DEPARTMENT OF PLANETARY SCIENCES
LUNAR AND PLANETARY LABORATORY
The University of Arizona · Tucson, Arizona 85721

PTYS 594A: Planetary Geology Field Practicum

Baja California II

9 – 13 November 2005

PTYS 594A Fieldtrip Handbook: Baja California
9 - 13 November 2005
Table of Contents

Reference

Presentations

Pre-Trip

Day 1

Day 2

Day 3

Day 4

Cover Picture Credit: NASA/MODIS

Editor's Note --

Graduate students from our noble department last ventured into the Baja Peninsula in the late winter/early spring of 1998. It was a tumultuous year in our world. On the political front, then-President Bill Clinton denied any wrongdoing in the Monica Lewinsky affair. Saddam Hussein negotiated a deal to allow weapons inspectors into his country, preventing military action from the US. On the environmental front, the El Nino produced a devastating ice storm in the Northeast, a tornado outbreak in Florida, and most relevant to our story, wetter than normal conditions in Northwest Mexico. It was this that led to the "Baja incident," where field trip vehicles were stuck in mud for several hours, camp was not reached one night until 1 am, and the department/administration almost cancelled the field trips permanently.

Fast forward to the autumn of 2005. The political landscape remains unsettled -- scandals and controversies plague the current administration while Saddam is currently on trial for his atrocities. The weather landscape is perhaps even more unsettled, as the unprecedented Atlantic hurricane season has fueled the debate on climate change and our effects on the planet. However, one factor has worked in our favor -- the absence of El Nino conditions in the Pacific for the past several months. However, just because the conditions for mud entrapment have evaporated does not necessarily mean a trip without incident. Just ask Moses and SOB Hill, or Brian and the snowbank in N. Arizona. (NB: former incident >> latter incident) Do incidents like these define a field trip? I'm sure Zibi hopes not.

Personally, this is my third fieldtrip out into the field as part of this course, and hopefully nowhere near my last. However, this IS my first time acting as fieldtrip handout editor, and hopefully I won't wind up being fired. (Can you even *be* fired from a voluntary position??) Anyway, here's to another excellent fieldtrip ... observing fascinating geology on the ground and contemplating its connections to the other bodies in our solar system, sharing stories underneath the stars by the campfire, and bonding with your fellow graduate students, postdocs, and faculty members. Hey -- it sure beats sitting on your butt in the mosquito preserve/arctic wasteland that is the LPL grad hallway, right? Let's go!

David Choi, editor
November 2005

Baja California 2005 : Itinerary

Drivers:

5 4WD carryalls (combo of Excursions and Suburbans)
2 2WD carryalls
- Baugh
- Bland, Bond
- Dundas
- Lanagan
- Okubo
- G. Barnes
- Keller

Backup drivers: Radebaugh, Marsh, Turtle, J. Barnes, Jackson, Hattori

1 4WD pick-up
- Daubar, Spitale

Pre-trip Talks:

Gardner: geologic overview of Western N. America
Marsh: geologic overview of Baja, plate tectonic formation, Peninsular ranges
Baugh: remote sensing view (Colorado river delta, shorelines)

Day 1:

7:30 -- depart LPL
(CB -- basin and range)

11:00 -- gas/lunch stop, Yuma
12:00 -- depart Yuma

2:00 -- Stop @ Cerro Prieto visitor center
Cooper: geothermal power
Choi: bubbling mudpots, fumaroles, and geysers

3:00 -- depart Cerro Prieto
(CB -- regional faulting, San Andreas/Laguna Salada fault scarps (1892 quake))
(CB -- Colorado river delta -- compare to Titan & interpret)
(point out alluvial fans)

4:00 Stop @ climbing dune field
Diniega: climbing dunes
4:30 depart climbing dunes

5:30 -- Stop for dinner in San Felipe?
Camp on beach south of San Felipe

Day 2:

7:00 optional swim/longshore current experimentation :)
7:30 talks
Hattori: tides
Donaldson Hanna: long-shore current

8:00 -- depart camp site
Lorenz: CB -- Colorado river tidal bore
8:45 -- get gas in San Felipe (N.B. limited facilities)
9:15-- depart San Felipe

10:45 -- Stop @ Laguna Diablo
Daubar: Laguna Diablo, playas
Palmer: evaporite deposits
(point out SPM)
11:30 -- depart Laguna Diablo
12:30 -- turn off at Colonia Lazaro Cardenas

1:00 -- lunch stop
(spheroidal weathering?)
(Wheelock: bajadas/pediment/alluvial fans)
2:00 -- depart

3:00 -- stop @ dikes
Dundas: San Marcos dike swarm
Bland: Peninsular ranges batholith -- Granite: why it's here and nowhere else
3:30 -- depart

Hays: CB -- Observatory site selection in general and Sierra San Pedro Martir specifically: future TMT &/| LSST, G. Kuiper

6:30 -- camp @ Laguna Figueroa

Day 3:

8:30 -- beach talks
Barnes G.: grain movement, aeolian/subaqueous ripples
Szwast: Fog, marine layer
Minton, Neish: algal mats, stromatolies, microbial scum
Berger: archaean Earth and early life

