- Planar cross-bedding
- Trough cross-bedding
- Ripple structures
- Cut and fill
- Load casts
- Foraminifers, general
- Foraminifers, large
- Fossils
- Fossils abundant
- Fossils sparse
- Gastropods
- Graptolites
- Leaves
- Ostracodes
- Pelecypods
- Root molds
- Spicules
- Stromatolites
- Tree trunk in place
- Scour casts
- Convolution
- Slumped beds
- Paleosol
- Mud cracks
- Salt molds
- Burrows
- Pellets
- Oolites
- Pisolites
- Intraclasts
- Stylolite
- Concretion
- Calcitic concretion

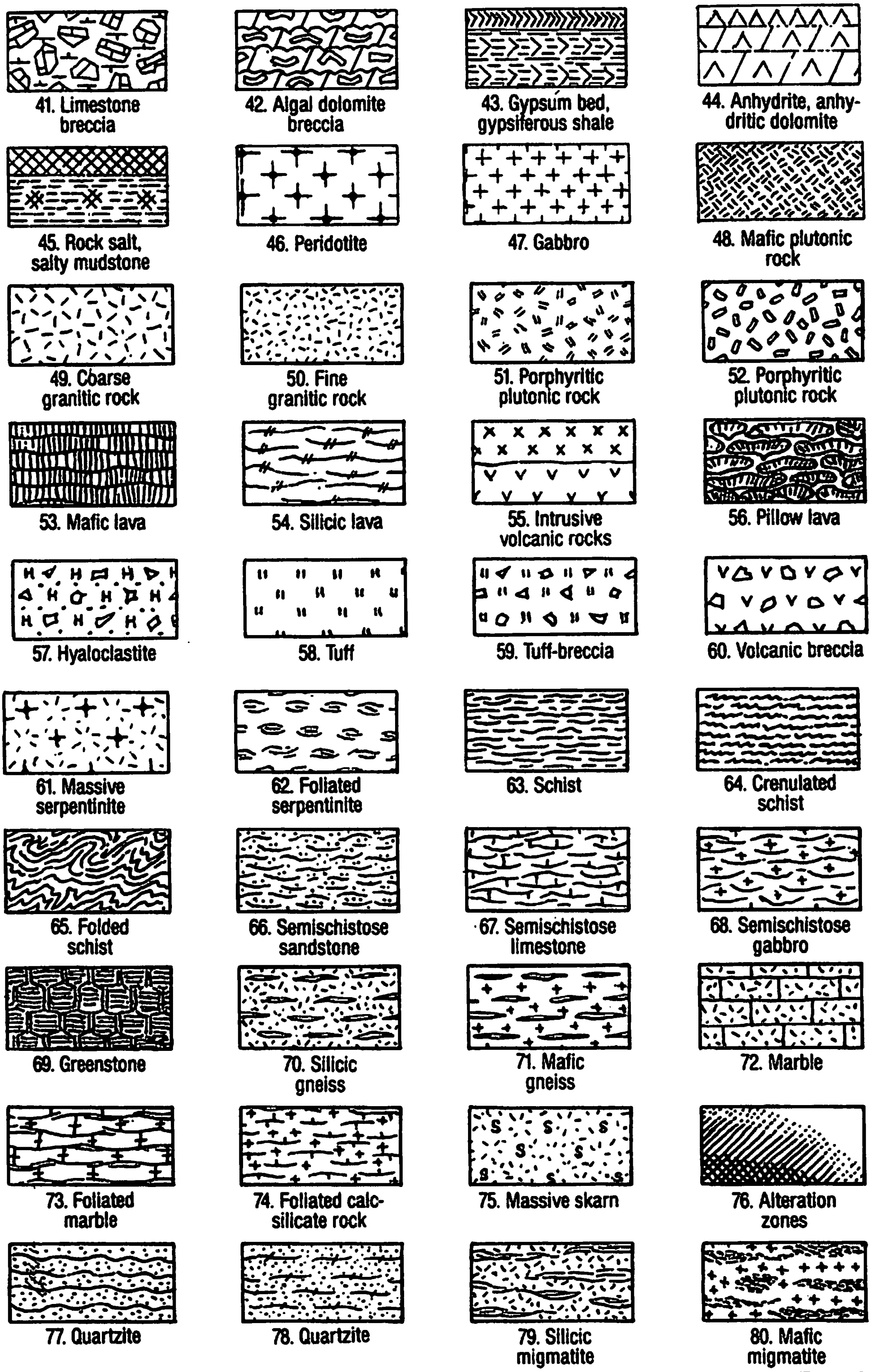
From Compton, 1985

Lithologic Patterns for Stratigraphic Columns & Cross Sections



From Compton, 1985

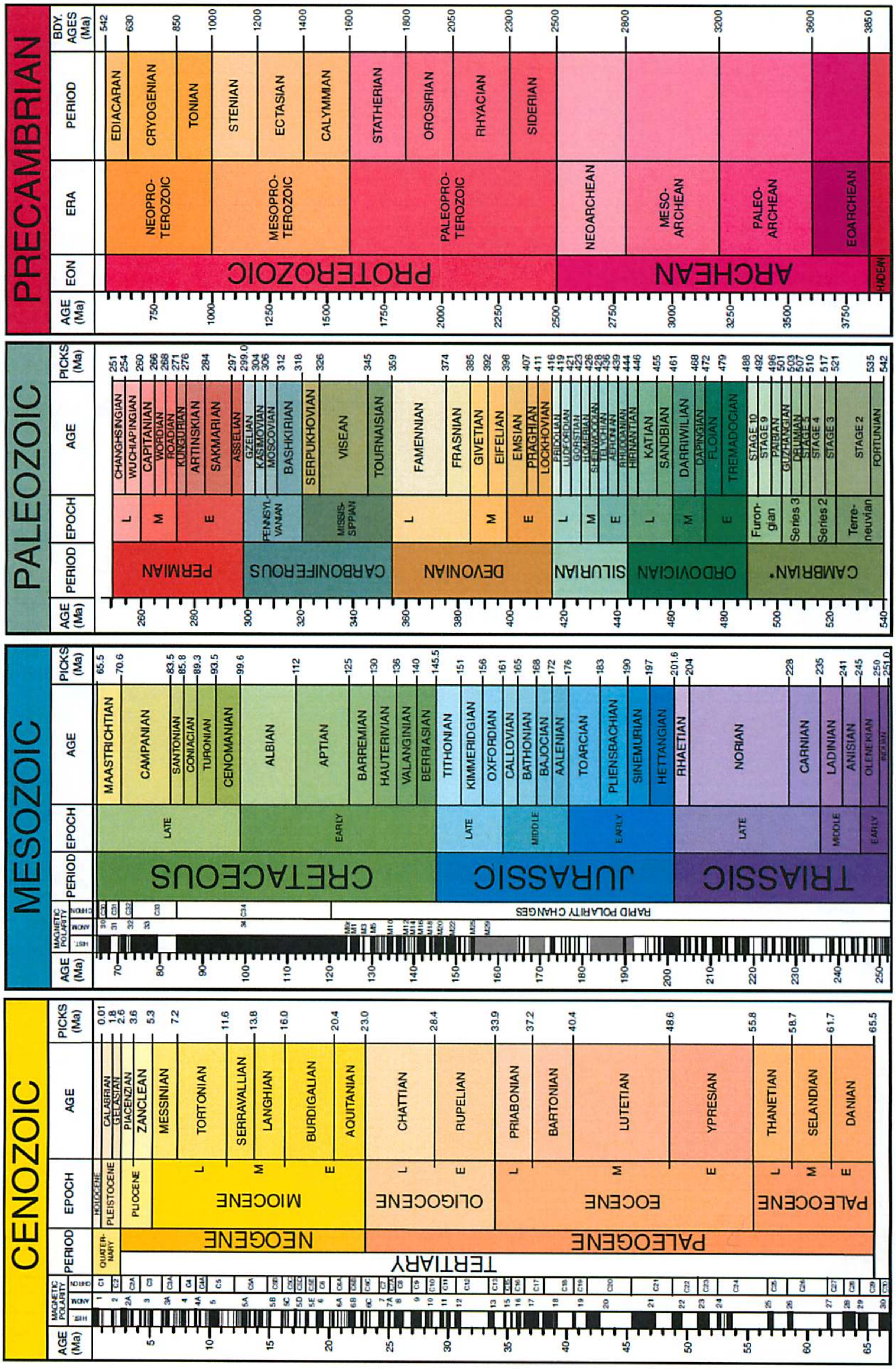
Lithologic Patterns for Stratigraphic Columns & Cross Sections



41. Limestone breccia
42. Algal dolomite breccia
43. Gypsum bed, gypsiferous shale
44. Anhydrite, anhydritic dolomite
45. Rock salt, salty mudstone
46. Peridotite
47. Gabbro
48. Mafic plutonic rock
49. Coarse granitic rock
50. Fine granitic rock
51. Porphyritic plutonic rock
52. Porphyritic plutonic rock
53. Mafic lava
54. Silicic lava
55. Intrusive volcanic rocks
56. Pillow lava
57. Hyaloclastite
58. Tuff
59. Tuff-breccia
60. Volcanic breccia
61. Massive serpentinite
62. Foliated serpentinite
63. Schist
64. Crenulated schist
65. Folded schist
66. Semischistose sandstone
67. Semischistose limestone
68. Semischistose gabbro
69. Greenstone
70. Silicic gneiss
71. Mafic gneiss
72. Marble
73. Foliated marble
74. Foliated calc-silicate rock
75. Massive skarn
76. Alteration zones
77. Quartzite
78. Quartzite
79. Silicic migmatite
80. Mafic migmatite

From Compton, 1985

Geologic Timescale



2009 version, from the Geologic Society of A

Sunrise and Sunset

THURSDAY MARCH 28th 2013

Event	Time	Altitude	Azimuth
Minimum altitude:	00:48	-52.0°	0°
Astronomical twilight begins:	05:10	-18.0°	73°
Nautical twilight begins:	05:40	-12.0°	77°
Civil twilight begins:	06:10	-6.0°	82°
Sunrise:	06:35	-0.8°	86°
Maximum altitude:	12:48	58.4°	180°
Sunset:	19:01	-0.8°	275°
Civil twilight ends:	19:27	-6.0°	278°
Nautical twilight ends:	19:56	-12.0°	283°
Astronomical twilight ends:	20:27	-18.0°	288°

FRIDAY MARCH 29th 2013

Event	Time	Altitude	Azimuth
Minimum altitude:	00:47	-51.6°	360°
Astronomical twilight begins:	05:08	-18.0°	72°
Nautical twilight begins:	05:38	-12.0°	77°
Civil twilight begins:	06:08	-6.0°	81°
Sunrise:	06:34	-0.8°	85°
Maximum altitude:	12:48	58.8°	180°
Sunset:	19:02	-0.8°	275°
Civil twilight ends:	19:27	-6.0°	279°
Nautical twilight ends:	19:57	-12.0°	283°
Astronomical twilight ends:	20:28	-18.0°	288°

SATURDAY MARCH 30th 2013

Event	Time	Altitude	Azimuth
Minimum altitude:	00:47	-51.2°	360°
Astronomical twilight begins:	05:07	-18.0°	72°
Nautical twilight begins:	05:37	-12.0°	76°
Civil twilight begins:	06:07	-6.0°	81°
Sunrise:	06:32	-0.8°	85°
Maximum altitude:	12:47	59.2°	180°
Sunset:	19:03	-0.8°	276°
Civil twilight ends:	19:28	-6.0°	279°
Nautical twilight ends:	19:58	-12.0°	284°
Astronomical twilight ends:	20:29	-18.0°	289°

SUNDAY MARCH 31st 2013

Event	Time	Altitude	Azimuth
Minimum altitude:	00:47	-50.8°	360°
Astronomical twilight begins:	05:05	-18.0°	71°
Nautical twilight begins:	05:35	-12.0°	76°
Civil twilight begins:	06:05	-6.0°	80°
Sunrise:	06:31	-0.8°	84°
Maximum altitude:	12:47	59.6°	180°
Sunset:	19:03	-0.8°	276°
Civil twilight ends:	19:29	-6.0°	280°
Nautical twilight ends:	19:59	-12.0°	284°
Astronomical twilight ends:	20:30	-18.0°	289°

Data from heavens-above.com, calculated for location at Kelso Dunes. Note: exact time and position may vary, depending on campsite location.

Satellite Predictions

Data from heavens-above.com, calculated for location at Kelso Dunes. Note: exact time, magnitude, and position may vary, depending on campsite location.

