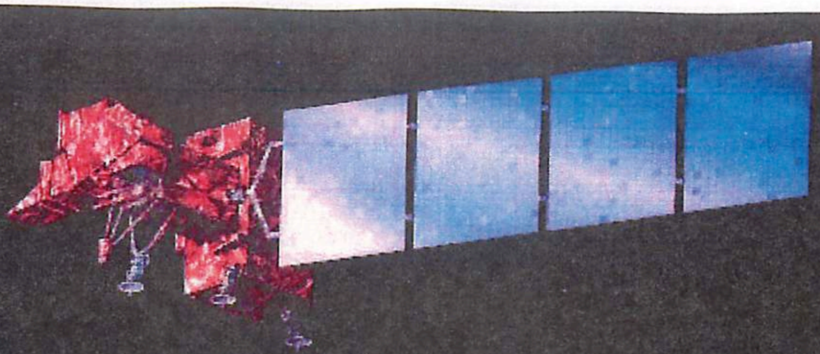
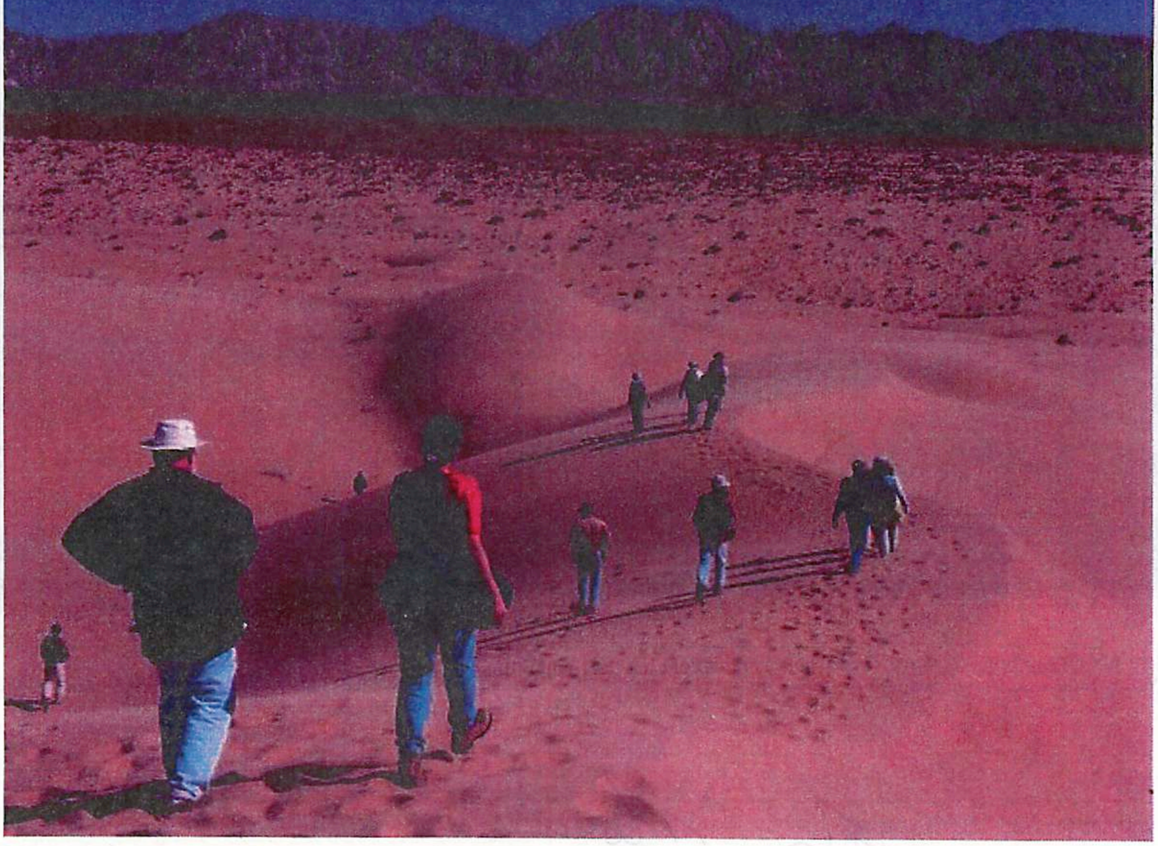


PTYS FIELD GEOLOGY PRACTICUM
SPRING 2005

SENTINEL-ARLINGTON VOLCANIC FIELD AND GILA GRABEN:

GROUND TRUTH



THE UNIVERSITY OF ARIZONA PRESENTS
A LUNAR AND PLANETARY LAB / DEPARTMENT OF PLANETARY SCIENCE CO-PRODUCTION OF
A JAY MELOSH FIELDTRIP
SENTINEL-ARLINGTON VOLCANIC FIELD AND GILA GRABEN: GROUND TRUTH
FEATURING PRESENTATIONS BY OLEG ABRAMOV · DOUG ARCHER · JASON BARNES · NICOLE BAUGH · MIKE BLAND
DAVID CHOI · CURTIS COOPER · INGRID DAUBAR · COLIN DUNDAS · CATHERINE NEISH · BRIAN JACKSON
JOHN KELLER · ERIC PALMER · MANDY PROCTOR · JANI RADEBAUGH AND JOE SPITALE WITH DRIVERS JASON BARNES · JOHN KELLER
BRIAN JACKSON AND MANDY PROCTOR FACULTY SUPPORT PROVIDED BY JASON BARNES · GARRETH COLLINS · RALPH LORENZ · BETTY PIZARRO
ADAM SHOWMAN AND ZIBI TURTLE FIELD GUIDE PREPARED BY JOHN MOORES PRODUCED AND DIRECTED BY JAY MELOSH

ARCHIVE COPY

Figure 7. A Sentinel Plain lava cone. The 5° slopes of this cone are the result of fluid lava flowing out of the central conduit and spreading radially outward, without significant pyroclastic activity. D. Lynch photo.

John Moore

FIELD GUIDE EDITOR
2005

PTYS 594a,
PLANETARY FIELD GEOLOGY PRACTICUM

Spring 2005 Sentinel-Arlington Volcanic Field and Gila Graben Itinerary

Saturday, 2 April

8:00 am	Depart LPL loading dock. Drive North on Cherry to Speedway, proceed West to I-10, drive North towards Phoenix. Exit at I-8 and drive West to Gila Bend. Exit I-8 at Gila Bend and proceed North on Rte 85. After 10 miles exit dirt road, stop at foot of Maricopa Mountians.
10:00 am	First stop. **Brian Jackson** (GH) will describe the Basin and Range tectonic regime.
10:45 pm	Reverse direction, travel South on Rte 85, through Gila Bend, then about 10 miles South. Take dirt road to East (if not gated by the Air Force, on whose bombing range we are now traveling) where **Mandy Proctor** (GH) will give us the lowdown on Pediments.
12:00	Return to I-8, proceed West to exit 102 for Painted Rock Dam road. Drive 2 miles North. Lunch stop.
1:00 pm	**John Keller** (SC) will described the "Gullies" site here. **Jason Barnes** (GH) will also give us an overview of geology of the Painted Rock Mountains.
1:45 pm	Proceed North about 6 miles on Painted Rock Dam road to overlook Gila River. **Oleg Abramov**(SC) will give us a remote sensing overview of the region. This is also **Mike Bland's** (SC) "Lobes" site. **Colin Dundas** (GH) will review the regional geology.
2:30 pm	Continue North to the Painted Rock Dam, where **Nicole Baugh** (GH) will describe the regime of the Gila River.
3:15 pm	Retrace our path South to the Rocky Point Road, turn right, travel West through Rocky Point, then North towards the roads' intersection with the Southern Pacific Railroad. About 6 miles North of Rocky Point is **Doug Archer's** (SC) "Dendritic" site.
4:00 pm	Continue North several miles to stop North of Oatman Mountain. **Catherine Neish** (GH) will describe the role of water in sculpting the landscape we can view.
4:45 pm	Retrace our path to Rocky Point, where we turn right and proceed Southwest to Oatman Flat. If possible, ford the wash (if not possible, we will return North and work our way to Agua Calienta along the Southern Pacific access road). After about 5 miles South of the wash, take the dirt road to the Southeast.
5:30 pm	Stop at the isolated volcanic vent near this road. Hike to the vent where **Eric Palmer** (GH) will tell us about volcanism in the Sentinel Volcanic Field.
6:30 pm	Camp in vicinity of this small vent.

Sunday, 3 April

8:00 am	Break camp, continue on dirt road to the Southeast. In about 2 miles we should reach **Ingrid Daubar's** (SC) "Dunes" site. If this is not on the road itself, we will hike a mile or two until we find it, relying on the magic of GPS. Here we will confront the Space Cadets about how well they can identify sand dunes from space.
9:30 am	Continue South a few miles until just North of I-8. A short hike of about 3 miles will take us to the (low) summit of Sentinel Peak, where **David Choi** (SC) will describe its relation to the rest of the field, and give us an overview of the field from its lofty top (we will try to drive closer if we can find a route). **Eric Palmer** (GH) may also add some information on volcanism
12:00	Return to the vehicles, stop for lunch.
1:00 pm	Continue South under the Interstate (no entrance is marked here), parallel the Southern Pacific tracks to the West until we come to the Sentinel entrance of I-8. Here we continue North on the dirt road to the tiny town of Agua Caliente, about 15 miles, to stop at **Curtis Cooper's** (SC) "River" site on the Gila River.
2:00 pm	Reverse direction, return to I-8. Travel West on I-8 about 8 miles, to view (in passing) **Jani Radebaugh's** (SC) "Dark Lava" site. Continue West on I-8 to exit 67 at the defunct town of Dateland. Proceed North 10 miles to stop just short of the Gila River. **Joe Spitale** (GH) will describe the nature and mechanics of the Gila Graben here.
3:30 pm	We are done!Return to I-8 and go back to Tucson.
5:30 pm	Arrive in Tucson, unpack and clean vehicles, go home.

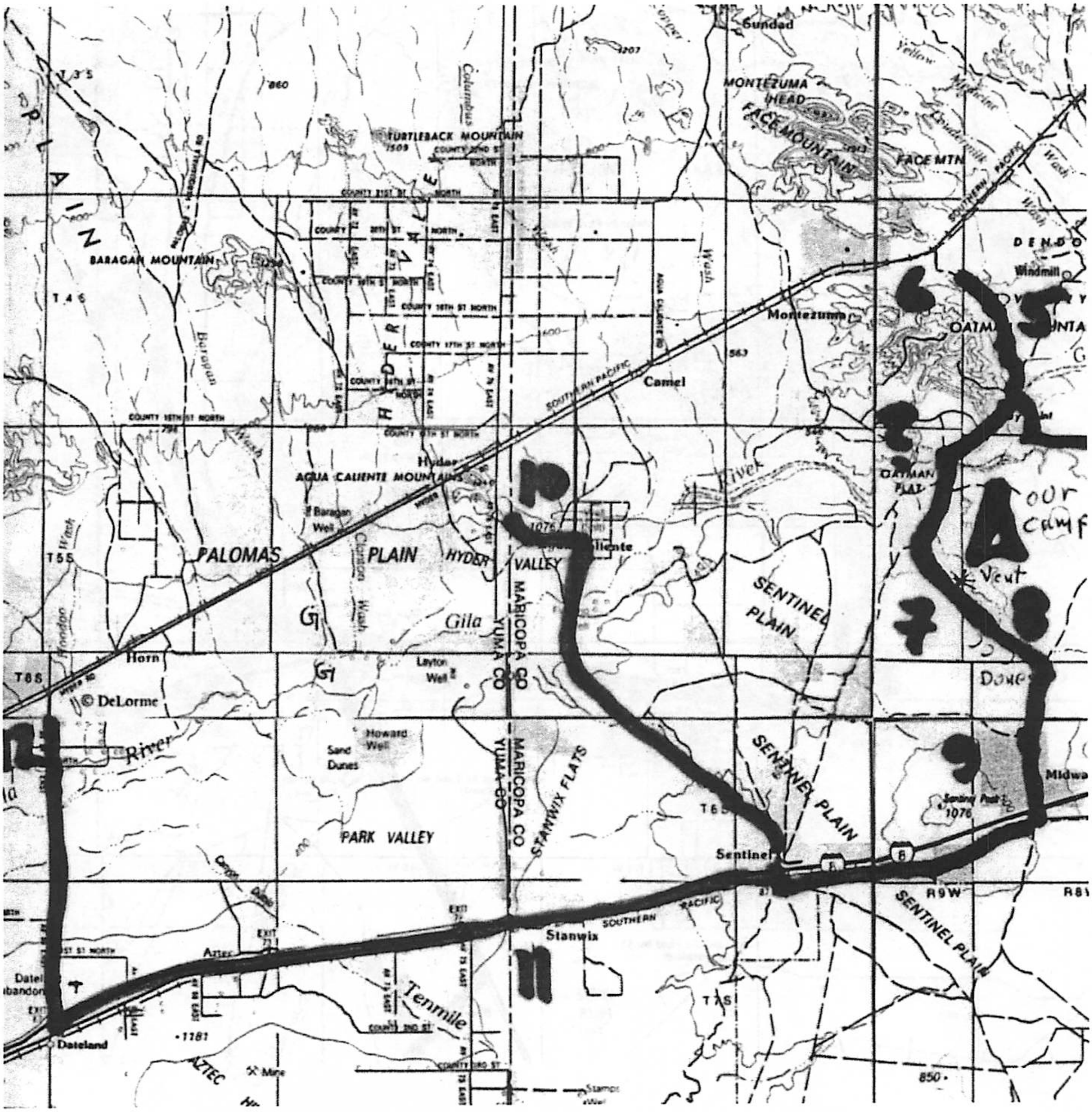
Primary Drivers: Barnes, Jackson, Keller, Proctor.
Faculty Co-Leaders: J. Barnes, G. Collins, R. Lorenz, B. Pierazzo, ZTurtle

Participants:

"Groundhogs"	"Space Cadets"
Barnes, J.	Abramov, O.
Baugh, N.	Archer, P.
Dundas, C.	Bland, M.
Hattori, M.	Choi, D.
Jackson, B.	Cooper, C.
Neish, C.	Daubar, I.
Palmer, E.	Keller, J.
Proctor, M.	Moores, J.
Spitale, J.	Radebaugh, J.
	Richardson, J.

Handout Volume Editor: John Moores

Cover Credit: Landsat7 Art (Courtesy Goddard Space Flight Center) combined with a photograph taken by John Moores in the Pinacates reserve in 2003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PALOMAS
PLAIN
HYDER VALLEY
Agua Caliente
OATMAN FLAT
OATMAN MOUNTAINS
DENDORA VALLEY
Windmill
our camp
Vent
Dunes
SENTINEL PLAIN
Sentinel Peak 1076
Midway
Sentinel
Gila River
MARICOPA CO YUMA CO
STANWIX FLATS
Layton Well
Howard Well
Sand Dunes
PARK VALLEY
Horn
© DeLorme
Stanwix
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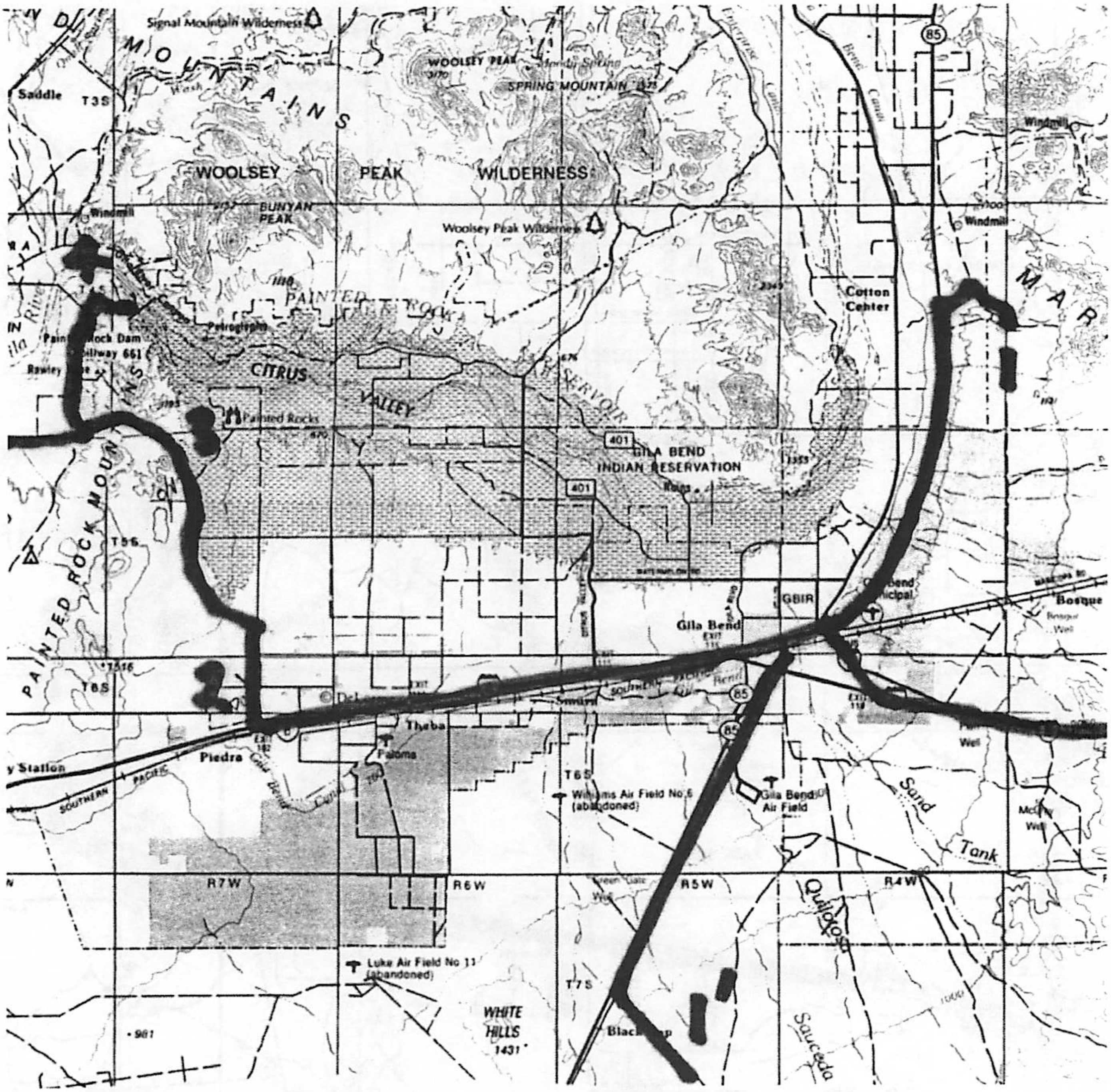
Signal Mountain Wilderness
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T3S
WOOLSEY PEAK
SPRING MOUNTAIN
Windmill
WOOLSEY PEAK WILDERNESS
BUNYAN PEAK
Woolsey Peak Wilderness
Windmill
Gila River
Painted Rock Dam
Spillway 661
Rawley
Petroglyphs
PAINTED ROCK RESERVOIR
CITRUS VALLEY
Painted Rocks
Cotton Center
MAR
401
GILA BEND INDIAN RESERVATION
Ruins
PAINTED ROCK MOUNTAINS
T5S
T6S
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GBIR
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Gila Bend Municipal
Bosque
Bosque Well
SOUTHERN PACIFIC
Gila Bend Canal
Piedra
Theba
Paloma
Smurr
Station
Williams Air Field No 6 (abandoned)
Gila Bend Air Field
Sand Tank
R7W
R6W
R5W
R4W
Green Gate Well
Quilotosa
Luke Air Field No 11 (abandoned)
WHITE HILLS 1431
T7S
Black Gap
Saucedo
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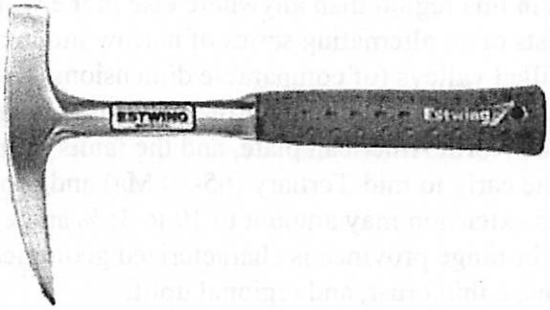
NOTES



SECTION 2:

GROUNDHOG HANDOUTS

(IN ORDER OF APPEARANCE)

BRIAN JACKSON
MANDY PROCTOR
JASON BARNES
COLIN DUNDAS
NICOLE BAUGH
CATHERINE NEISH
ERIC PALMER
JOE SPITALE

Basin-Range Structure in the Southwest United States:

a talk for the Sentinel Plains LPL field trip – April 1-3, 2005

by Brian Jackson

Introduction

The basin-range province of North America extends from Oregon into Mexico and is more prominent in this region than anywhere else in the world. In essence, basin-range geography consists of an alternating series of narrow mountain ranges (15-20 km across) and alluvium-filled valleys (of comparable dimensions) (Stewart, 1978; hereafter S78). The mountains and basins meet along normal faults due to late Cenozoic extension of the western end of the North American plate, and the faults probably follow geologic patterns laid down in the early to mid-Tertiary (65-30 Ma) and probably even Cretaceous (71.3 Ma) periods. This extension may amount to 10 to 35% and even 100% in some regions (ibid.). The basin-range province is characterized geologically by anomalous upper mantle formations, a thin crust, and regional uplift.

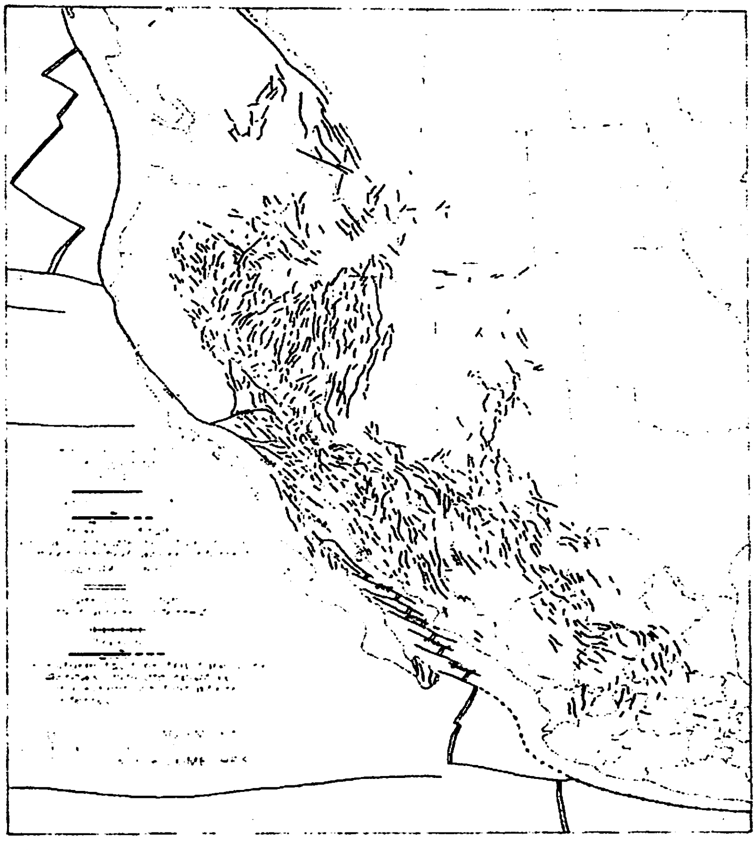
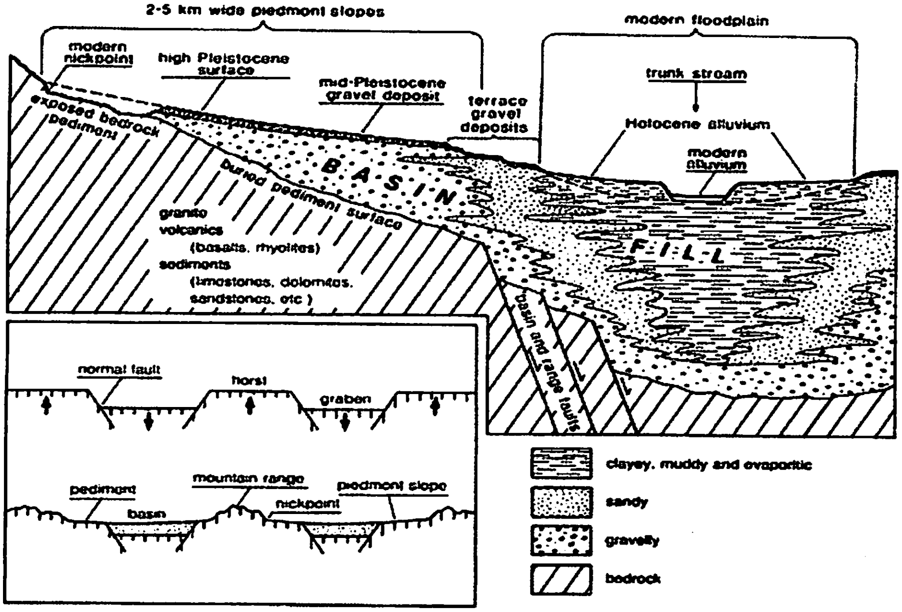


Figure 1-1. Distribution of late Cenozoic extensional faults and a few major strike-slip faults in western North America and present-day lithospheric plate boundaries. Faults are generalized and, in part, inferred. Based on various sources, including King (1969b).

Morphology

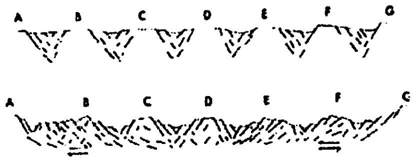
Basin-Range structure basically represents a series of normally faulted major blocks, the large scale equivalent of horsts and grabens. In this case the horst (basin) and graben (mountain range) meet at an angle anywhere from a few degrees to as much as 30 degrees in some places. Basins and Ranges owe their formation to the down-dropping/uplifting of adjacent bedrock units. Some may also form due to down-warping listric faulting which causes the bedrock units to tilt (S78).



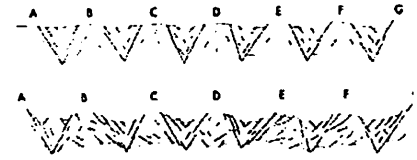
The above figure (Hendricks, 1985) shows the modern morphology of basin-range formations. Walking downward from the top of the range, one first encounters the nickpoint, the beginnings of range erosion. This is also near the point where the last of the range bedrock is exposed to the surface. As one continues down the slope, the alluvium fill overlies the down-slopping bedrock pediment. Continuing down the slope, one encounters more modern alluvium, each age of alluvium differing in composition from gravel deposits nearest the mountain to clay and evaporites in the newest region.

The uplifted blocks tend to be granite or other crystalline bedrock, while the basins are filled with several hundred to 2000m of alluvium consisting of gravel, sand and other conglomerates.

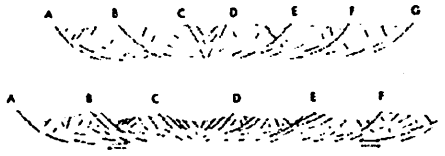
While the underlying model tends to be simple, the actual geomorphology tends toward complexity with each basin-range assemblage comprising many faults. In addition, the basin-range structure seems to have formed penecontemporaneously with the second wave of igneous activity which swept through the western United States about 11 Ma, further complicating geologic exploration.