10:00 -- depart Laguna Figueroa

Gas up in San Quintin

12:00 -- stop beach cliffs
lunch
Bond: spits/bars
Okubo: shorelines/marine terraces
Abramov: sedimentary deposition, conglomerates
1:30 -- depart beach cliffs

3:15 -- Arrive Canon San Fernando
Smith: Chicxulub and the K/T boundary impact, Baja-specific distal effects
Jackson, Keller: K/T landslide deposits (Busby, Yip, et al. 2002)
4:00 -- explore

Fireside discussion about K/T landslide controversy

Day 4:

8:00 -- depart Canon San Fernando
8:45 -- stop @ gullies
Lanagan: gullies

9:15 -- depart
(CB -- Climate and vegetation of Baja California)
12:30 -- arrive San Vicente -- gas/lunch
1:30 -- depart San Vicente

2:15 -- turnoff to Punta San Jose
~3:30 -- Punta San Jose
Sheffer: Ammonites?
Archer: K/T boundary

Day 5:

8:30 -- depart Punta San Jose
9:30 -- N on MEX 1
11:00 -- Ensenada, NE on MEX 3

lunch

1:30 -- cross border in Tecate, E on 8 to 10 to Tucson

Gas stop (Yuma?)
Dinner?

7:30 -- Tucson

MINERAL NAMES

Mineral	Formula
Åkermanite	$Ca_2MgSi_2O_7$
Alabandite	$(Mn,Fe)S$
Albite	$NaAlSi_3O_8$
Andradite	$Ca_3Fe_2Si_3O_{12}$
Anorthite	$CaAl_2Si_2O_8$
Apatite	$Ca_3(PO_4)_2$
Aragonite	$CaCO_3$
Armalcolite	$FeMgTi_2O_5$
Augite	$Mg(Fe,Ca)Si_2O_6$
Awaruite	Ni_3Fe
Baddeleyite	ZrO_2
Barringerite	$(Fe,Ni)_2P$
Bassanite	$CaSO_4\cdot 1/2H_2O$
Bloedite	$Na_2Mg(SO_4)_2\cdot 4H_20$
Brezinaite	Cr_3S_4
Brianite	$CaNa_2Mg(PO_2)$
Buchwaldite	$NaCaPO_4$
Calcite	$CaCO_3$
Carlsbergite	CrN
Caswellsilverite	$NaCrS_2$
Chalcopyrite	$CuFeS_2$
Chamosite	$Fe_6Mg_3[(Si_4O_{10})(OH)_8]_2$
Chaoite	C
Clinopyroxene	$(Ca,Mg,Fe)SiO_3$
Chlorapatite	$Ca_5(PO_4)_3Cl$
Chromite	$FeCr_2O_4$
Cohenite	$(Fe,Ni)_3C$
Copper	Cu
Cordierite	$Mg_2Al_4Si_5O_{18}$
Corundum	Al_2O_3
Cristobalite	SiO_2
Cronstedtite	$(Mg,Fe)_2Al_3Si_5AlO_{18}$
Cubanite	$CuFe_2S_3$
Daubreelite	$FeCr_2S_4$
Diamond	C
Diopside	$CaMgSi_2O_6$
Djerfisherite	$K_3CuFe_{12}S_{14}$
Dolomite	$CaMg(CO_3)_2$
Enstatite	$MgSiO_3$
Epsomite	$MgSO_4\cdot 7H_2O$
Farringtonite	$Mg_3(PO_4)_2$
Fassaite	$Ca(Mg,Ti,Al)(Al,Si)_2O_6$
Fayalite	Fe_2SiO_4
Feldspar solid solution	
albite (Ab)	$NaAlSi_3O_8$
anorthite (An)	$CaAl_2Si_2O_8$
orthoclase (Or)	$KAlSi_3O_8$
Ferrosilite	$FeSiO_3$
Forsterite	Mg_2SiO_4
Gehlenite	$Ca_2Al_2SiO_7$
Gentnerite	$Cu_8Fe_3Cr_{11}S_{18}$
Graftonite	$(Fe,Mn)_3(PO_4)_2$
Graphite	C
Greigite	Fe_3S_4
Grossular	$Ca_3Al_2Si_3O_{12}$
Gypsum	$CaSO_4\cdot 2H_2O$
Haxonite	$Fe_{23}C_6$
Heazlewoodite	Ni_3S_2
Hedenbergite	$CaFeSi_2O_6$
Heideite	$(Fe,Cr)_{1+x}(Ti,Fe)_2S_4$
Hematite	Se_2O_3
Hercynite	$(Fe,Mg)Al_2O_4$
Hibonite	$CaAl_{12}O_{19}$
Ilmenite	$FeTiO_3$
Kaersutite	$Ca_2(Na,K)(Mg,Fe)_4TiSi_6Al_2O_{22}F_2$
Kamacite	α-(Fe,Ni)
Krinovite	$NaMg_2CrSi_3O_{10}$
Lawrencite	$(Fe,Ni)Cl_2$
Lonsdaleite	C
Mackinawite	FeS_{1-x}
Maghemite	Se_2O_3
Magnesiochromite	$MgCr_2O_4$
Magnesite	$(Mg,Fe)CO_3$
Magnetite	Fe_3O_4
Majorite	$Mg_3(MgSi)Si_3O_{12}$
Marcasite	FeS_2
Melilite solid solution	
åkermanite (Ak)	$Ca_2MgSi_2O_7$
gehlenite (Ge)	$Ca_2Al_2SiO_7$
Merrihueite	$(K,Na)_2Fe_5Si_{12}O_{30}$
Merrillite	$Ca_9MgH(PO_4)_7$
Mica	$(K,Na,Ca)_2Al_4[Si_6Al_2O_{20}](OH,F)_4$
Molybdenite	MoS_2
Monticellite	$Ca(Mg,Fe)SiO_4$
Montmorillonite	$Al_4(Si,Al)_8O_{20}(OH)_4Mg_6(Si,Al)_8O_{20}(OH)_4$
Nepheline	$NaAlSiO_4$
Niningerite	$(Mg,Fe)S$
Oldhamite	CaS
Olivine	$(Mg,Fe)_2SiO_4$
Olivine solid solution	
fayalite (Fa)	Fe_2SiO_4
forsterite (Fo)	Mg_2SiO_4
Orthoclase	$KAlSi_3O_8$
Orthopyroxene	$(Mg,Fe)SiO_3$
Osbornite	TiN
Panethite	$(Ca,Na)_2(Mg,Fe)_2(PO_4)_2$
Pentlandite	$(Fe,Ni)_9S_8$
Perovskite	$CaTiO_3$
Perryite	$(Ni,Fe)_5(Si,P)_2$
Pigeonite	$(Fe,Mg,Ca)SiO_3$
Plagioclase	
albite	$NaAlSi_3O_8$
anorthite	$CaAl_2Si_2O_8$
Portlandite	$Ca(OH)_2$
Potash feldspar	$(K,Na)AlSi_3O_8$
Pyrite	FeS_2
Pyrope	$Mg_3Al_2(SiO_4)_3$
Pyroxene solid solution	
enstatite (En)	$MgSiO_3$
ferrosilite (Fs)	$FeSiO_3$
wollastonite (Wo)	$CaSiO_3$
Pyrrhotite	$Fe_{1-x}S$
Quartz	SiO_2
Rhönite	$Ca_4(Mg,Al,Ti)_{12}(Si,Al)_{12}O_{40}$
Richterite	$Na_2CaMg_5Si_8O_{22}F_2$
Ringwoodite	$(Mg,Fe)_2SiO_4$
Roaldite	$(Fe,Ni)_4N$