THURSDAY MARCH 28th 2013

Satellite		Start			Highest Point			End		
	(mag)	Time	Alt.	Az.	Time	Alt.	Az.	Time	Alt.	Az.
H-2A R/B	4.4	17:15:51	10°	WSW	17:20:46	58°	S	18:00:13	10°	ESE
Sich 1 Rocket	3.6	19:21:32	10°	N	19:26:03	73°	E	19:30:29	10°	SSE
Meteor 2-2 Rocket	4.2	19:22:51	10°	S	19:28:25	65°	E	19:33:58	10°	NNE
Cosmos 1605 Rocket	4.4	19:26:17	10°	SSE	19:31:51	39°	E	19:37:25	10°	NNE
H-2A R/B	2.9	19:26:44	10°	N	19:31:24	84°	WNW	19:35:56	10°	SSW
GOCE	3.3	19:27:06	10°	SE	19:29:00	33°	ENE	19:30:55	10°	N
CZ-2D R/B	4.4	19:29:49	10°	SE	19:33:31	37°	ENE	19:37:14	10°	N
Helios 1A Rocket	3.7	19:31:26	10°	N	19:35:39	61°	WNW	19:39:48	10°	SSW
SL-8 R/B	2.7	19:31:49	10°	SSE	19:35:00	67°	ENE	19:38:11	10°	N
CZ-2C R/B	3.8	19:32:12	10°	ESE	19:35:26	18°	ENE	19:38:36	10°	NNE
Cosmos 1733 Rocket	3.3	19:34:00	10°	N	19:38:13	47°	E	19:42:23	10°	SSE
DELTA 2 R/B (1)	4.1	19:35:07	10°	W	19:40:37	58°	N	19:46:09	10°	ENE
Cosmos 1607	4.2	19:36:13	10°	NNW	19:42:12	51°	ENE	19:48:06	10°	SE
COSMOS 2455	3.5	19:43:02	10°	SSE	19:48:16	32°	ESE	19:53:31	10°	NE
SPOT 1/Viking Rocket	4.1	19:43:51	10°	SE	19:48:35	37°	ENE	19:53:22	10°	N
SJ-12	4.2	19:44:52	10°	S	19:49:02	76°	WSW	19:53:13	10°	NNW
Okean 2 Rocket	3.8	19:48:40	10°	NNE	19:52:38	32°	ENE	19:56:35	10°	SE
Cosmos 1220	4.3	19:51:35	10°	W	19:53:58	18°	NW	19:56:22	10°	N
Cosmos 1943	3.7	19:52:26	10°	SSW	19:58:04	65°	WNW	20:03:44	10°	NNE
Cosmos 2369 Rocket	2.2	19:53:58	10°	NNW	19:59:30	59°	ENE	20:04:59	10°	SSE
CENTAUR R/B	3	19:55:34	10°	NNW	20:03:12	81°	ENE	20:11:05	10°	SSE
Cosmos 1544	4.2	20:10:21	26°	E	20:10:21	26°	E	20:13:23	10°	NNE
Cosmos 2123 Rocket	4	20:08:53	10°	N	20:15:11	82°	E	20:21:29	10°	S
Skynet4D Del rocket	4.5	20:11:48	10°	WSW	20:17:01	38°	S	20:20:00	24°	SE
COSMOS 2406	3.9	20:12:33	10°	SW	20:18:12	59°	WNW	20:23:54	10°	NNE
Cosmos 1703	4.2	20:13:05	10°	NNE	20:16:35	28°	ENE	20:16:41	28°	E
Cosmos 1674	2.7	20:14:46	10°	N	20:18:44	88°	W	20:22:42	10°	S
Cosmos 1153 Rocket	4.4	20:16:10	10°	S	20:22:18	78°	E	20:28:33	10°	N
HST	3	20:18:11	10°	S	20:19:35	13°	SSE	20:19:35	13°	SSE
PAYLOAD A	3.8	20:19:05	10°	SSE	20:23:57	87°	ENE	20:28:42	10°	NNW
ADEOS II	4.3	20:22:10	10°	SSW	20:26:29	26°	W	20:30:50	10°	NW
Cosmos 2100 Rocket	4	20:23:52	10°	SSE	20:29:48	54°	E	20:35:46	10°	NNE
Cosmos 1452 Rocket	3.7	20:25:32	10°	NNW	20:30:48	72°	WSW	20:35:48	11°	S
Fregat R/B Cluster 11	3	20:26:02	10°	NNW	20:29:13	80°	ENE	20:29:26	70°	ESE
Cosmos 2016 Rocket	4.4	20:28:47	23°	SE	20:32:03	39°	E	20:37:52	10°	NNE
Cosmos 1782 Rocket	3.6	20:27:40	10°	N	20:32:06	61°	E	20:33:41	37°	SE
Cosmos 1484 Rocket	3.1	20:31:33	42°	ENE	20:31:33	42°	ENE	20:34:58	10°	N
Cosmos 1340	2.6	20:28:02	10°	S	20:31:59	75°	E	20:35:58	10°	NNE
Cosmos 1908 Rocket	3.7	20:28:08	10°	N	20:32:37	79°	W	20:36:49	12°	S
OAO 1	4.4	20:28:33	10°	WSW	20:34:04	80°	S	20:36:18	37°	E
OAO 2 Rocket	3.3	20:29:21	10°	W	20:34:32	88°	N	20:36:28	40°	E
Atlas Centaur 2	4.2	20:32:42	10°	WSW	20:37:49	24°	SSW	20:42:03	15°	SSE
Cosmos 1943 Rocket	3.8	20:37:45	10°	NNE	20:41:10	18°	NE	20:41:10	18°	NE
YAOGAN 11	4.2	20:43:32	54°	ESE	20:44:14	62°	ENE	20:48:45	10°	N
Cosmos 2061 Rocket	4	20:41:05	10°	S	20:47:16	84°	W	20:53:34	10°	N
USA 229 DEB	3.8	20:41:22	10°	NNW	20:48:08	56°	NE	20:50:07	42°	ESE
USA 229	3.8	20:41:28	10°	NNW	20:48:15	56°	NE	20:50:13	42°	ESE
EXPRESS MD2	3.8	20:43:35	10°	SW	20:47:00	41°	SSW	20:47:00	41°	SSW
OAO 3 Rocket	3	20:45:23	10°	W	20:50:16	85°	S	20:50:56	67°	E
Aureole 1 Rocket	4	20:50:03	10°	NW	20:52:40	28°	WSW	20:53:11	26°	WSW
IDEFIX/ARIANE 42P	3.4	20:56:21	35°	NE	20:56:21	35°	NE	21:00:15	10°	N
Geosat	4.4	20:54:16	30°	S	20:56:41	59°	WSW	21:01:39	10°	NNW
Cosmos 44 Rocket	3	21:04:58	1°	NNE	21:04:58	1°	NNE	20:58:25	70°	NE
Milstar 3	4.1	20:59:35	10°	W	21:07:25	51°	S	21:11:57	36°	SE
Cosmos 2173 Rocket	3.9	21:01:06	10°	S	21:07:16	81°	W	21:13:24	10°	N
Cosmos 2151 Rocket	4.4	21:03:33	10°	N	21:06:39	42°	NNE	21:06:39	42°	NNE
Meteor 1-30 Rocket	4.4	21:03:48	10°	N	21:06:58	38°	WNW	21:06:58	38°	WNW
Cosmos 489 Rocket	4.4	21:04:26	10°	N	21:10:44	64°	ENE	21:11:01	63°	E
Cosmos 1048 Rocket	4.1	21:06:05	10°	SSW	21:11:18	75°	WNW	21:16:38	10°	NNE
Okean 1-7	3.7	21:12:04	45°	SW	21:12:58	55°	W	21:17:16	10°	N
CZ-2C R/B	3.5	21:10:44	21°	SSW	21:13:25	39°	W	21:17:50	10°	NNW
SL-14 R/B	4.5	21:10:06	10°	NNW	21:12:42	39°	NNW	21:12:42	39°	NNW
Cosmos 1459 Rocket	4.4	21:11:26	10°	SSW	21:17:35	62°	W	21:23:52	10°	N
DELTA 2 R/B (1)	4	21:22:05	10°	WNW	21:27:20	57°	N	21:27:20	57°	N
COSMOS 2455	4.3	21:28:37	10°	WSW	21:34:04	35°	WNW	21:39:33	10°	N
SL-08 R/B	4.5	21:36:19	73°	W	21:36:31	74°	W	21:42:38	10°	N
ATLAS 2AS CENTAUR R/B	3.3	21:34:24	10°	NNW	21:41:49	53°	NE	21:41:49	53°	NE
BREEZE-M DEB (TANK)	4.4	22:08:12	23°	NE	22:08:12	23°	NE	22:02:19	39°	W
Cosmos 1943 Rocket	4	22:20:13	10°	NNW	22:22:44	27°	NW	22:22:44	27°	NW

Satellite Predictions

FRIDAY MARCH 29th 2013

Satellite			Start			Highest Point			End	
	(mag)	Time	Alt.	Az.	Time	Alt.	Az.	Time	Alt.	Az.
Cosmos 1821 Rocket	4.3	19:15:57	10°	SSE	19:21:48	46°	E	19:27:45	10°	NNE
Meteor 2-2 Rocket	4.2	19:22:52	10°	S	19:28:29	78°	E	19:34:06	10°	NNE
Cosmos 1624 Rocket	4.1	19:24:02	10°	NNW	19:29:24	89°	WSW	19:34:43	10°	SSE
USA 234	3.9	19:31:15	10°	NE	19:37:38	58°	NW	19:43:59	10°	WSW
Cosmos 1862 Rocket	3.6	19:31:21	10°	S	19:35:39	58°	E	19:39:57	10°	NNE
OAO 2 Rocket	3.4	19:32:50	10°	W	19:37:58	89°	N	19:43:06	11°	E
OAO 3 Rocket	3.3	19:32:55	10°	WSW	19:37:48	67°	SSE	19:42:33	10°	E
CSL-04 DEB	4.4	19:34:37	10°	NNE	19:38:43	76°	ESE	19:42:53	10°	S
Cosmos 2221 Rocket	3.6	19:36:21	10°	S	19:40:52	67°	E	19:45:24	10°	NNE
Cosmos 1934 Rocket	4	19:37:18	10°	S	19:43:38	80°	E	19:50:01	10°	N
Cosmos 1943	3.7	19:37:42	10°	SSW	19:43:20	68°	WNW	19:49:02	10°	NNE
Cosmos 2369 Rocket	2.3	19:38:48	10°	NNW	19:44:19	56°	ENE	19:49:46	10°	SE
H-2A R/B	3.5	19:41:19	10°	N	19:45:53	57°	WNW	19:50:19	10°	SSW
Helios 1A Rocket	4.3	19:42:06	10°	N	19:46:11	45°	WNW	19:50:12	10°	SW
MOZ.5/SAFIR/RUBIN 5/SL-8	4.4	19:44:22	10°	NNE	19:48:44	35°	E	19:53:05	10°	SSE
COSMOS 2455	3.1	19:46:35	10°	S	19:52:15	45°	ESE	19:57:57	10°	NE
Okean 1-7	4.4	19:48:44	10°	SE	19:51:47	19°	E	19:54:51	10°	NE
Cosmos 1452 Rocket	3.5	19:50:04	10°	N	19:55:20	66°	ENE	20:00:34	10°	SSE
Cosmos 1605 Rocket	3.9	19:51:10	10°	S	19:57:13	76°	E	20:03:18	10°	N
Cosmos 1733 Rocket	3.1	19:51:15	10°	N	19:55:38	84°	W	19:59:57	10°	S
Cosmos 1703 Rocket	4	19:51:58	10°	SSE	19:55:57	38°	E	19:59:58	10°	NNE
Cosmos 1607	3.9	19:54:17	10°	NNW	20:00:28	89°	ENE	20:06:34	10°	SSE
Cosmos 44 Rocket	4	19:55:17	10°	S	19:59:16	28°	ESE	20:03:21	10°	NE
ADEOS II	3.2	19:55:41	10°	S	20:00:42	46°	W	20:05:46	10°	NNW
Cosmos 1544	4.3	19:56:17	12°	SE	19:59:00	23°	E	20:02:04	10°	NE
USA 229 DEB	4.4	19:57:03	10°	NNW	20:03:20	36°	NE	20:07:28	19°	ESE
USA 229	4.4	19:57:10	10°	NNW	20:03:26	36°	NE	20:07:34	19°	ESE
Milstar 3	3.7	19:58:32	10°	W	20:05:33	54°	S	20:14:03	18°	ESE
COSMOS 2406	3.9	20:01:32	10°	SW	20:07:09	58°	WNW	20:12:51	10°	NNE
Cosmos 468	4.5	20:04:06	10°	S	20:09:24	78°	ESE	20:14:44	10°	NNE
Cosmos 1674	2.8	20:07:37	10°	N	20:11:34	86°	W	20:15:33	10°	S
EXPRESS MD2	3.6	20:07:45	10°	SSW	20:12:34	40°	SE	20:13:27	32°	ESE
Cosmos 1802 Rocket	4.4	20:09:02	10°	SSE	20:14:45	38°	E	20:20:24	10°	NNE
Okean 2 Rocket	2.9	20:09:45	10°	N	20:14:09	74°	E	20:18:32	10°	SSE
ATLAS 5 CENTAUR R/B	3.6	20:10:45	10°	S	20:12:00	13°	SSE	20:12:00	13°	SSE
Cosmos 1703	4	20:11:06	10°	NNE	20:14:47	34°	E	20:15:42	30°	ESE
FREGAT/IRIS	3	20:12:34	10°	S	20:16:03	85°	WSW	20:19:34	10°	NNW
HST	2.6	20:12:39	10°	SSW	20:15:21	16°	SSE	20:15:38	16°	SSE
Geosat	4.1	20:17:42	23°	SE	20:20:45	56°	ENE	20:25:41	10°	NNW
BREEZE-M R/B	4	20:17:18	10°	SSW	20:21:51	26°	SE	20:21:51	26°	SE
Sakura Rocket	4	20:17:49	10°	SW	20:20:39	22°	SSE	20:20:49	22°	SSE
Cosmos 1943 Rocket	3.8	20:19:06	10°	NNE	20:22:33	16°	NE	20:23:03	16°	ENE
Cosmos 1340	2.6	20:20:02	10°	S	20:23:58	77°	E	20:27:57	10°	NNE
CZ-2C R/B	2.3	20:22:55	20°	SSE	20:26:13	62°	ENE	20:30:51	10°	N
IDEFIX/ARIANE 42P	3.9	20:28:00	21°	ENE	20:28:00	21°	ENE	20:31:34	10°	NNE
Cosmos 1484 Rocket	3.2	20:27:41	38°	ENE	20:27:41	38°	ENE	20:31:12	10°	N
Lacrosse 4 Rocket	2.7	20:34:35	1°	NE	20:34:35	1°	NE	20:26:46	27°	SSE
Cosmos 1048 Rocket	3.9	20:29:43	10°	S	20:34:52	62°	ESE	20:40:07	10°	NNE
NOSS 2-2 (D)	3.7	20:30:44	10°	SSW	20:35:17	84°	ESE	20:40:28	10°	NNE
Meteor 1-30 Rocket	2.9	20:31:40	10°	NNE	20:34:51	63°	ENE	20:34:51	63°	ENE
NOSS 2-2 (C)	3.7	20:32:42	10°	SSW	20:37:15	90°	ESE	20:42:27	10°	NNE
Atlas Centaur 2	4.5	20:35:02	10°	WSW	20:39:20	18°	SSW	20:43:45	11°	SSE
Cosmos 1782 Rocket	3.9	20:46:11	10°	NNW	20:50:37	65°	W	20:53:07	25°	S
ATLAS 2AS CENTAUR R/B	3.7	20:50:01	10°	NNW	20:57:11	36°	NE	20:58:53	33°	ENE
Cosmos 2100 Rocket	4	20:50:07	10°	S	20:56:14	78°	W	21:02:25	10°	N
Cosmos 2016 Rocket	3.9	20:50:38	10°	S	20:56:55	74°	E	21:03:17	10°	N
Cosmos 2251 Rocket	3.7	20:50:46	10°	SSW	20:56:06	75°	WNW	21:01:27	10°	NNE
NOSS 2-2 (E)	4.4	20:51:37	10°	SW	20:56:10	60°	NW	21:01:28	10°	NNE
DELTA 2 R/B (1)	3.9	20:51:40	10°	WNW	20:57:10	56°	N	20:58:33	44°	NE
Skynet4D Del rocket	4.4	20:53:02	10°	WSW	20:58:20	38°	S	20:58:58	37°	SSE
CENTAUR R/B	4.4	20:58:51	10°	NW	21:05:30	33°	WSW	21:12:19	10°	S
SL-14 R/B	3.8	21:04:22	10°	NNW	21:07:43	56°	NW	21:07:43	56°	NW
YAOGAN 11	4.4	21:09:21	61°	SW	21:09:49	67°	W	21:14:23	10°	NNW
OAO 3 Rocket	3.7	21:16:36	10°	W	21:20:32	58°	W	21:20:32	58°	W
OAO 2 Rocket	3.7	21:17:44	10°	W	21:22:09	62°	WSW	21:22:09	62°	WSW
Centaur D-1AR AC-36	4.1	22:10:20	10°	E	22:10:20	10°	E	21:39:21	29°	SSW
Tsikada Rocket	4.3	21:43:09	10°	N	21:48:11	61°	NNW	21:48:11	61°	NNW
Cosmos 2278	4.4	21:43:35	10°	NNW	21:47:43	50°	NNW	21:47:43	50°	NNW
USA 229	4.5	21:48:04	10°	NW	21:54:23	41°	WSW	21:55:04	40°	SW
HST	4.3	21:52:41	10°	SW	21:51:22	4°	WSW	21:51:22	4°	WSW
Cosmos 1943 Rocket	3.4	22:01:13	10°	NNW	22:04:37	37°	NW	22:04:37	37°	NW
IDEFIX/ARIANE 42P	4.2	22:08:50	31°	NW	22:08:50	31°	NW	22:12:00	10°	NNW
ATLAS 2AS CENTAUR R/B	3.9	22:40:48	10°	NW	22:46:21	42°	WNW	22:46:21	42°	WNW