MODEL A. HORSTS AND GRABENS FORMED BY FRAGMENTATION ABOVE PLASTICALLY EXTENDING SUBSTRATUM



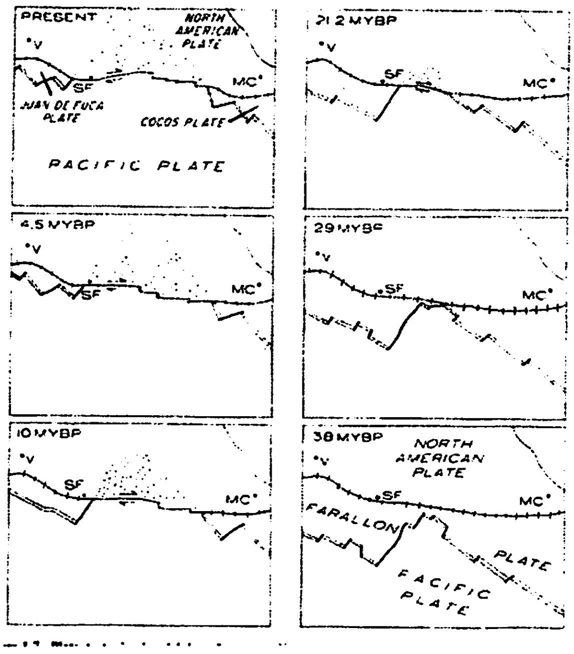
MODEL B. HORSTS AND GRABENS FORMED BY FRAGMENTATIO AND SEGMENTATION INTO BUOYANT BLOCKS



MODEL C. TILTED BLOCKS RELATED TO DOWNWARD-FLATTENIN (LISTRIC) FAULTS

Tectonic Origins

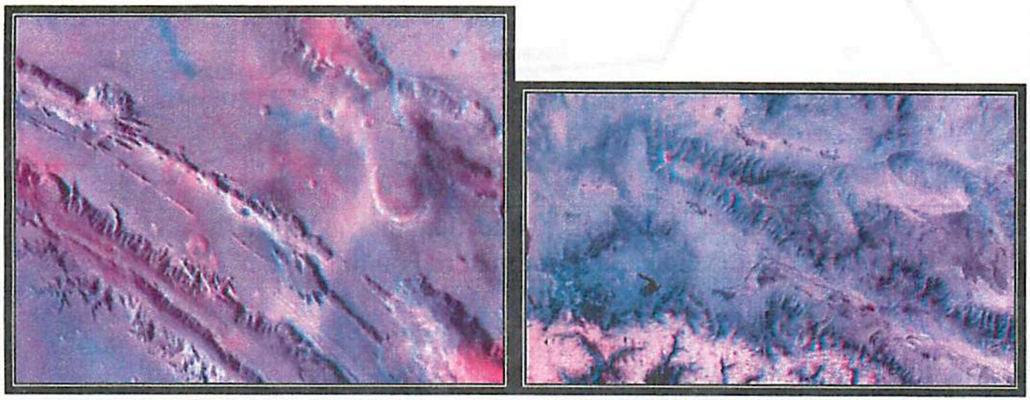
The details of the origin of the basin-range province are not entirely clear, but the big picture seems to be fairly well understood. Almost certainly the basin-range formation resulted from a regional extension of the western end of the North American plate during the late Cenozoic period (~20 Ma). The extension was due to a change in the geometries between several tectonic plates, namely the North American, Pacific and now extinct Farallon plates.



Thirty-eight Ma, the Farallon and Pacific plates shared a spreading ridge between them and to the west of the North American plate. The Farallon plate, meanwhile, was being subducted under the western end of the NA plate. About 29 Ma, the spreading ridge between the P and F plates become overridden by the subduction zone, forming the San Andreas strike-slip fault. This induced a shearing stress on the NA plate as the P plate moved northwestward. This gave rise to the extension of the NA plate and the subsequent faulting which created the basin-range province through your favorite faulting scheme.

Planetary Connection

While there are many basins and mountain ranges on other planets, only Earth shows evidence for plate tectonics, the integral cause of North America's basin-range province. However some regions on Mars have similar morphologies to Earth basin-range structures. Understanding the geologic environment under which formed Earth's basin-range structure may facilitate the understanding of extraterrestrial geology and geophysics.



Valles Marineris on left; Owens Valley in the Sierra Nevadas on right (from http://www.astro.washington.edu/labs/clearinghouse/labs/Mars/comgeol.html)

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Stewart, J.H. 1978. Basin-Range Structure in Western North America: A Review., in Smith, R. B. and Eaton, G.P.. eds., Cenozoic Tectonics and Regional Geophysics and the Western Corderilla: Boulder CO, GSA, pp. 1-32.

Pediments

By: MANDY PR☺CT☺R

What is a pediment?

"Pediments are erosional surfaces of low relief, partly covered by a veneer of alluvium, that slope away from the base of mountain masses or escarpments in arid and semiarid environments." (Hadly 1967)

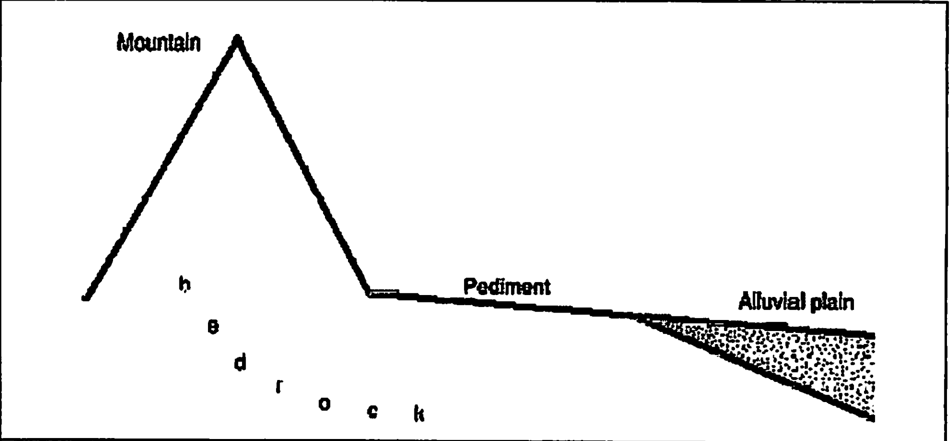

Fig 1: A schematic of a pediment. Note that the pediment has a low slope. This slope can develop a layer of material on top of it.

How are they different than alluvial fans?

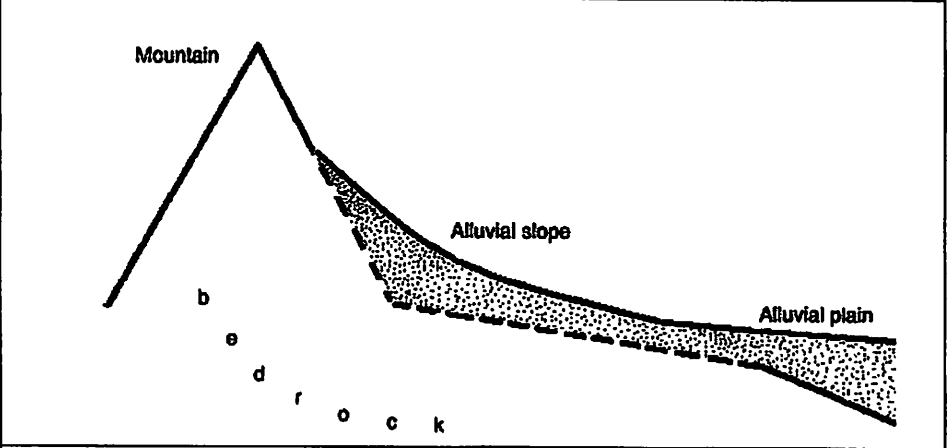

Figure 2: A schematic of an alluvial fan. Not the steep alluvial slope.

Where do pediments come from?

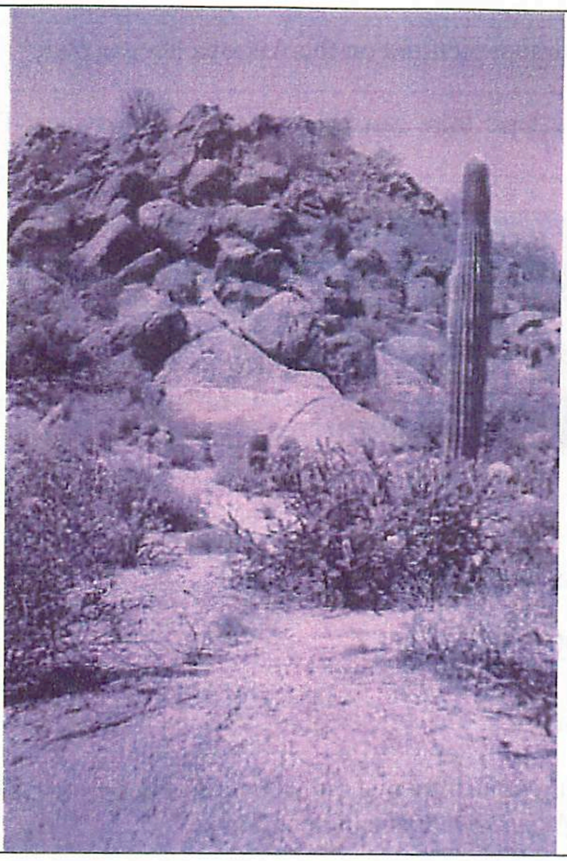

Figure 3: Sloping rise of a pediment near Phoenix.

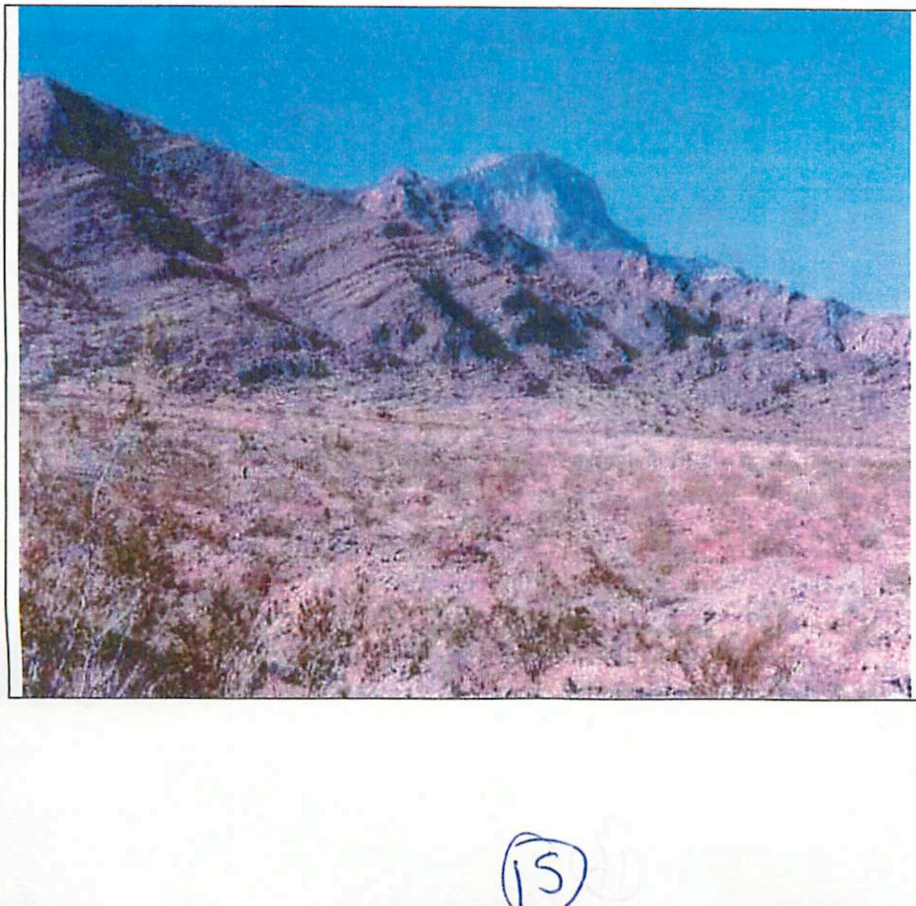

Figure 4: A picture of a pediment in the Basin and Range .

Where can I see more pediments?

Just drive around, there is a pediment pictured on the Arizona license plate!

And according to Stephanie Fussner they can be seen on I-10 between Tucson and Casa Grande!

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http://southwest.library.arizona.edu/azso/body.1_div.2.html

http://pubs.usgs.gov/of/2004/1007/fans.html

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Applegarth, MT (2004) Assessing the Influence on Mountain Slope Morphology on Pediment Form, South Central Arizona. Physical Geography.

http://www.geocities.com/scott_cotter/pediment.htm

Southwest Arizona's Painted Rock Mountains

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Department of Planetary Sciences
University of Arizona
Tucson, AZ 85721
`jason@barnesos.net`

ABSTRACT

The Painted Rock Mountains are located at the eastern edge of the Sentinel Peak Volcanic Field. They are a late Cretaceous/early Tertiary andesitic extrusive volcanic deposit. They are completely unrelated to the Sentinel Peak volcanism. Painted Rock Mountains debris forms distinctively colored alluvial fans as a result of chemical weathering on the rocks' exterior. Stream channels on those fans show up light in color. The extensive Native American rock art here was created taking advantage of this light/dark inside/outside dichotomy.

Subject headings: Painted Rock Mountains – alluvial fans – Titan connection – Native American art

1. INTRODUCTION

At the Space Cadet location marked (I think?) as 'gullies' in the southeast of the map (but north of the 8), orbital imagery shows light-colored water runoff channels in darker surrounding terrain. You can also see strange light-colored circles between the channels.

The entire area is located within the **Painted Rock Mountains**, a volcanic range totally unrelated to the Sentinel Peak vulcanism. The dark color of the background rocks in the area is caused by **desert varnish**, a process by which the exterior layers of rocks darken with time. The gullies are located on rocky debris washed out of the mountains known as **alluvial fans**, a feature that Ralph thinks he sees in Cassini RADAR images of Titan. By selectively scraping desert varnish off of rocks, intelligent beings have left their mark on this area as **rock art**.

2. PAINTED ROCK MOUNTAINS

The Painted Rock Mountains are a relatively low (1511 ft max) and small mountain range extending north of the 8 on the eastern edge of the Sentinel Peak Volcanic Field centered at about 32.927°N113.0335°W. In LandSAT visible color images (Figure 1), this mountain range is distinct in color, different from the black neutrally colored lava flows of the Sentinel Peak Field.

The rocks that make up the Painted Rock Mountain range are andesitic in composition. Extrusive lavas behave very differently depending on how much silica (SiO_2) they contain, with viscosity rising with silica content. Basalts are very silica-poor. When extruded, they flow easily. Rhyolites are basically extruded granites; they're very silica-rich and extraordinarily viscous. Andesite is between the two.

The Painted Rock Mountain's andesites were erupted about 70 million years ago, late in the Cretacous to early in the Tertiary. I don't know if any K/T boundaries are preserved here, but I doubt it – the environment was likely erosional except for the lava deposition. The timing of the eruptions leads me to think that the Painted Rock volcanoes were part of the wave of volcanism that has swept west to east and back throughout the southwestern US since the Laramide Orogeny (Rocky Mountain building episode starting maybe 80 Myr ago).

The present location and extent of the Painted Rock range appears to me to be the result of basin and range extension. We're not still seeing the original mountains built up 70 million years ago, we're seeing rocks that were initially buried but have been brought up by basin and range and are now eroding. I'm guessing at a lot of this based on two sentences that I found in Roadside Geology of Arizona, so please correct me if you know better.

3. DESERT VARNISH

The rocks making up these mountains are naturally light in color. Not yet undetstood processes convert the outer few millimeters of the rock into a metal-rich dark coating known as desert varnish. The process could be either chemical or biological, or maybe a combination of the two. It seems to require both water in the form of rainfall and high evaporation rates (hence it is confined to deserts). Areas under overhangs on cliffs that don't receive water don't get desert varnished, or don't get converted as quickly.

Many species of bacteria and fungus are present on desert varnishes, or at least lots of things grow when you take a cotton swab, rub it on desert varnish, and then rub it into a petri dish. The varnishes themselves do contain biological proteins (they're the same handedness as those produced by Earth life). However, its not yet clear whether

Fig. 1.— Painted Rock Mountains, looking west from a point above the agricultural fields. 7x vertical exaggeration.

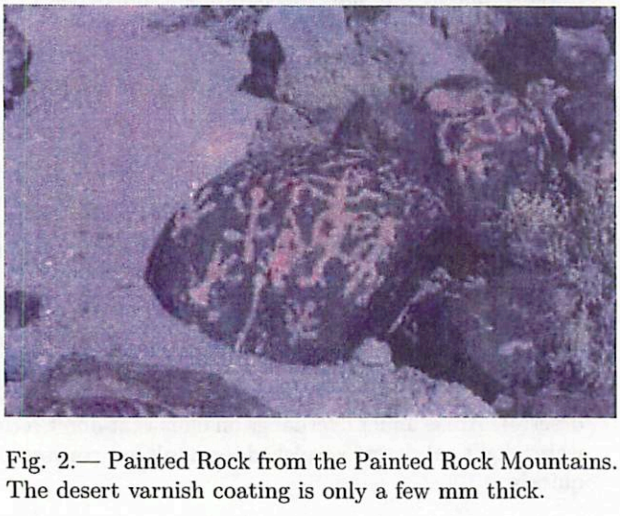


Fig. 2.— Painted Rock from the Painted Rock Mountains. The desert varnish coating is only a few mm thick.

those proteins are incorporated into the varnish accidently or whether the single-celled organisms living on the rocks actually help to form the varnish.

Some rocks at the Mars Pathfinder landing site show evidence of "desert varnish-like coatings" (Murchie et al. 2004 LPSC abstract). Murchie et al. conclude that these must have formed during Mars' wetter past, and are now being eroded away to different degrees by aeolean processes (dustblasting).

See Perry & Kolb scientific article "Biological and Organic Constituents of Desert Varnish: Review and New Hypotheses" for more details.

4. ALLUVIAL FANS

During the monsoon season, the dark rocks of the Painted Rock Mountains get washed into mountain gullies and washes. When these washes exit the edge of the mountains, the water they carry slows down and dumps out rocks from the mountains into the surrounding terrain. Over time this process results in lobate, sloped, rocky areas of quite large extent that now surround the mountains. The Space Cadets' gullies exist within these alluvial fans.

Alluvial fans have developed a surprising new planetary connection. Cassini RADAR images (Figure 3) show what may be rocky (light in the radar image) areas that seem to have been deposited by a possible stream. Until VIMS and ISS get to look at this same area its difficult to be sure, but this might indicate bulk transport of material from the light colored highlands into the darker lowlands by fluvial processes.

5. ROCK ART

Striking and improbable erosion patterns on some rocks in this area have led some to speculate that the markings might be artificial in origin. They have invoked a species of intelligent beings inhabiting the area we are now in.

If there were such beings, they almost certainly have died out by now. As anyone following the news can tell you, there are no reliable signs of intelligent life on Earth.

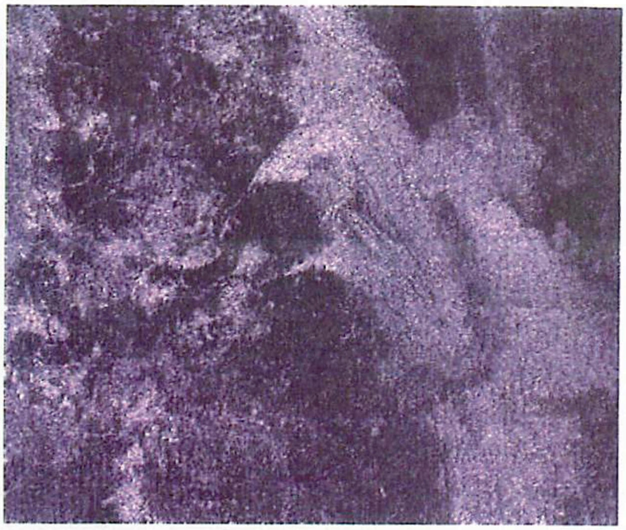


Fig. 3.— Possible alluvial fan on Titan. From RADAR, so be careful in interpreting.

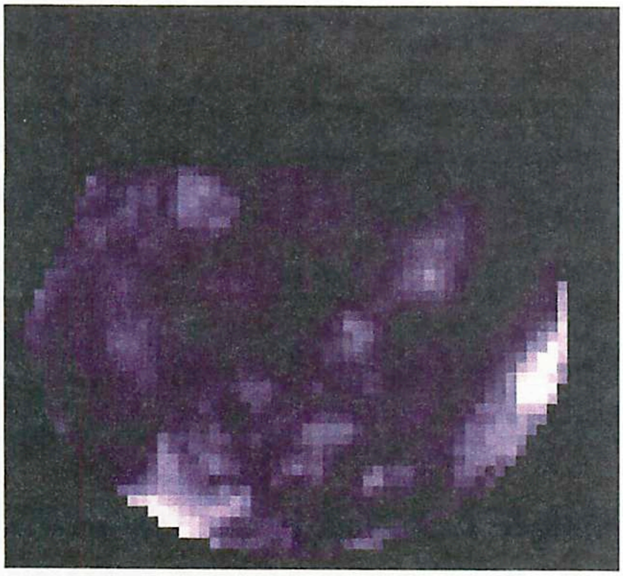


Fig. 4.— Orthographically projected view of Pioneer Venus altimetry data for Venus, same geometry as IR view below. Pretty unrelated, but I think that it is the planetary connection for some of the Space Cadets' weather data.

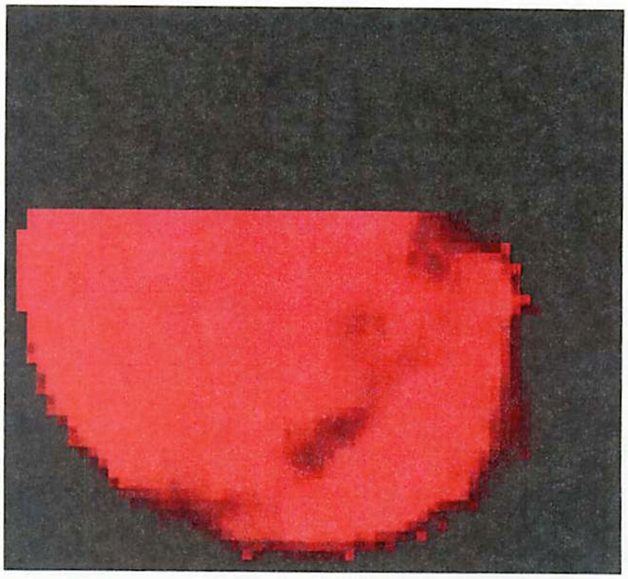
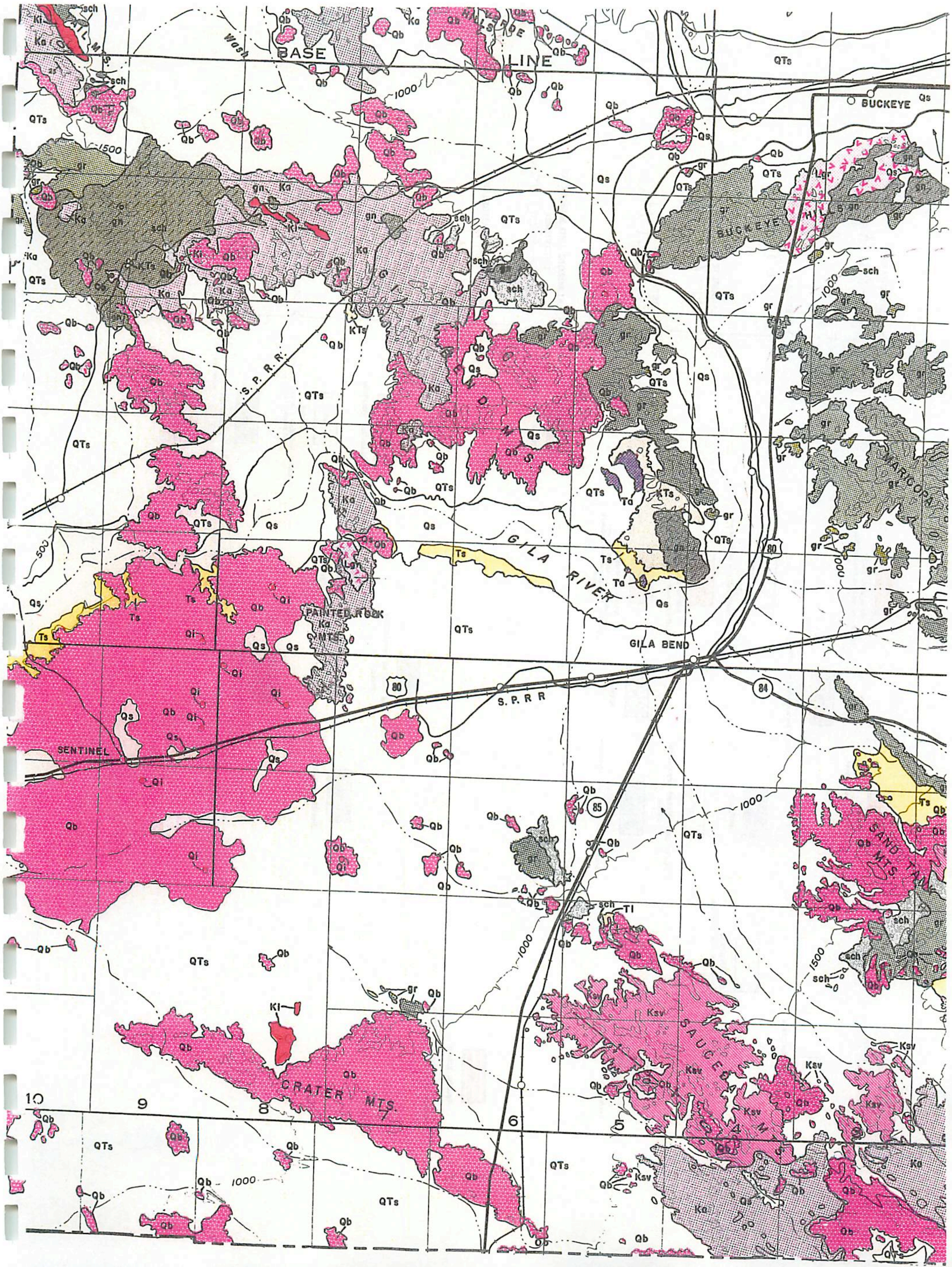


Fig. 5.— Near IR (1.18μm view of Venus' nightside taken April 28, 1993 at the AAT 4m near Coonabarabran, Australia by my former boss at JPL, Vikki Meadows. The cloud contribution has been subtracted off by hand (by an undergrad with the time for such manual image processing: me). High areas are cold, and therefore dark in the IR view. You can see the tentacles of Aphrodite Terra peeking over the limb at bottom left, and Maxwell Montes lost in crescent-subtracted light at the bottom right.


BASE LINE
Wash
BUCKEYE
BUCKEYE HILLS
GILA BEND MTS
S.P.R.R.
S. P. R R
GILA RIVER
GILA BEND
PAINTED ROCK MTS.
SENTINEL
MARICOPA
SAND TANK MTS
SAUCEDA M
CRATER MTS.
80
84
85
1000
1500
500
10
9
8
7
6
5
QTs
Qs
Qb
Qi
Ts
Ta
KTs
Ka
Ki
Ksv
Lgr
gr
gn
sch
Tl

QUATERNARY
0-1.8 Ma

Qs Silt, sand, and gravel

Qb **Basalt**
Locally includes tuff and gravel.

Qi **Dikes and plugs**
Mainly basaltic in composition.

QTs Sand, gravel, and conglomerate

QTb **Basalt**
Locally includes tuff and gravel.

TERTIARY
1.8-65 Ma

Ts l, gravel, and conglomerate

Tl **Lake Deposits**
Siltstone, sandstone, and limestone.

Ta **Andesite**

Td **Dacite**
Includes dacite tuff and agglomerate.

LARAMIDE
35-70 Ma

Lgr Granite and related crystalline rocks

Ki **Dikes and plugs**
Rhyolitic to andesitic in composition.

CRETACEOUS
65-251 Ma

KTs **Sandstone, shale and conglomerate**
Includes some basalt.

Ka **Andesite**
Locally includes tuff and agglomerate.

Kr **Rhyolite**

Ksv **Sauceda volcanics**
Includes rhyolite, latite, and andesite. Locally contains volcanic glass.

PALEOZOIC AND MESOZOIC UNDIVIDED
251 - 550 Ma

[illegible] Shale, quartzite, and limestone

YOUNGER PRECAMBRIAN

Ag **Apache group**
Includes small area of Cambrian Troy quartzite and Devonian Martin limestone at Roosevelt Dam.

OLDER PRECAMBRIAN

gr Granite and related crystalline rocks

di Diorite porphyry

Pyroxenite

rhy Red Rock rhyolite

mq Mazatzal quartzite

sch **Schist**
Locally includes diorite, rhyolite, and greenstone.

gst **Greenstone**
Predominantly altered volcanics.

gn Granite gneiss

Arizona Bureau of Mines $\frac{1}{375000}$

Geologic Overview of Southwest Arizona

Colin Dundas

Precambrian (4.5 Ga--~550 Ma): In the beginning, the Earth formed. Without this event, this handout would be pointless. Plate tectonics begins, continental cratons (stable, low-relief deposits) begin forming, and rocks are deposited and eroded. There are few Precambrian rocks exposed in southwest Arizona, mostly heavily metamorphosed. Around 600 Ma, the supercontinent Pannotia formed and Arizona was uplifted. Extensive erosion removed most rocks from 1000-600 Ma.

Cambrian (~550--~505 Ma): Breakup of Pannotia places Arizona near a passive continental margin, which subsides and is covered by an epeiric sea (a shallow sea covering continental rock) near the Equator. The same happens across most of North America; the Sauk transgression covers much of the continent. This is characterized initially by deposition of sandstone, followed by formation of limestone once the supply of sand eroded from elsewhere is exhausted.

Ordovician (505-440 Ma): Subduction begins near Eastern North America, accompanied by the Taconian orogeny (mountain-building event). A brief fall in sea level leads to the retreat and return of the epeiric sea and formation of an unconformity. Arizona is mostly covered by water.