MINERAL NAMES *continued*

Mineral	Formula	Mineral	Formula
Roedderite	$(K,Na)_2Mg_5Si_{12}O_{30}$	Stanfieldite	$Ca_4(Mg,Fe)_5(PO_4)_6$
Rutile	TiO_2	Suessite	Fe_3Si
Sanidine	$KAlSi_3O_8$	Sulfur	S
Sarcopside	$(Fe,Mn)_3(PO_4)_2$	Taenite	γ-(Fe,Ni)
Scheelite	$CaWO_4$	Tetrataenite	$FeNi$
Schöllhornite	$Na_{0.3}(H_2O)\ [CrS_2]$	Thorianite	ThO_2
Schreibersite	$(Fe,Ni)_3P$	Tridymite	SiO_2
Serpentine (or chlorite)	$(Mg,Fe)_6Si_4O_{10}(OH)_8$	Troilite	FeS
Sinoite	Si_2N_2O	Ureyite	$NaCrSi_2O_6$
Smythite	Fe_9S_{11}	V-rich magnetite	$(Fe,Mg)(Al,V)_2O_4$
Sodalite	$Na_8Al_6Si_6O_{24}Cl_2$	Valleriite	$CuFeS_2$
Sphalerite	$(Zn,Fe)S$	Vaterite	$CaCO_3$
Spinel	$MgAl_2O_4$	Whewellite	$CaC_2O_4\cdot H_2O$
Spinel Solid Solution		Wollastonite	$CaSiO_3$
spinel	$MgAl_2O_4$	Yagiite	$(K,Na)_2(Mg,Al)_5(Si,Al)_{12}O_{30}$
hercynite	$FeAl_2O_4$	Zircon	$ZrSiO_4$
chromite	$FeCr_2O_4$		
magnesiochromite	$MgCr_2O_4$		
V-rich magnetite	$(Fe,Mg)(Al,V)_2O_4$		

"Meteorites & The Early Solar System" Kerridge & Matthews, ed.
U of A Press (1988).