Satellite Predictions

SATURDAY, MARCH 30th 2013

Satellite		Start			Highest Point			End		
	(mag)	Time	Alt.	Az.	Time	Alt.	Az.	Time	Alt.	Az.
Meteor 2-2 Rocket	4.3	19:22:56	10°	S	19:28:34	89°	W	19:34:13	10°	N
Cosmos 1943	3.6	19:22:57	10°	SSW	19:28:36	72°	WNW	19:34:19	10°	NNE
Cosmos 2369 Rocket	2.4	19:23:39	10°	N	19:29:08	53°	ENE	19:34:33	10°	SE
Cosmos 2056 Rocket	3.7	19:24:58	10°	NNW	19:30:07	80°	WSW	19:35:20	10°	SSE
Cosmos 1908 Rocket	4.5	19:27:32	10°	NNE	19:31:28	29°	ENE	19:35:23	10°	SE
ADEOS II	2.2	19:29:45	10°	SSE	19:35:01	84°	WSW	19:40:18	10°	NNW
Cosmos 2084	3.6	19:32:02	10°	NW	19:36:10	74°	WSW	19:40:13	10°	SSE
SL-8 R/B	2.7	19:33:51	10°	SSE	19:37:02	69°	ENE	19:40:12	10°	N
Aureole 1 Rocket	2.8	19:35:33	10°	N	19:38:20	35°	ENE	19:41:16	10°	SE
CZ-2C R/B	3.7	19:35:52	10°	ESE	19:39:17	20°	ENE	19:42:38	10°	NNE
Sakura Rocket	4.3	19:36:08	10°	SSW	19:38:48	19°	SSE	19:41:21	10°	ESE
ATLAS 5 CENTAUR R/B	3.6	19:40:09	10°	S	19:42:01	13°	SSE	19:43:37	11°	ESE
Cosmos 1821 Rocket	4	19:40:57	10°	S	19:47:09	88°	E	19:53:29	10°	N
Skynet4D Del rocket	4.5	19:42:28	10°	WSW	19:47:30	38°	S	19:52:18	13°	ESE
Cosmos 1269 Rocket	4.2	19:44:21	10°	SSW	19:49:38	79°	WNW	19:54:58	10°	NNE
Cosmos 1544	4.4	19:44:53	10°	SE	19:47:48	21°	E	19:50:44	10°	NE
FREGAT/IRIS	3.6	19:45:50	10°	SE	19:49:03	36°	ENE	19:52:18	10°	N
NOSS 2-2 (D)	4.1	19:46:50	10°	S	19:51:05	41°	ESE	19:55:50	10°	NE
NOSS 2-2 (C)	4	19:48:44	10°	S	19:53:02	45°	ESE	19:57:51	10°	NE
Cosmos 1862 Rocket	4	19:49:35	10°	SSW	19:53:57	67°	W	19:58:19	10°	N
COSMOS 2455	2.8	19:50:22	10°	SSW	19:56:17	64°	ESE	20:02:15	10°	NNE
COSMOS 2406	4	19:50:30	10°	SW	19:56:07	57°	WNW	20:01:48	10°	NNE
Cosmos 2061 Rocket	4.1	19:55:10	10°	SSE	20:01:07	52°	E	20:07:09	10°	NNE
Lacrosse 5	4.1	19:55:41	10°	SE	19:54:23	8°	SE	19:54:23	8°	SE
H-2A R/B	4.3	19:56:01	10°	N	20:00:20	39°	WNW	20:04:32	10°	SW
IDEFIX/ARIANE 42P	4.5	19:59:39	11°	ENE	20:00:15	11°	ENE	20:01:34	10°	NE
BREEZE-M R/B	4	20:00:01	10°	SSW	20:04:52	25°	SE	20:06:03	22°	ESE
Meteor 1-30 Rocket	4.2	20:00:19	10°	NE	20:02:43	21°	E	20:02:43	21°	E
Cosmos 1674	2.8	20:00:27	10°	N	20:04:25	85°	W	20:08:24	10°	S
Cosmos 1943 Rocket	3.9	20:00:31	10°	NNE	20:03:30	14°	NE	20:04:59	13°	ENE
BREEZE-M DEB (TANK)	3.8	20:03:06	10°	SSW	20:07:33	33°	SE	20:12:21	10°	ENE
Okean 1-7	3.6	20:03:55	10°	SSE	20:07:54	35°	E	20:11:52	10°	NNE
OAO 3 Rocket	3.2	20:04:02	10°	W	20:08:57	88°	S	20:12:06	22°	E
ATLAS 2AS CENTAUR R/B	4.2	20:05:47	10°	N	20:12:02	25°	NE	20:16:00	17°	E
Cosmos 2173 Rocket	4.2	20:06:06	10°	SSE	20:11:51	44°	E	20:17:35	10°	NNE
NOSS 2-2 (E)	3.7	20:07:01	10°	SSW	20:11:34	71°	ESE	20:16:48	10°	NE
HST	2.4	20:07:27	10°	SSW	20:10:35	20°	SSE	20:11:35	19°	SE
Cosmos 1733 Rocket	4.4	20:08:52	10°	NNW	20:12:57	40°	W	20:16:59	10°	SSW
Cosmos 1703	3.7	20:09:10	10°	N	20:12:58	40°	E	20:14:48	25°	SE
Cosmos 1703 Rocket	3.4	20:10:06	10°	S	20:14:24	81°	E	20:18:46	10°	N
CENTAUR R/B	3.6	20:10:14	10°	NW	20:17:39	56°	WSW	20:25:17	10°	S
Cosmos 1340	2.6	20:12:01	10°	S	20:15:58	78°	E	20:19:57	10°	NNE
Cosmos 1459 Rocket	4.1	20:13:36	10°	SSE	20:19:40	56°	E	20:25:51	10°	NNE
TELKOM 3	4.4	20:13:56	10°	SW	20:19:09	69°	NW	20:21:06	19°	NE
Cosmos 2251 Rocket	3.5	20:17:28	10°	S	20:22:46	67°	ESE	20:28:03	10°	NNE
Cosmos 1484 Rocket	3.4	20:23:50	34°	ENE	20:23:58	34°	ENE	20:27:26	10°	N
OAO 2 Rocket	3.3	20:21:14	10°	W	20:26:24	86°	S	20:28:46	33°	E
DELTA 2 R/B (1)	4	20:21:15	10°	WNW	20:26:44	55°	N	20:29:45	26°	ENE
SPOT 1/Viking Rocket	3.5	20:22:33	10°	SSE	20:27:46	90°	E	20:33:01	10°	NNW
PSLV R/B	3.9	20:23:59	10°	SW	20:28:01	53°	SSE	20:28:58	42°	ESE
MOZ.5/SAFIR/RUBIN 5/SL-8	3.9	20:24:50	10°	N	20:29:37	82°	WNW	20:34:24	10°	SSW
Okean 2 Rocket	4	20:31:18	10°	NNW	20:35:32	48°	W	20:39:45	10°	SSW
Lacrosse 4 Rocket	1.5	20:33:10	10°	SSW	20:37:42	65°	ESE	20:42:15	10°	NNE
TITAN 4B R/B	4.4	20:33:44	10°	S	20:32:03	3°	S	20:32:03	3°	S
Cosmos 1802 Rocket	3.9	20:36:07	10°	S	20:42:23	76°	E	20:48:36	10°	N
Cosmos 44 Rocket	3.4	20:37:02	10°	SW	20:41:42	73°	WNW	20:46:32	10°	NNE
Cosmos 1725 Rocket	4.4	20:54:21	42°	E	20:54:21	42°	E	21:00:00	10°	NNE
SL-14 R/B	3.6	20:58:37	10°	NNW	21:02:34	62°	W	21:02:48	61°	WSW
OAO 1	4.4	21:02:00	10°	W	21:07:32	88°	N	21:08:02	75°	E
USA 229 DEB	3.8	21:03:04	10°	NW	21:09:52	68°	WSW	21:12:24	40°	S
USA 229	3.8	21:03:09	10°	NW	21:09:59	69°	WSW	21:12:30	40°	S
Cosmos 1461	4.1	21:12:49	10°	NNW	21:16:31	42°	NNE	21:16:31	42°	NNE
CZ-2C R/B	3.7	21:14:33	19°	SSW	21:17:19	35°	W	21:21:37	10°	NNW
Cosmos 2016 Rocket	4.5	21:15:43	10°	SSW	21:21:57	61°	W	21:28:16	10°	N
ATLAS 5 CENTAUR R/B	4.2	21:17:14	10°	WSW	21:17:43	13°	SW	21:17:43	13°	SW
Cosmos 1864 Rocket	4.5	21:36:33	76°	N	21:36:33	76°	N	21:42:20	10°	N
Cosmos 2278	3.9	21:30:15	10°	NNW	21:35:11	68°	NNW	21:35:11	68°	NNW
IDEFIX/ARIANE 42P	3.2	21:40:29	51°	NNW	21:40:29	51°	NNW	21:44:21	10°	NNW
Milstar 3	4.4	21:40:01	10°	W	21:48:06	40°	SSW	21:49:44	39°	S
Cosmos 1943 Rocket	2.8	21:42:13	10°	NNW	21:46:33	54°	NW	21:46:33	54°	NW
HST	4	21:47:54	10°	WSW	21:47:19	7°	WSW	21:47:19	7°	WSW
Centaur D-1A AC-31	4.1	21:54:07	10°	W	21:58:11	14°	SW	21:58:45	14°	SW
ATLAS 2AS CENTAUR R/B	3	21:55:54	10°	NNW	22:03:29	78°	W	22:03:29	78°	W

Satellite Predictions: Iridium Flares

Data from heavens-above.com, calculated for location at Kelso Dunes. Note: exact time, magnitude, and position may vary, depending on campsite location.

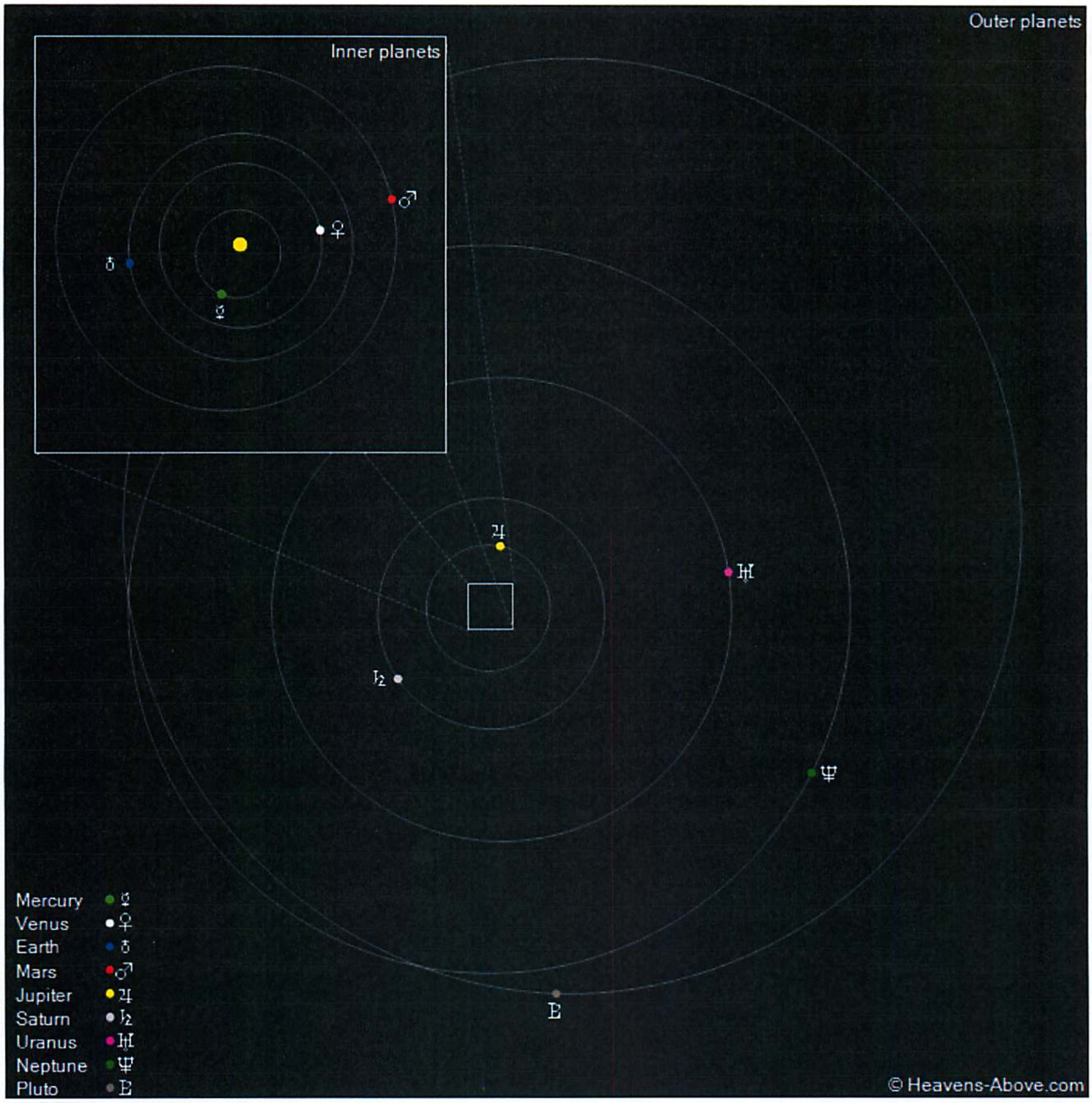
Time	Brightness	Altitude	Azimuth	Satellite	Distance to flare centre	Brightness at flare centre	Sun altitude
Mar 28, 20:16:10	-0.9	57°	132° (SE)	Iridium 77	31 km (W)	-8.4	-16°
Mar 29, 20:10:08	-0.7	54°	129° (SE)	Iridium 82	31 km (E)	-8.4	-15°

Planet Positions

Data from heavens-above.com, calculated for Kelso Dunes, on Friday, March 29th. Note: exact rise and set times change slightly, daily.

	Mercury	Venus	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Right ascension	$22^h\ 55^m\ 7.1^s$	$0^h\ 38^m\ 33.9^s$	$0^h\ 51^m\ 41.0^s$	$4^h\ 40^m\ 16.1^s$	$14^h\ 34^m\ 50.4^s$	$0^h\ 32^m\ 28.4^s$	$22^h\ 25^m\ 4.2^s$	$18^h\ 48^m\ 58.3^s$
Declination	-8° 21' 48"	2° 43' 44"	4° 53' 50"	21° 46' 18"	-12° 22' 36"	2° 46' 28"	-10° 33' 46"	-19° 40' 1"
Range (AU)	0.864	1.724	2.404	5.485	8.944	21.051	30.796	32.429
Brightness	0.5	-3.8	1.2	-1.9	0.8	5.9	8	14.1
Constellation	Aquarius	Pisces	Pisces	Taurus	Libra	Pisces	Aquarius	Sagittarius
Meridian transit	11:07	12:50	13:04	16:52	2:49	12:45	10:38	7:02
Rises	5:31	6:43	6:51	9:48	21:21	6:39	5:09	2:01
Sets	16:43	18:57	19:17	23:56	8:13	18:52	16:07	12:04

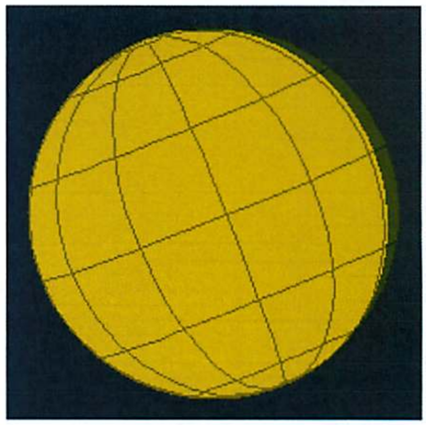
Planet Positions



Planet	Distance from Sun (AU)	Distance from Earth (AU)	Velocity (km/s)
Mercury	0.47	0.86	38.99
Venus	0.73	1.72	34.90
Earth	1.00	0.00	29.82
Mars	1.41	2.40	26.00
Jupiter	5.09	5.49	13.34
Saturn	9.81	8.94	9.37
Uranus	20.05	21.05	6.50
Neptune	29.99	30.80	5.45
Pluto	32.41	32.43	5.68

Lunar Phases

THURSDAY MARCH 28th 2013



Range	369,587 km
Constellation	Virgo
Diameter	32.33'
Illumination of disk	96%
Libration in longitude	-3.190°
Libration in latitude	1.945°

Event	Time	Altitude	Azimuth
Sets	7:06	0.1°	256°
Rises	20:56	0.1°	107°
Maximum altitude	1:28	44.3°	179°

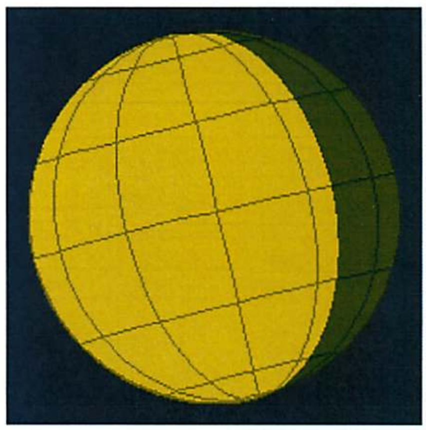
FRIDAY MARCH 29th 2013

Position

Range	368,025 km
Constellation	Libra
Diameter	32.47'
Illumination of disk	91%
Libration in longitude	-2.120°
Libration in latitude	0.291°

Event	Time	Altitude	Azimuth
Sets	7:48	0.1°	251°
Rises	22:04	0.1°	112°
Maximum altitude	2:22	40.1°	179°

SATURDAY MARCH 30th 2013



Range	367,505 km
Constellation	Libra
Diameter	32.52'
Illumination of disk	83%
Libration in longitude	-0.997°
Libration in latitude	-1.388°

Event	Time	Altitude	Azimuth
Sets	8:35	0.1°	247°
Rises	23:10	0.1°	115°
Maximum altitude	3:19	36.8°	179°