Silurian (440-410 Ma) and Devonian (410-360 Ma): Epeiric seas continue to cover much of the continent, with occasional retreats. Arizona continues to build marine deposits. Collision with Europe leads to the Acadian and Caledonian orogenies in the east. In the late Devonian, probable collision with a microcontinent leads to the minor Antler orogeny in the west.

Mississippian (360-325 Ma) and Pennsylvanian (325-286 Ma): More epeiric seas, massive limestone deposition. By the late Pennsylvanian, multiple continental collisions are producing the supercontinent Pangea and uplifting the cratons, draining the epeiric sea. Arizona, near the margin, continues to acquire sediment.

Permian (286-251 Ma): Pangea dominates. The supercontinent causes the marginal seas to recede, and after this time the formation of marine deposits ceases. The north American craton is still near the equator at this time. Beginning of near-worldwide deposition of red beds, continuing into the Triassic. The Appalachian orogeny occurs in the east.

Triassic (251-206 Ma): The opening of the Atlantic ocean begins the breakup of Pangea. Occasional transgressions of the sea occur, but deposition from this point on in the west is dominated by continental sedimentation. The opening of the Atlantic ocean forces the west to collide with the Pacific plate, resulting in rapid subduction and volcanism in the west.

Jurassic (206-144 Ma): Subduction and volcanism continue in the west, forming a volcanic range similar to the modern Andes. Erosion in the north leads to deposition of a massive sandstone unit across much of the continent. Africa detaches from North America, which moves north of the equator.

Cretaceous (144-65 Ma): A worldwide rise in sea level leads to another temporary sea which covers parts of Arizona and lays down more marine sediments. The subduction occurring in the west results in several episodes of thrust faulting and mountain building, culminating in the Laramide orogeny around 70 Ma. The dinosaurs are killed off by the K/T impact at Chicxulub.

Paleocene (65-55 Ma) and Eocene (55-34 Ma): Laramide mountain building continues, driven by shallow subduction of the Pacific; volcanism is relatively inactive near the coast, probably related to the angle of subduction. Instead, volcanism sweeps inland, crossing Arizona over several million years. In the late Eocene, the angle of subduction steepens.

Oligocene (34-24 Ma), Miocene (24-5 Ma), and Pliocene (5-1.8 Ma): Steeper subduction leads to a resumption of volcanism closer to the subduction zone, which persists from approximately 40-20 Ma. Volcanism sweeps back westward, crossing Arizona again. By the early Miocene, subduction of the Farallon plate reaches a transform fault attached to the mid-ocean ridge, and the plate motions of western North America begin to turn from subduction to strike-slip motion, beginning the San Andreas Fault. Extension in the southwest begins the formation of the Basin and Range province.

Quaternary (1.8 Ma-present): Large-scale repeated glaciation affects the north and influences the climate in Arizona. Not much changes in this period; this isn't long enough for much to happen. However, much of the surface we see is Quaternary alluvium or a thin sedimentary layer.

Sentinel-Gila Bend Area

The region is underlain by Proterozoic bedrock, a combination of metamorphic rocks and plutonic granitic rocks, which are exposed in the Gila Mountains in several places. Some of these rocks were emplaced by the early Proterozoic; for instance, one granite unit has a minimum age of 994 Myr. Little trace remains of the Paleozoic seas in this area, as those rocks have likely been eroded away during uplift in the Mesozoic. The ancient marine deposits are better exposed elsewhere in the state. Instead, the old basement is overlain by Cretaceous or later volcanics related to the subduction of the Pacific plate. Andesite and granite are exposed at several places, including the Gila Bend Mountains and the Painted Rock mountains. Volcanic deposits from the Tertiary also occur in the area, but are less well exposed. Small exposures of Tertiary lakebed are exposed, mostly along the Gila River valley which has cut through the cover. Basin and Range normal faulting has uplifted a number of blocks of older material and created depressions which are currently filling with alluvium. Finally, the Sentinel volcanic field formed in extremely recent time (2-3 Ma) by basalt eruption. Basaltic cones and flows cover a large part of the area and may have temporarily influenced the river. Areas marked Qs or Qts on the geologic map consist of relatively thin layers of alluvial debris which are completely uninteresting and simply in the way, at least until they have been aged sufficiently.

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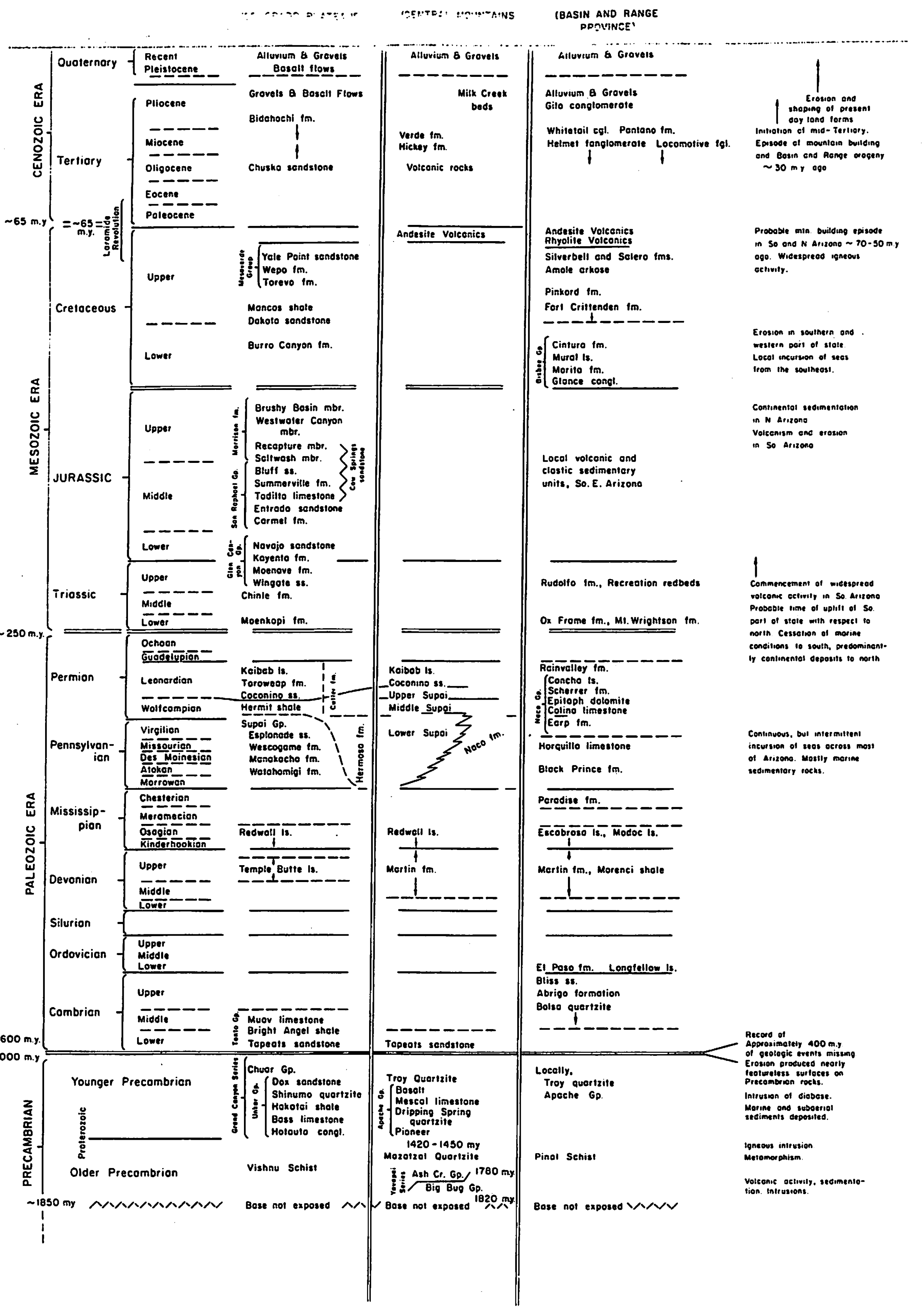
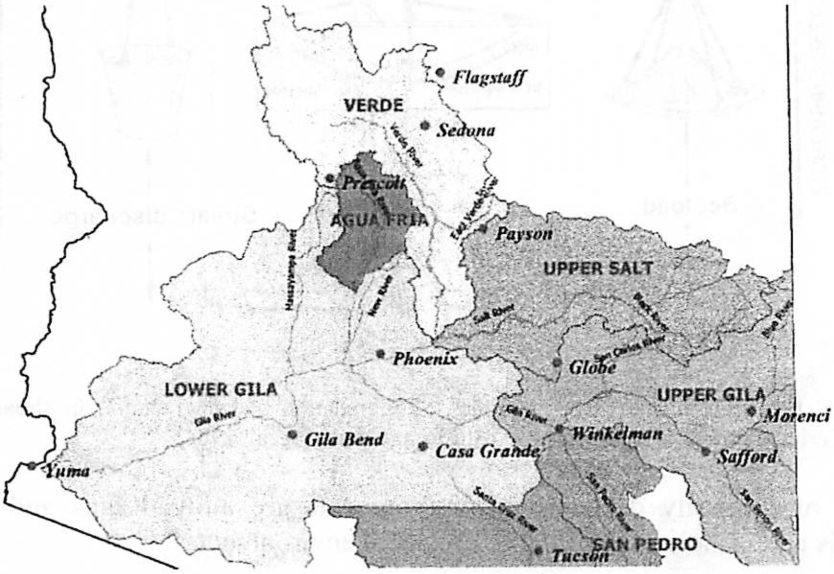


Fig. 3.1 A highly simplified geology record of "column of rocks" in Arizona showing the period, eras, epochs, and their duration in years.

From Smiley et al, Landscapes of Arizona, 1984

A Brief History of the Gila River

Nicole Baugh



Length: 1014 km
Drainage Area: approx. 150,000 km^2
Origin: Mogollon Mountains, New Mexico
Major Tributaries: San Pedro River, Salt River, San Francisco River, Verde River
Confluence: Colorado River
Status: Large sections in Arizona flow only during heavy rainfall
Age: 50-60 Ma

River Processes

Stream Flows
- laminar vs turbulent
- streaming vs shooting

Channel Patterns
- braided
- meandering
- straight
- sinuosity

Movement of Particles in Streams
- suspension load
- bed load
- competence

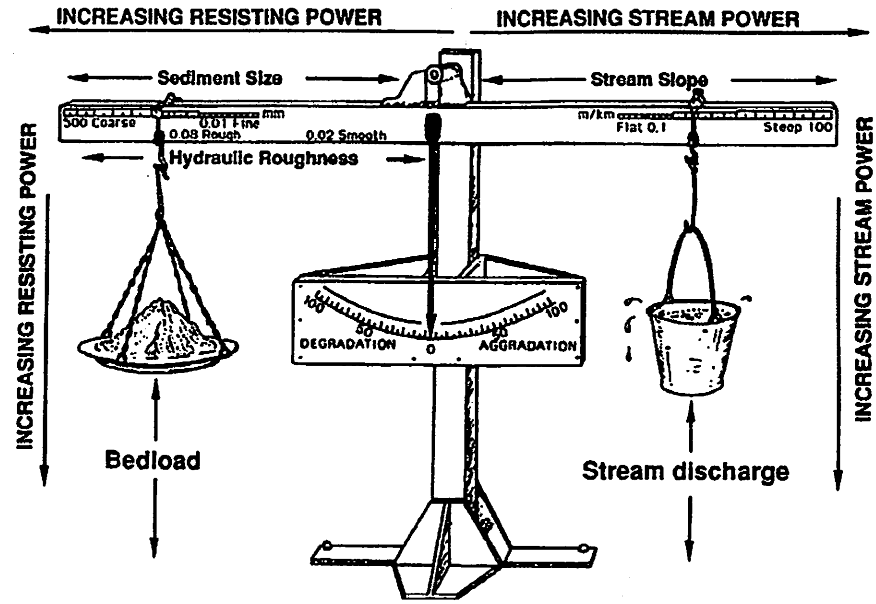


Figure 1: Schematic balance between modes of aggradation and degradation in streams; zero is the threshold of critical power. (modified by B. Bill from Chorley et. al. 1984)

Examples of primarily depositional environments are alluvial fans and bajadas. A pediment is an example of a primarily erosional environment.

alluvial fan:	cone-shaped deposit of sediment at the base of a mountain, sorted by water into large fragments upslope and smaller particles downslope
bajadas:	shallow slopes found at the base of rocky hills where materials accumulate from the weathering of rocks; consists of a mixture of boulders → silt, creating a complex soil structure good for vegetation.
pediment:	an erosion surface formed by the retreat of an escarpment; degradation fills the basin downslope from the escarpment.

Many arid mountains are sites of local intense rainfall, generating short-lived streamflow that quickly sinks into dry streambeds downvalley. Such flash floods degrade upstream reaches, and aggrade downstream reaches (Figure 2). Though arid regions have slow integrated rates of change, massive amounts of sediment can be moved in these single flood events.

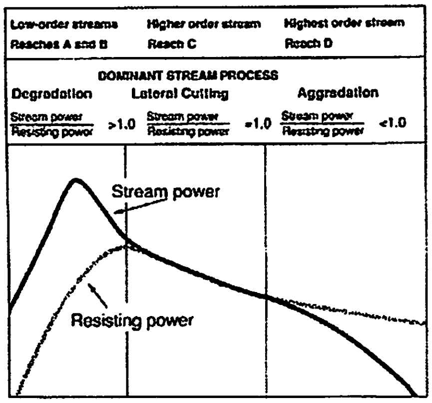


Figure 2: Changes in stream power and resisting power in an arid rocky drainage basin where local rainfall of 22mm falls in 30 minutes in the headwaters. Stream power exceeds resisting power in the steep upper reaches, but resisting power eventually wins out as water is lost by infiltration into the permeable and progressively wider streambed.

An example of a system in which these geomorphic changes are occurring is the Chemehuevi Mountain piedmont (Figure 3a), located just to the west of the Sentinel Volcanic Range, and the Tinajas Atlas Mountains in southwestern Arizona (Figure 3b).

piedmont: the area of land lying at the foot of a mountain

The sediment on the piedmont is generated by bedrock weathering in the mountains and on the pediment, and is transported into a shallow short-lived channel network.

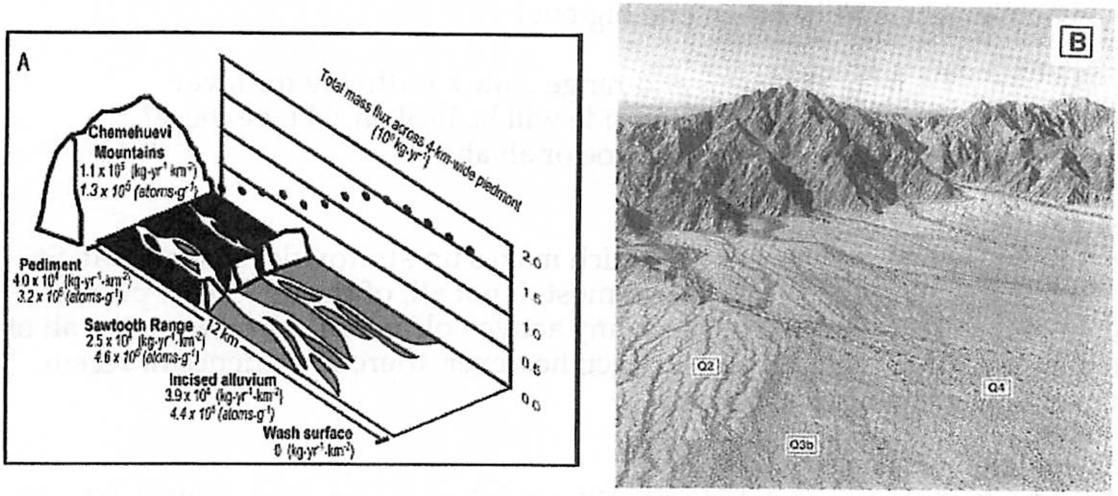


Figure 3: a.) Diagram of Chemehuevi Mountain piedmont from source basins to wash basin. Black represents bedrock surfaces, gray represents alluvial surfaces, and white represents short-lived channels. b.) Photo of the Tinajas Atlas Mountains. Dendritic drainage channels are seen cut into the alluvium.

Further examples of fluvial systems on Earth and Mars are shown in Figure 4.

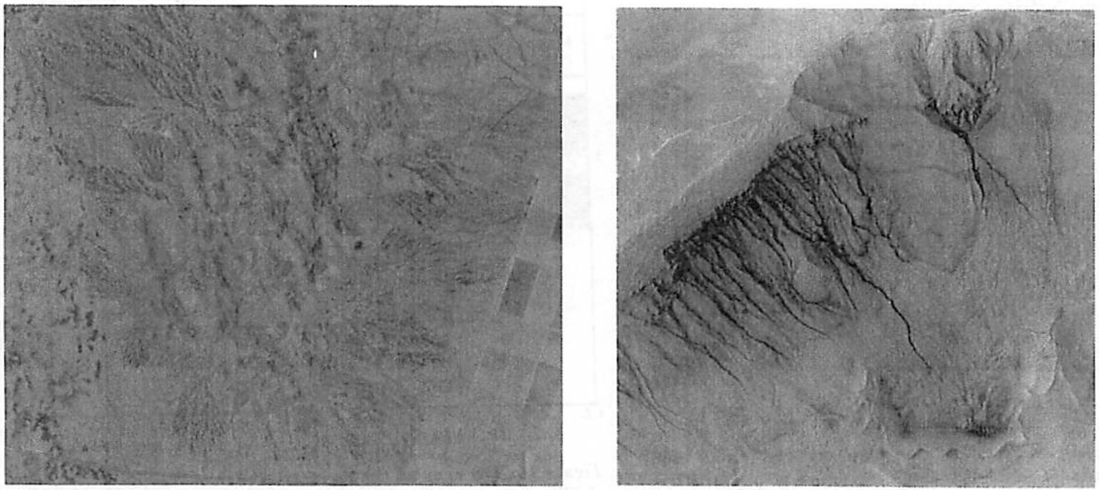


Figure 4: Fluvial systems on Earth and Mars. The photo of Earth (left) shows a gully system west of the Sentinel Volcanic Field. The photo of Mars (right) shows gullies emerging from outcrops on the wall of a crater. The gullies are thought to have formed by fluvial erosion and mass wasting, creating alluvial fans.

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Older Volcanism

The Painted Rock mountains and most of the Gila Bend Mts are comprised of andesite and are older than the Sentinel volcanic field. They date back into the Cretaceous period, about 70 to 144 Ma. Additionally, there is a small amount of granite (silisic magma which never reached the surface) in the Painted Rocks which is a bit younger, dating back to the Laramide period, about 35 to 70 Ma. Finally, the southern part of the Gila Bend Mts are comprised of a very old granite from the precambrian era.

Big Questions

Why so many craters rather than one big one?
Why is this lava different?
Did the normal faults of the basin and range crate a pathway for lava?
Typically, cones will be breached (one side will be broken.) Have these?
What type of flows will we see, pahoehoe or ah ah?

Planetary Outlook

Earth is the only planet with granite which makes up stratovolcanos (e.g. Mt. St. Helens). Volcanism has been important in most, if not all, of the terrestrial planets. However, except for IO, we have not seen any active volcanism. Until recently, all other planets were thought to have become extinct; however, there is evidence of recent volcanism on Mars (as young as 5 Ma).

Age of Volcanism

The Earth is the only terrestrial planet with on going volcanism (omitting IO with its very unique sulfur volcanism.) It is assumed that the rest of the planets have lost the energy required to run volcanism, most due to their smaller size and lack of plate tectonics.

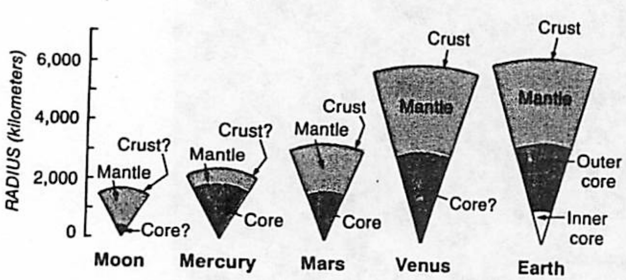

Figure 18. **Interiors of the terrestrial planets, as deduced from a wide range of observations. The *crust, mantle,* and *core* of a planet are distinguished from one another on the basis of their geochemistry. It is not clear whether the Moon and Venus have discrete cores, nor does Mercury necessarily have a chemically distinct crust.**

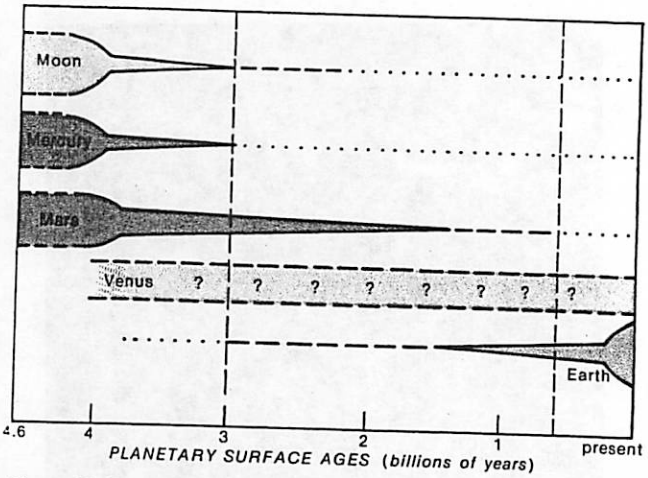

Figure 16. **The ages of the terrestrial planets' surfaces, with colored shading representing the total surface area of each planet. Most regions on the Moon, Mars, and Mercury are several billions of years old, while two-thirds of the Earth's surface (its ocean basins) formed only within the last 200 million years. The age of Venus' surface is uncertain, but the paucity of craters seen in radar images from Veneras 15 and 16 indicate that the northern high latitudes are in general no more than about 1 billion years old.**

Mars - All basaltic flows
- Dominated by volcanism, 50% of martian surface is lava flows
- Estimate mafic to ultra-mafic (lots of Fe and Mg, little SiO_2)
- Has vast planes with lobate flows
- Many shield volcanos with similar slope to Sentinel Plains, 4-5%
- Most 2.5 Ga, Tharis as young as 5 to 10 Ma

Venus - All basaltic flows
- Has abundant volcanism with many shield volcanos
- Vast plains of lava flows
- Rocks similar to sea floor basalt
- Entire planet resurfaced 500 Ma

Moon - All basaltic flows
- Dark mare are lava flows
- 20% of lunar surface is lava flows
- Has lobate flows and sinuous rilles
- Volcanic closure at 3.5 Ga

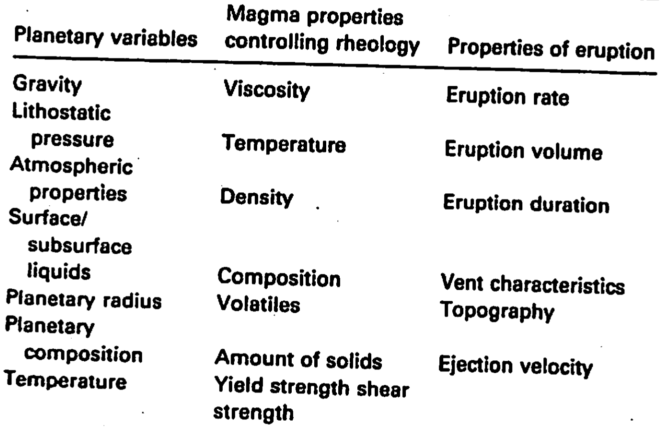

Table 3.3 Factors governing the morphology of volcanic landforms (from Whitford-Stark 1982).

Planetary variables	Magma properties controlling rheology	Properties of eruption
Gravity	Viscosity	Eruption rate
Lithostatic pressure	Temperature	Eruption volume
Atmospheric properties	Density	Eruption duration
Surface/ subsurface liquids	Composition	Vent characteristics
Planetary radius	Volatiles	Topography
Planetary composition	Amount of solids	Ejection velocity
Temperature	Yield strength shear strength	

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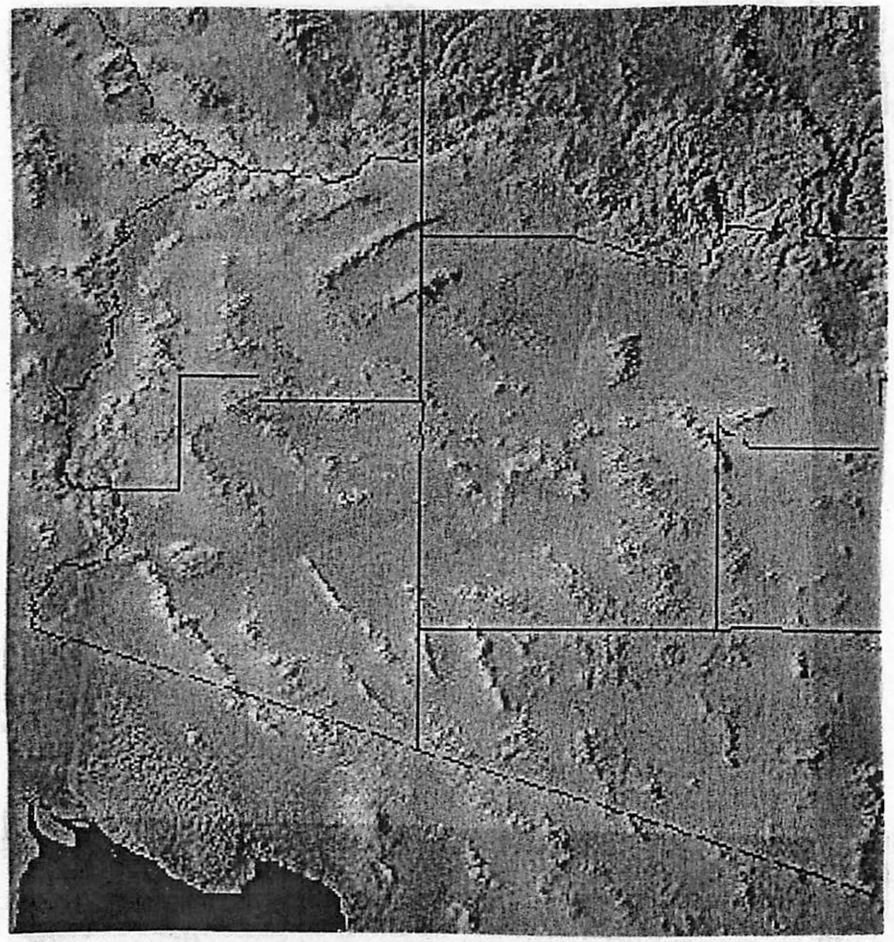
The Gila Trough
Joe Spitale

In southwestern Arizona, the Gila river flows southwest toward the Colorado river for about 100 miles along a nearly straight path that shows little relation to the local topography [1] and which is nearly perpendicular to the regional basin-and-range texture.

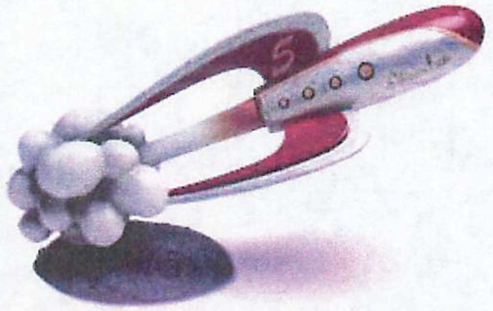
Seismic surveys show that the Gila trough is a roughly 10-mile-wide graben, consisting of several structural basins associated with a complex of mid-Tertiary faults [2].

This extensional feature may be associated with large-scale crustal upwarping seen in other parts of Arizona, Southern California, and Sonora [3].



[1] H. Chronic; Roadside Geology of Arizona. Mountain Press, 1983
[2] D. A. Okaya; Crustal structure of the Gila Trough region, SW Arizona, from extended correlation of industry seismic data. Abstracts with Programs - Geological Society of America. 18; 2, Pages 166. 1986.
[3] C. L. Pridmore; Mid-Tertiary detachment faulting and large-scale folding in the Baker Peaks-Copper Mountains-Wellton Hills region of southwesternmost Arizona and northern Sonora and their genetic association with syntectonic sedimentation. Abstracts with Programs - Geological Society of America. 15; 5, Pages 425. 1983.