Uniform Time Scale
0
PHANEROZOIC
575
PRECAMBRIAN
~4,650

Subdivisions Based on Strata/*Time*				Radiometric Dates (millions of years ago)	Outstanding Events	
		Systems/*Periods*	Series/*Epochs*		In Physical History	In Evolution of Living Things
				0		
PHANEROZOIC	CENZOIC	Quaternary	Recent or Holocene Pleistocene	2?	Several glacial ages Making of the Great Lakes; Missouri and Ohio Rivers	*Homo sapiens*
		Tertiary	Pliocene	6		Later hominids
			Miocene	22	Beginning of Colorado River Creation of mountain ranges and basins in Nevada	Primitive hominids Grasses; grazing mammals
			Oligocene	36		
			Eocene	58	Beginning of volcanic activity at Yellowstone Park	Primitive horses
			Paleocene	65	Beginning of making of Rocky Mountains	Spreading of mammals
	MESOZOIC	Cretaceous	Many	145	Beginning of lower Mississippi River	Dinosaurs extinct Flowering plants Climax of dinosaurs
		Jurassic		210		Birds
		Triassic		250	Beginning of Atlantic Ocean	Conifers, cycads, primitive mammals Dinosaurs
	PALEOZOIC	Permian		290	Climax of making of Appalachian Mountains	Mammal-like reptiles
		Pennsylvanian (Upper Carboniferous)		340		Coal forests, insects, amphibians, reptiles
		Mississippian (Lower Carboniferous)		365		Amphibians
		Devonian		415	Earliest economic coal deposits	
		Silurian		465		Land plants and land animals
		Ordovician		510	Beginning of making of Appalachian Mountains	Primitive fishes
		Cambrian		575	Earliest oil and gas fields	Marine animals abundant
PRECAMBRIAN (Mainly igneous and metamorphic rocks; no worldwide subdivisions.)				1,000 2,000 3,000	Oldest dated rocks	Primitive marine animals Green algae Bacteria, blue-green algae
Birth of Planet Earth				4,650		

Flint & Skinner, "Physical Geology"
2 ed (1977)

TABLE 7-3 Classification of Chemical and Biochemical Sedimentary Rocks

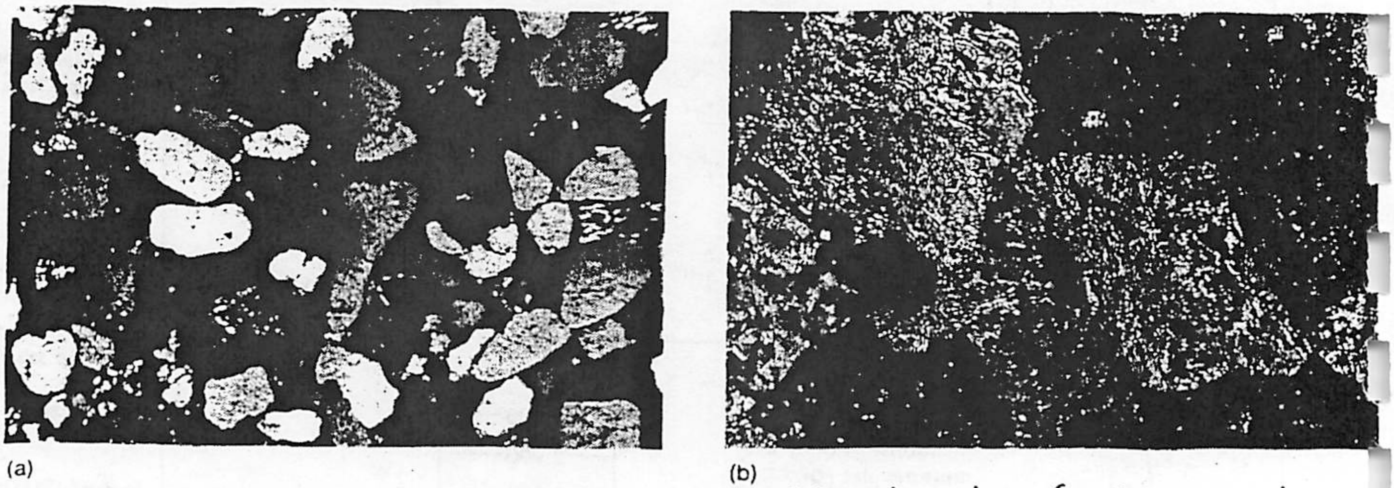
Texture	Composition	Rock Name	
Clastic or crystalline	Calcite ($CaCO_3$)	Limestone (includes coquina, chalk, and oolitic limestone)	Carbonates
	Dolomite [$CaMg(CO_3)_2$]	Dolostone	
Crystalline	Gypsum ($CaSO_4 \cdot 2H_2O$)	Rock gypsum	Evaporites
	Halite (NaCl)	Rock salt	
Usually crystalline	Microscopic SiO_2 shells	Chert	
—	Altered plant remains	Coal	

TABLE 7-2 Classification of Detrital Sedimentary Rocks

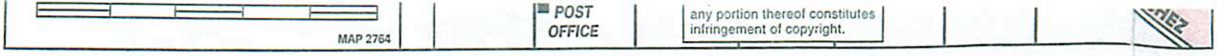
Sediment Name and Size	Description	Rock Name	
Gravel (>2 mm)	Rounded gravel	Conglomerate	
	Angular gravel	Sedimentary breccia	
Sand (1/16–2 mm)	Mostly quartz	Quartz sandstone	
	Quartz with >25% feldspar	Arkose	
Mud (<1/16 mm)	Mostly silt	Siltstone	Mudrocks
	Silt and clay	Mudstone*	
	Mostly clay	Claystone*	