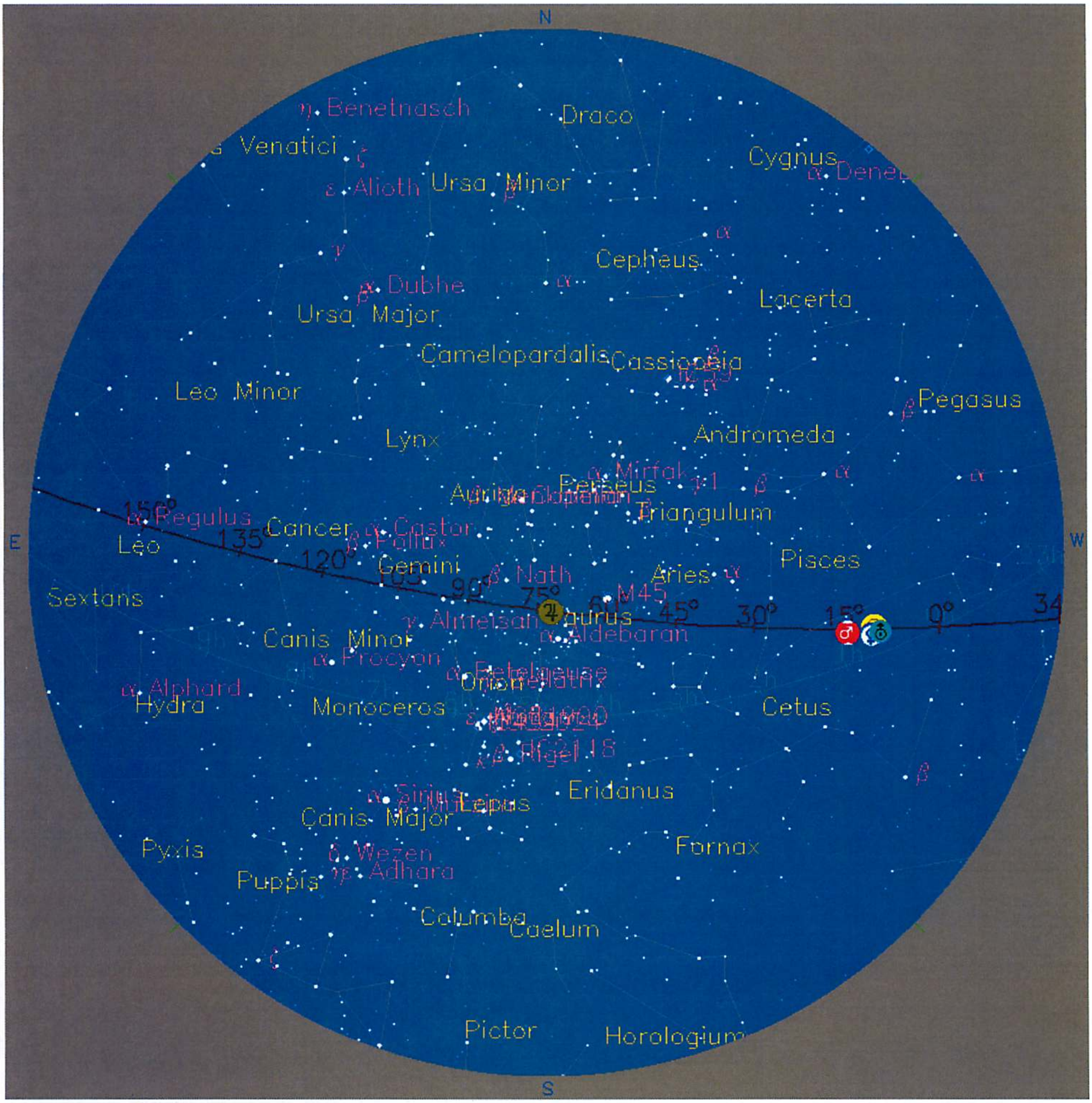
Monthly phases

Full moon	3/27/13 2:27
Last quarter	4/2/13 21:37
New moon	4/10/13 2:35
First quarter	4/18/13 5:31
Full moon	4/25/13 12:57

Lunar Nearside Map

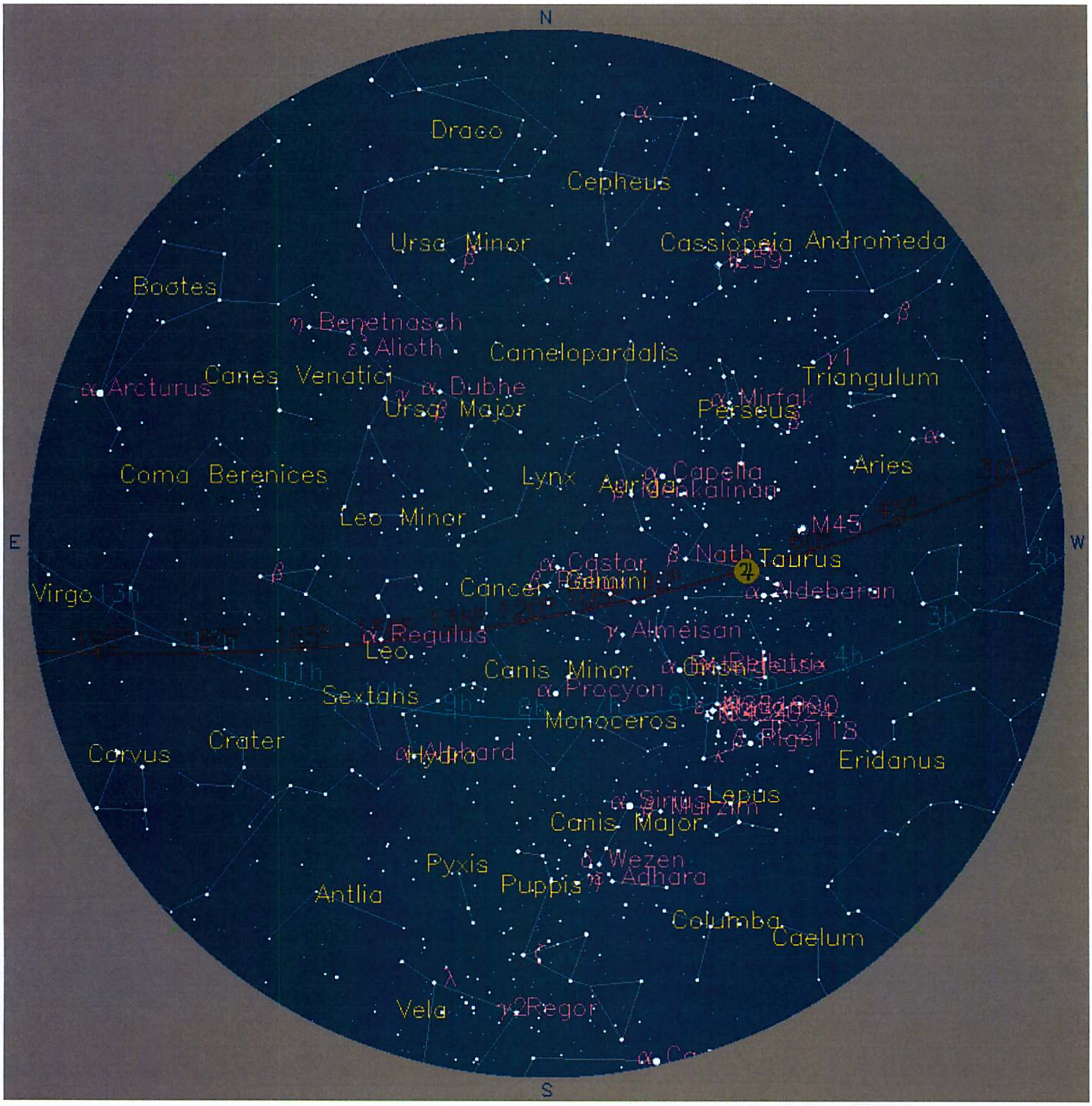
Night Sky: 5pm, Friday, March 29th

Data from http://www.fourmilab.ch/cgi-bin/Yoursky.



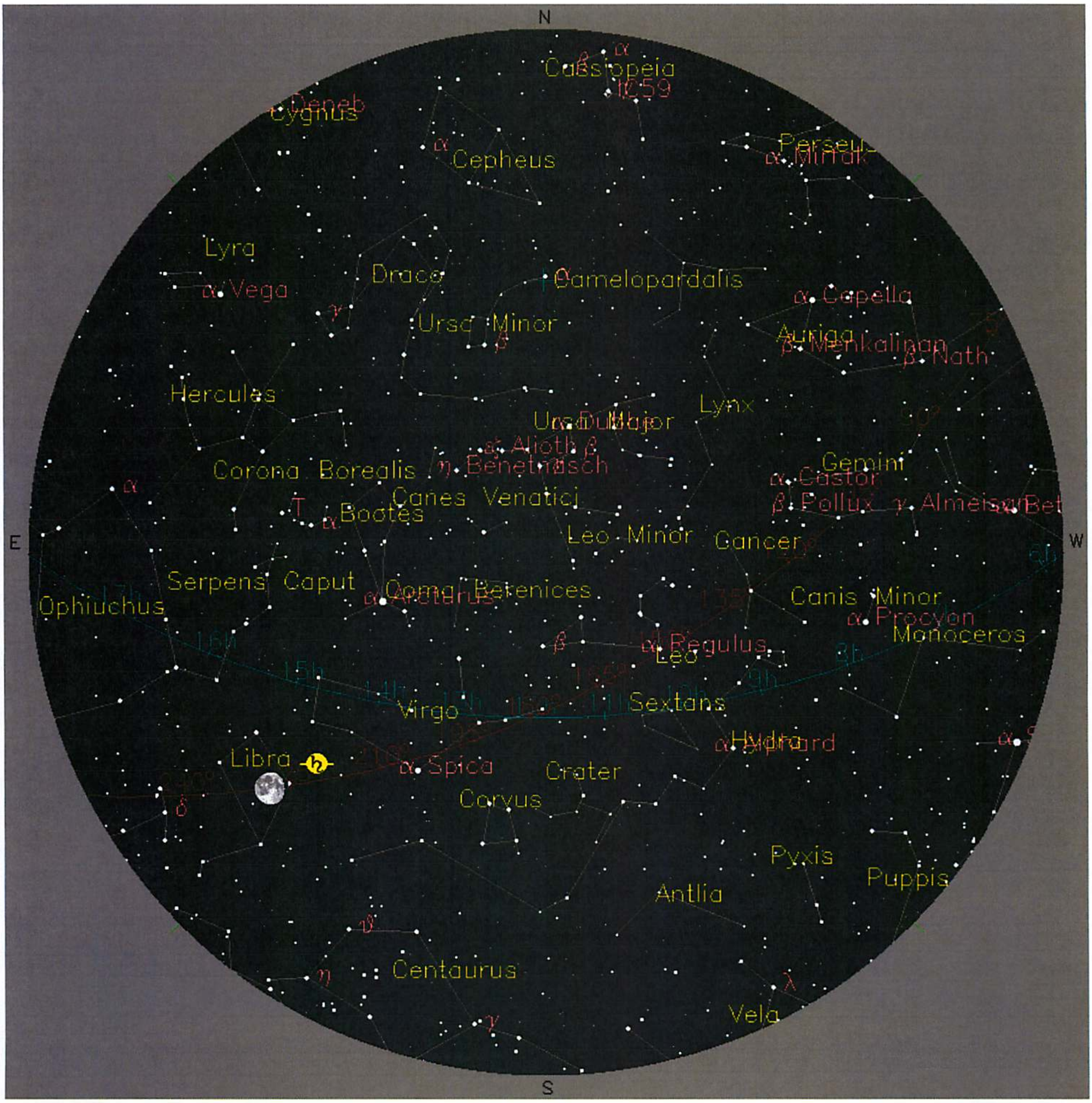
Night Sky: 8pm, Friday, March 29th

Data from http://www.fourmilab.ch/cgi-bin/Yoursky.



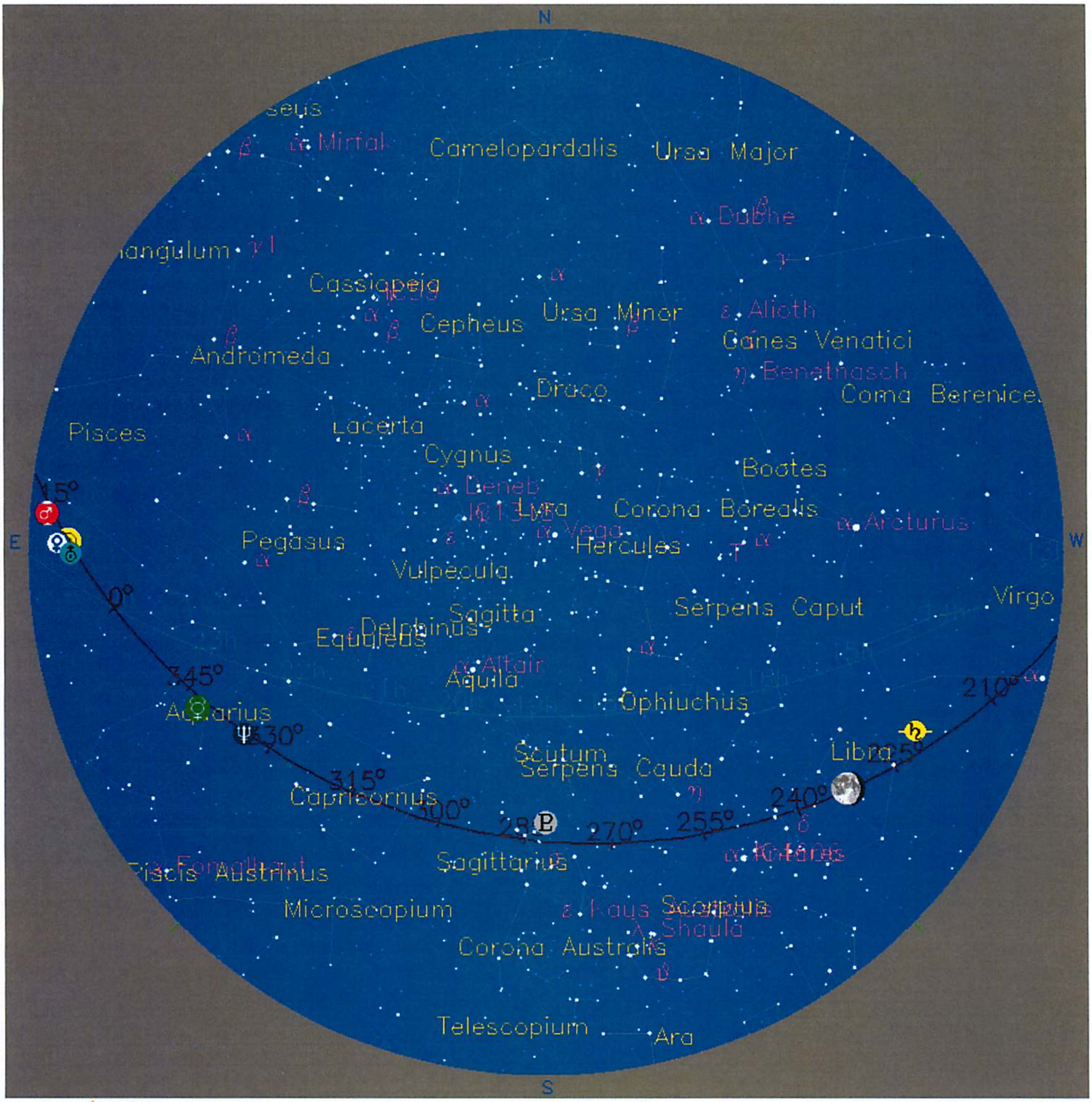
Night Sky: 12am, Saturday, March 30th

Data from http://www.fourmilab.ch/cgi-bin/Yoursky.



Night Sky: 7am, Saturday, March 30th

Data from http://www.fourmilab.ch/cgi-bin/Yoursky.



Dear Friends,

I wish I could be with you right now! Even on Day 4 of a fieldtrip, you still smell better than a classroom full of 8th graders after gym class. I thought I'd add something fun for you to look at during your long drive into the Mojave. Enjoy!

Love,
Ms. Cassidy

P.S. Please go volunteer to speak to elementary and middle schools as often as possible. Kids will love you and make you feel like an astronaut.