Satellite image from http://www.prcafss.faa.gov/aztopo.htm



SECTION 3:

SPACE CADET HANDOUTS

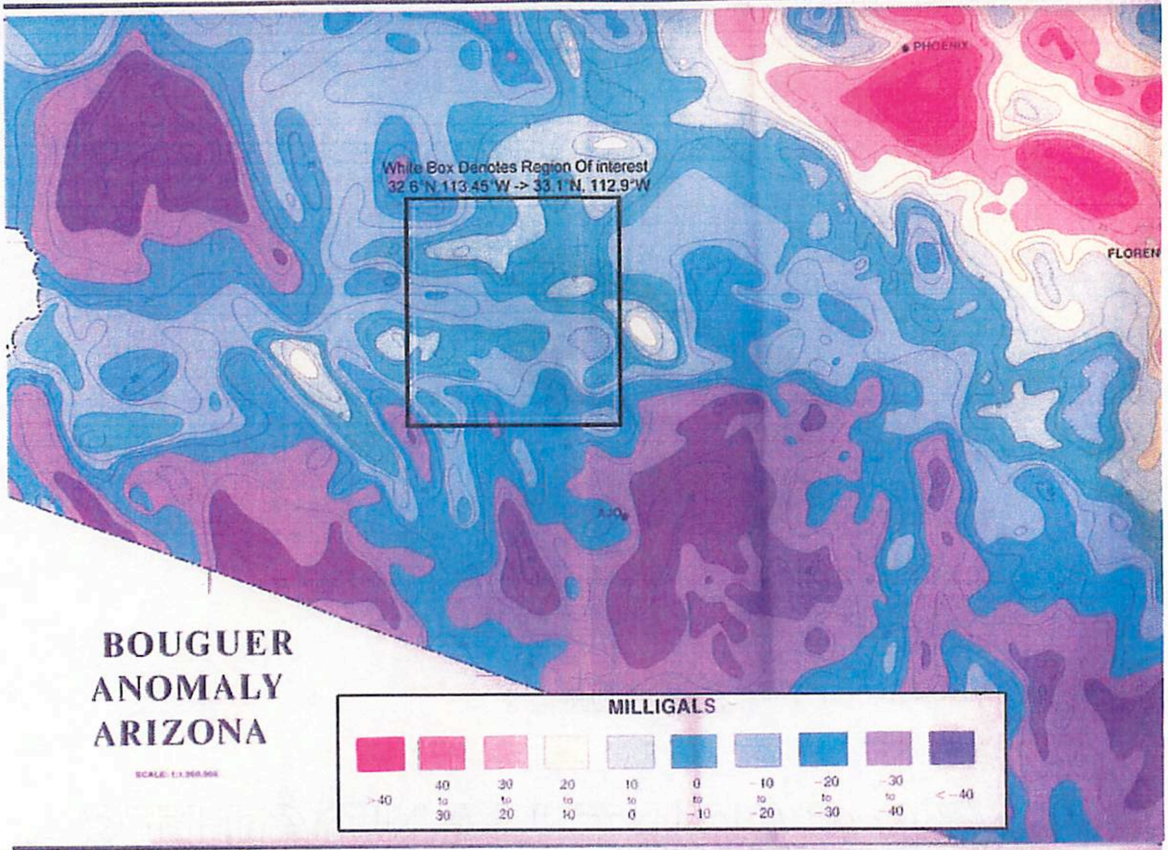
REMOTE SENSING DATASETS
OVERVIEW:

GRAVITY (BOUGUER)
GRAVITY (FREE-AIR)
AERIAL PHOTOGRAPHY
THERMAL AND INFRARED MAPPING
SPECTROMETER (TIMS)
SHUTTLE SYNTHETIC APERTURE RADAR (SAR)
SRTM TOPOGRAPHIC MAP
MAGNETICS
MODERATE RESOLUTION IMAGING
SPRCTRORADIOMETER (MODIS)

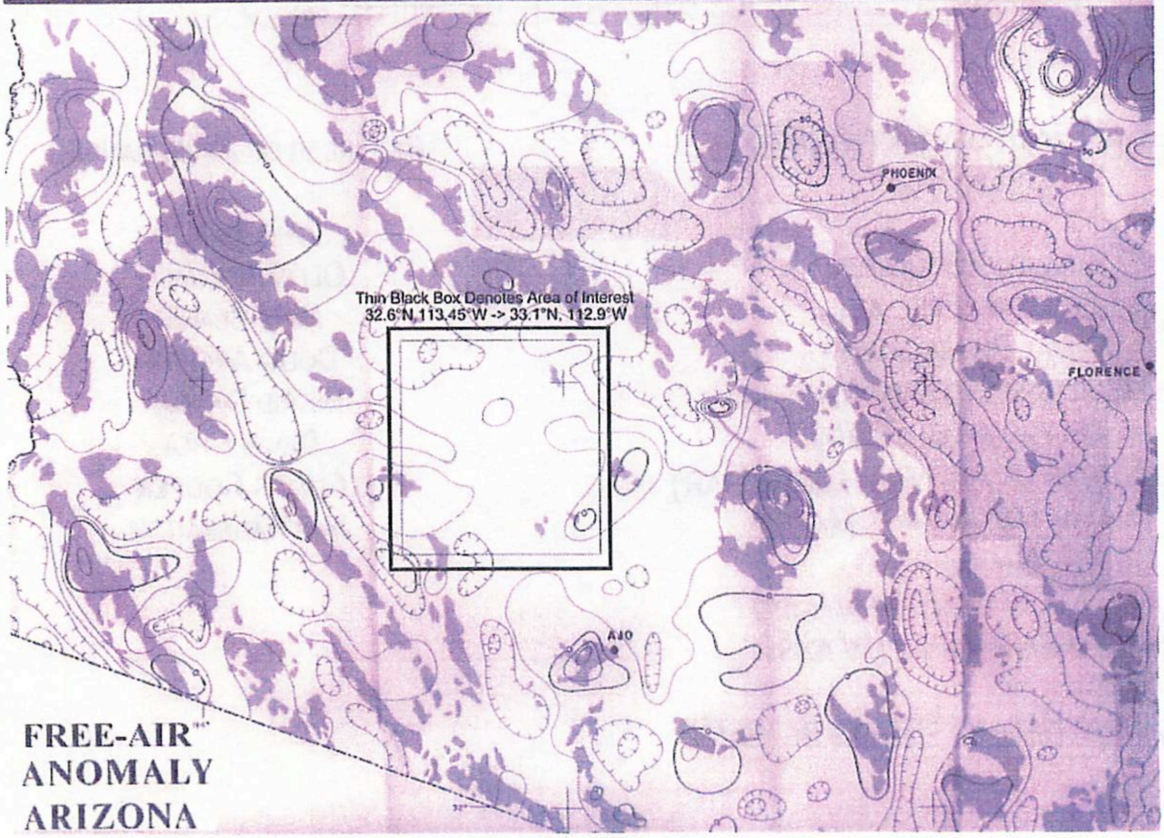
USGS AERIAL DATA OF SITES TO BE VISITED

(IN ORDER OF APPEARANCE)

JOHN KELLER
OLEG ABRAMOV
MIKE BLAND
DOUG ARCHER
INGRID DAUBAR
DAVID CHOI
CURTIS COOPER
JANI RADEBAUGH



BOUGUER
ANOMALY
ARIZONA

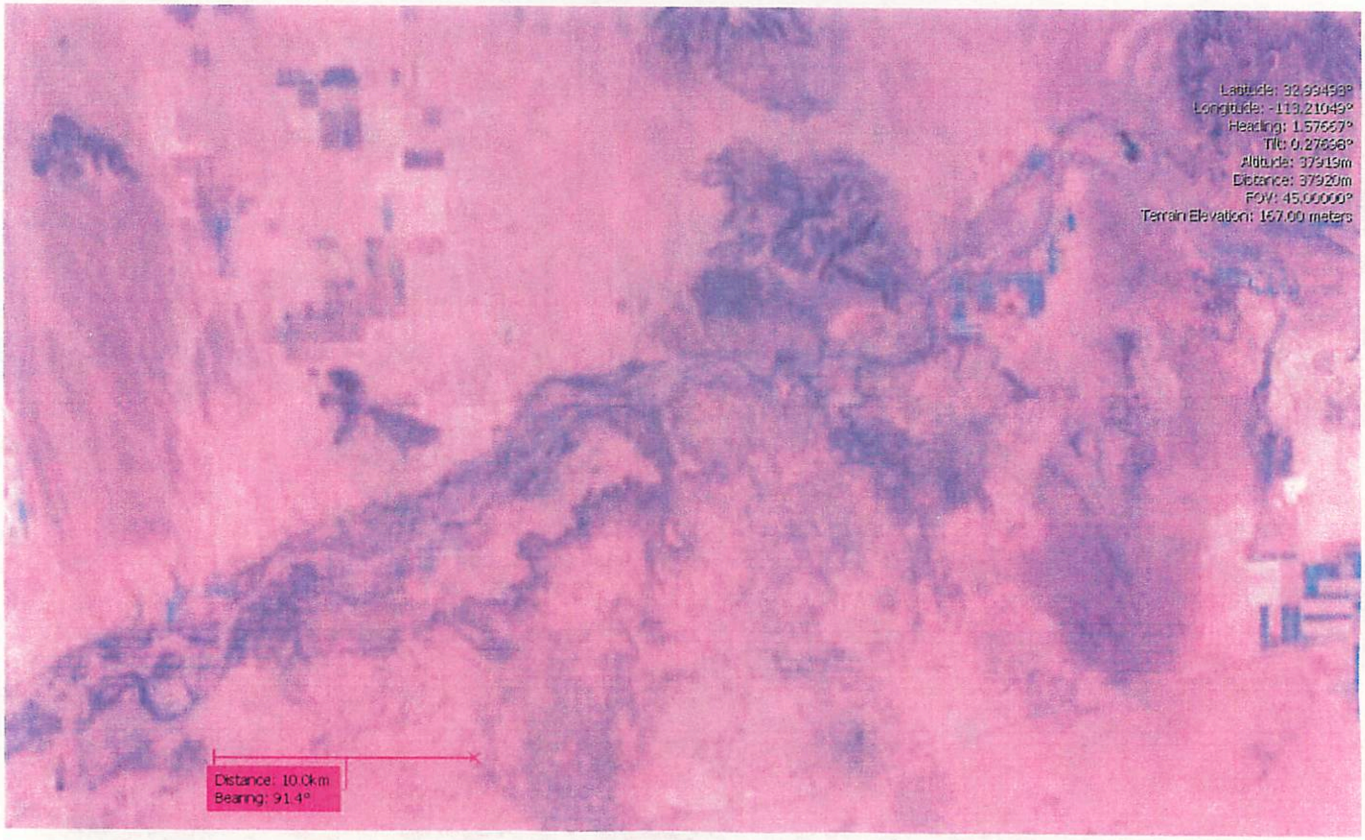


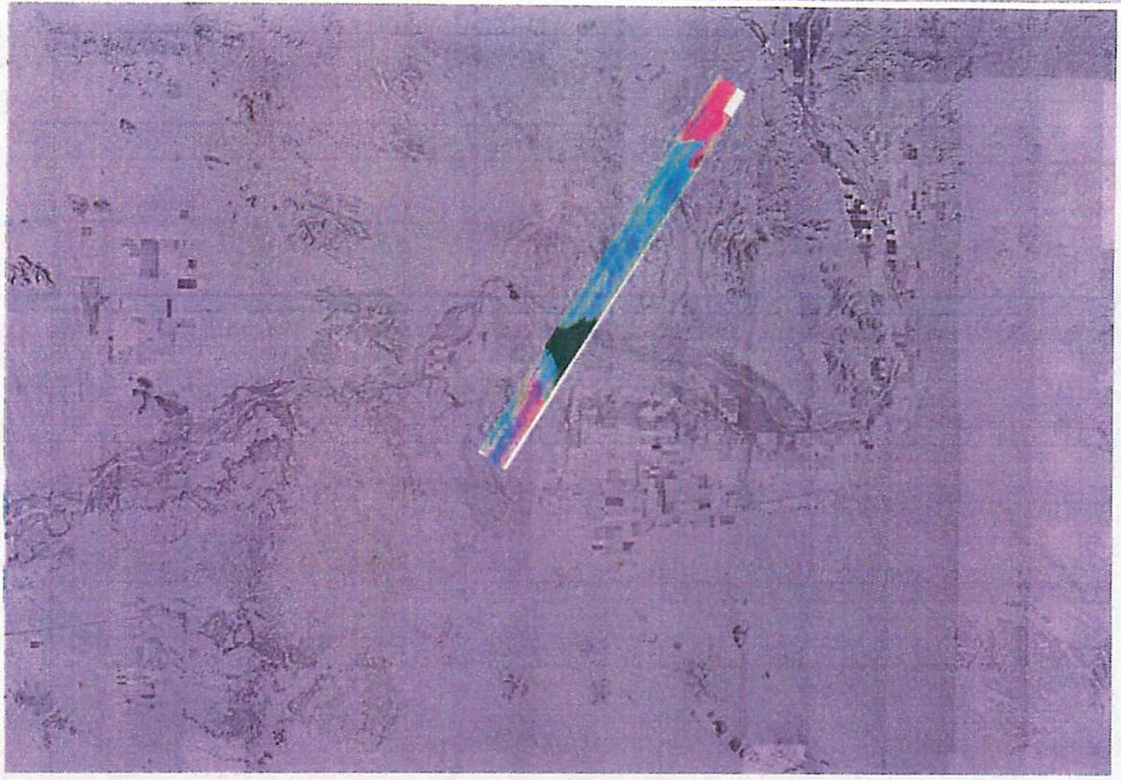
FREE-AIR
ANOMALY
ARIZONA


Latitude: 33.02123°
Longitude: -113.08443°
Heading: 0.18558°
Tilt: 0.00000°
Altitude: 47649m
Distance: 47643m
FOV: 45.00000°
Terrain Elevation: 160.00 meters
Distance: 10.0km
Bearing: 90.4°


Latitude: 32.94794°
Longitude: -113.14971°
Heading: 1.57670°
Tilt: 0.07636°
Altitude: 67412m
Distance: 67412m
FOV: 45.00000°
Terrain Elevation: 227.00 meters
Distance: 10.1km
Bearing: 91.7°


Latitude: 32.99498°
Longitude: -113.21049°
Heading: 1.57657°
Tilt: 0.27638°
Altitude: 37919m
Distance: 37920m
FOV: 45.00000°
Terrain Elevation: 167.00 meters
Distance: 10.0km
Bearing: 91.4°


Latitude: 32.99498°
Longitude: -113.21049°
Heading: 1.57657°
Tilt: 0.27638°
Altitude: 37919m
Distance: 37920m
FOV: 45.00000°
Terrain Elevation: 167.00 meters
Distance: 10.0km
Bearing: 91.4°



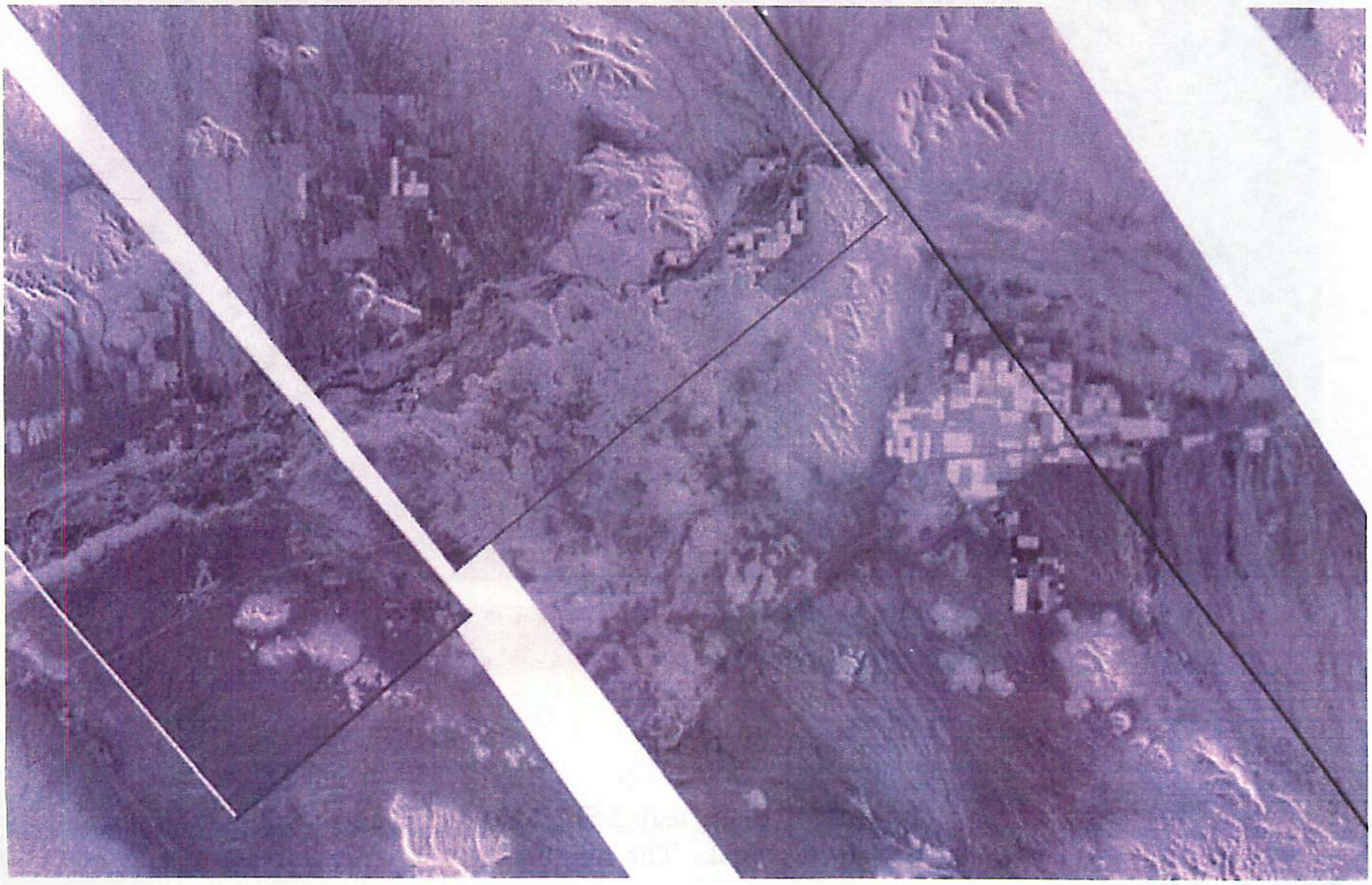
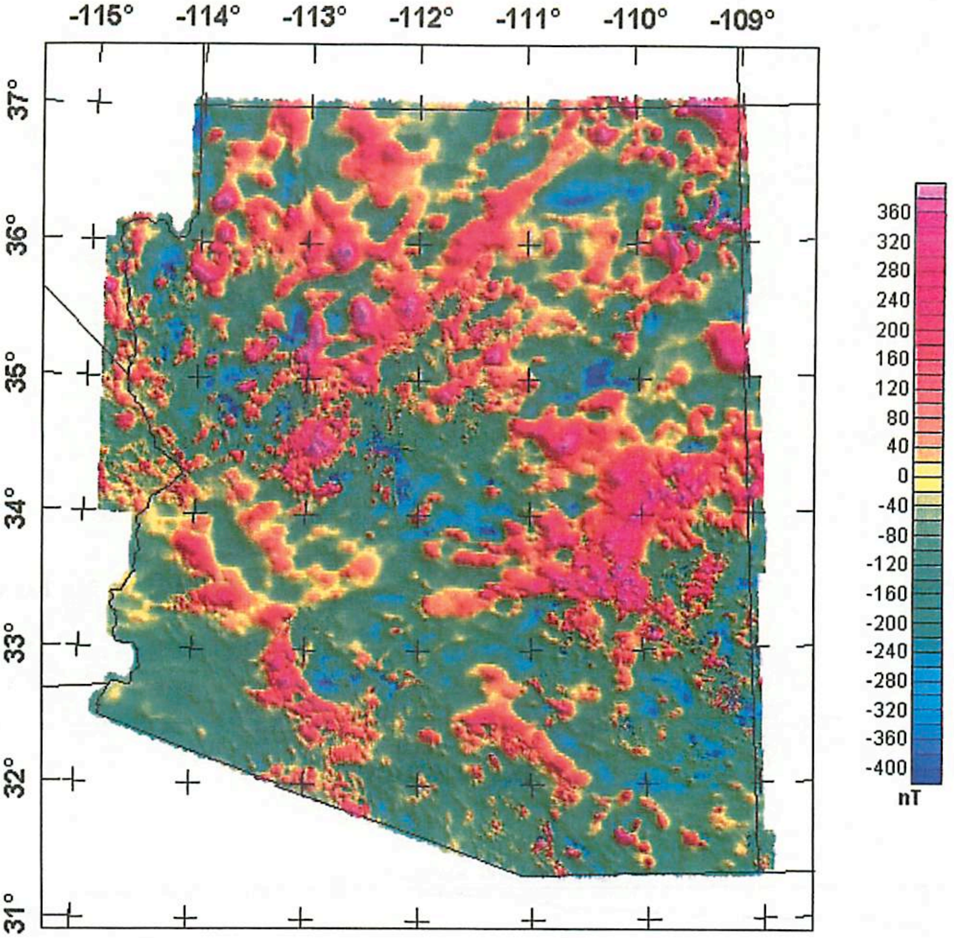
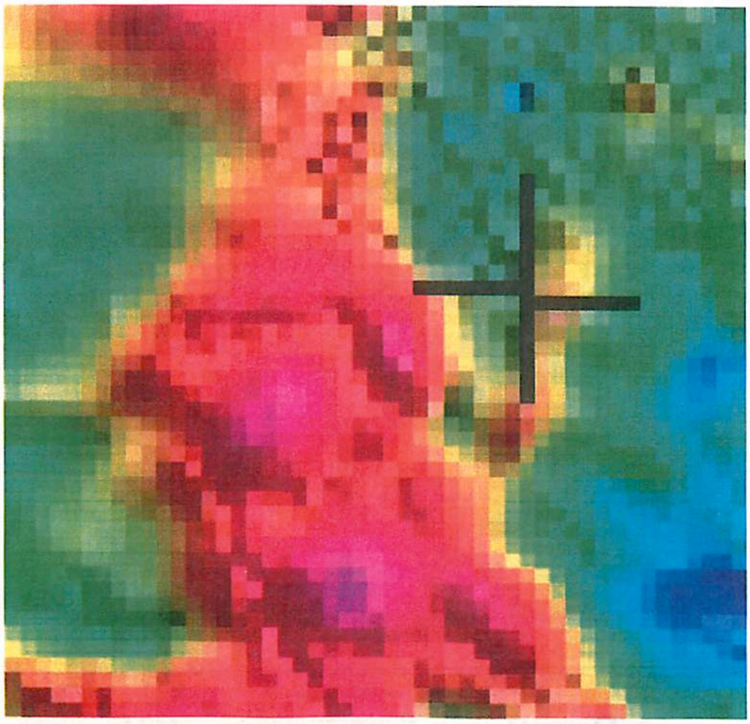
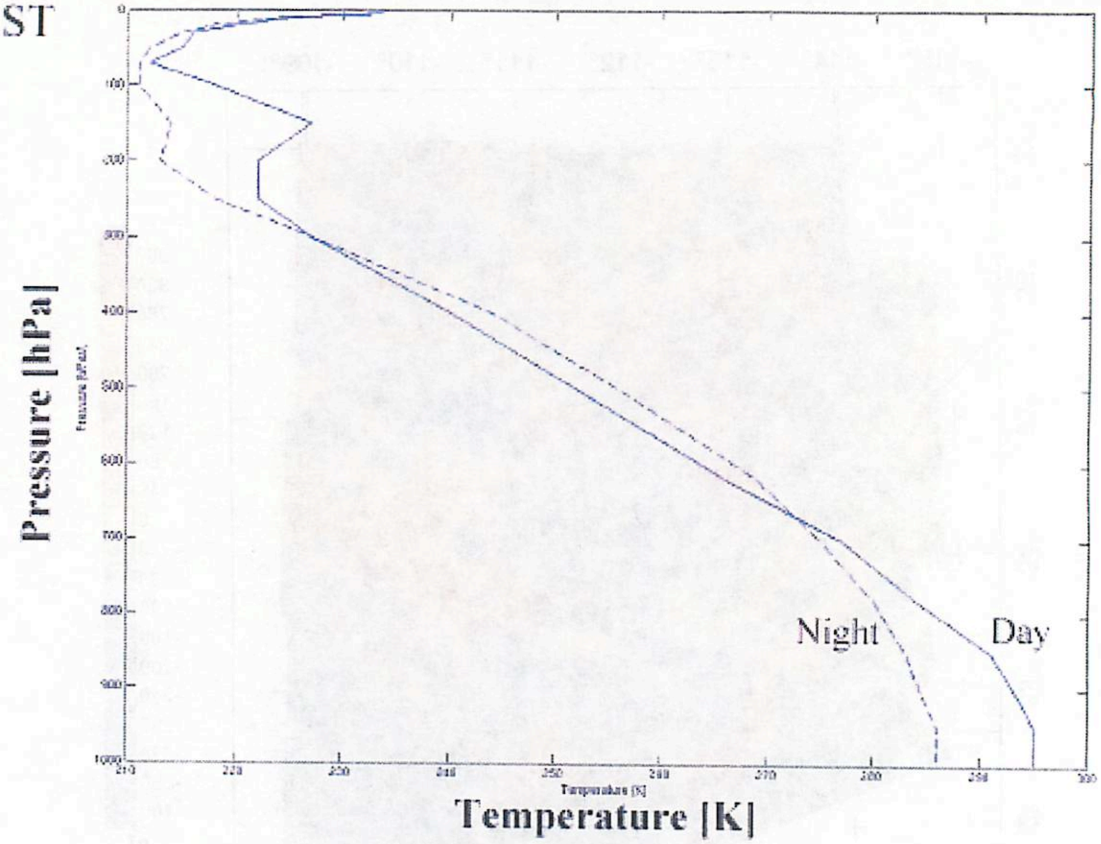


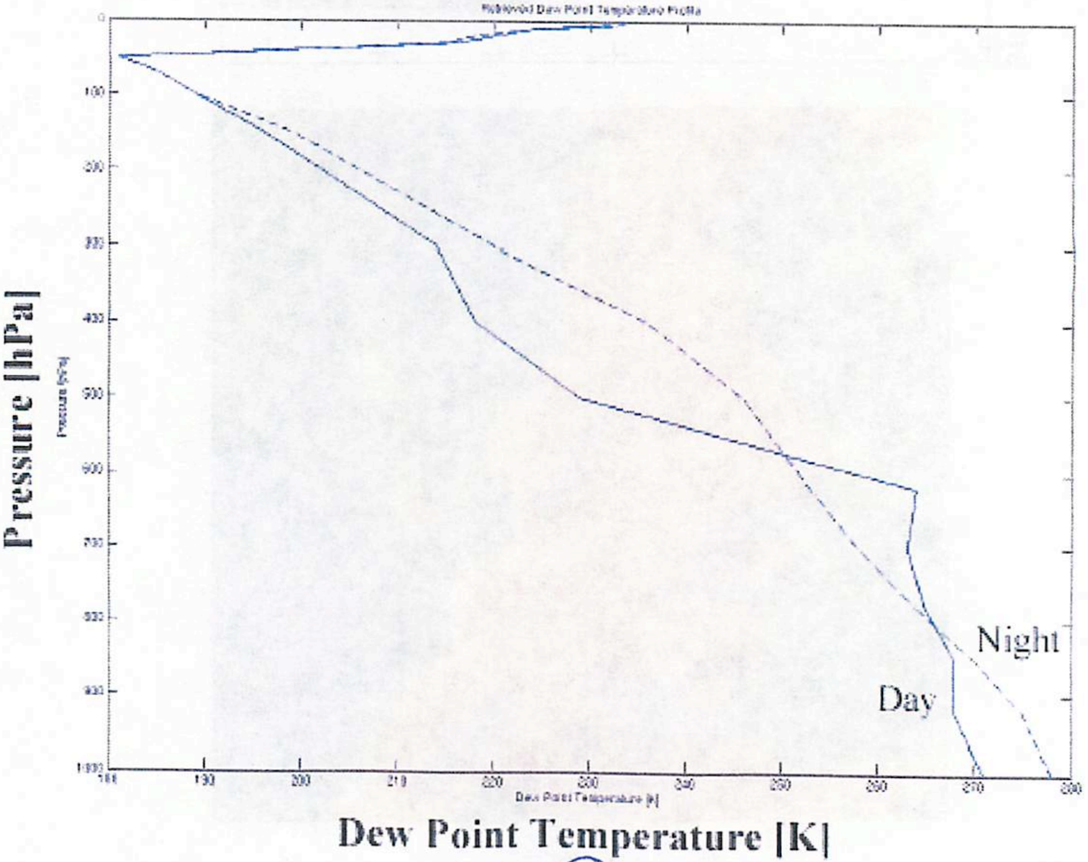
Figure 1: Topographic map of Sentinel Plain using SRTM data. The purple spot a little above the center of the image is Sentinel Peak. The numbers in the scale bar are in meters. North is at top.