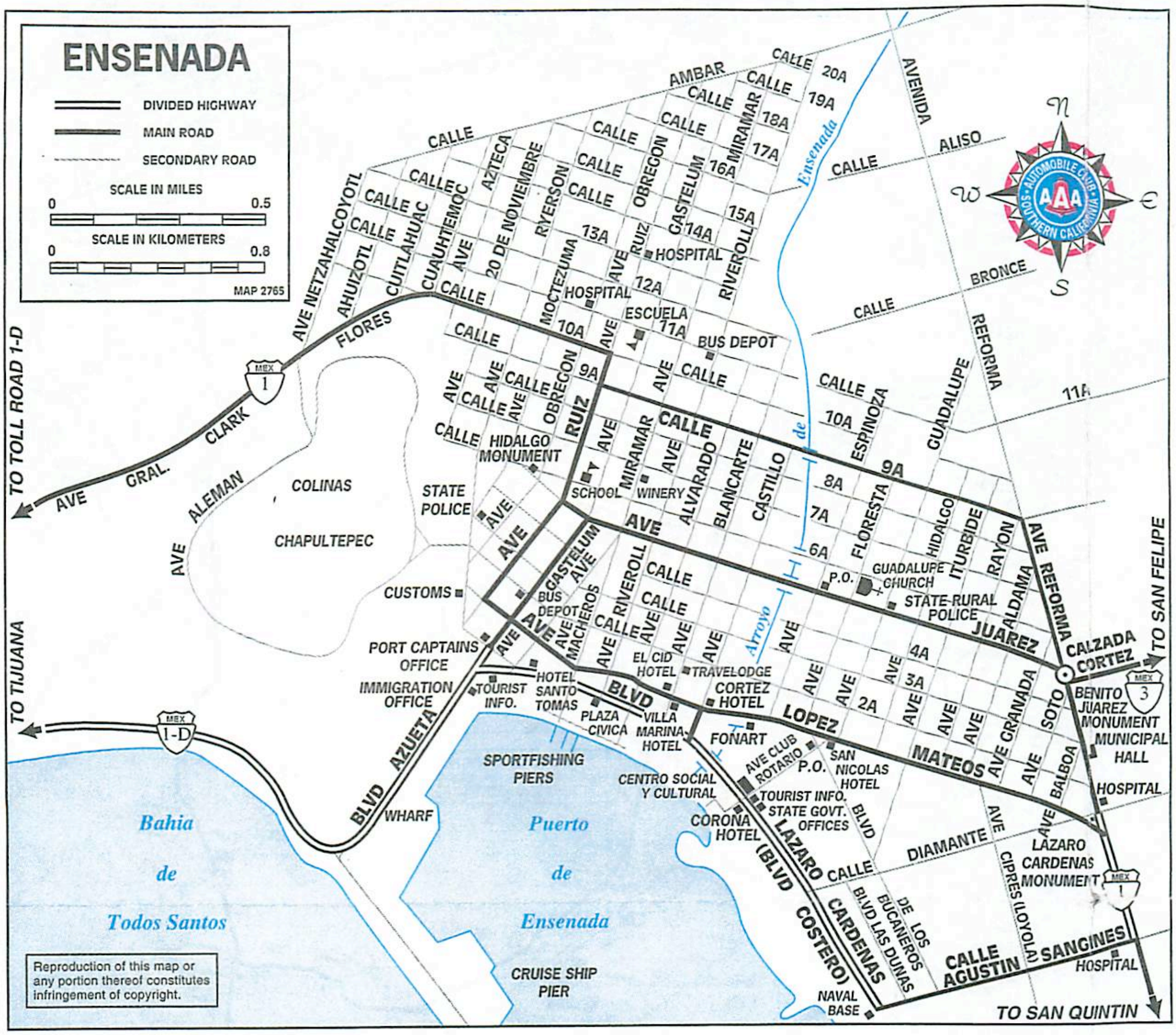
*Mudrocks possessing the property of fissility, meaning they break along closely spaced, parallel planes, are commonly called *shale*.

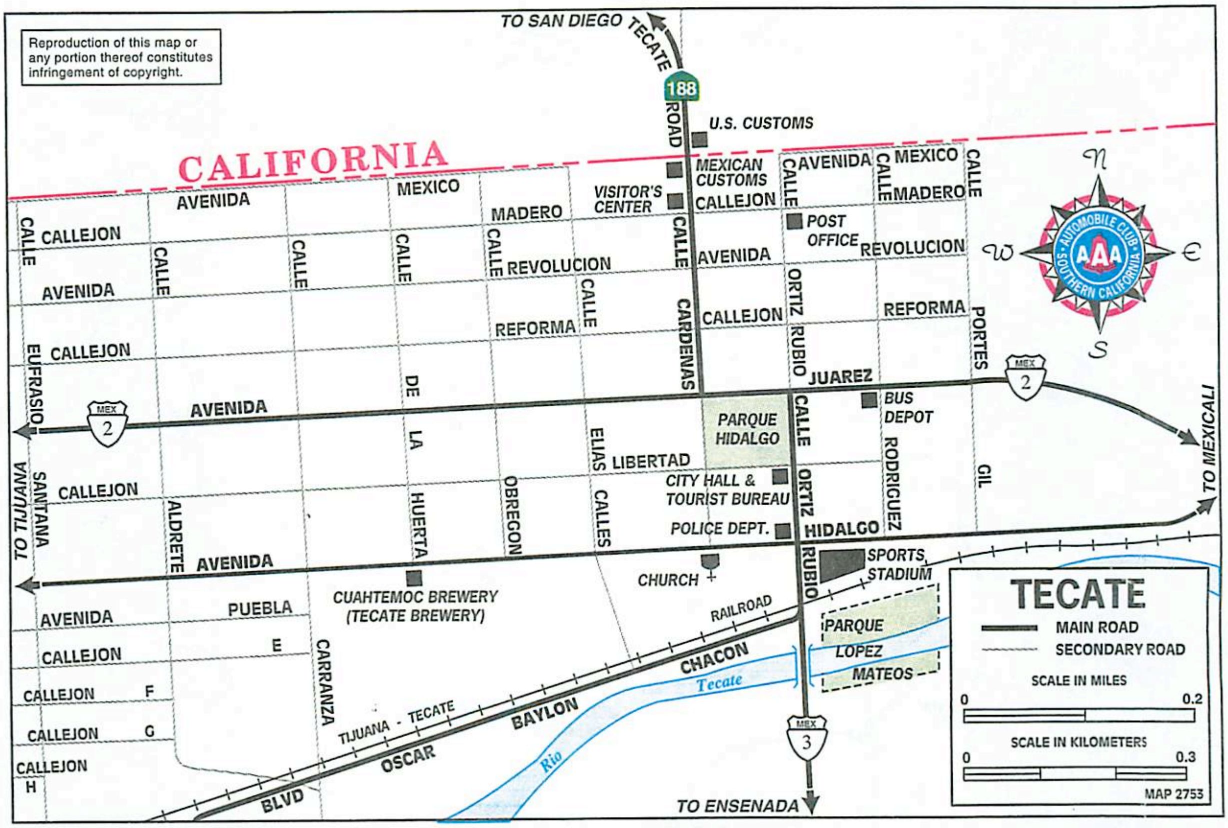
FIGURE 7-9 (*a*) Photomicrograph of a sandstone showing a clastic texture consisting of fragments of minerals, mostly quartz in this case. (*b*) Photomicrograph of the crystalline texture of a limestone showing a mosaic of calcite crystals.