<u>**Life on Mars?**</u>

Only a few of my fifth students were in my morning class one day due to snow. We were studying habitability on planets in our solar system unit, so as a bonus on their quiz for being present, I asked them this question:

Imagine that scientists found a way for humans to safely live on Mars. Would you want to live there? Why? If you would want to live there, what would you bring with you?

"I wouldn't want to go live on Mars even if it was able to have life because I'm fine with Earth."

"No because the spaceship taking me there could blow up and I don't want to die at an early age. I want to live for a long time."

"I'm not shure. There are pros and khans to both places. Earth Pro is our Life is here. Pro for Mars it's not polluted. If I went to Mars I would bring my mom, dad, and sister because they mean the most to me in the whole world."

"I would go live there because there would be a clean atmosphere that's not polluted and dirty and three things I would bring is 1. I would bring a frapacino machine 2. my dog and 3. my computer."

"Yes I would. I think it would be funny. I would bring my family and Devin and his family and a store with lots of food."

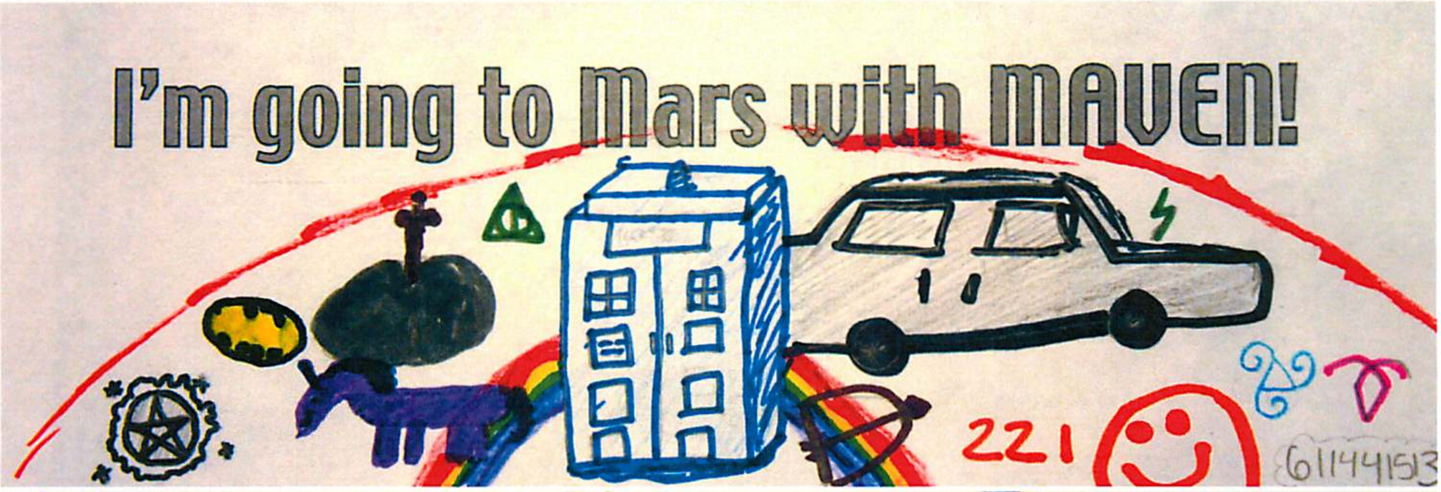
"No. I don't trust Mars."

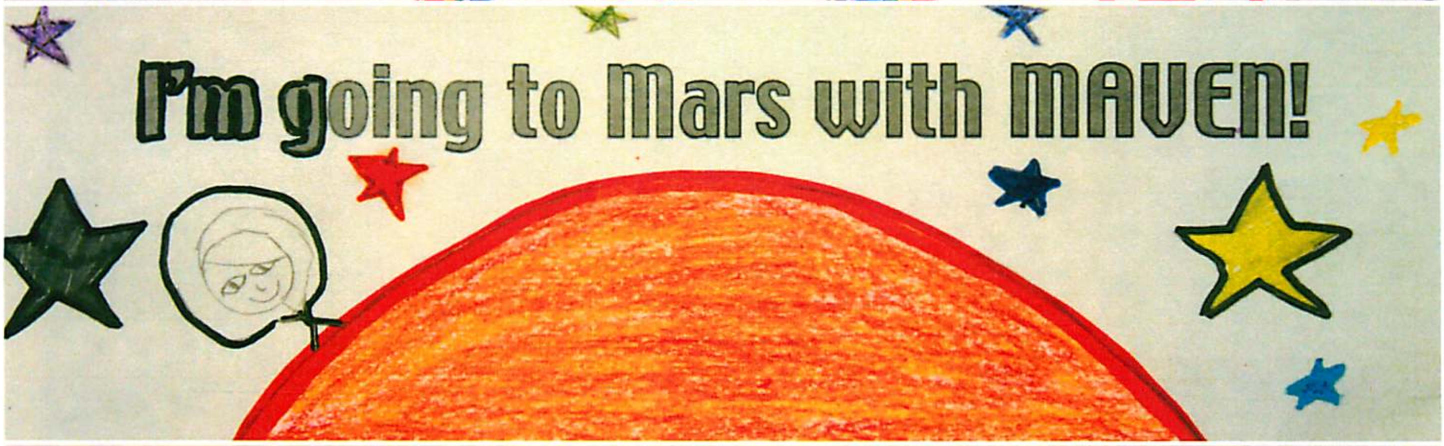
"Yes because I want to live with less gravity. I would bring my family, inclooding my dog, my friends, and my iPad."

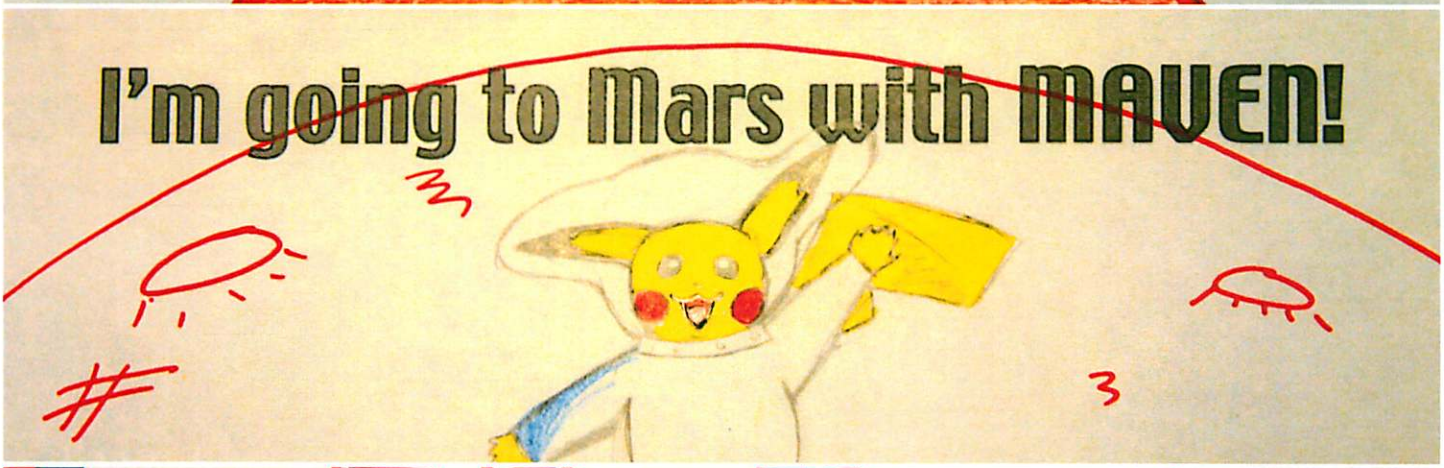
"I would go to Mars for a few days because I would like to explore it or see if there is anything cool there. I would bring my family, games so I don't get bored, my toothbrush, and my toothpaste."

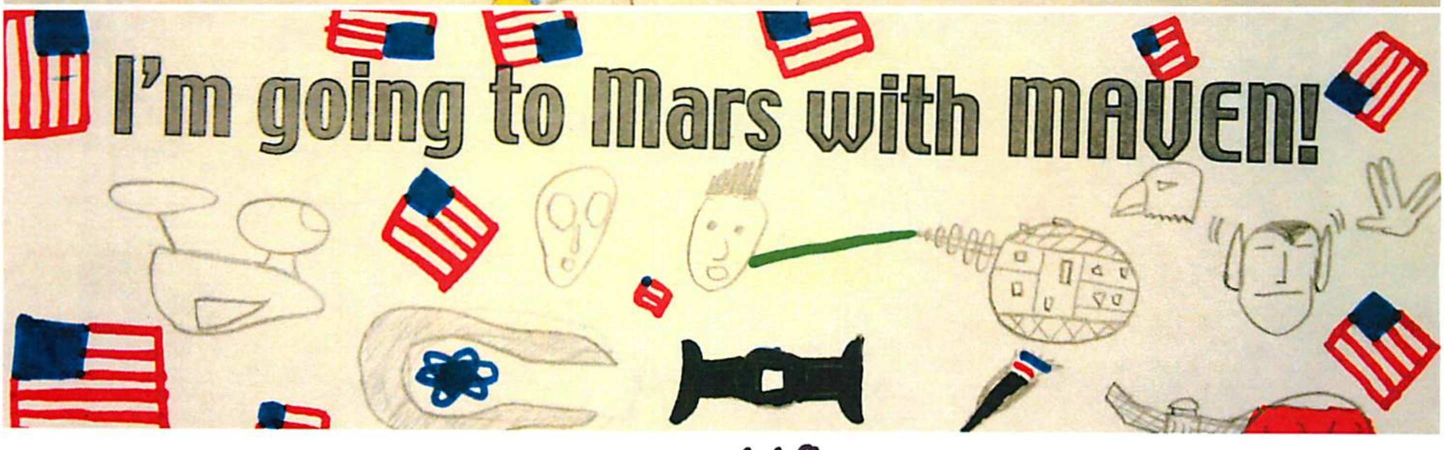
<u>I'm going to Mars with MAVEN!</u>

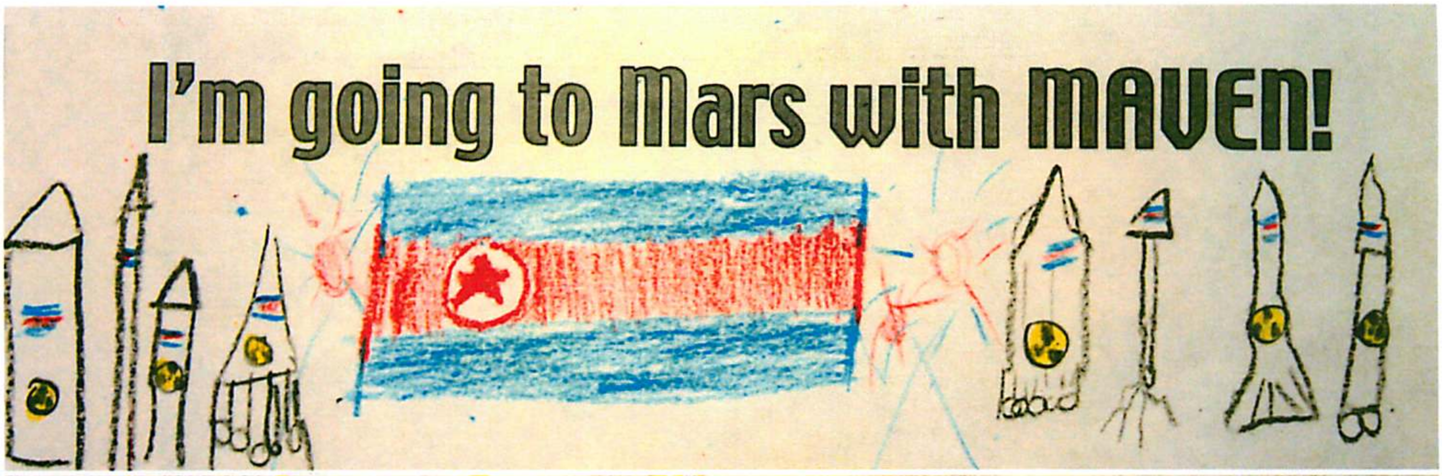
I had all of my students submit an entry to the Going to Mars campaign art contest. The winning artwork, as chosen by the public via online voting, will fly to Mars with MAVEN! Here's a look at a few ☺