-115°
-114°
-113°
-112°
-111°
-110°
-109°
37°
36°
35°
34°
33°
32°
31°
360
320
280
240
200
160
120
80
40
0
-40
-80
-120
-160
-200
-240
-280
-320
-360
-400
nT



MODIS, 33° N, -113.1° E: March 21, 2005 at 11:35 and 22:40 MST

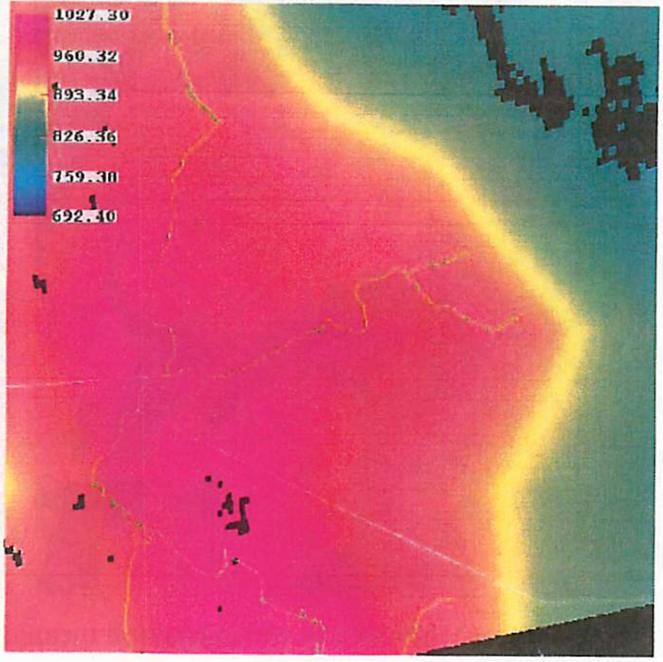




MODIS Near Fieldtrip Region

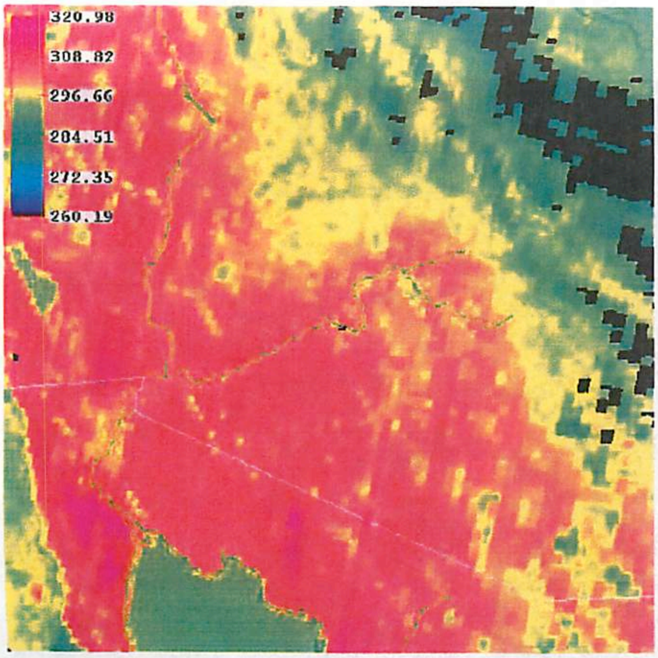
Surface Pressure [mbar]
March 21, 11:35 MST

Surface Pressure [mbar]
March 21, 22:40 MST

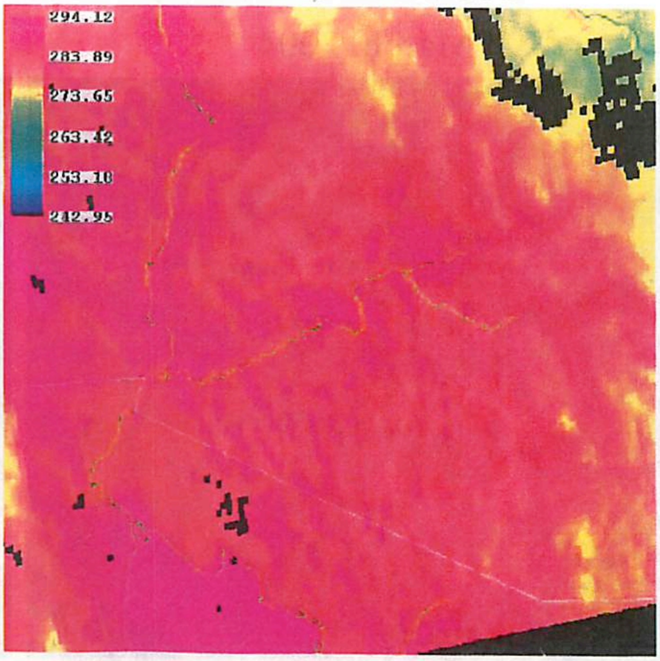


MODIS Near Fieldtrip Region

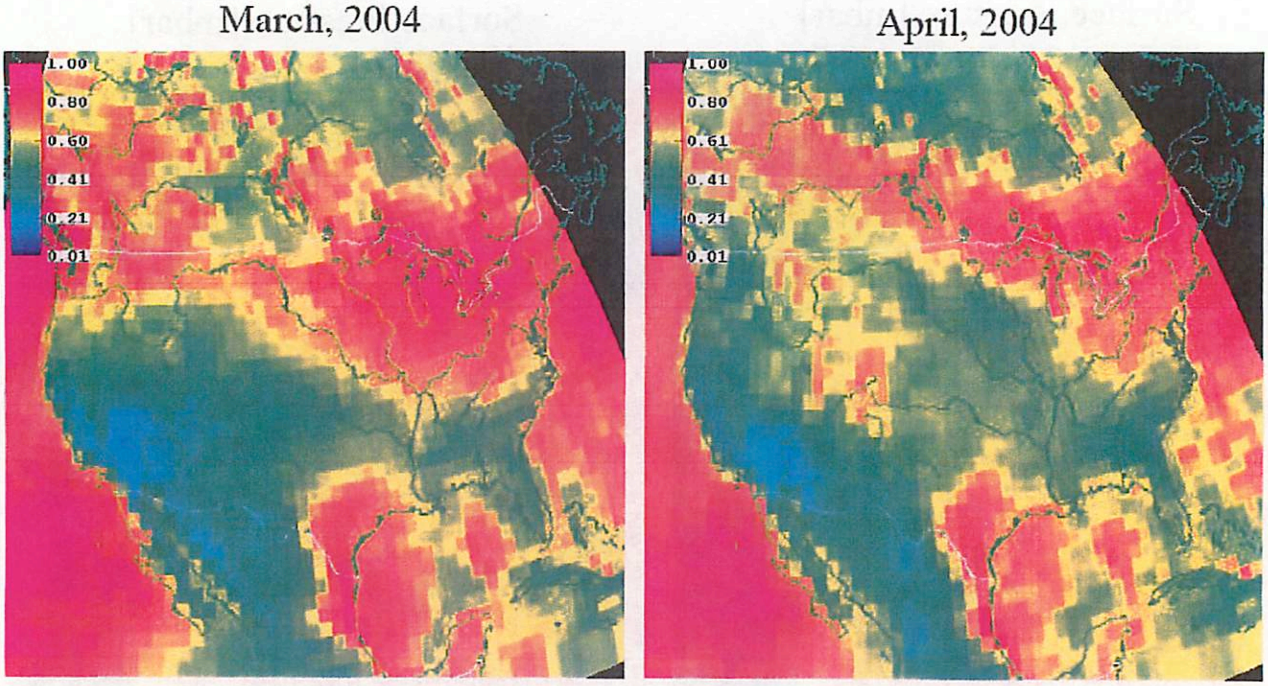
Surface Temperature [K]
March 21, 11:35 MST



Surface Temperature [K]
March 21, 22:40 MST



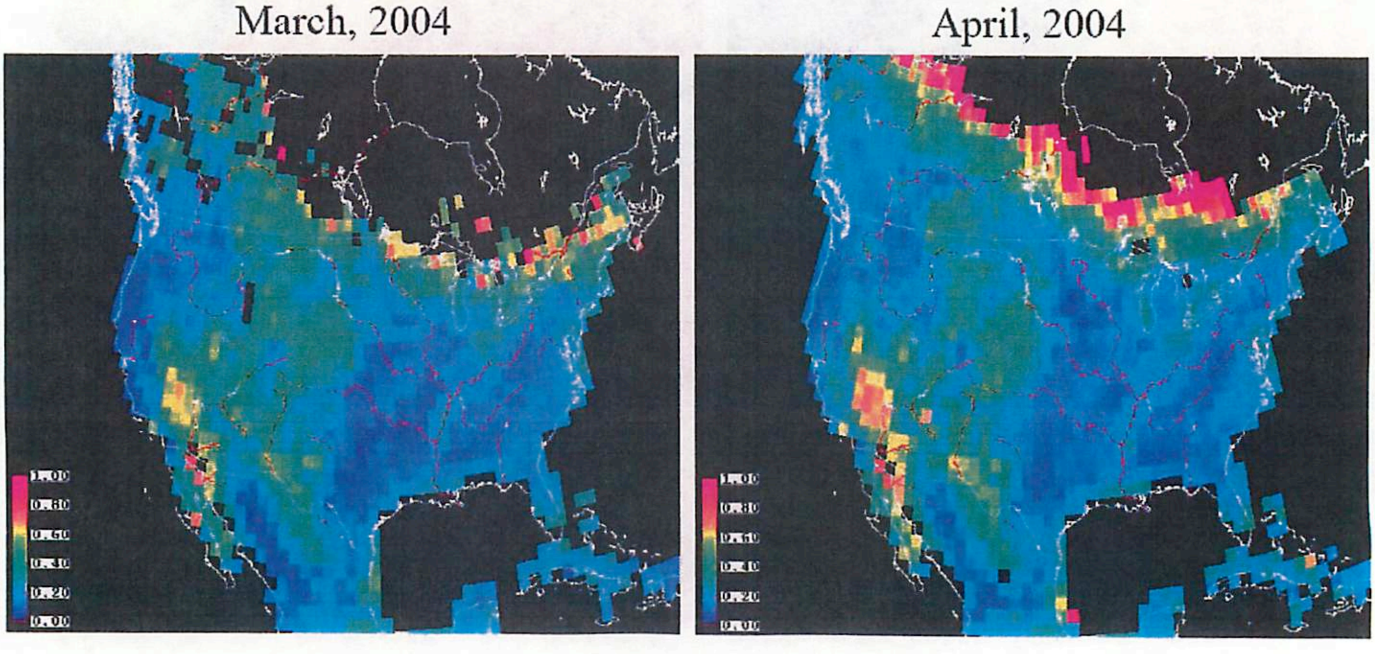
Cloud Fraction Mean


March, 2004

April, 2004

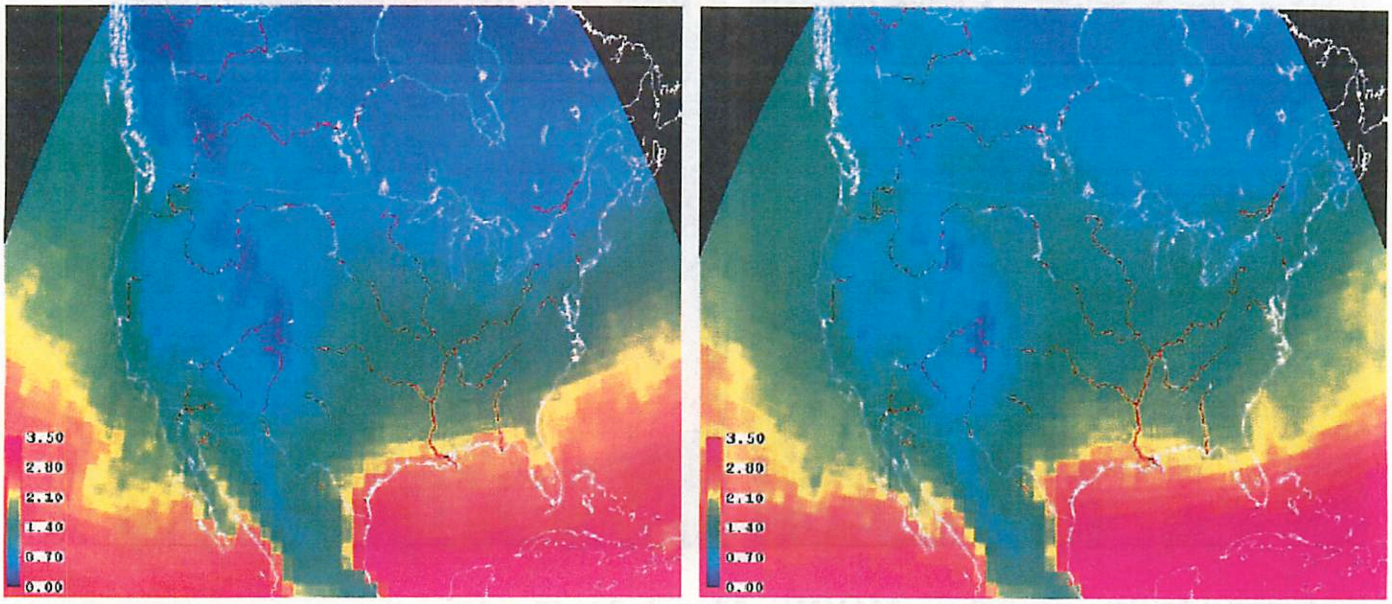
Notice variations in cloud fraction mean over the Rockies and the Great Lakes.

Corrected Optical Depth, Land Mean


March, 2004

April, 2004

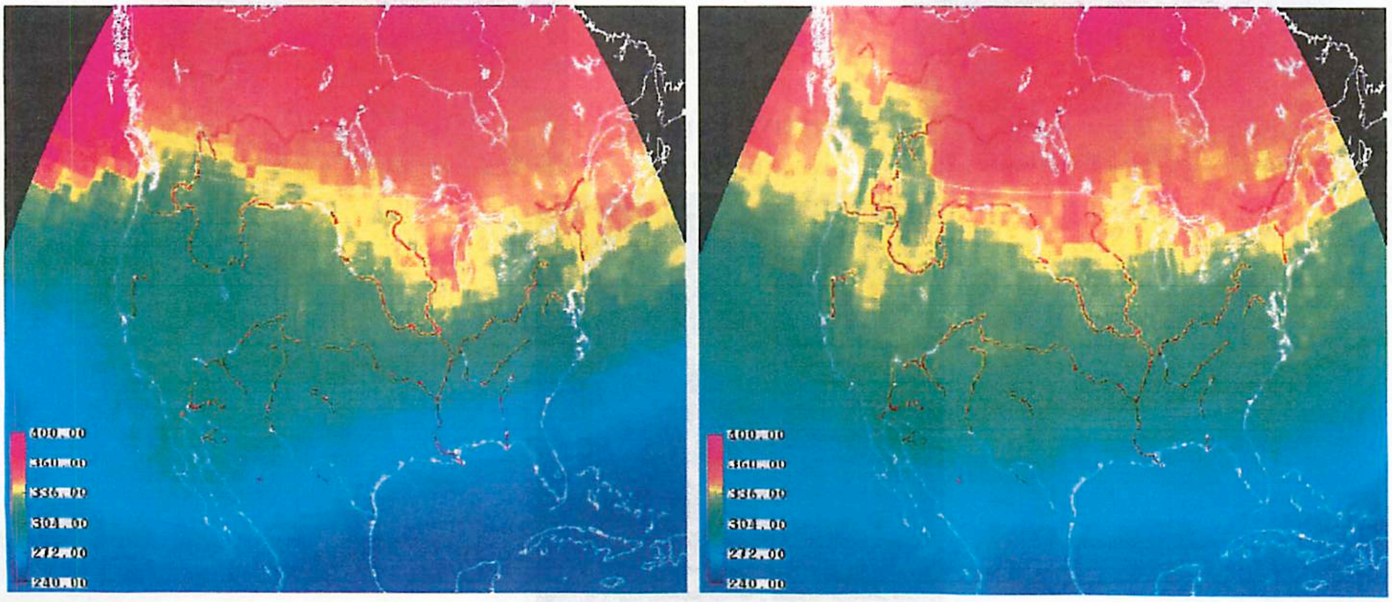
Atmospheric Water Vapor [precipitable cm]



March, 2004

April, 2004

Total Ozone Mean [Dobson Units]

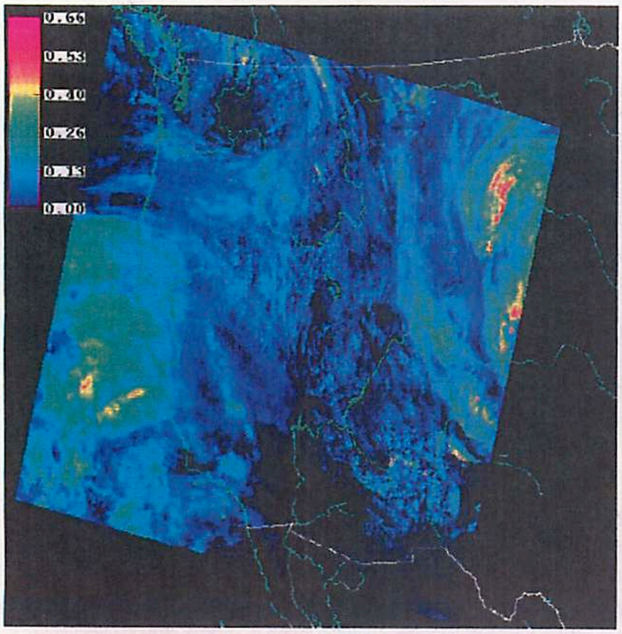


March, 2004

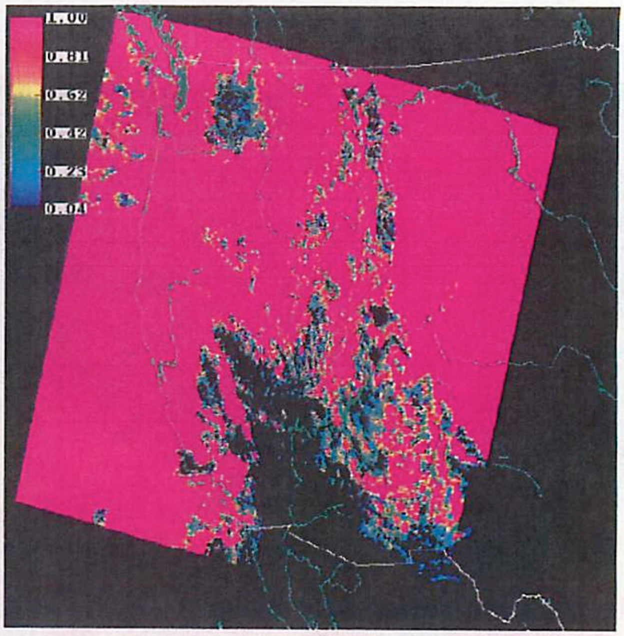
April, 2004

MODIS: March 21, 2005, 11:35 MST

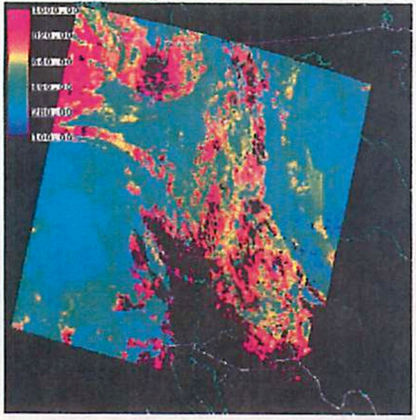
Cirrus Reflection



Cloud Fraction

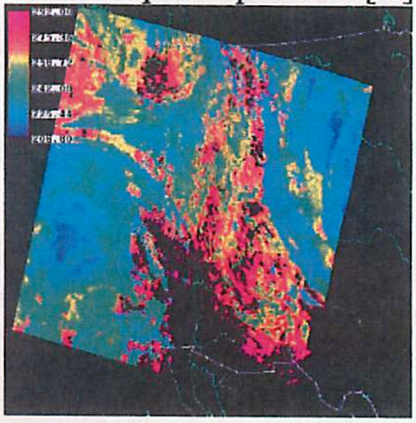


Cloud Top Pressure [mbar]

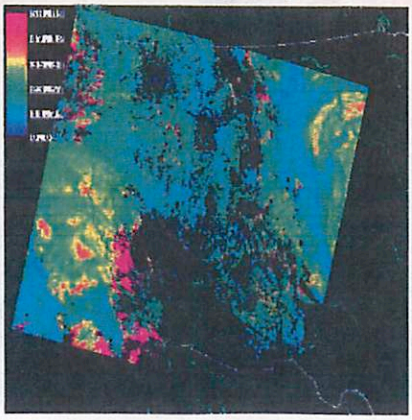


MODIS: March 21, 2005, 11:35 MST

Cloud Top Temperature [K]

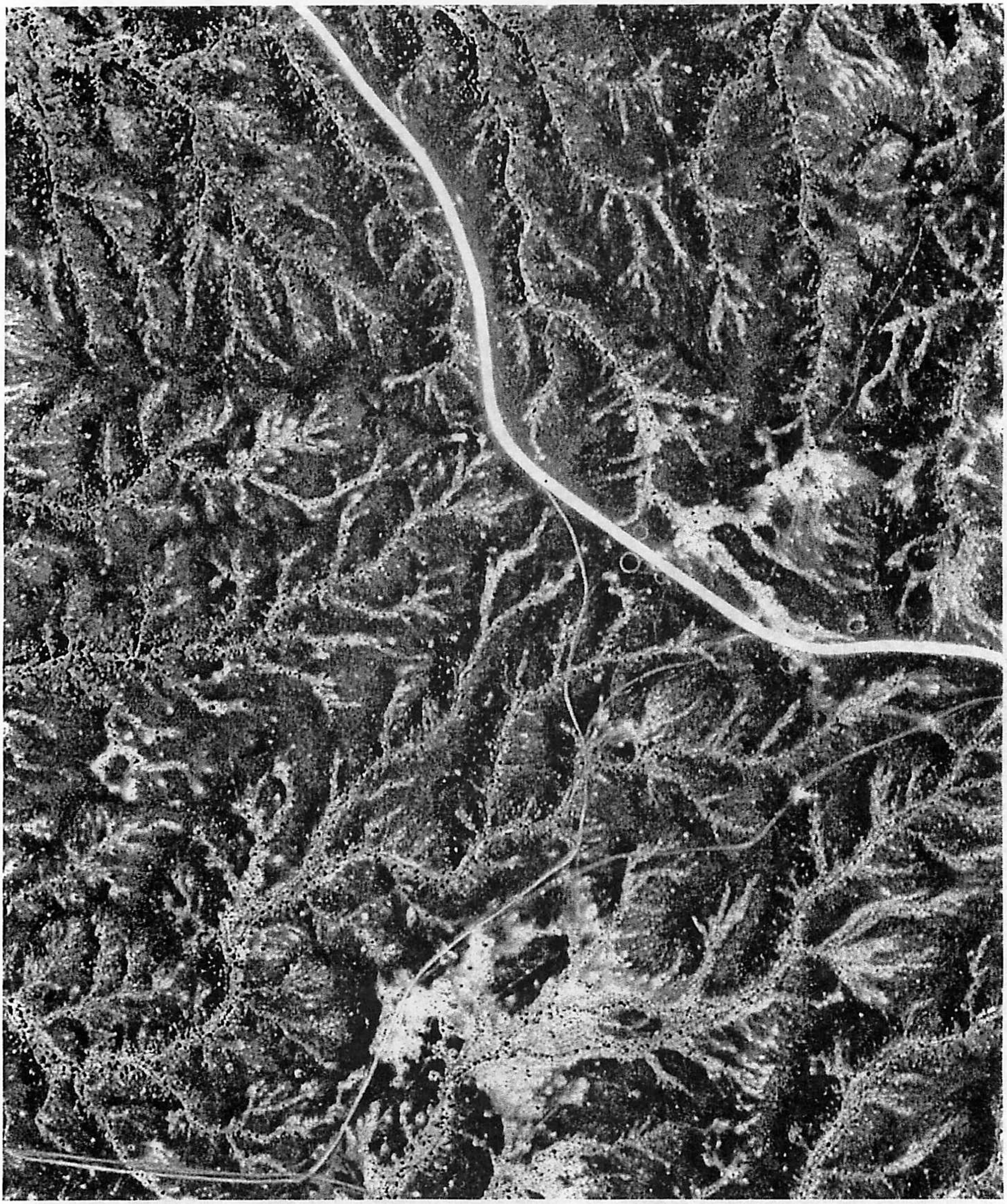


Effective Particle Radius [μm]



Dark Flows (USGS aerial data, 1 m/pixel)

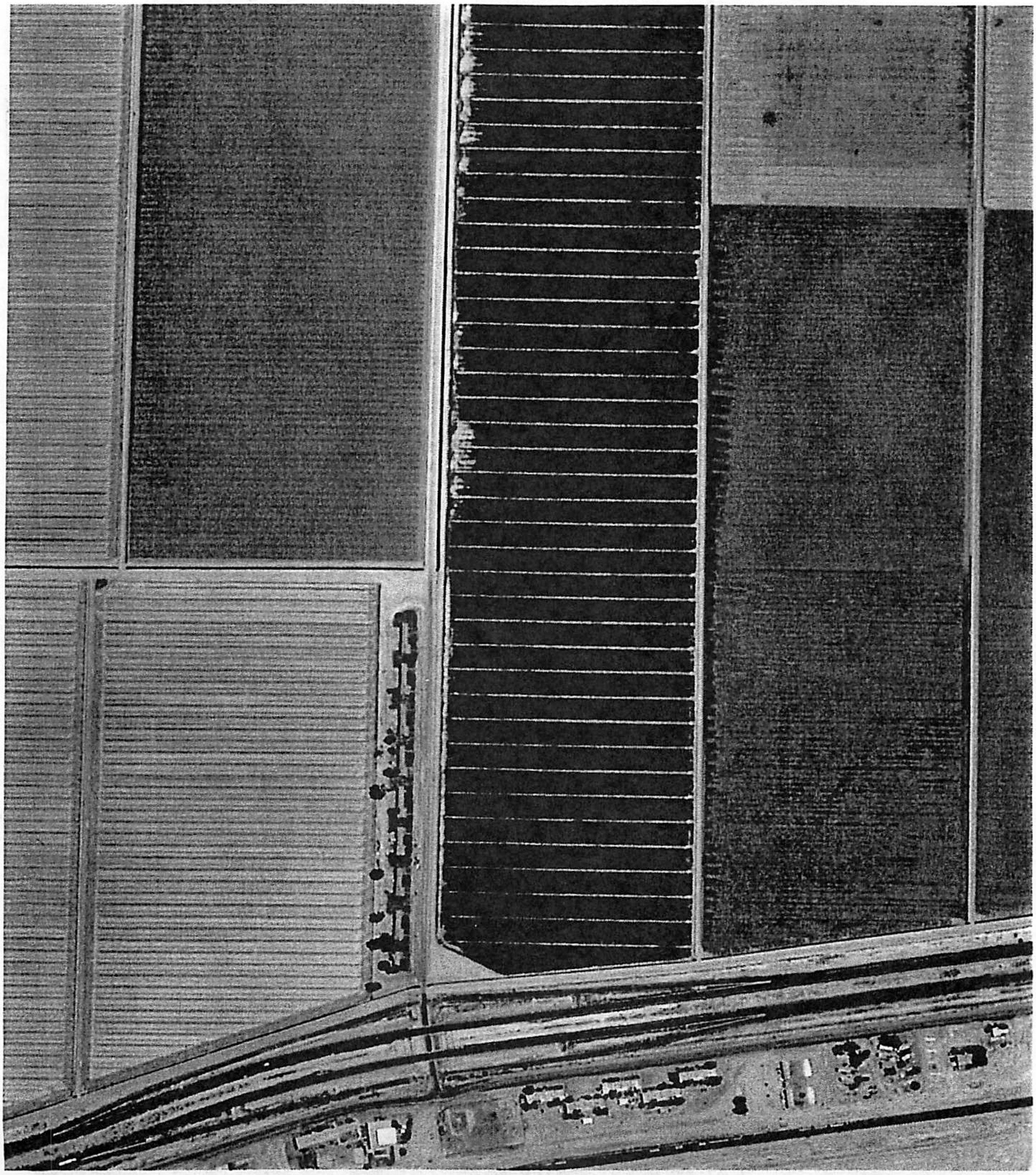
Denditic Channels (USGS aerial data, 1 m/pixel)