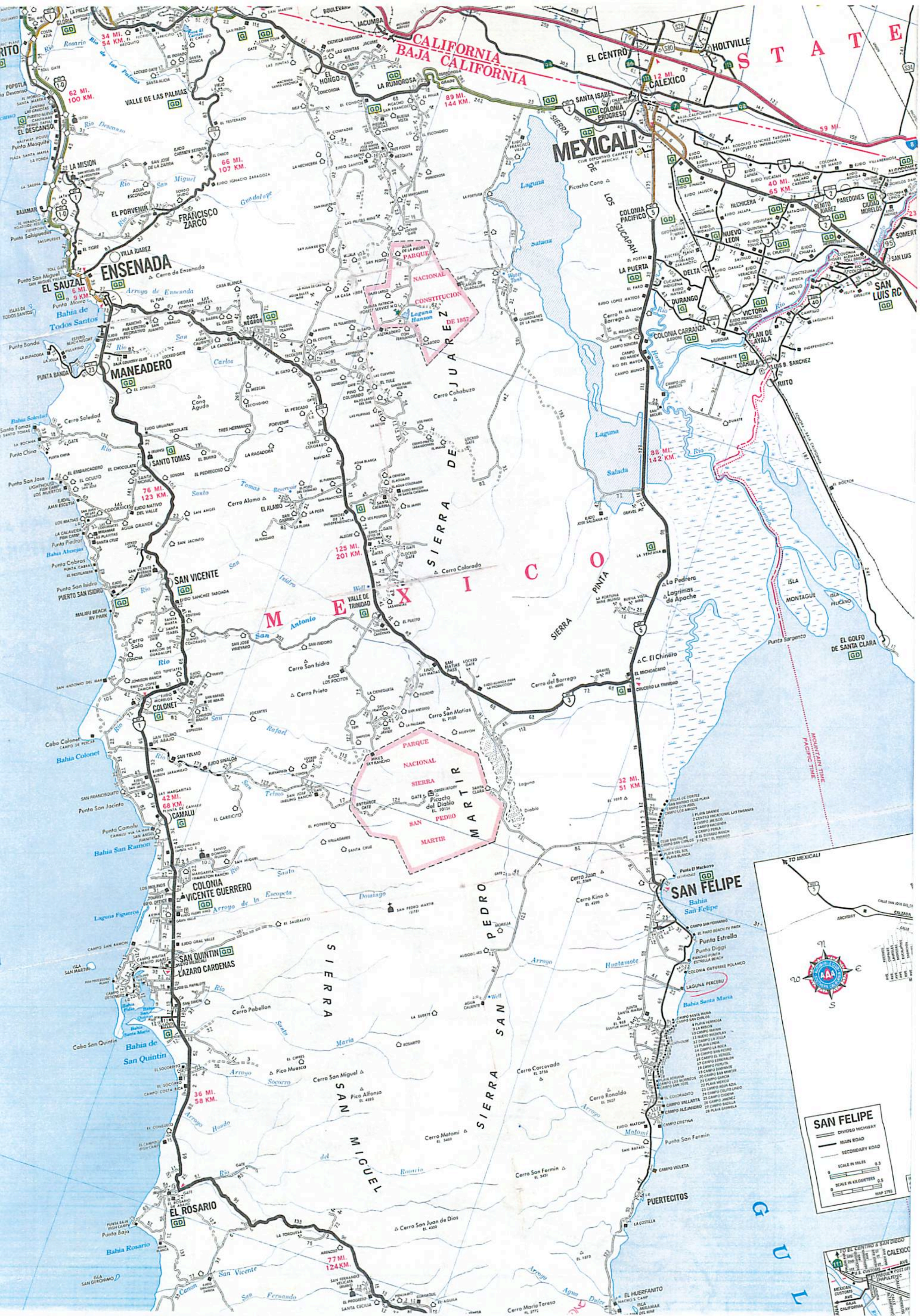


Physical Geology
Monroe + Wicander (199