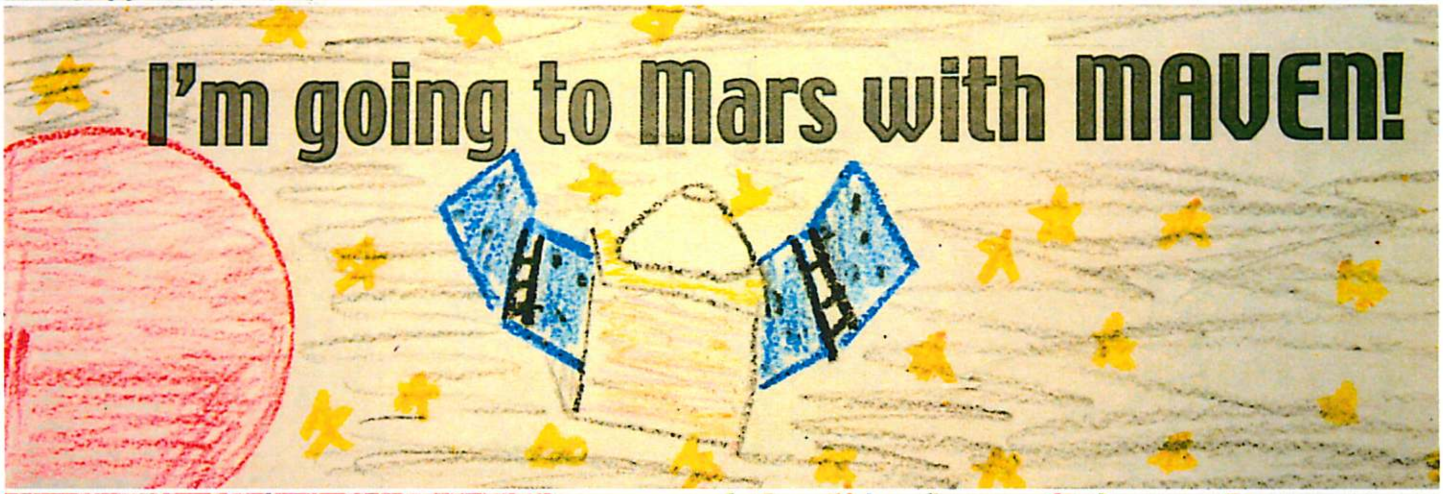


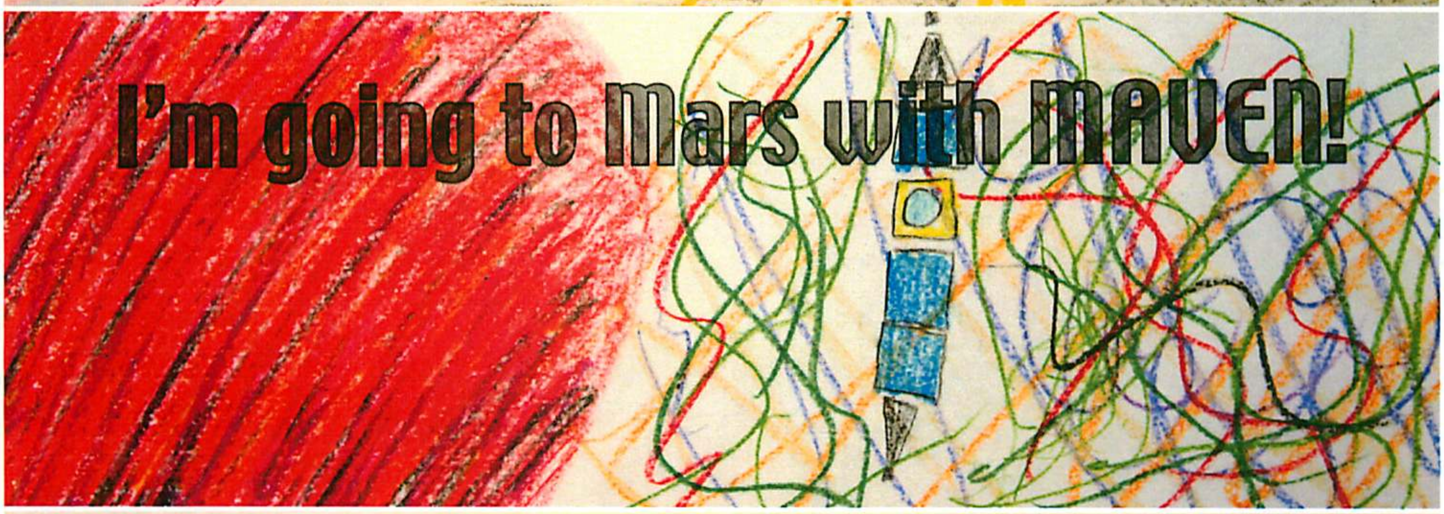


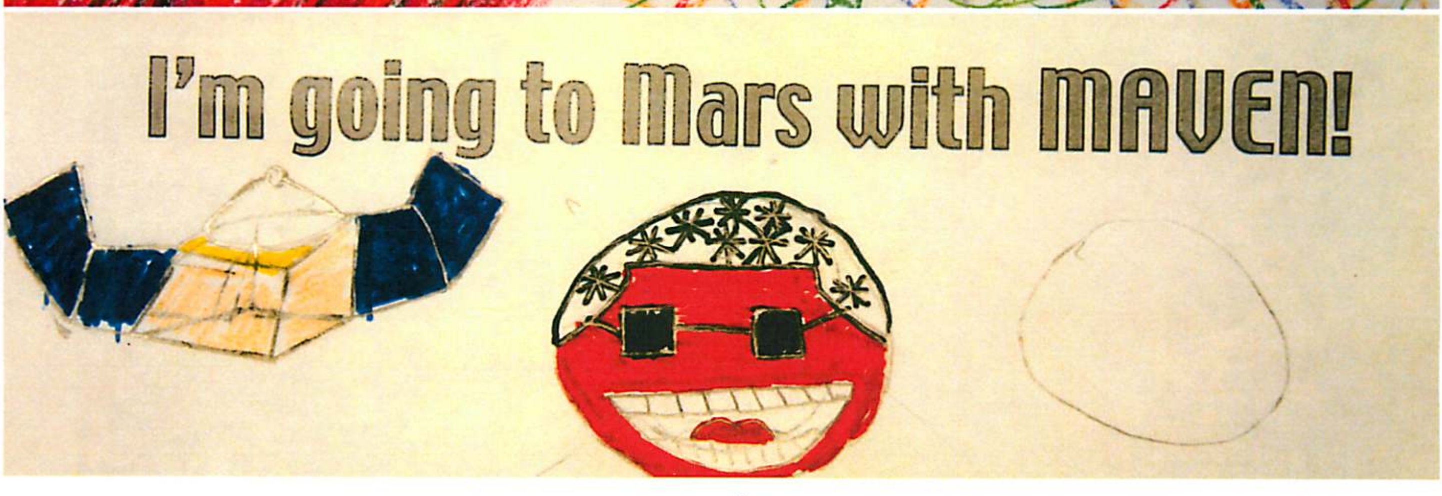





I'm going to Mars with MAVEN!


I'm going to Mars with MAVEN!


I'm going to Mars with MAVEN!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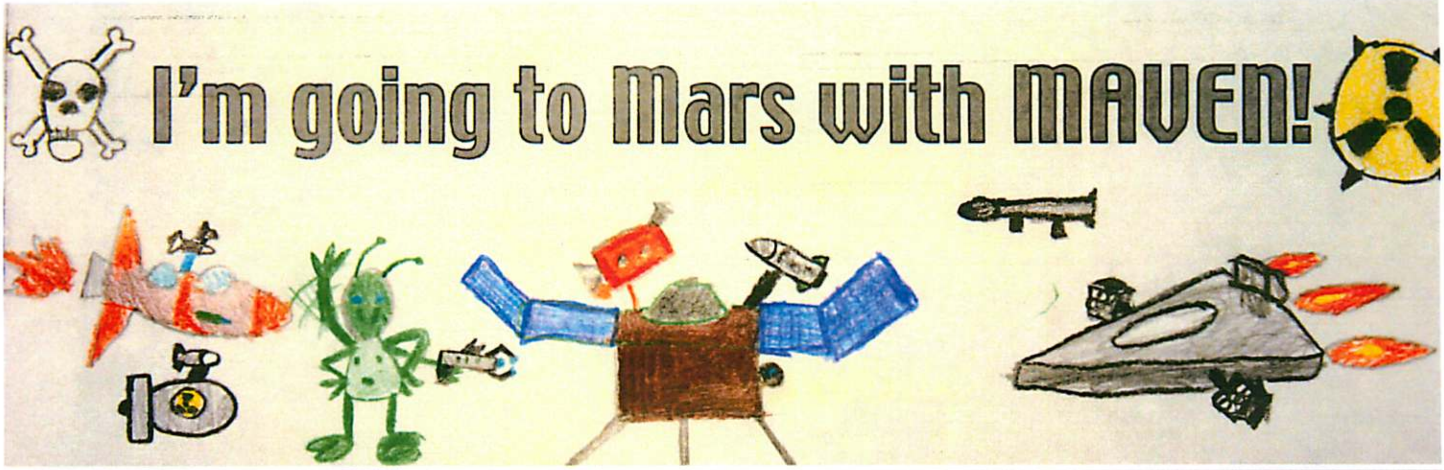
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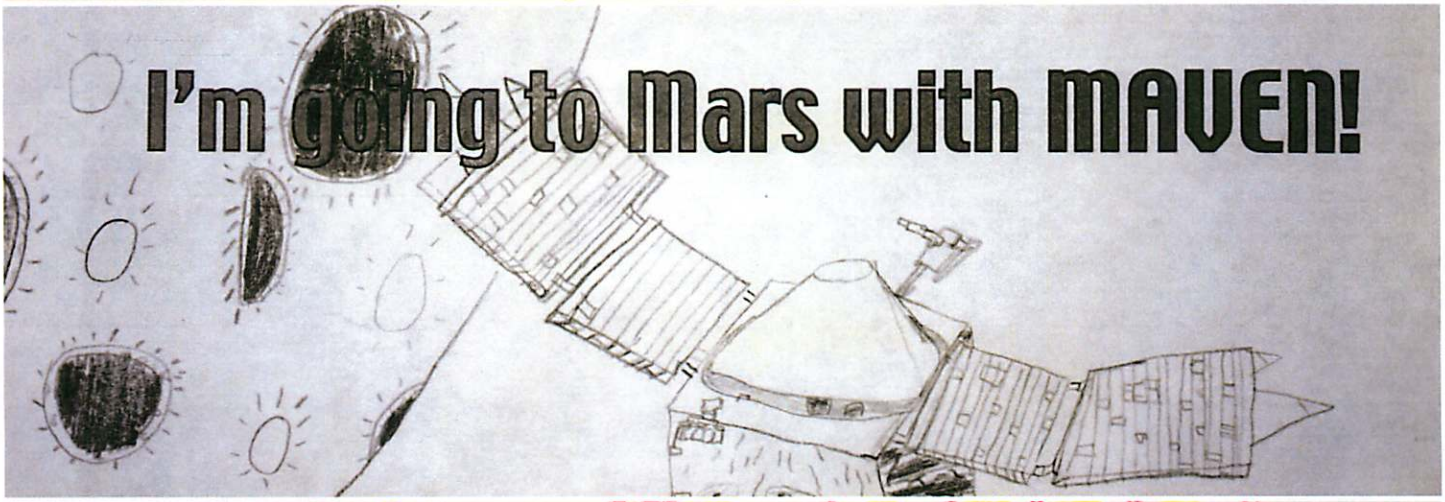
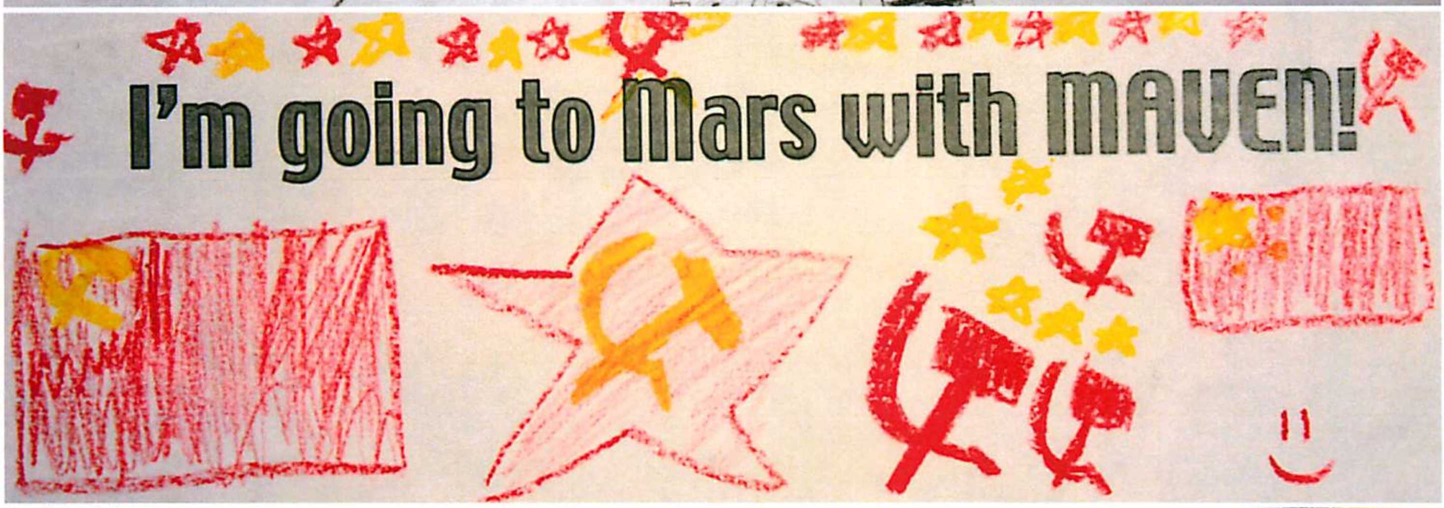
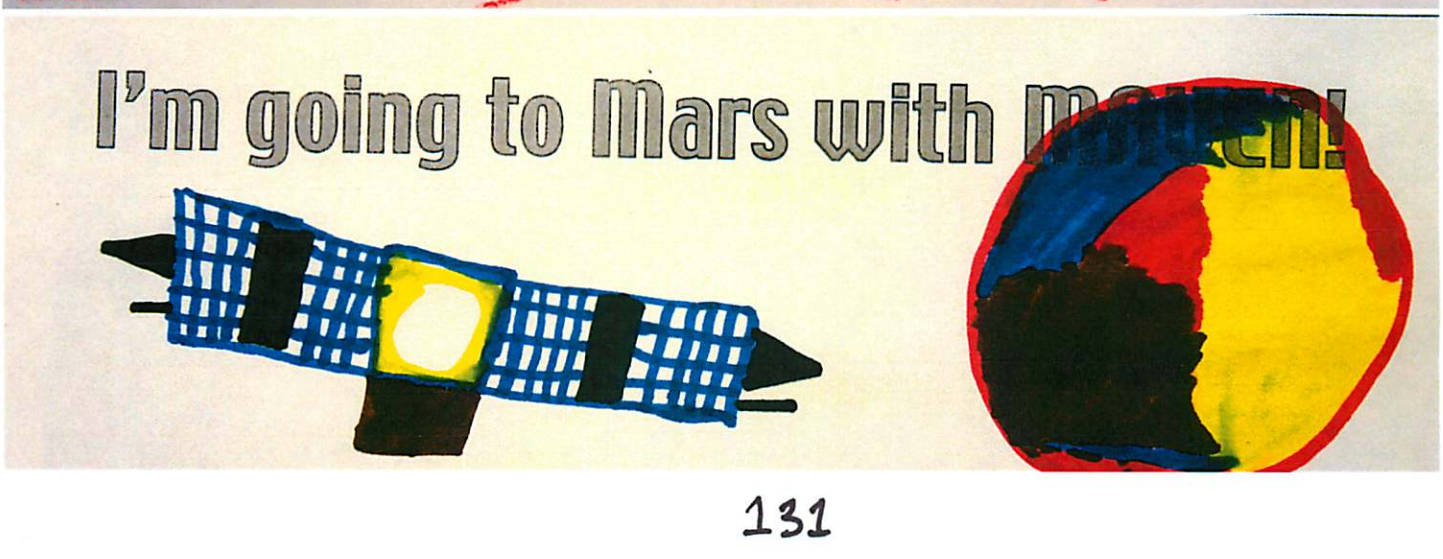
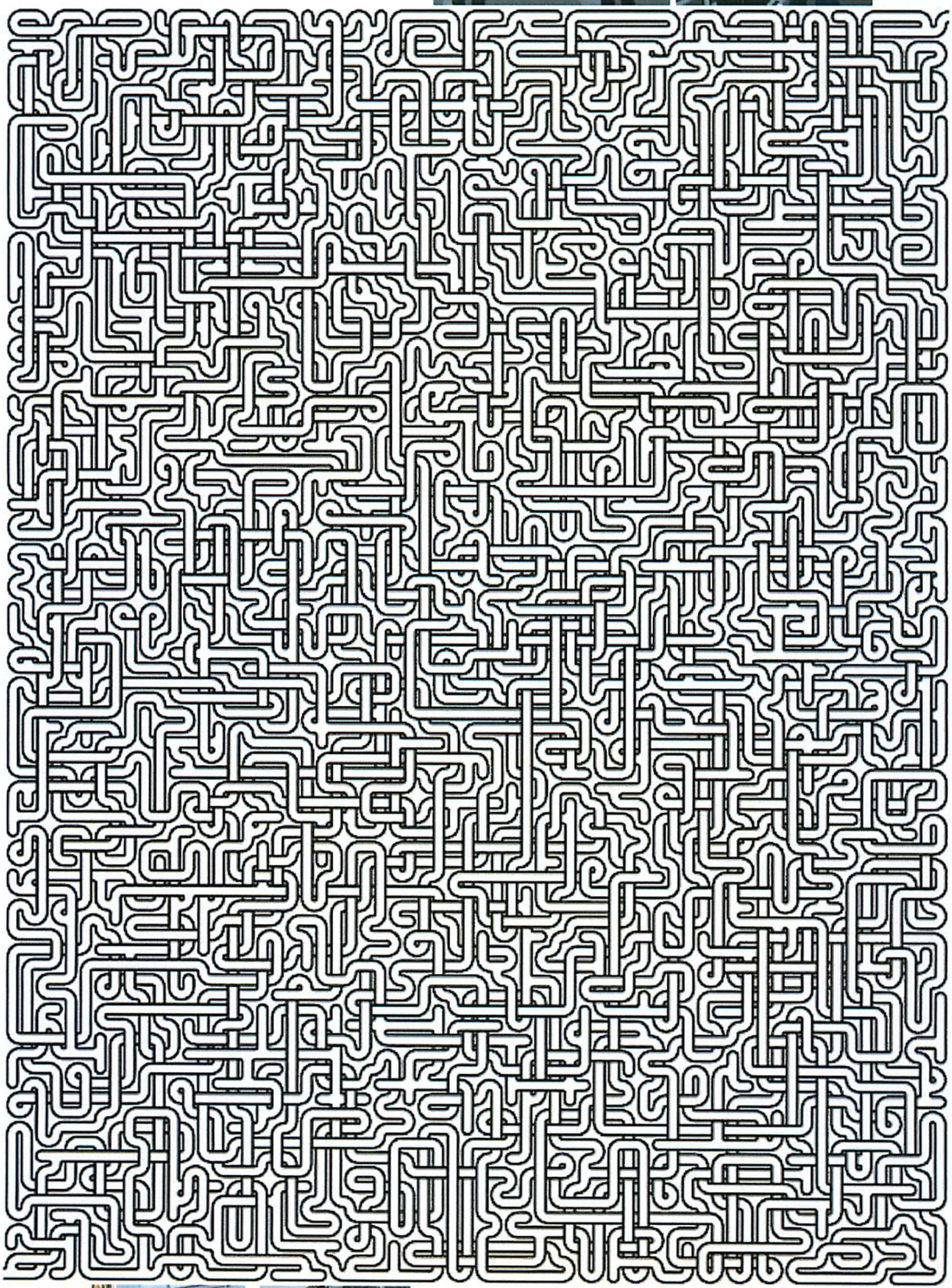

I'm going to Mars with MAVEN!


I'm going to Mars with MAVEN!