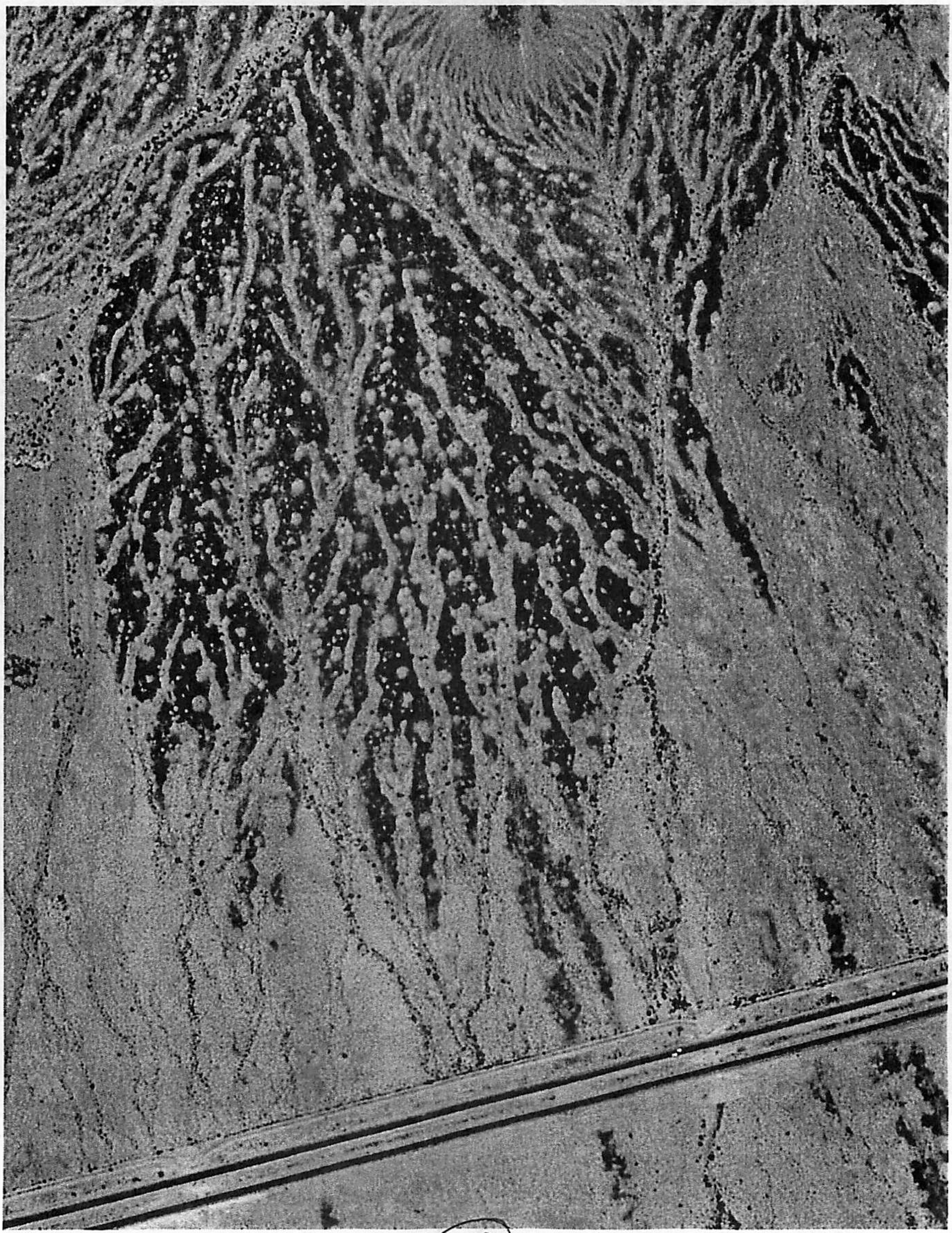
Dunes (USGS aerial data, 1 m/pixel)

Dunes (USGS aerial data, 1 m/pixel)

Farmland (USGS aerial data, 1 m/pixel)

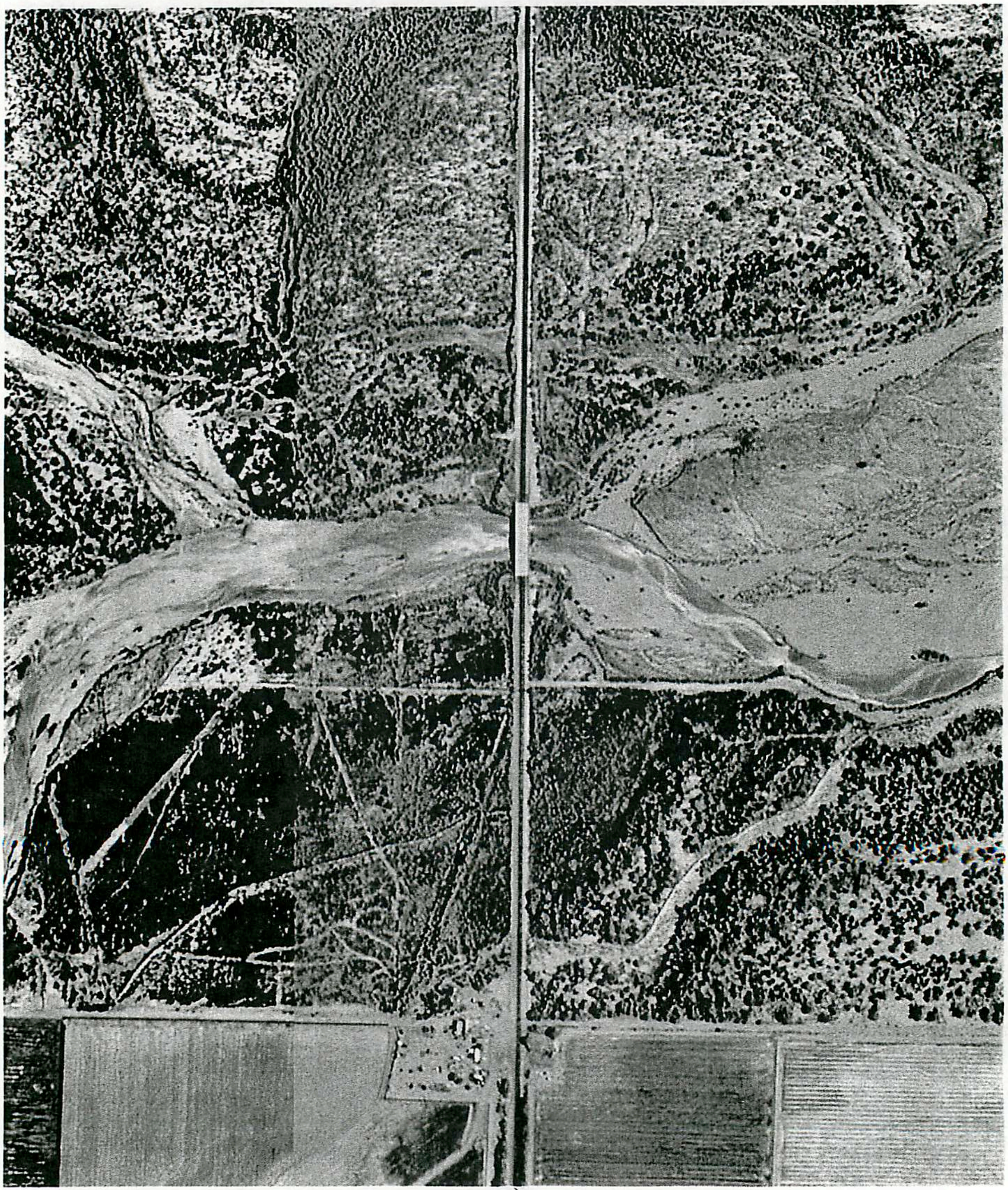


Gullies (USGS aerial data, 1 m/pixel)

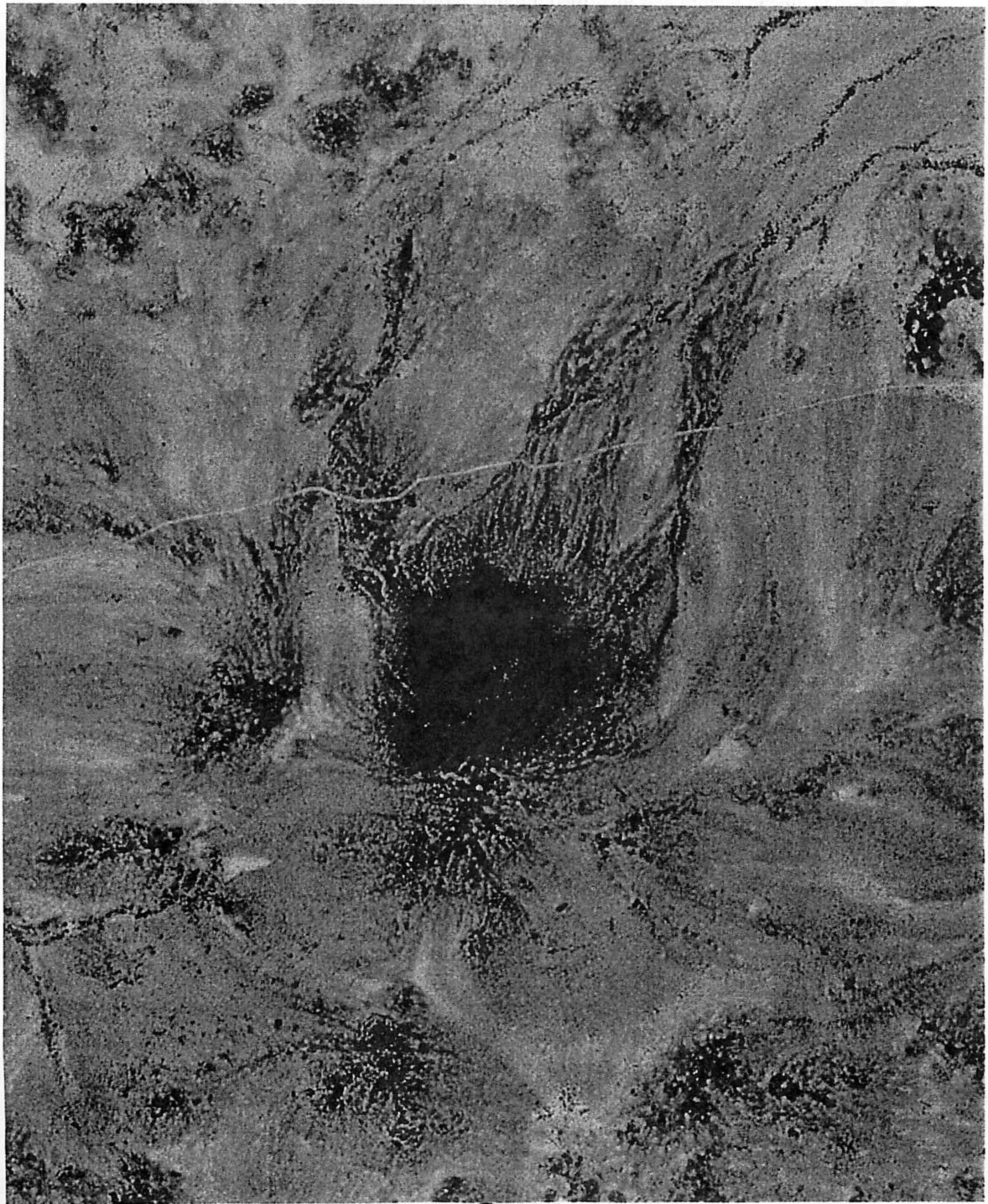


Lobes (USGS aerial data, 1 m/pixel)

River (USGS aerial data, 1 m/pixel)



Sentinel Peak - Cinder Cone (USGS aerial data, 1 m/pixel)



Streaks in the Painted Rock Mountains

John Keller

A patterned albedo feature was identified through aerial photography in the shallower slopes descending off of the Painted Rock Mountains centered around 32.9N, 113.0W in our research site. Two examples of this feature are provided in Figures 1 and 2 below as both plan view aerial images and as 3-dimensional images with vertical exaggeration based upon Shuttle Digital Elevation Data. Figure 3 shows the entire Painted Rock Mountain region as both an aerial image and as a radar image and provides regional context for the features shown in Figure 1 and 2.

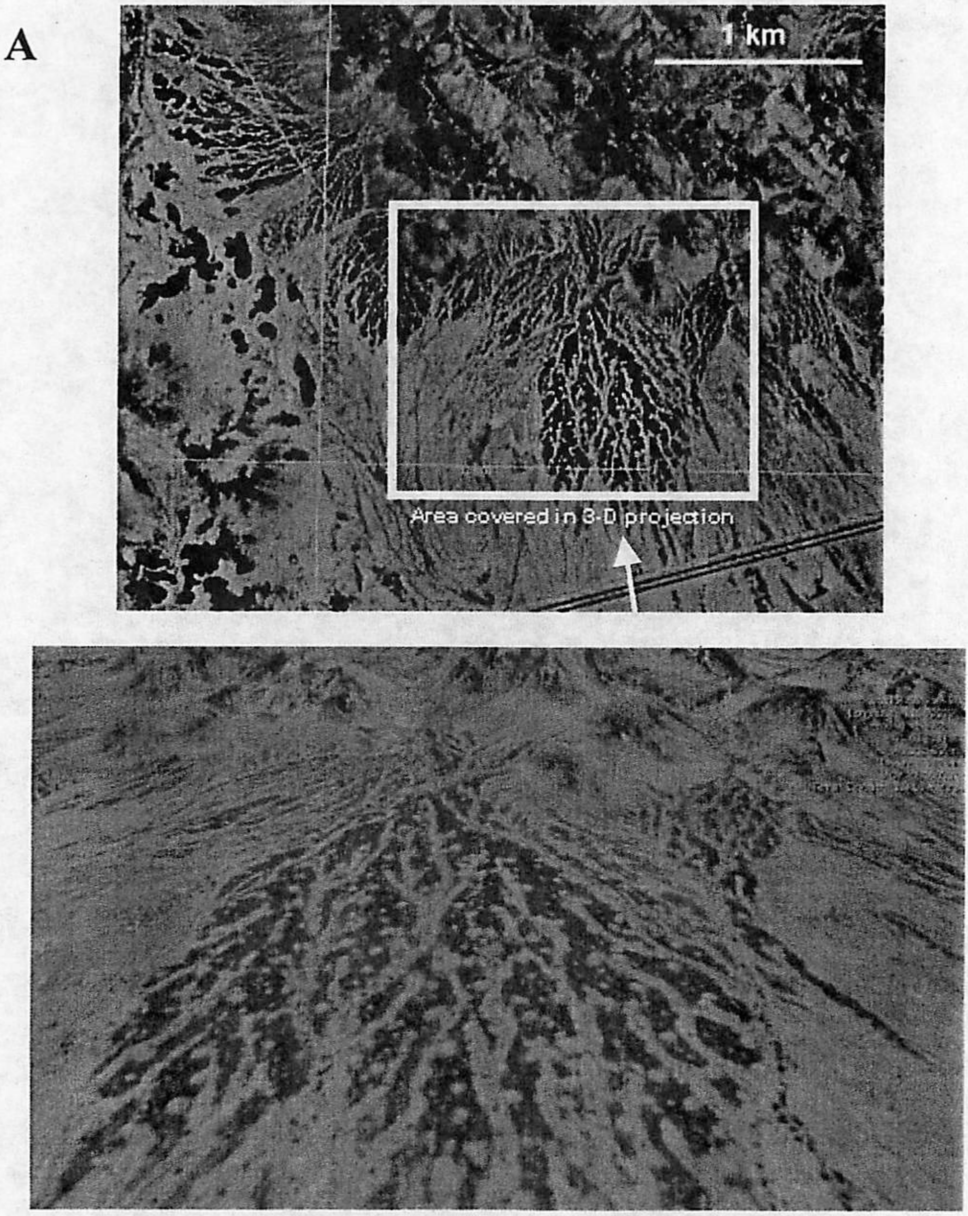


Figure 1: Patterned feature immediately north of I-10 at southern end of Painted Rock Mountains: A) aerial image, B) 3-D projection with vertical exaggeration looking from south.

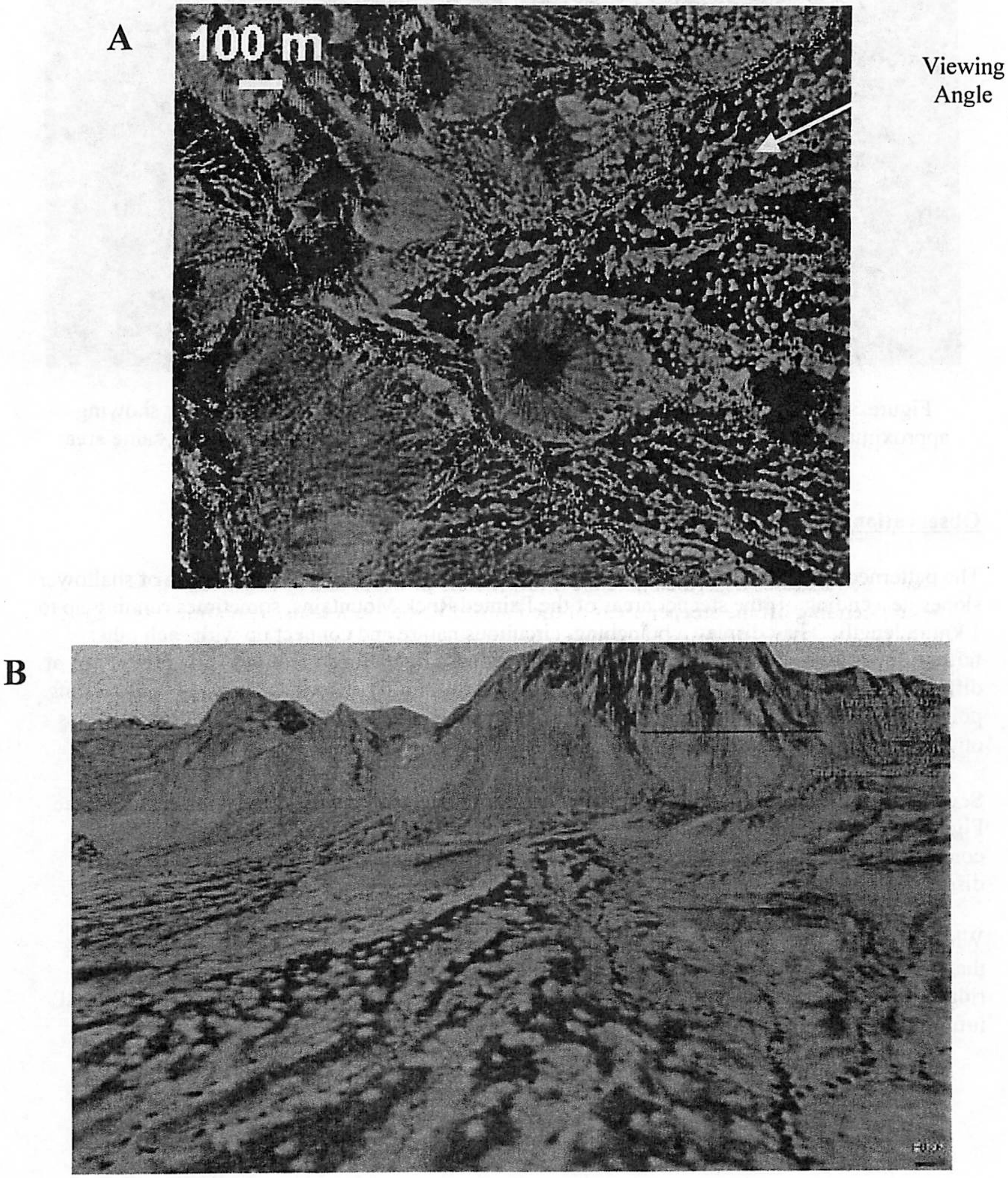


Figure 2: Patterned feature on eastern slope of Painted Rock Mountains:
A) aerial image, B) 3-D projection with vertical exaggeration looking from northeast.

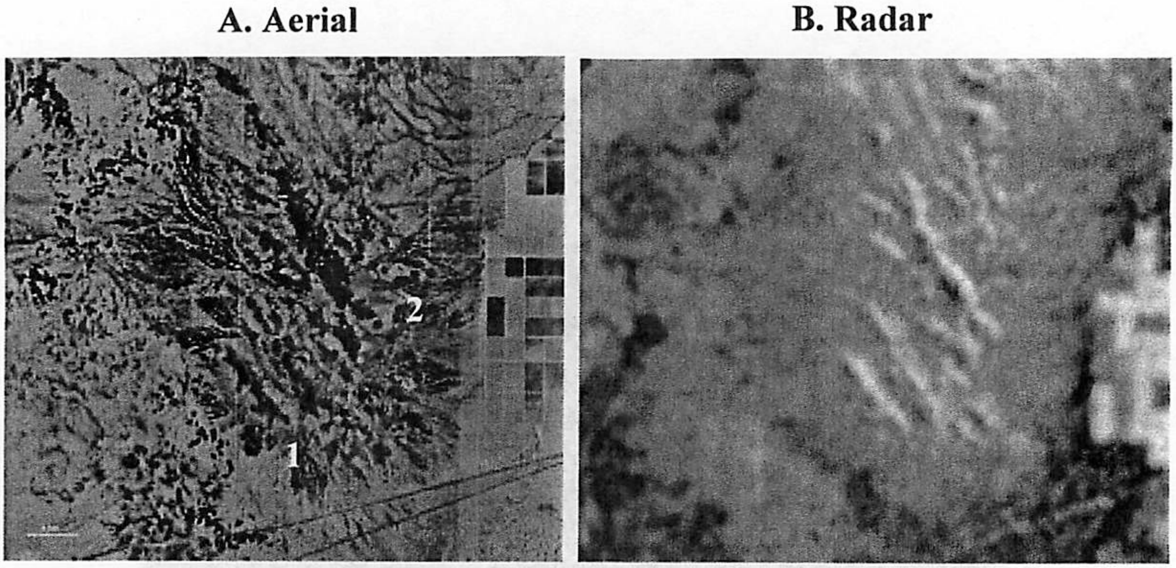


Figure 3: Aerial and radar images of Painted Rock Mountains: A) aerial image showing approximate location of patterned features in Figures 1 and 2, B) radar image of same area. 1 km scale bar is provided in the bottom left corner.

Observations

The patterned features described here are a few meters in width and span the length of shallower slopes descending off the steeper areas of the Painted Rock Mountains, sometimes running up to 1 km in length. They display a branching, circuitous nature and connect up with each other farther downslope. An important characteristic of these light albedo features is that they start at different elevations throughout the slope and also show similar shapes and sizes at their starting points. Also, there are many bright circular features interspersed between the brighter features on the dark albedo surface.

Several examples were found in which the features connected up with alluvial fan features (see Figure 1) in which the darker albedo material is not present. Additionally, the features often connect up with larger drainages that show what appear to be bushes and vegetation and a distinctive streamlike appearance (see Figure 2).

While not shown here, images from the Thermal Image Mapping Spectrometer (TIMS) show that the channels have a different mineralogical composition than the surrounding peaks and ridges. This will be shown in the field using a larger poster image which overlays this thermal infrared data over the aerial images shown here.

Interpretations

Gullies: One working hypothesis to explain the light patterned features described here is that they are gullies associated with water drainage. The gullies are found on the shallower slopes of the region and do not appear to be related to rockslides or regions of mass wasting. Rather we suspect flowing water as the primary mechanism for the formation of these gully-like features. The starting point of the gullies could be due either to sapping of underground water or to vegetation established on these shallower slopes. This latter idea is supported by the many circular light albedo features found between the gullies that look like they may be related to smaller bushes that do not show up at the resolution of the imagery. If creosote and other desert bushes can become established on the slopes, the root action of these plants may provide looser soils. These regions may then be more susceptible to washing out during floods and forming gullies following small scale topography.

While in the field, we expect to find these light features to be depressions relative the surrounding darker albedo material. The gullies will be a few meters increasing in size to up to 10 meters before draining into either wash beds or alluvial fans. We plan to look at the minerals and rocks found in both the gullies and the surround darker albedo material to provide ground truth data regarding the mineralogy shown in the thermal infrared spectral images. Finally, we will investigate the starting points of these gullies as well as the circular features to determine whether sapping of ground water and/or vegetation are important in the incipient formation of these features.

RUSes: A second working hypothesis is that these features are trenching trails created by Rodents of Unusual Size (RUS) *[Morgenstern, 1998]* burrowing through the slopes of the region. We do not have elevation data at high enough resolution to determine if these light albedo features are depressed or elevated relative to the darker material. As rodents burrow through the ground, the leave behind an elevated trail of turned over soil that is lighter in color. In the field we will determine whether these features indeed show positive relief. We will also look to see if there is organic material left in the rodent trails that could explain the spectral differences shown in the TIMS data. The sudden disconnected starting points of the features may be explained as locations in which the RUSes dug down deeper and then resurfaced for air at different point along the slope. With a characteristic width of a few meters, the organisms required to make these trails were indeed unusually sized and we suspect that the trails may be relics of an extinct species of rodents.

References

Morgenstern, S. 1998. Princess Bride: S. Morgenstern's Classic Tale of True Love and High Adventure. Ed. William Goldman. Ballantine Books.

Overview of Remote Sensing Datasets and Summary of Results

Edited and presented by Oleg Abramov

1. Gravity – John Moores

Description: Free-air and Bouguer gravity datasets used in this project were obtained from the U.S. Geological Survey with the help of Jay Melosh. The Bouguer gravity dataset consists of measurements taken on the ground and has had the assumed effect of topography (i.e. a certain elevation of crustal material) removed. The free-air gravity dataset, on the other hand, is the gravity field that would be seen by an observer at constant elevation (such as in an aircraft or a spacecraft). Basically, the gravity datasets can tell us about the state of compensation of the crust; i.e. is a given mountain a recent feature, or has it isostatically relaxed? The gravity data can also tell us about the general material characteristics of the region, for example, extensive fracturing lowers density and leads to a negative gravity anomaly, which magma intrusions increase density and lead to positive gravity anomalies.

Results: The gravity values in the study area are generally mid-range, and no large topographic features are present. This, coupled with the overall low elevation of the area (~200 m) indicates that the density of the crust is about average. The resolution of the dataset is insufficient to resolve specific features such as Sentinel Peak.

2. Magnetic – Jani Radebaugh, Mike Bland

Description: In much the same way we use variations in gravity measured at the surface, we can use magnetic fields measured at the surface to determine properties of underlying materials. These measurements are usually quite easy to make, because they require a simple recording of the magnetic field strength variations across a location; however, the interpretations of data are often nonunique. Variations in the field strength in a location exist due to variations in amounts of magnetic minerals, commonly found in ore bodies or igneous materials, but less commonly in sedimentary rocks. Interpretations are difficult because a shallow, broad, weak signature can appear similar to a deep, focused, strong signature, and these represent two very different bodies.

This data set has been pieced together from 43 separate magnetic surveys (of varying quality) which were carried out between 1947 and 1999. Each survey was continued to 1000 ft above ground level and regridded to a spacing of 500 m (essentially giving a resolution of 500 m per pixel) before being merged into a state-wide mosaic.

Results: A region of elevated magnetic field strength (~250 nT) correlates with our area of study. This observation, coupled with other datasets, indicates that deposits in this region are primarily volcanic, and likely mafic, in composition. This means we would expect to find deposits rich in magnetic minerals at least several tens of meters thick, as is common in mafic volcanic regions. The region just to the east of our study area is a populated area with much agriculture (according to Landsat imagery). The magnetic signature here is very low (<-300 nT) which may indicate there is a basin with deep deposits of sedimentary materials with few magnetic minerals.

3. Radar – Mike Bland

Description: The radar data set is a mosaic of X-SAR "quick look" radar images. X-SAR (X-band Synthetic Aperture Radar) was a German/Italian instrument flown aboard the shuttle, and has a wavelength of 3.1 cm. These "quick look" images are at a lower resolution then the actual X-SAR data acquisitions, however, no true acquisitions occur over our study area (or are not publicly available). The spatial resolution of this dataset is 150m in both range and azimuth and each strip is ~103 km long (azimuth) and 10-60 km wide (range).

Results: The study region appears to have lava flows with well-defined boundaries corresponding to those observed in aerial images. The lava flows are more radar-bright than the surrounding area, indicating a higher roughness. However, the relative brightness of the lava flows is not particularly high (many other regions in the mosaic that have a higher brightness), ruling out fresh aa-type flows. Coupled with the high degree of fluvial erosion seen in aerial images, this indicates an old, degraded lava field. The nearby farming fields have widely varying brightness, which likely depends on the presence and type of vegetation and whether the field has been recently plowed.

4. Topography – David Choi

Description: The topography dataset used in this study was produced by the Shuttle Radar Topography Mission (*http://www2.jpl.nasa.gov/srtm/*), which sought to create the first high-resolution global scale digital topography model of the Earth's surface. Single-pass radar interferometry was used to create this elevation model. In February 2000, the shuttle Endeavour was launched (STS-99), carrying a payload consisting of two radar antennas. One antenna remained in the cargo bay of the shuttle while the other was placed at the end of a mast extended 60 meters away. The mission generated data on nearly 80% of the land surface of the Earth, which was essentially everything between 60 degrees North and 54 degrees South latitude. The data set covers an area representing 95% of the world's population.