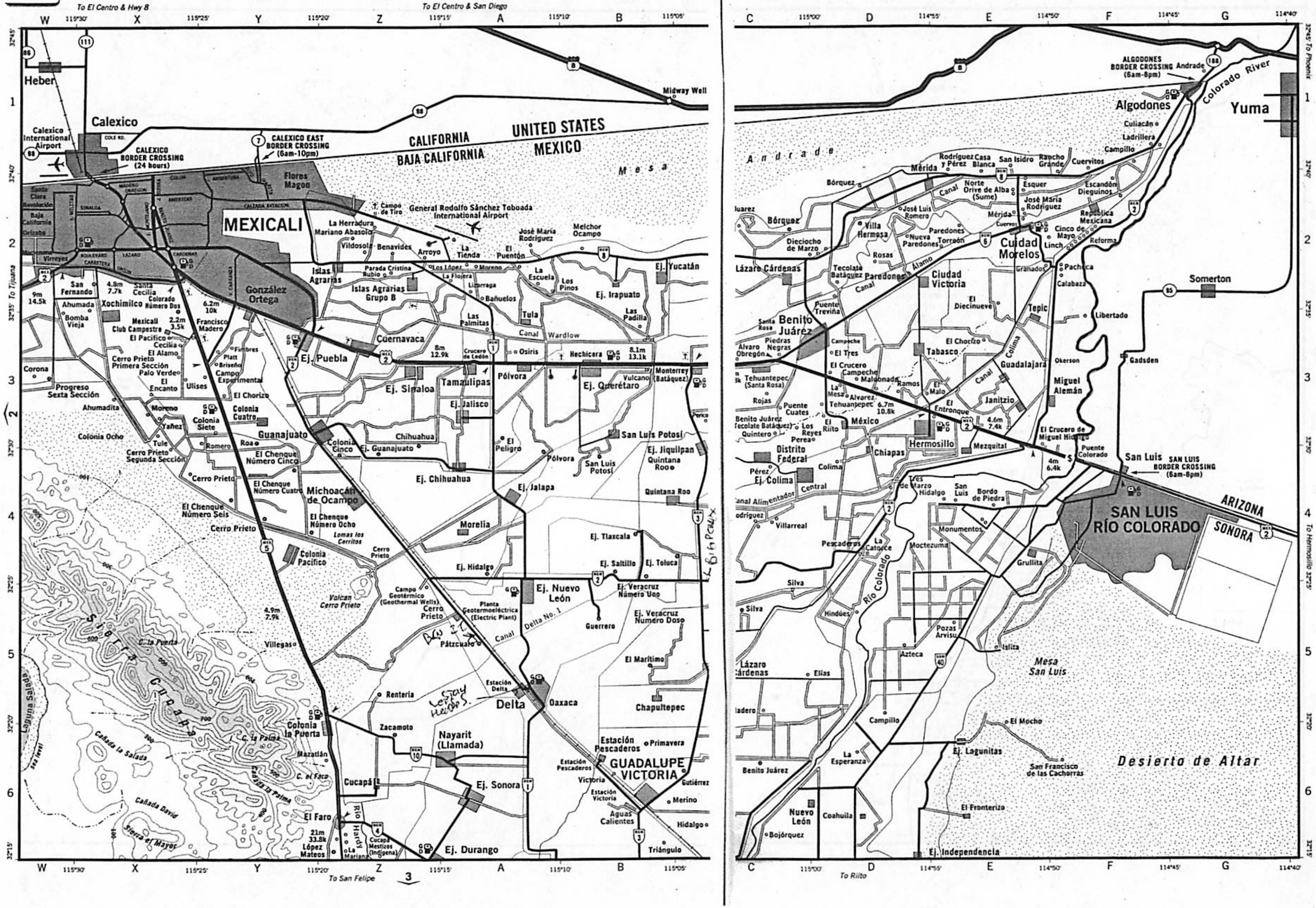

MAP 2764
POST OFFICE
any portion thereof constitutes infringement of copyright.