I'm going to Mars with

Help Shane Byrne Escape from Zombies!

start



finish

Rescued by Tom Zega!

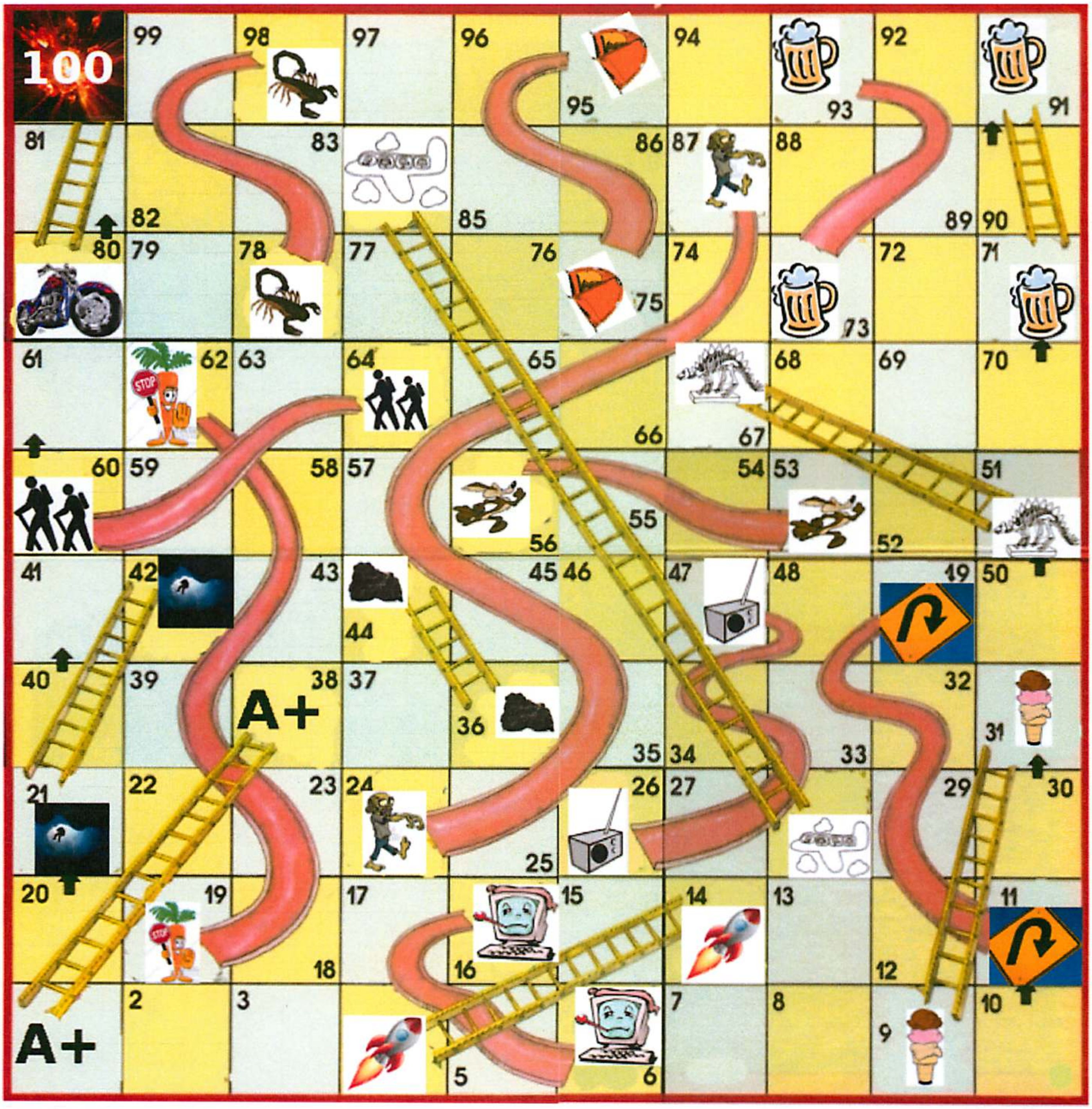
http://www.mazestoprint.com/mega/crossover/maze15.shtml

When the field trip went wrong... Mad Lib

Adjective ______________________________
Place ______________________________
Any person on the field trip ______________________________
Noun ______________________________
Time ______________________________
Type of vehicle ______________________________
Place ______________________________
Person on the field trip #1 ______________________________
Noun ______________________________
Adjective ______________________________
Person on the field trip #1 ______________________________
Medical issue or disease ______________________________
Body part ______________________________
Different person on field trip #2 ______________________________
Noun ______________________________
Place ______________________________
Person on the field trip #1 ______________________________
Same medical issue ______________________________
Noun - Plural ______________________________
Person on the field trip #1 ______________________________
Place ______________________________
food ______________________________
Any person on the field trip ______________________________
number ______________________________
Verb - Present ends in ING ______________________________
Different person ______________________________
Noun ______________________________
Same noun ______________________________
Same noun ______________________________
Verb - Base Form ______________________________
Person on field trip #2 ______________________________
Person on field trip #2 ______________________________
Body part ______________________________
Adverb ______________________________
Person on field trip #2 ______________________________
Same noun ______________________________
Same noun ______________________________
weapon ______________________________
Any person on the field trip ______________________________
Meat food ______________________________
Asian food ______________________________
Generic food ______________________________
Any person on the field trip ______________________________
Type/brand of alcohol ______________________________
Any person on the field trip ______________________________
Song ______________________________
Animal plural ______________________________
Any person on the field trip ______________________________
Any person on the field trip ______________________________

When the field trip went wrong...

On a ________ Adjective day in March, the LPL field trip began. Everybody met at the__________ Place, except ______ Any person on the field trip, who was running late. Apparently s (he) forgot their ______ Noun ______, causing them to not show up until ______ Time ___. When the ________ Type of vehicle was packed up, we finally left. When driving on the I-10 towards __________ Place , suddenly the tire pressure light came on. The vehicle pulled over and alerted the rest on the CV. Unfortunately everybody's elses CV's were turned off so nobody else heard and continued on their way. While pulled over, __________ Person on the field trip #1 checked the tires and noticed there was a ___________ Noun in the rear left tire. They tried to get it out of the tire, but unfortunately it was __________ Adjective , which gave __________ Person on the field trip #1 __________ Medical issue or disease in their __________ Body part . __________ Different person on field trip decided to put__________ Noun on it while the others in the car patched up the tire. Finally, the vehicle was back on its way but decided to stop at__________ Place to check on __________ Person on the field trip#1's __________ Same medical issue . After a heavy dose of __________ Noun – Plural, __________ Person on the field trip #1 feels well enough to continue with the trip. The other vehicles finally realize they are missing a vehicle and call the others. Everybody decides to meet up at __________ Place to get food. However, the __________ food gives __________ Any person on the field trip food poisoning and within ________ number hours of being on the road, s(he) is __________ Verb - Present ends in ING all over the place. Still not even close to the Mojave, everybody decides to stop early. Those feeling up to it decide to go hiking. While hiking, __________ Person on field trip #2 steps on a __________ Noun . The __________ Same Noun , obviously disgruntled, goes in to __________ Verb – Base Form __________ Person on field trip #2 's __________ Body part. Fortunately, __________ Person on field trip #2 moves ________ Adverb and avoids yet another mishap. Whew! That was a close one. Meanwhile, __________ Different person on field trip , part of the meat food group, decides the __________ Same noun would make excellent dinner and catches the __________ Same Noun using a __________ weapon . Back at camp, everybody is setting up for dinner when__________ Any person on the field trip realizes they forgot the cooler back at campus! Everybody else reluctantly gives them some of their dinners, so they end up eating a random dinner of __________ Meat food , __________ Asian food and __________ Generic food from the meat, asian and boring food groups, respectively. To let off steam,__________ Any person on the field trip busts out a bottle of ________ Type/brand of alcohol and it gets passed around the fire. When no one is looking, __________ Any person on the field trip takes a big swig and proceeds to get drunk and start singing __________ Song . Everybody, exhausted, goes to bed. In the middle of the night, a pack of __________ animal plural surround the camp and scare__________ Any person on the field trip , who screams and wakes everybody up. Nobody can get back to sleep, and it is decided to get an early go at the day. After everybody packs up, one of the suburbans won't start. No one brought jumper cables. __________ Any person on the field trip takes a vehicle off-roading to find cell phone reception and calls AAA. AAA refuses to drive on ATV trails, however, and says they can't help us. So, everybody packs into the remaining vehicles and they drive back to Tucson, leaving the UA motor pool to deal with it. Everybody goes home and sleeps forever, skipping the rest of the semester's classes. The end.



Use your trip meter's least significant digit as a "spinner," or find some other clever way to randomly select numbers to advance!

Ladders

1→ 38: Turn in your handout early!
4→ 14: Motor pool fits the SUVs with turbo boost
9→ 31: Find gas station ice cream
21→ 42: Shane lets you go caving
28→ 84: Get a ride in Rick's plane!
36→ 44: Find a meteorite and strike it rich!
51→ 67: Find dinosaur bones!
71→ 91: Get drunk
80→ 100: Get a ride with Shane Byrne!

Chutes

16→ 6: ENVI crashes! Data and work lost
47→ 26: CB malfunctions and no one can hear you
49→ 11: Wrong turn toward El Paso
56→ 53: Chased by coyotes while using a bush
62→ 19: Supper meat rots, beg from the veggie group
64→ 60: The unconformity is "just over the next hill"...
87→ 24: Zombie apocalypse!
93→ 73: Wake up hung over
96→ 75: Cold front, wind blows your tent over
98→ 78: Scorpions in your sleeping bag

GET READY TO PLAY.....THERE ARE THREE CANADIANS ON THIS FIELD TRIP, MAYBE IT'S TIME YOU LEARNED SOMETHING ABOUT CANADA!

Hint	Answer	Hint	Answer
Official Name		Largest Religious Denomination	
Flag Color		Prime Minister Residence	
Flag Color		Official Language	
Monarch		Official Language	
Prime Minister		Nationality (Demonym)	
Governor General		Drives on the...	
Chief Justice		Major Political Party	
Official Motto		Major Political Party	
Capital City		Major Political Party	
Largest City		Major Political Party	
National Anthem		Longest River	
Royal Anthem		Official Mammal	
Currency		Official Mammal	
Independence From		# of Provinces	
Primary Continent		Largest Lake*	
Official Tree		Age of Suffrage	
Canada Day		Largest Stadium	
Largest Province		Bordering Ocean	
Largest Territory		Bordering Ocean	
Smallest Province		Bordering Ocean	
Largest Island		Official Winter Sport	
First Prime Minister		Official Summer Sport	
Bordering Country		Last City to Host the Olympics	
Highest Point (5,959 m)		Tallest Freestanding Structure	
Lowest Point (0 m)		National Police Force of Canada	

Name the 13 states that border Canada:

GET READY TO PLAY…..THERE ARE THREE CANADIANS ON THIS FIELD TRIP, MAYBE IT'S TIME YOU LEARNED SOMETHING ABOUT CANADA!

Name these Canadian Expressions:

Canadian Phrase	Missing Word	Canadian Phrase	Missing Word
___ Shatner		___ Brunswick	
Governor ___ of Canada		Toronto Maple ___	
___ Edward Island		Degrassi ___ High	
Royal Canadian ___ Police		Crash ___ Dummies	
Toronto ___ Jays		Newfoundland and ___	
Keanu ___		Bob and ___ McKenzie	
___ Scotia		Toronto ___ International Airport	
Anne of ___ Gables		Neil Young & ___ Horse	
___ J. Fox		The ___ in the Hall	
___ Fraser University		Sault Ste. ___	

Name the Canadian Expression:

Clue	Answer
Addendum to spoken sentences, indicating a subtle request for approval or agreement.	
One-dollar coin	
Two-dollar coin	
Coffee with extra cream and extra sugar (hyphenated).	
Living room furniture that two or three people can simultaneously sit on.	
A knitted woolen cap, often topped with a pon-pon.	
Section of a home or public building where people dispose of bodily waste.	
A case containing two dozen beer.	
Milk with fat content of 3.5% or higher	
Electrical power or the company that provides it.	
A writing implement with a wooden shell covering a coloured lead in the centre.	
A dry paper product, usually available in restaurants, used to wipe one's face or fingers.	

GET READY TO PLAY.....THERE ARE THREE CANADIANS ON THIS FIELD TRIP, MAYBE IT'S TIME YOU LEARNED SOMETHING ABOUT CANADA!

Extra-Tough trivia:

Clue	Answer	Begins With Letter
Production of this delta-winged interceptor aircraft was controversially cancelled February 20, 1959.		A
Jurist - war crimes Chief Prosecutor for International Tribunals for Rwanda and the Former Yugoslavia.		A
2001 film retells an Inuit legend. First feature film in Inuktitut language.		A
Award winning author: work includes theocratic dystopia The Handmaid's Tale.		A
Toronto-based band taken off bill of 1991 New Year's Eve City Hall concert. City staffer felt band's name objectified women.		B
Popularizer of Canadian history, born Whitehorse 1921. Books incl. Klondike and The National Dream.		B
Quebec politician - 1st separatist leader of federal Opposition. Lost leg in 1994 to necrotizing fasciitis.		B
Officially credited with 72 victories, he was Canada's top WWI flying ace.		B
Toque-wearing cheerful snowman mascot of wintertime Carnaval de Quebec.		B
Montreal-born often reclusive singer, songwriter, poet & novelist. Extensively honoured in Canada; inducted into American Rock and Roll Hall of Fame in 2008.		C

Clue	Answer	Begins With Letter
The created Native Canadian identity of conservationist and writer Archibald Belaney. His British origins were discovered after his death.		G
Explosion in this harbour, caused by collision of two ships, one fully loaded with munitions, in 1917 is the world's largest man-made accidental explosions.		H
English name of de Brebeuf written Xmas carol 'Jesus Ahattonia', beginning 'Twas in the moon of wintertime...'.		H
Broadcaster credited with coining the phrase, 'He shoots. He scores!'		H
One of the deadliest & costliest storms of the 20th century, this 1954 hurricane name was retired. It killed 81 Canadians after reaching Toronto area considerably weakened.		H
Medical student Charles Best won a coin toss to become lab assistant to Frederick Banting, leading to him being credited as co-discoverer of this.		I
Canada has become world's largest producer of this dessert wine, made from grapes that have frozen while still on the vine.		I
Her 'For Better or For Worse' comic strip appears in approx. 2000 newspapers in over 20 countries.		J

Clue	Answer	Begins With Letter
Red Green's lodge. Oath = 'I'm a man but I can change if I have to I guess.'		P
One co-host of long-running children's show, also featuring Marigold and Bear, would always 'just miss' seeing this large green kangaroo-like creature.		P
Canada is only foreign country permitted to have embassy on this Washington, D.C. street.		P
WWI-formed regiment named after daughter of Governor General Duke of Connaught. One of the most decorated in Canadian Forces.		P
Oldest walled city north of Mexico.		Q
Square-headed alternative to slotted & Phillips screwdriver, named after its inventor.		R
When frozen in winter, this Ottawa waterway is world's longest skating rink.		R
Provincial capital located on the site of hunters' camp that was named Pile O' Bones.		R
Called Canada's 'Last Father of Confederation' for role in making independent Newfoundland into Canada's 10th province in 1949.		S
Trio of children's entertainers who 'skinnamarink'ed' their way to success, and into the Order of Canada in		S

GET READY TO PLAY.....THERE ARE THREE CANADIANS ON THIS FIELD TRIP, MAYBE IT'S TIME YOU LEARNED SOMETHING ABOUT CANADA!