The SRTM data is useful for creating a digital elevation model (DEM) of whatever area is being studied, and for analyzing the topographic features and gradients of an area. Currently, the resolution of the publicly-available data is 1 arc second (~30 meters) over the US, and 3 arc seconds (~90 meters) for the rest of the globe. As data is processed, 1 arc second resolution data will become available for more continents. The vertical accuracy of the data is 16 meters. Data is available freely online through the USGS Seamless Distribution System (*http://seamless.usgs.gov*) or at the following ftp site: *ftp://e0mss21u.ecs.nasa.gov/srtm/*. Files at the ftp site are .hgt format and require special GIS software to be used correctly.

In addition, the WorldWind software package from NASA (available at worldwind.arc.nasa.gov) automatically incorporates SRTM data into whatever dataset you are using (for example, Landsat 7 photographs) to generate useful 3D models of the Earth's surface. Currently, this is, in my personal opinion, the most useful and painless way of using the SRTM data without more powerful GIS software.

A color map of Sentinel Plain showing SRTM topographic data is included in this field trip booklet.

Results: Overall, Sentinel Plain does not have the remarkable topographic features reminiscent of mountain chains or sinuous canyons, but it does possess some humble features. The average elevation is 200 meters above sea level. There are scattered 'peaks' in the area, with Sentinel Peak being the highest of these at about 300 meters above sea level or ~100 meters above surrounding terrain. The area extending away from Sentinel Peak to the west and north slopes up at a fairly gentle angle overall. There is one fairly stark contrast to be seen, which is the boundary between the plain and lowlands (the Gila River Channel) to the north, where the change in elevation can be up to 100 meters.

5. Atmospheric – Curtis Cooper and John Keller

Description: Remote atmospheric data for the region of study is available through the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard the TERRA (EOS AM) and AQUA (EOS PM) satellites. Using 36 spectral bands spanning between 405-2155 nm and between 3.6-14.4 microns, this instrument is able to extract a diverse set of measurements including the following: aerosol properties (optical thickness; size distribution; mass concentration; reflected and transmitted fluxes), precipitable column water vapor over both clouds and land, cloud properties (cloud top temperature, pressure, emissivity; cloud phase; optical depth, effective particle radius, water path; cirrus reflectance; contrails), total ozone burden, atmospheric stability, temperature and moisture profiles, and total tropospheric column water vapor.

Results: For purposes of this fieldtrip, we have provided some samples of these datasets obtained on March 21 during both the morning (at 11:35 MST) and evening (at 22:40 MST) by the MODIS instrument aboard the TERRA satellite. Surface pressure and temperature at 5 km resolution are shown in high detail for our site. Monthly averages for cloud fraction, optical depth, atmospheric water vapor, and total ozone are shown for the months of March and April 2004 at 1-degree resolution for the entire United States. Finally, cirrus reflectance, cloud fraction, cloud top temperature and pressure, and effective particle radius are shown for a swath taken on March 21, 2005 at 11:35 AM local time. While on the fieldtrip, we plan to make ground truth observations of surface temperature, surface pressure, relative humidity, cloud fraction, and cloud types at the times that TERRA and AQUA are passing overhead.

6. Thermal Imaging – Ingrid Daubar

Description: TIMS (Thermal Infrared Multispectral Scanner) data are shown of site 522, Gila Bend, Arizona. Emissivity in the TIMS spectral bands 1 (8.2 - 8.6 microns), 3 (9.0 - 9.4 microns), and 5 (10.2 - 11.2 microns) are shown in blue, green, and red, respectively. A decorrelation stretch has been applied to these data, resulting in enhanced color contrast and de-emphasis on variations due to temperature.

In these data, brightness indicates temperature differences (cool areas are darker), and color correlates to spectral differences. Mineral emission spectra combine linearly, so these colors are not necessarily correlated with a unique composition. However, some generalizations can be made: volcanic rocks (basalts, granites, etc.), clays, and shales are blue-purple, carbonates are green to green-blue, limestone is green, and quartz-rich rocks (sandstone, rhyolite, etc.) are red.

Spatial resolution for the TIMS instrument is 7.6 meters/pixel from an altitude of 10,000 feet. These two observations (site 522, flight 95-007-003) were taken from an altitude of 6600 and 6700 feet. The resolution would presumably be about 5.0 m/pix, assuming resolution would improve linearly with decreasing altitude. The resulting dimensions of the mosaic are about 4.7 km wide by 63 km long.

More information on this specific dataset can be found here: *http://elwood.la.asu.edu/grsl/jdata/tims_ns001.html* and an extensive library of thermal emission spectra is located here: *http://tes.asu.edu/speclib/index.html* We thank Jayme Harris of ASU for providing these data.

Results: The SW corner of the TIMS strip crosses the aerial mosaic near the "Lobes" site. The part of the TIMS strip that overlaps with the presumed lava flows observed in aerial images is mainly blue and purple, confirming that these are volcanic rocks. These colors are unique to the lava field and are not seen elsewhere in the TIMS strip.

7. Landsat – Doug Archer

Description: One of the imaging datasets used for this study was acquired by the Landsat 7 satellite, which was launched in 1999 and is in an orbit with an altitude of 705 km. The Landsat 7 camera has the following bands:

Band Number	Spectral Range(microns)	Ground Resolution(m)

1	.45 to .515	30
2	.525 to .605	30
3	.63 to .690	30
4	.75 to .90	30
5	1.55 to 1.75	30
6	10.40 to 12.5	60
7	2.09 to 2.35	30
Pan	.52 to .90	15

Land Sat 7 Pseudo Color is obtained by using two infrared bands and one visual for color and the panchromatic, high resolution band for luminance. This is known as the 542 color, pansharpened color scheme, or pansharpened pseudocolor.Visible Color images are primarily generated using bands 1-3, assigning a RGB value from each band.

Results: See Aerial Imaging results (the two datasets are complementary).

8. Aerial Imaging – Oleg Abramov

Description: The visible-light aerial imagery used in this study was acquired by the U.S. Geological Survey on June 8,1996, at a resolution of 1 m/pixel. The images were downloaded using TerraServer (*http://terraserver.microsoft.com*) and two data products were generated – a large mosaic of the study area, at a resolution of 4 m/pixel, and close-ups of areas of interest at the native resolution of 1 m/pixel (included in this field trip guide). A minimum of processing (brightness/contrast enhancement) was performed on the original images.

Results: The central feature in the study area appears to be a lava field, the boundaries of which are poorly defined in some areas and well-defined in others. In particular, the northern boundary of the lava field is well defined and has numerous lobes (The "lobes" site). Judging solely from the aerial images, it appears that the thickness of the lava is ~10 m in this part of the field. A river cuts through the lava field; however, no water was flowing at the time the images were taken. Some fault lines are seen along the river, suggesting that its basin is a graben. At least two distinct lava units were identified based on albedo (the "light unit" and the "dark unit" – seen at the "dark flows" site), suggesting multiple eruptions at the site. The light unit appears to be superimposed over the dark unit, suggesting that it is younger. Several hills in the area appear to be cinder cones, the most prominent of which is Sentinel Peak. The lava field is in an advanced stage of degradation by fluvial processes; numerous gullies (e.g. "gullies" site) and dendritic channels (e.g. "dendritic" site) were identified. Aeolian processes also appear to be active, and numerous potential sand dunes were identified (e.g. "dunes" site). However, an alternate explanation for these "dunes" is that they're volcanic features, or more specifically, tops of lobes formed during viscous flow, e.g. pahoeoe "toes." (see Ingrid's handout).

The lobate scarp (33.006 N, 113.074 W):

Mike Bland

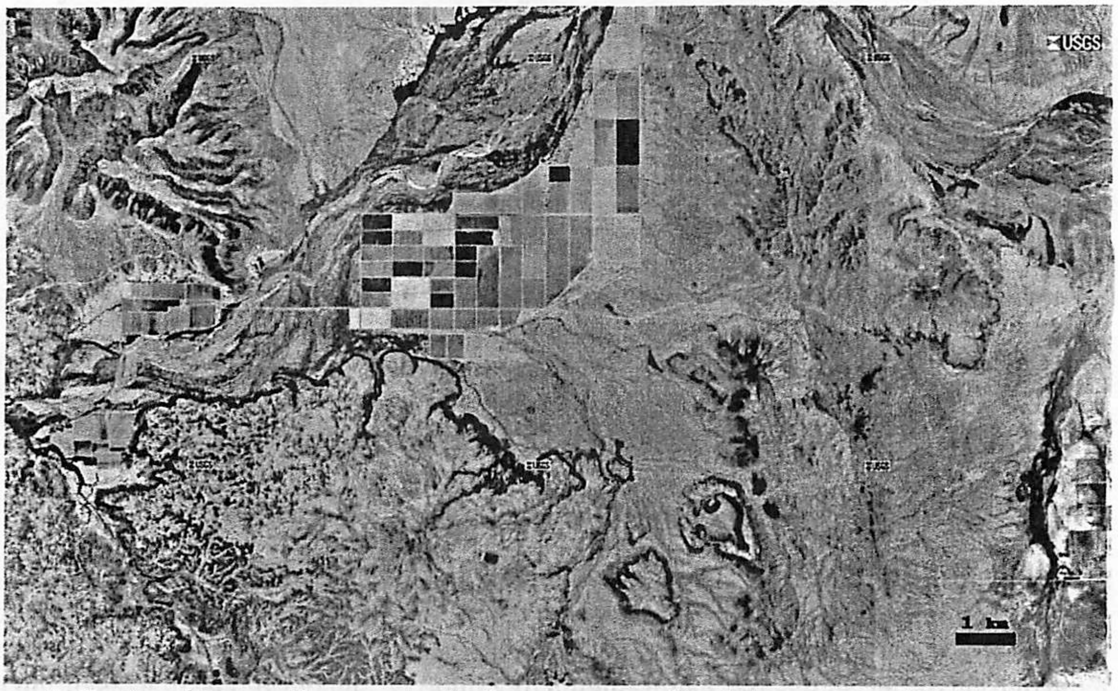


Figure 1: Regional image (1m per pixel) of area surrounding lobate scarp. The image above is ~19 km x 11.5 km.

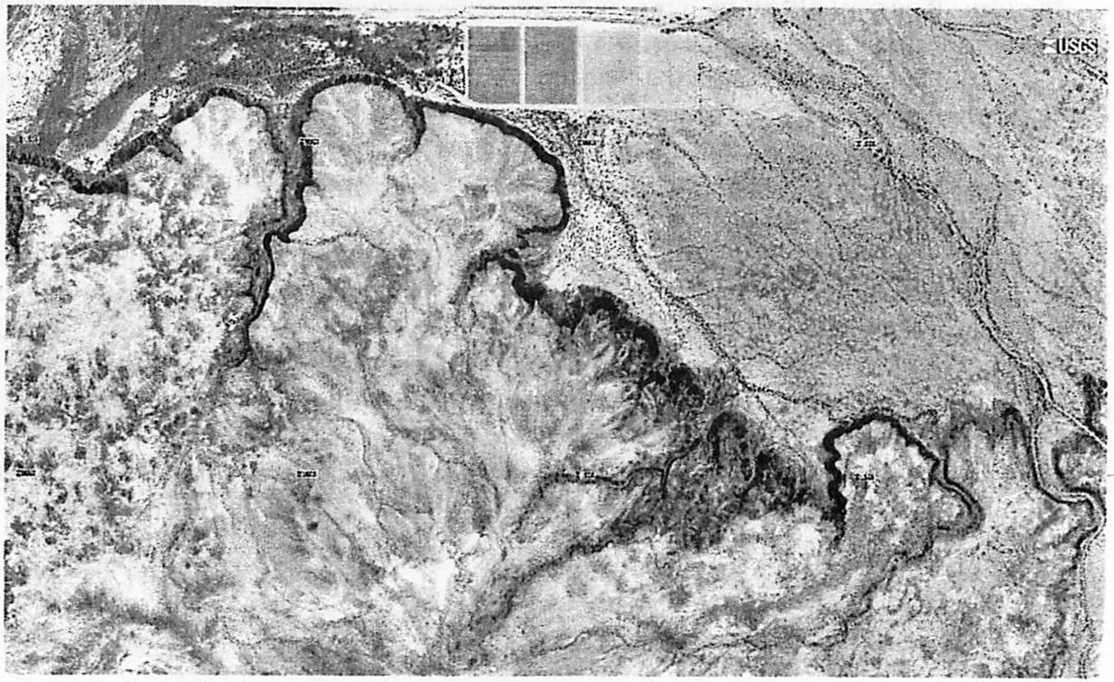


Figure 2: High resolution image of lobate features showing pronounced scarp and significant drainage networks.

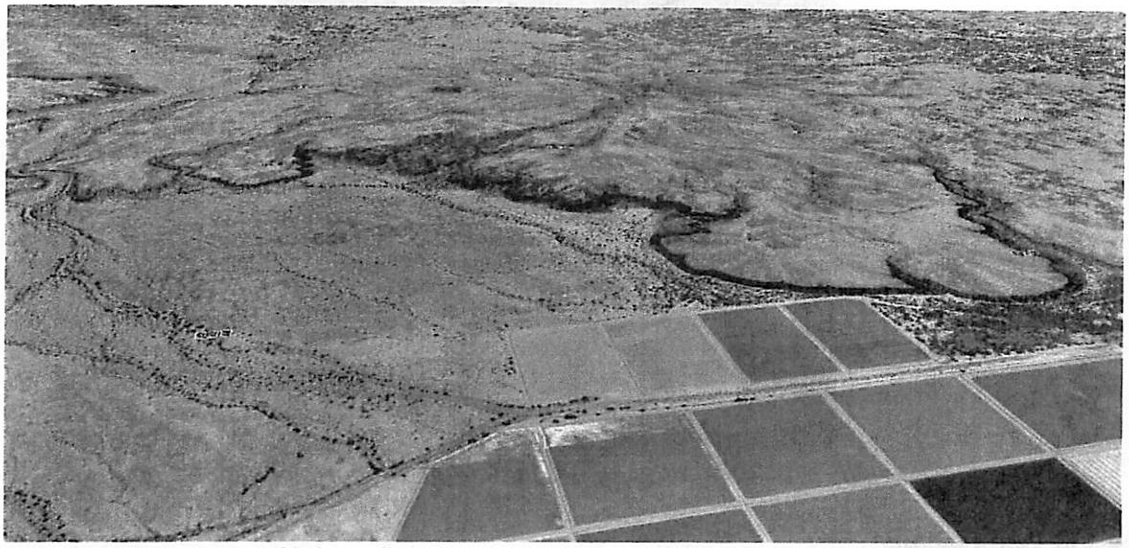


Figure 3: Oblique view of lobate flow front with 10x vertical exaggeration. Image resolution is ~1 m per pixel.

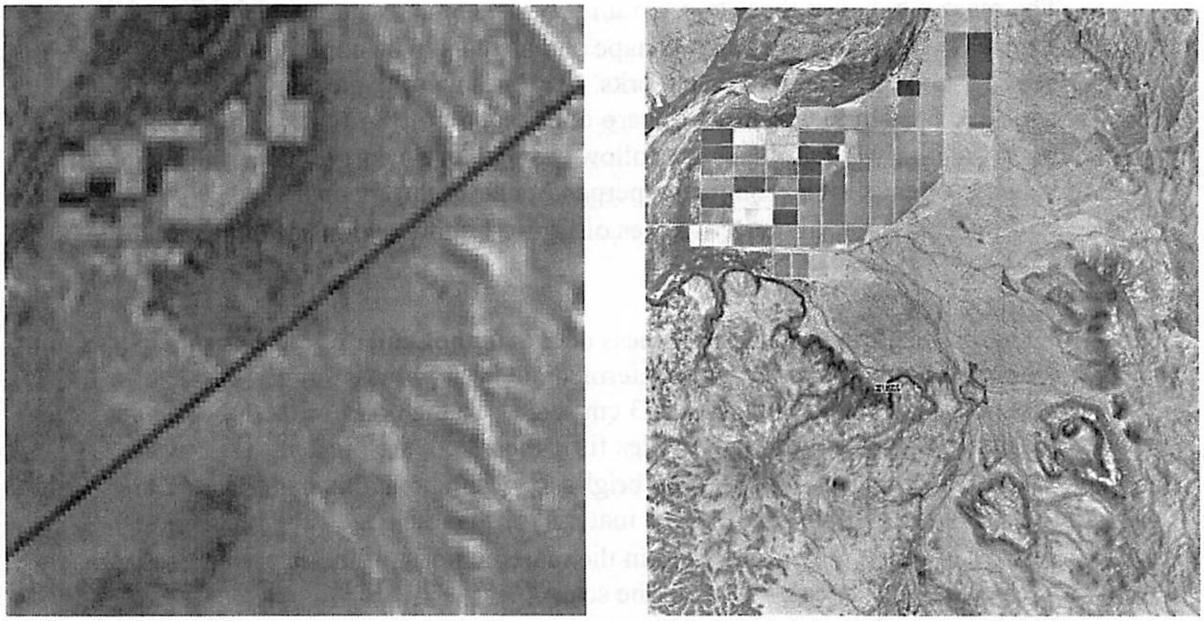


Figure 4: Comparison of RADAR image (X-SAR 150m/pix, 3.1 cm) with visible image (1 m/pix). The black line running across the RADAR image is an artifact due to sloppy mosaicing.

Figure 5: Landsat Visible image of lobate region in approximate true color.

General Description:

VIZ(figure 1,2,3,4):

- Regional images show this region to be at the boundary between two types of terrain: relatively smooth, flat terrain to the north (possibly alluvium) and rough terrain to the south (possibly volcanic).
- The margin between these two terrains consists of an escarpment 2-10 m high.
- The scarp is generally lobate in shape and appears to be continuous for ~12 km. It is heavily incised by drainage networks. At times these dendritic drainages become complex enough to obscure the scarp edge (center of figure 2).
- In this region the scarp does not follow the path of the large channel to the north. Instead it trends to the southeast (perpendicular to the channel).
- The eastern and northwestern edges of figure 1 show regions of high standing terrain.

RADAR (figure 4):

- A sharp transition in radar brightness occurs in the center of the radar image. South of the lobate scarp the terrain is intermediate in brightness suggesting that the lobate material is relatively rough at the 3 cm scale. To the north of the lobate features the material is dark suggesting particles finer then 3 cm are present.
- The rim of the scarp is especially bright suggesting that this material is either slightly rougher then the rest of the lobate material or that the edge is high standing.
- There is a subtle darkening trend in the material north of the scarp suggesting a shift to finer particle sizes away from the scarp.
- The Eastern edge of the image is composed of bright (probably rocky) material that is elongeated in the NW-SE direction.
- In context the lobate scarp seen here is part of a much longer margin between radar bright and dark material that seems to correlate with a channel like feature in the visible images (see radar mosaic).

LANDSAT (figure 5):

- The Landsat 7 image above shows a subtle color variation between the lobate material and the material below suggesting a compositional difference between the two.
- There is an obvious color difference between the brownish material just north of the scarp and the yellowish material further to the north. This suggests that the transition hinted at by the RADAR data is real.
- The eastern edge of the image shows a definite color contrast with the rest of the image suggesting this material is unrelated to the features seen in the central part of the image.

OTHER DATA:

- The magnetic survey suggests that the region is adjacent to an area of very high magnetic anomaly (200-360 nT) consistent with large amounts of iron bearing rocks (volcanics?). However the immediate area appears to have a substantially smaller positive anomaly (0-80 nT).
- TIMS data was acquired for an area to the east of the scarp. This data suggests that the material in the eastern edge of images 2-4 is volcanic. However the data is otherwise inconclusive.
- Gravity data suggests only minor free-air and Bouguer anomalies in the region.

Interpretation:

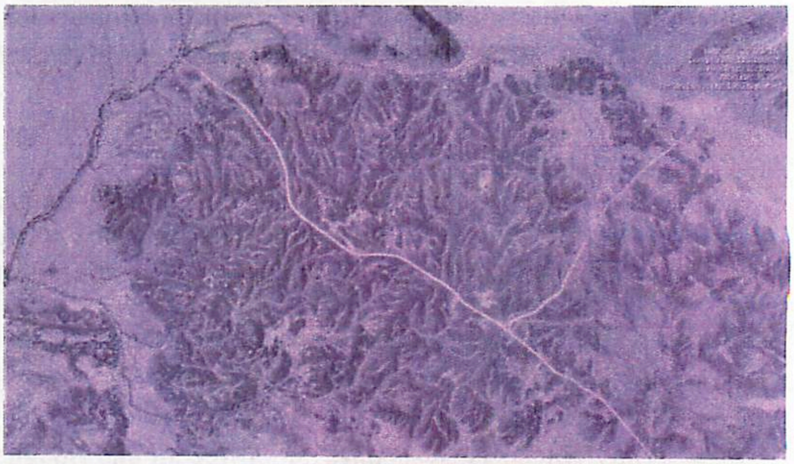
- The lobate scarp marks the boundary between volcanic flows and alluvial deposits. A volcanic origin for the scarp is suggested by its lobate appearance and by the intermediate roughness at 3.1 cm radar wavelength.
- This scarp marks the approximate northeastern termination of the flow rather than an erosional margin created by the channel to the north.
- The material immediately to the north of the scarp is most likely relatively fine grained material whose source is the volcanic field immediately to the south. This material grades into even finer alluvium that has been transported some distance by volatile flow in the channel to the north. The source region for this material is most likely the high standing topography to the east of the lobate scarp.

- **The remote sensing data are consistent with the region being dominated by volcanic processes. These volcanic landforms have been modified by erosion due to the presence of fluids on the surface. The region has also seen significant tectonic processing that has created several nearby areas of high standing topography.**

Dendritic Channels

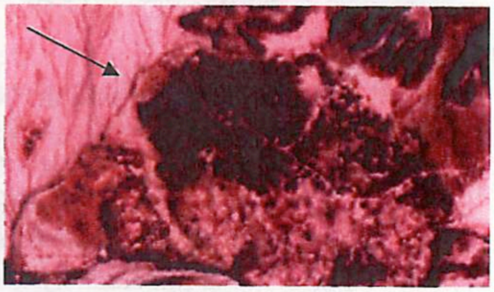
General Information:

So I was talking to Jani a few weeks ago and she made the crazy claim that at almost every scale, river ("dendritic") channels are the dominant feature of the terrestrial landscape. After spending most of the intervening weeks of my life using the "Coolest Program Ever," AKA Worldwind, I'd have to say that she is right. Dang it.



Even in the desert in which we live (some call it "Arizona") there are dendritic channels everywhere. I am going to give you a little more information about a specific area containing dendritic features in the Sentinal Plains

This picture shows an outcrop about 2km across, covered with a dendritic network. In the Landsat 7 visible color image, the color difference between this feature and the surrounding terrain is very obvious.



What is interesting is that the radar data does not show any difference between the dendritic area and the regions immediately below it.

A topographic map (figure 1) gives a good profile that is not easily seen in the images. The highest elevation of the region is on the right of the feature, falling off slowly as you move towards the plains to the left, above, and below the region. From right to left, the slope is gentle, dropping about 7 meters every kilometer (~.5°). The dendritic formation drops off to essentially the same elevation to the west and to the north, but does not drop off as much to the south.

The USGS 1m aerial images clearly show that the channels themselves are much lighter than the original material. As we zoom in, smaller white dots are seen throughout the area as well. The road runs along what appears to be a sort of ridgeline, as it does not appear to cut through many dendritic features.

It is interesting to note that in many cases, the channels seem less well-defined near their points of origin. In the bottom left of the higher resolution image (below), we see a good example of this. Most likely, this is because precipitation forms many small rivulets before joining to create the more well-defined channels.

My Interpretation:

Starting with the basics, simply due to the color and the lobate structures of the dendritic channel area (DCA), I guess that it is a basaltic lava flow. Precipitation is forming erosional valley networks, that changes the color of the material. As this region receives little rainfall, the white color could simply be a crust of precipitates from the parent rock, or could be indicative of leeching out the dark-colored material. I predict that the white spots are local minima that fill up with water, but do not connect to other drainage features, leaving the water to evaporate away. There is nothing overly special or complicated about the fluvial features in this area.

However, the relation of this area to it's surroundings has been very hard to define. Let's start off with the radar image. Using this data set, it appears that the DCA is simply the end of a lobate flow moving from south to north. The flow must be older than the river as the river cuts through the flow. This seems fairly straightforward and is most likely true. However, the DCA is higher in elevation than the rest of the flow it appears attached to by about 100 feet. Which seems to indicate that the area was emplaced after the previously described flow. Additionally, the color difference between the DCA and it's surroundings are most likely due to age and not compositional differences—the darker color also being indicative of a younger age.

There are two peaks (about 100 feet higher than the DCA) to the southeast, but they are surrounded by lower lying areas, making it impossible for them to be the source of any kind of lava flow that created the DCA.

So the area is higher and younger than the surrounding terrain, though there is no readily apparent reason why this is so.

Doug Archer

Figure 1

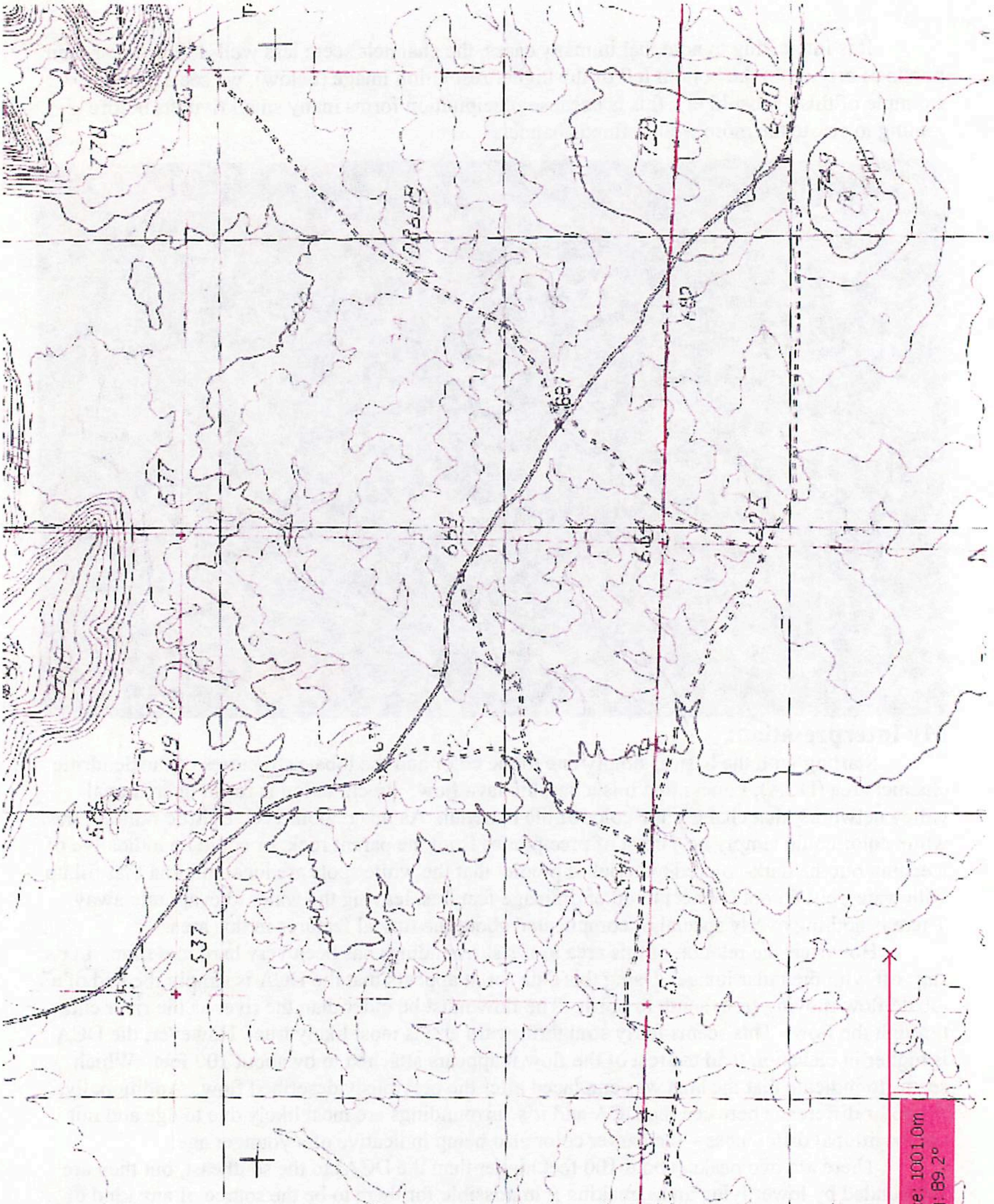


Figure 2


Latitude: 38.03702°
Longitude: -119.19131°
Heading: 39.37222°
Tilt: 63.03878°
Altitude: 1497m
Distance: 3532m
FOV: 45.00000°
Terrain Elevation: 192.00 meters

Mysterious Albedo Stripes

Ingrid Daubar

Observations:

- Albedo features first identified in aerial photography: **dark, roughly parallel, discontinuous, irregular, curving lines alternating with higher-albedo areas** (Fig 1) . Stripes are darkest at their center, grading to lighter at edges. Edges are usually indistinct.
- Site 1 is the most clear in aerial photography, but several other areas show similar patterns (Fig. 2).
- Stripes often occur in a series of concentric curves **aligned perpendicular to striping** (Fig. 1)
- Dark stripes may consist of discrete dark spots? Close to resolution limit.

Fig. 1. Albedo "stripes" seen at 32.92°W, 113.12°S. Image is ~1km across. North is up in all images.

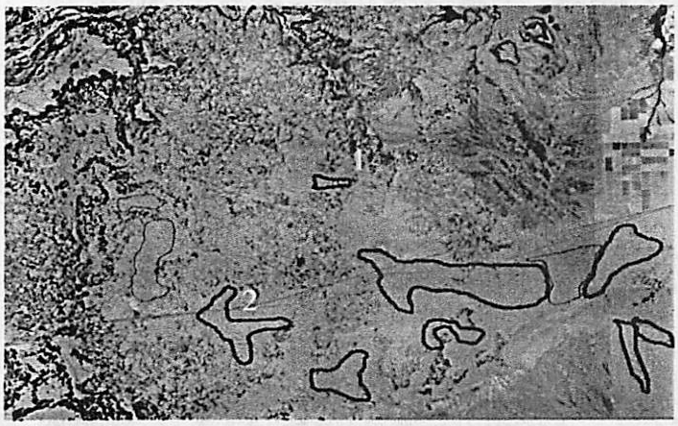


Fig. 2. Area map with locales of stripe features outlined (thick lines). Possible related features outlined in thin lines. Site 1 is main site. Site 2 is shown in Fig. 6.

- ***Scale:***
  - Main site: Dark stripes are **~100m wide** at their centers; separated by ~200m (center to center)
  - Other areas with similar patterns, most dark stripes are thinner (~50m), but roughly the same separation between them.
- ***Locales:*** These stripes appear to be **present in almost all high-albedo areas**, as seen in the aerial photography and Landsat visible data. (Fig. 2)

- ***Topography:*** *very* small vertical relief seen in topography - ? Near resolution limit of data. Dark stripes appear to occur at **topographic highs**. There is some indication that the **stripes "follow" topographic contours** (Fig. 3)

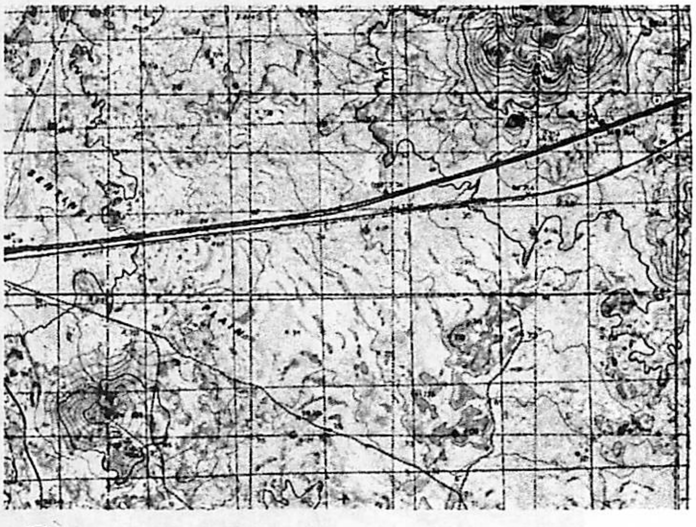


Fig. 3. Topographic map on top of aerial photography. Stripes appear to follow topographic contours. Centered at 32.85°W, 133.15°S. Site 2 marked in Fig. 2. Image is

- ***Landsat:*** Albedo variations seen in visible bands, darker brown alternating with light tan-pink (Fig. 4).
- ***Radar:*** Radar resolution is not high enough to resolve individual stripes, but locales of stripes are **strongly correlated with radar-dark areas** (Fig. 5).
- Other data (Landsat from Jani, magnetic data, gravity data) do not have adequate resolution to resolve these features.

Fig. 4. Landsat visible image. Same location as Fig. 1.

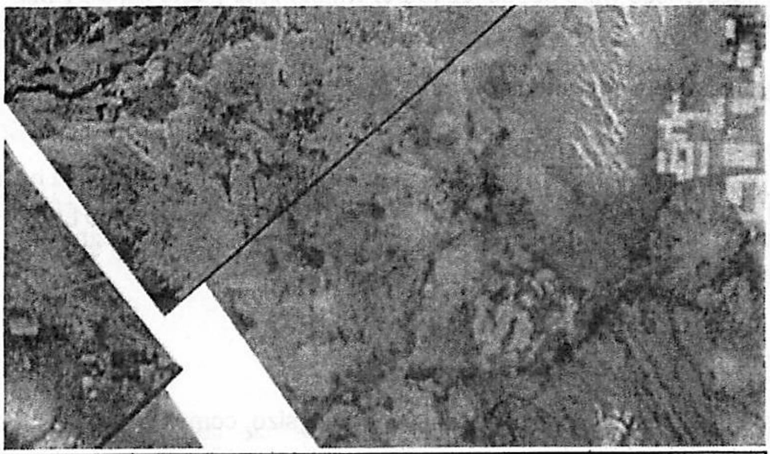


Fig. 5. Radar data. Locations of stripes correlate with radar-dark areas.

Image courtesy of the U.S. Geological Survey

Conclusions

Fig. 6. Closeup of site 2 marked in Fig. 2. All aerial photos are contrast-enhanced.

- Stripes are comp
- Smooth on centimeter scale (or weird electrical properties).
- Process is occurring / has occurred over a wide area, many locations affected similarly within the study area.
- Albedo patterns are probably correlated with small topographic variations; dark stripes are on topographic highs. Alignment of stripes may follow topographic contours.

Hypotheses: (in order of least to most likely)

1. ***Fluvial deposits (ripples)***
    - Ripples of different-albedo substances were deposited under water in the past (climate data indicates H_20 is the main fluid present at planet's surface, but not currently present at these specific locations).
    - Correlated with topography because that controlled water flow.
    - BUT...
        - o Large scale – atypical for fluvial deposits?
        - o The amount of water necessary to form deposits over an extended area wouldn't have been present for a long time (climate data) --> ripples most likely would have been eroded away by now. It's possible that they are very old deposits, recently exhumed.
        - o ==> Not very likely.

2. ***Aeolian features (dunes)***
    - High-albedo sand (?) is forming dunes.
    - Dark stuff might be:
        - o **Darker sand** (different albedo --> different density, particle size, composition?) is being deposited on crests or lees of dunes.
        - o **Vegetation** (atmospheric & climate data indicate presence of oxygen-producing life...) is present at crests, like stabilized dunes. This might explain discrete dark spots, if present.
    - BUT...
        - o Not smooth like dunes, irregular shapes...?
        - o No evidence of a prevailing wind direction.
        - o ==> ... maybe?

3. ***Volcanic features (lava flows)***
    - Dark stripes are tops of lobes formed during viscous flow, e.g. pahoeoe "toes."
    - Explains concentricity, curves, and parallel shapes.
    - *If* they follow topography, that makes sense for flows.
    - Light sand (?) may be filling in topographic lows, leaving crests of darker lava exposed.
    - BUT...
        - o No buts ... ?
        - o ==> Most likely.

Tests:

Remote sensing:

- o High-resolution compositional data
- o Near-IR would distinguish vegetation (radar might, too, if resolution was better?)
- o Shallow subsurface radar might determine what's below top layer (if it's just a thin layer of something covering something else, i.e., case 3) (need high resolution)

Ground truth: Dig!

Sentinel Peak: A Remote Sensing Perspective

David S. Choi

April 2005

1 Introduction

Sentinel Peak is the highest peak located on the Sentinel Plain of central Arizona. It is one of roughly 8 peaks that are found throughout the plain. These peaks are modest features with a relatively gentle slope. Sentinel Peak was observed using the following datasets: Landsat 7 + SRTM (using the NASA WorldWind software package), SAR, USGS Digital Ortho Quadrangles (Aerial Photography), and USGS Topography Maps[1].

2 Landsat 7 + SRTM

Figure 1 shows a Landsat 7 image, integrated with SRTM elevation data and rendered using Worldwind software. Although Sentinel Peak is the highest point in the immediate vicinity, it is dwarfed by other mountains in the distance. The lighter material in true color is a sandy, light brown, while the darker material seen in the image is dark brown/black. Sentinel Peak appears to be dominated by this dark-albedo material. The overall slope of Sentinel Peak appears to be relatively gentle, especially when compared to the other mountains in the distance. Further analysis of the SRTM data shows that the north side of Sentinel Peak has a steep gradient in elevation, contrasted with a shallower gradient on the south side of the feature. When analyzing the dataset in the context of the entire plain, it appears that Sentinel Peak is located at roughly the center of the plain (though slightly offset), and that dark-colored areas surrounding the peak form an arc around it. The darker material in the plain appears to prefer the areas north and west of Sentinel Peak.

3 SAR Radar

Figure 2 shows a portion of a SAR strip taken from space. The resolution is limited, but when taken in the context of the entire Sentinel Plain, Sentinel Peak appears to be dominated by radar-bright material. In fact, it is one of the brighter areas in the radar image for the

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[1] Although the topography/contour maps are compiled using ground data, similar maps could be constructed with the SRTM data. However, this task was made difficult by limited access to and knowledge of GIS software that could handle this task. Besides, to get the topography map provided here, all I had to do was click a button on WorldWind.

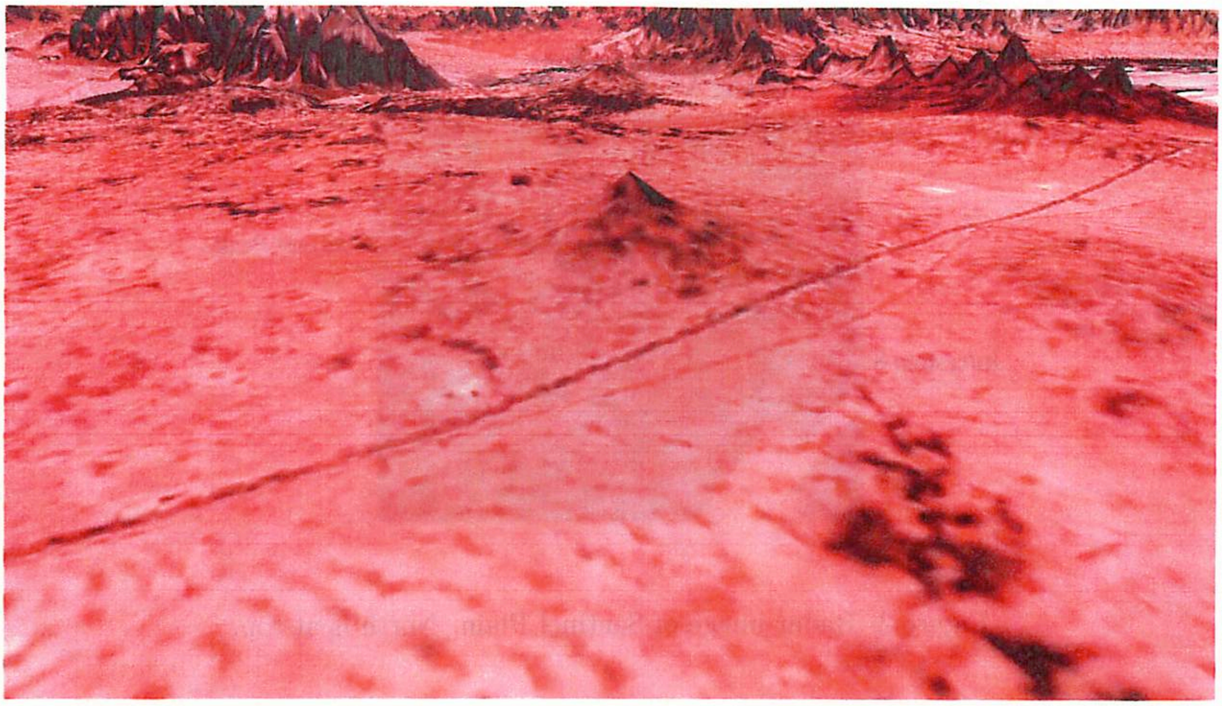

Figure 1: Worldwind screenshot of Sentinel Peak, 7x vertical exaggeration. View is looking to the northeast.

region. There are some small areas near the peak with darker material. When comparing the radar and visible images, it appears that radar-bright areas are correlated with dark areas in the visible Landsat 7 images. Thus, the same rounded appearance that was seen for the dark areas in the Landsat 7 data is seen for the bright areas in the radar data.

4 USGS Digital Ortho

The USGS Digital Ortho aerial photographs have the best resolution of the datasets and the clearest picture of Sentinel Peak. Figure 3 shows that the central area of Sentinel Peak is composed mainly of visibly dark material. Small pockets of brighter material surround the peak, and these pockets are also accompanied by dark material. What appears to be a second peak is located to the north. The areas around the peak appear to have been shaped by some sort of erosion process. The contrast between the light and dark areas here is relatively subdued, especially compared to the contrasts found to the northeast of the peak. Flow channels also appear to meander away from the peak.

5 USGS Topography Maps

The USGS contour maps of Sentinel Peak and Sentinel Plain merely confirm what we have suspected with the topography data—the area overall is characterized by relatively shallow

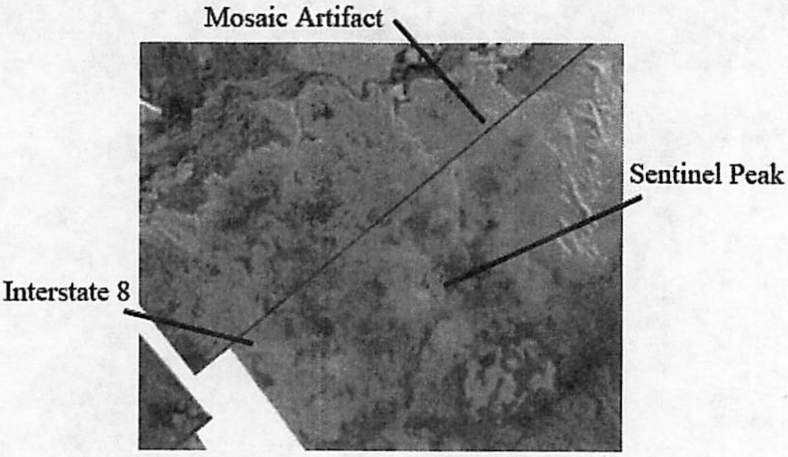

Figure 2: Radar image of Sentinel Plain. North is at top.

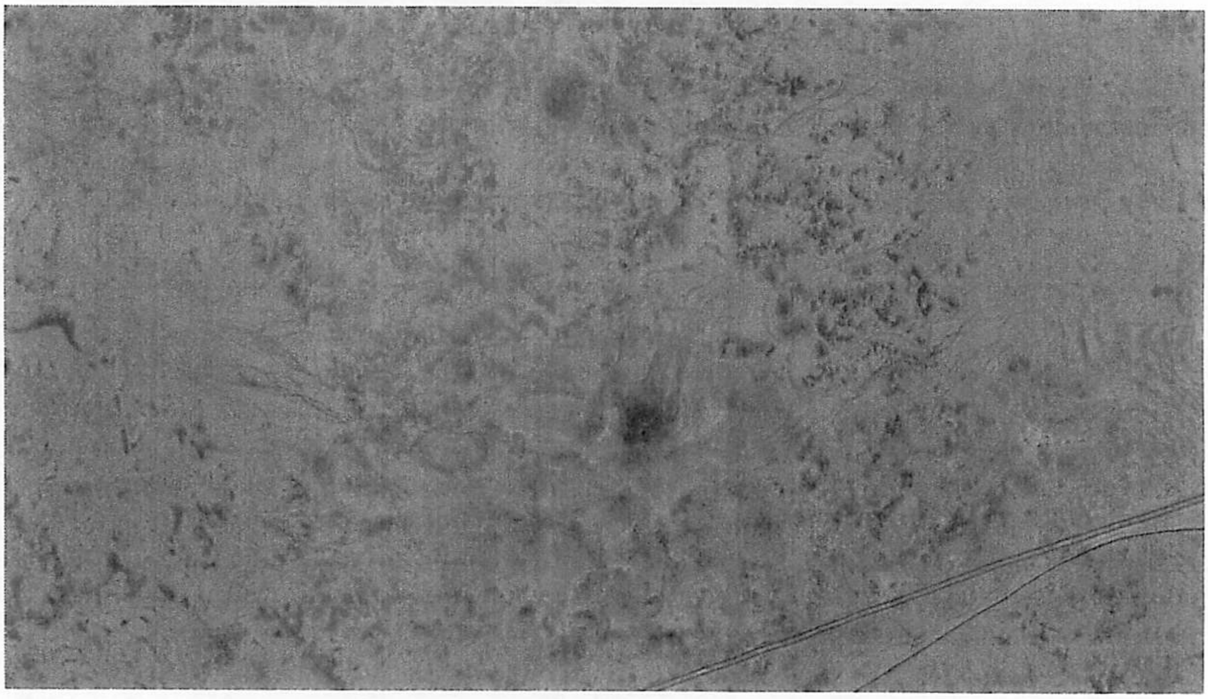

Figure 3: USGS Digital Ortho Image of Sentinel Peak. North is at top.

slopes. Sentinel Peak is measured to be 328 meters above sea level according to this dataset. Also, the contours are somewhat rounded to the northwest of the peak.

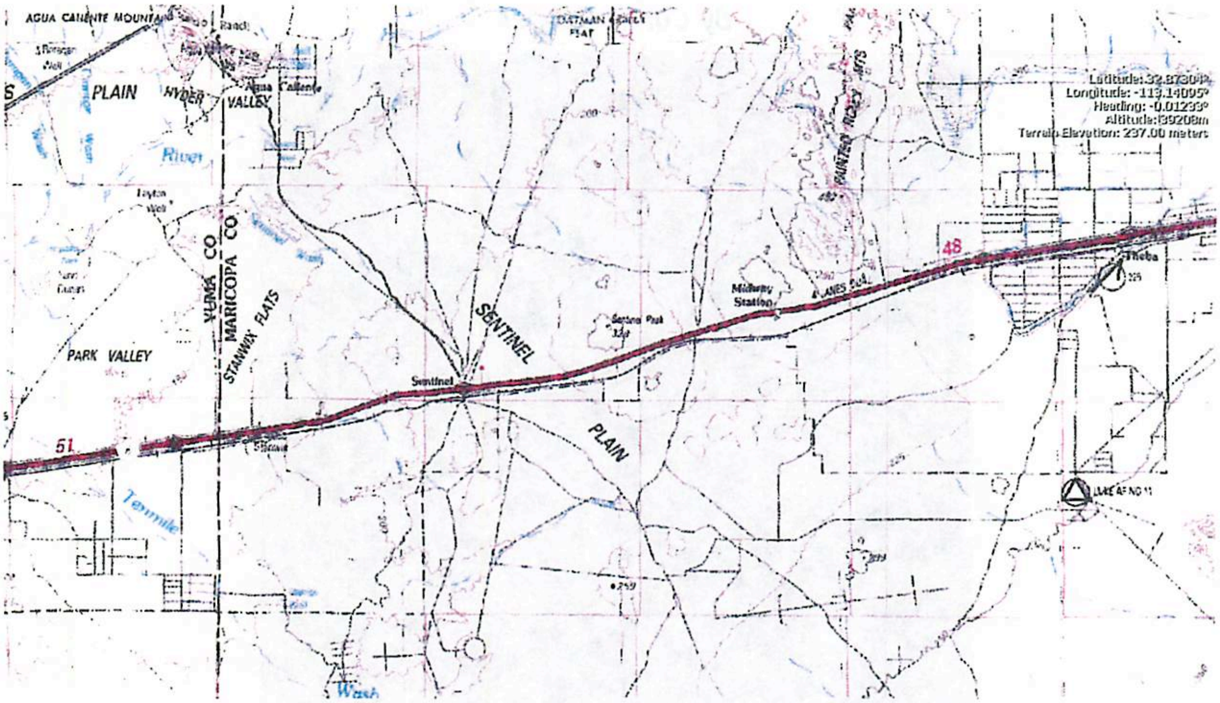

Figure 4: USGS Topography Map of Sentinel Plain. North is at top.

6 Interpretation

Overall, Sentinel Peak is the highest point in an area characterized by visibly dark and radar-bright material. Sentinel Plain itself follows a gentle slope that culminates with the peak. The best interpretation of the data is that Sentinel Peak is a volcanic feature, and that the dark features that form an arc around the peak are lava flows that oozed out of the peak. Because the dark areas are radar bright, it is likely that these lava flows are aa flows that are rough in texture. The aerial photography data provides evidence that the peaks are being shaped by either wind or water erosion. The lava flows are somewhat asymmetrical as they appear to dominate the areas north and west of the peak. This could be a result of erosion of the other lava flows, or a result of the pre-existing topographical gradient that existed before the volcanoes formed.

The Riverbed

By Curtis Cooper

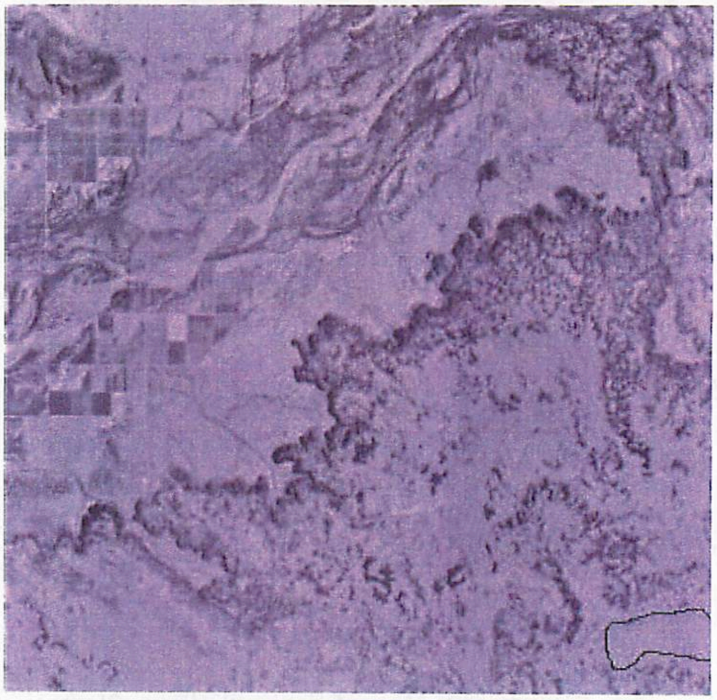

Figure 1: Aerial close-up near riverbed.

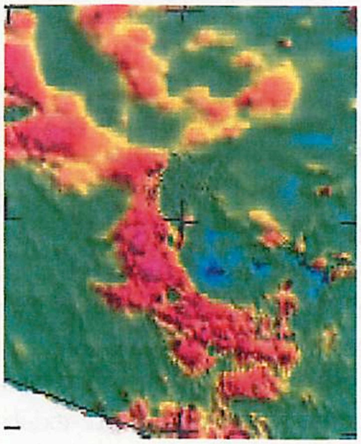

Figure 2: Magnetic close-up in region.

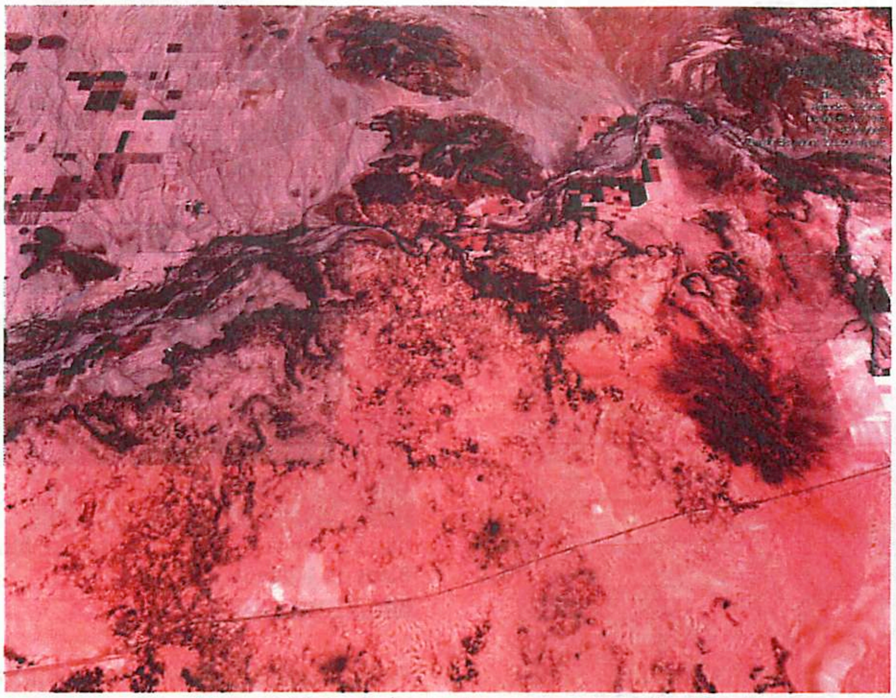

Figure 3: Landsat close-up of region

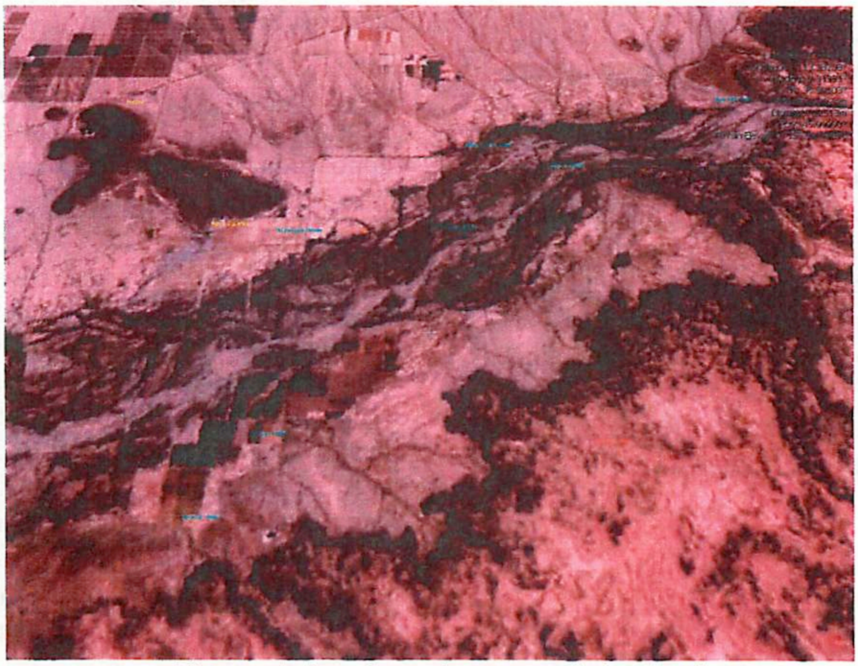

Figure 4: Landsat close-up of riverbed

DARK FLOWS site
Frontage road S of I-8
32.84 N, -113.32 W
Jani "Chill Lava" Radebaugh

Some particularly dark flows with sharp outlines (Fig. 1) are seen in Oleg's DEM mosaic across which the highway has cut; they warrant a field stop because of ease of access and potential scientific interest.

Fig. 1. DEM of dark flow area S of I-8. Notice dark, lobate margins, characteristic of basalt lava flows. Image ~4 km across.

An aerial photo of basalt lava flows on Kilauea, Hawaii (Fig. 2) shows that the most recent lava flows are the darkest (dark tendril-like flows overlie the lighter underlying lava). Fresh lava is emplaced black, then the minerals within the lava begin to break down chemically. In particular, the iron in some minerals oxidizes, changing the minerals to a reddish color, and some other minerals weather to clays. These erosion products are lighter and often more red or brown than the original lava flow.

Fig. 2. Aerial photograph of fresh basalt flows on Kilauea, from http://www.seismo.unr.edu

A dark lava flow with sharp outlines is likely relatively fresh or was emplaced in a region with slow erosion processes (low humidity and rainfall, no other materials covering the flows, such as dunes). We should be able to find some fresh exposures at this outcrop, helping us to identify the composition of the supposed lava flows in this region through analysis of minerals and their percentages in the rocks.

These flows do not show up as different from the rest of the features in the region in the radar-SAR data. This is possibly explained if there is little structural change in the lava flows during the early stages of degradation. Lack of structural change would prevent the flows from looking different in radar-SAR data, since this is primarily a measurement of roughness, or shape, of materials.