Scored the winning overtime goal in the 2010 Olympic gold-medal hockey game.		C
'There are strange things done in the midnight sun, by the men who moil for gold.'		C
Albertan sporting event - attendance over one million, prize money totalling two million dollars. Yee haw!		C
Yvonne, Annette, Cecile, Emilie, & Marie. Born 1934		D
Politician - Father of Canadian Medicare, voted 'The Greatest Canadian'.		D
Artist whose works include iconic hockey-themed 'At the Crease' and 'Lacing Up'.		D
From popular 1990's TV show 'Due South', this lip-reading wolf was named after a former prime minister.		D
Disastrous Aug. 19, 1942 Allied WWII raid with predom. Canadian infantry. Almost 60% who landed - killed, wounded, or captured.		D
Spike, Joey, and friends lived, learned, and went to junior high and high school on this street. Now onto the next generation.		D
Mary Walsh character, sometimes dressed as warrior princess, who corners and questions politicians. Showed up at a Sarah Palin booksigning.		D

Long-serving Prime Minister who used seances to communicate with spirits of his dead mother and Irish setters.		K
Completing an enormous engineering project and fulfilling a national dream, this was famously driven in, located in Craigellachie, B.C.		L
Politician & diplomat. Served as United Nations special envoy for HIV-AIDS in Africa.		L
This vegetarian, lesbian, and enormously talented singer sang 'Hallelujah' at the opening ceremonies of 2010 Olympics.		L
In 1915, this WWI soldier & surgeon, Lieutenant Colonel, wrote 'In Flanders Fields'.		M
Comedian & political satirist from Newfoundland known for 'Talking to Americans' and internet petition to make politician Stockwell Day change first name to Doris.		M
Province of Quebec produces 80% of world's supply of this sticky, sweet treat.		M
Last time this hockey team won the Stanley Cup was Canada's centennial year.		M
In one of his many books he describes intentionally subsisting on mice while studying wolves in the Arctic.		M
Founded in 1786, oldest		

2002.		
Walked approx. 30 km to warn British Lieutenant Fitzgibbon of impending surprise attack at Beaver Dams by Americans in 1813.		S
Take a shot of this strong Newfoundland rum, kiss a codfish on the mouth, and answer the question, 'Is ye an honorary Newfoundlander?'		S
'Just watch me.' 'Fuddle duddle.' 'The state has no place in the bedrooms of the nation.'		T
Game invented by Scott Abbott and Chris Haney, released in 1981-1982. This would be a good question.		T
Wrongfully convicted of murdering classmate, he was sentenced to death at age 14 in 1959. Formally acquitted of crime in 2007.		T
Named for its founding hockey player, it's where Canadians go to 'roll up the rim' of their 'double double'. (full name)		T
British colony from 1791-1841, consisting roughly of what is now Southern Ontario. Capital was Newark, then York (renamed Toronto in 1834).		U
WWI battle in April 1917 - 1st time all 4 divisions of Canadian Expeditionary Force fought together. Its success became a matter of national pride.		V

GET READY TO PLAY.....THERE ARE THREE CANADIANS ON THIS FIELD TRIP, MAYBE IT'S TIME YOU LEARNED SOMETHING ABOUT CANADA!

Sarah Palin booksigning.		
Rolling Stones performed at this Toronto club in 1977 using pseudonym The Cockroaches, with then first lady Margaret Trudeau in attendance.		E
This writer used a barn on his Stone Orchard property as inspiration for Noah's ark in his novel 'Not Wanted on the Voyage'.		F
Inventor of standard time zones. Surveyed route for cross-Canada CPR railway. Designed Canada's 1st postage stamp, the Threepenny Beaver.		F
Famous for low-sitting position at keyboard, this classical pianist abandoned concert performance at age 31 to focus on studio recording.		G
Newfoundland town opened their airport and community to many displaced planes and passengers when American airspace closed on Sept. 11, 2001.		G

[illegible]		
Founded in 1786, oldest brewery in North America, and is behind iconic 'I Am Canadian' ad campaign.		M
Over 218,000 people moved, less than 48 hours, no lives lost - prior to Hurricane Katrina, evacuation of this city (train derailment) was largest North American peacetime evac.		M
Sam Steele wore the traditional red serge uniform of this Royal Canadian Mounted Police forerunner, during the Klondike Gold Rush.		N
Layered sweet treat named after a city in British Columbia.		N
Born 1948, in Parry Sound, with game-changing hockey style, remains only defenceman to win NHL scoring trophy.		O
Name of Okanagan Lake's resident lake monster.		O
Heart-stopping Quebec treat combining French fries, cheese curds, and gravy.		P
This Toronto-born Indian-descent comedian made Forbes list of top 10 earning comedians from June 2008-2009. 'Somebody's going to get a hurt real bad.'		P

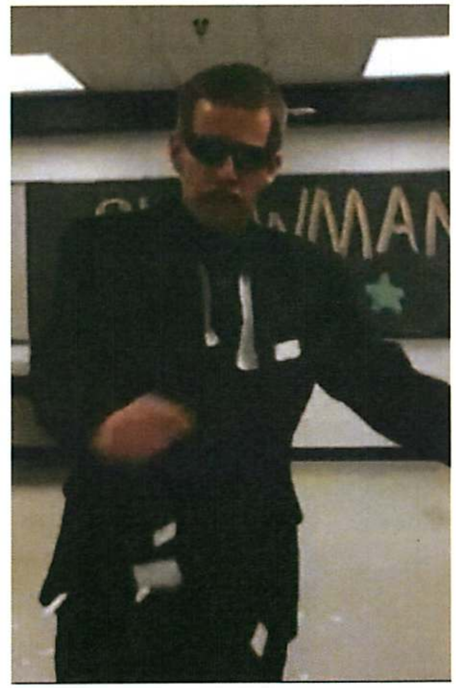
success became a matter of national pride.		
Britain's monarch at the time of Canadian confederation. Celebrated in Canada with long weekend in May and fireworks.		V
1970 kidnappings of gov't officials by Front de liberation du Quebec led to Canada's only peacetime invocation of this emergency powers act.		W
Gordon Lightfoot song about 1975 sinking of Great Lakes freighter in Lake Superior with all 29 hands lost.		W
World's longest freshwater beach.		W
Unofficial name of paramilitary & commando training camp near Whitby-Oshawa.American FBI & OSS agents secretly attended before USA entered WWII.		X
Hey Hey, My My, this singer-songwriter's 4-decade career includes refusing to be filmed at Woodstock, Scorsese having to edit Last Waltz to obscure cocaine hanging from his nose.		Y
Finally, the correct way to pronounce the last letter of the alphabet is...		Z

Michelle has all the answers! But also, your local Canadian (as in the one in your car) might know most of them...

Showman Style Word Search

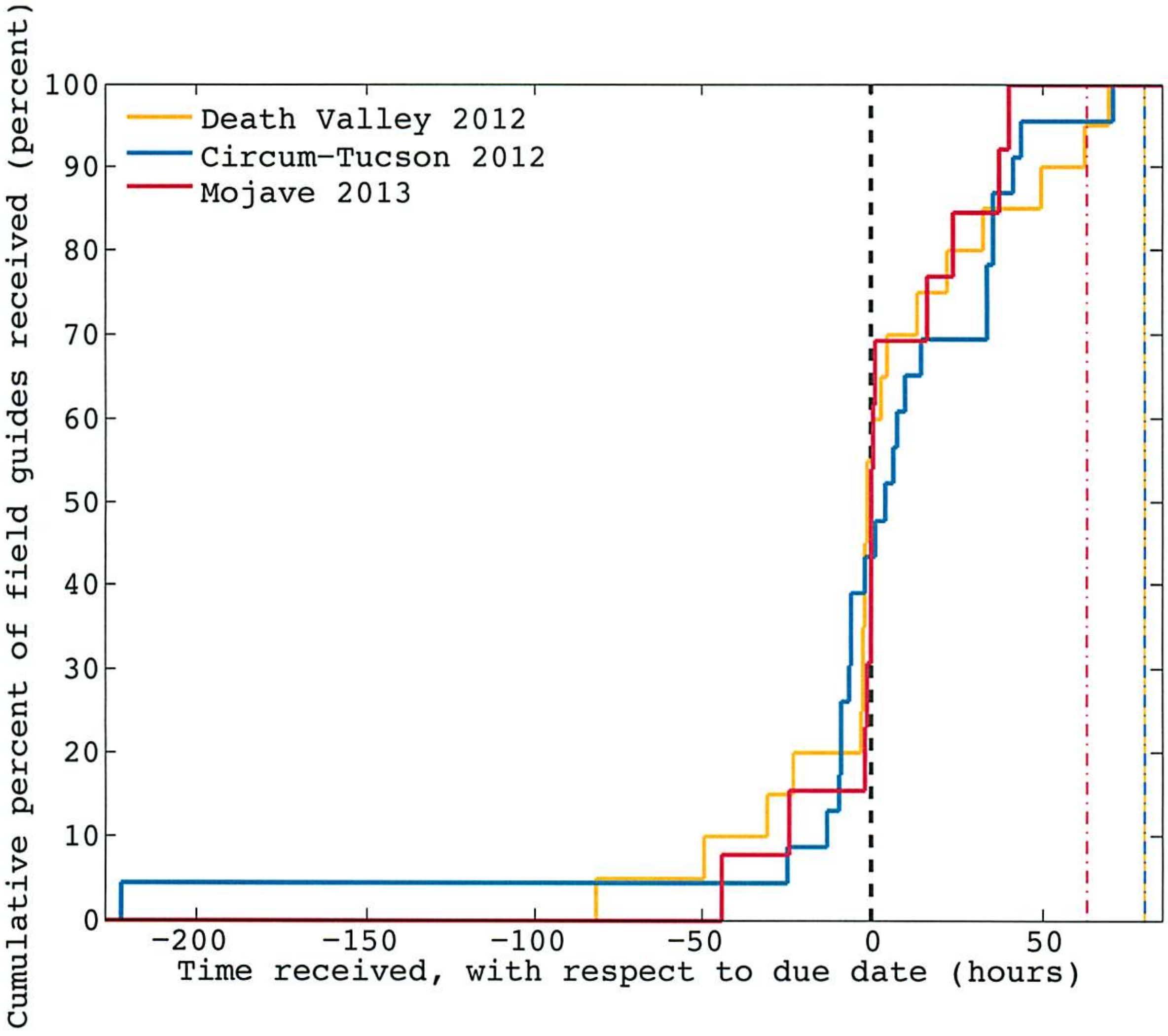
Q M X
O A L P J I T S X
A B G Q B S I T V V J Q R
W H C R V L E A M R Y Y N C B C W
D V M S N O M U C A K J A H O I X I V
B K T A U D Y Y W T Y M M P B I U Z R O N
N S T E N A L P O X E W Q A X F O G C L U
S Q U M R A   S A O N T   F S Z C I W
J N P C D R   P H Z E K   T E N W C L
R O E T E D U U X R S E A A Z D U U F F L P C F K
E M L D Y E C Y N M P E T V W W D U F C H S H E L
T A K N F J Z Y D T L W Y H O E Y T B U P K I D Y
R I D Z O B M B F R Y K M L D N E T A M I L C N D P A
E P A F G O P T K T P G T B T H W D E E P S N E T I C
Q U E L I K W I S A A I U S W A P L A N E T S S F N E
J V L A   P X L T T T W I L I G H T J W   Q E I V
X G Q S   T Q V I Z Z V F M L Z Z E   H A C W
J L X L K   L L A W S J I B L C Q   U S C A J
F O U Q Y   E L U V U
F C C N D D   B L W N N Z
O O L O V I C Z K R D K X Q O R Y K L M S
P O M N D Z V F Z P G N J X O E K A D M R
J F U U C Z I U W D B K S N O L I I G
B R K A W I N T J Z I O X D R A C
D Q X R N G O V M X V A Y
D J T P D U T G T
A Q I

CHINESE
PLANETS
TENSPEED
CLIMATE
GLUTEN
BOBATEA
ADVISOR
MONEY
ADAM
SHOWMAN
STYLE
STUDENTS
SKYDIVING
TWILIGHT
SAIGON
DREAM
EXOPLANETS
JUPITER
URANUS



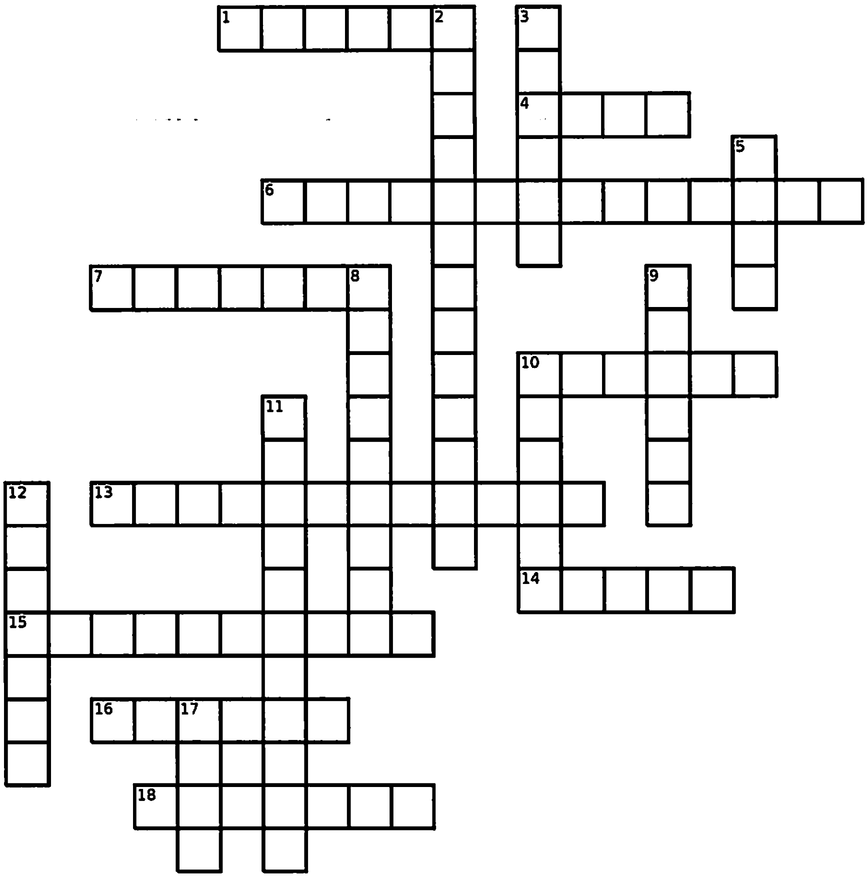
Grad Students and Deadlines

The plot below shows the cumulative percent of field guides received by the editors, as a function of time, with respect to the due date (black dashed line), for the past three field trips. Departure times for each of the field trips are shown as the dash-dot lines.



Arizona Trivia
K Miller

No spaces included in solutions.



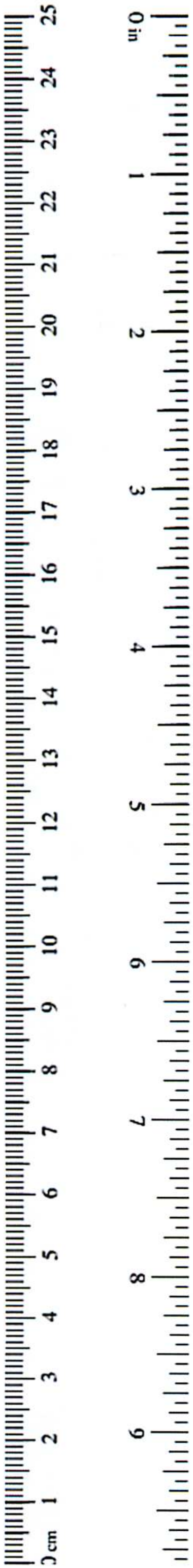
Across

1 In terms of fractions, about one [ ] of the state is federal land designated for Native Americans Reservations.
4 Actor [ ] Stone is from Scottsdale.
6 Where is the 1831 London Bridge? (3 Words)
7 The largest employer in Arizona as of 2010 was [ ].
10 There are 91 [ ] in Arizona.
13 [ ] [ ] can live up to 200 years (2 Words)
14 Arizona is the [ ] largest state
15 Arizona has the largest population of all the [ ] states.
16 "Arizona" probably either comes from the O'odham "ali sonak", which means small [ ]. (The word is a time, a verb, and something you might find outside.)
18 The official state neckwear is the [ ]. (2 Words)

Down

2 The highest elevation in Arizona is [ ] [ ] at 12.643 ft. (2 Words)
3 Arizona became a state in the year nineteen [ ].
5 How many different national flags have flown over Arizona land?
8 [ ] is the state gemstone.
9 The [ ] of a saguaro is closely related to its age.
10 Arizona is popular for Major League Baseball spring training because it has the [ ] League.
11 The Arizona state slogan is [ ] State. (2 Words)
12 In 2009, the five largest ancestry groups in Arizona were Mexican, German, Irish, English, and [ ].
17 The amount of copper on the Capitol's [ ] is equal to 4,800,000 pennies.

Scale bar



0 cm 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
0 in 1 2 3 4 5 6 7 8 9