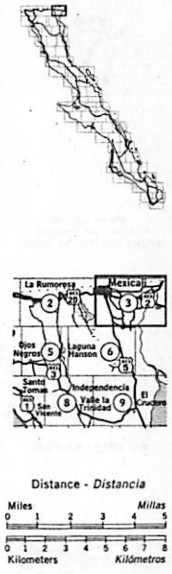

ENSENADA
DIVIDED HIGHWAY
MAIN ROAD
SECONDARY ROAD
SCALE IN MILES
0
0.5
SCALE IN KILOMETERS
0
0.8
MAP 2765
N
W
E
S
AUTOMOBILE CLUB SOUTHERN CALIFORNIA
AAA
TO TOLL ROAD 1-D
TO TIJUANA
AVE GRAL. CLARK FLORES
MEX 1
MEX 1-D
AVE NETZAHALCOYOTL
AHUIZOTL
CUITLAHUAC
CUAUHTEMOC
AZTECA
20 DE NOVIEMBRE
RYERSON
MOCTEZUMA
OBREGON
RUIZ
CASTELUM
MIRAMAR
RIVEROLL
AMBAR
CALLE 20A
CALLE 19A
CALLE 18A
CALLE 17A
CALLE 16A
CALLE 15A
CALLE 14A
CALLE 13A
CALLE 12A
CALLE 11A
CALLE 10A
CALLE 9A
CALLE 8A
7A
6A
4A
3A
2A
HOSPITAL
ESCUELA
BUS DEPOT
AVENIDA
ALISO
BRONCE
REFORMA
GUADALUPE
ESPINOZA
Arroyo de Ensenada
AVE ALEMAN
COLINAS
CHAPULTEPEC
STATE POLICE
HIDALGO MONUMENT
SCHOOL
WINERY
ALVARADO
BLANCARTE
CASTILLO
FLORESTA
HIDALGO
ITURBIDE
RAYON
ALDAMA
AVE REFORMA
CUSTOMS
BUS DEPOT
MACHEROS
P.O.
GUADALUPE CHURCH
STATE-RURAL POLICE
JUAREZ
CALZADA CORTEZ
TO SAN FELIPE
MEX 3
BENITO JUAREZ MONUMENT
MUNICIPAL HALL
PORT CAPTAINS OFFICE
IMMIGRATION OFFICE
TOURIST INFO.
HOTEL SANTO TOMAS
EL CID HOTEL
TRAVELODGE
CORTEZ HOTEL
PLAZA CIVICA
VILLA MARINA HOTEL
BLVD
LOPEZ MATEOS
FONART
AVE CLUB ROTARIO
P.O.
SAN NICOLAS HOTEL
GRANADA
SOTO
BALBOA
HOSPITAL
SPORTFISHING PIERS
CENTRO SOCIAL Y CULTURAL
TOURIST INFO. STATE GOVT. OFFICES
CORONA HOTEL
BLVD AZUETA
WHARF
Bahia de Todos Santos
Puerto de Ensenada
CRUISE SHIP PIER
BLVD LAZARO CARDENAS (BLVD COSTERO)
CALLE DIAMANTE
AVE CIPRES (LOYOLA)
LAZARO CARDENAS MONUMENT
MEX 1
DE LOS BUCANEROS
BLVD LAS DUNAS
CALLE AGUSTIN SANGINES
HOSPITAL
NAVAL BASE
TO SAN QUINTIN
Reproduction of this map or any portion thereof constitutes infringement of copyright.


Reproduction of this map or any portion thereof constitutes infringement of copyright.
TO SAN DIEGO
TECATE ROAD
188
U.S. CUSTOMS
CALIFORNIA
MEXICAN CUSTOMS
VISITOR'S CENTER
AVENIDA MEXICO
CALLE MADERO
CALLEJON MADERO
POST OFFICE
AVENIDA REVOLUCION
CALLEJON REFORMA
AVENIDA REFORMA
CALLE CARDENAS
ORTIZ RUBIO
PORTES
AVENIDA JUAREZ
EUFRASIO SANTANA
MEX 2
PARQUE HIDALGO
BUS DEPOT
DE LA HUERTA
ELIAS CALLES
CALLEJON LIBERTAD
CITY HALL & TOURIST BUREAU
POLICE DEPT.
RODRIGUEZ
GIL
OBREGON
ALDRETE
AVENIDA HIDALGO
TO TIJUANA
TO MEXICALI
SPORTS STADIUM
CHURCH
CUAHTEMOC BREWERY (TECATE BREWERY)
RAILROAD
AVENIDA PUEBLA
CALLEJON E
CALLEJON F
CALLEJON G
CALLEJON H
CARRANZA
PARQUE LOPEZ MATEOS
CHACON
Rio Tecate
TIJUANA - TECATE
BLVD OSCAR BAYLON
MEX 3
TO ENSENADA
TECATE
MAIN ROAD
SECONDARY ROAD
SCALE IN MILES
0
0.2
SCALE IN KILOMETERS
0
0.3
MAP 2753
N
W
E
S
AUTOMOBILE CLUB SOUTHERN CALIFORNIA
AAA


CALIFORNIA
BAJA CALIFORNIA
STATE
MEXICO
GU
EL CENTRO
HOLTVILLE
CALEXICO
12 MI. 19 KM.
JACUMBA
LA RUMOROSA
89 MI. 144 KM.
EL HONGO
SANTA ISABEL
COLONIA PROGRESO
MEXICALI
59 MI.
40 MI. 65 KM.
SAN LUIS RC
BENITO JUAREZ
PAREDONES
CIUDAD MORELOS
NUEVO LEON
DELTA
VICTORIA
DURANGO
PLAN DE AYALA
LUIS B. SANCHEZ
COAHUILA
RIITO
COLONIA CARRANZA
LA PUERTA
COLONIA PACIFICO
Laguna Salada
SIERRA DE LOS CUCAPAH
88 MI. 142 KM.
Rio Colorado
ISLA MONTAGUE
ISLA PELICANO
Punta Sargento
EL GOLFO DE SANTA CLARA
MOUNTAIN TIME
PACIFIC TIME
SIERRA PINTA
La Pedrera
Lagrimas de Apache
C. El Chinero
EL MICHOACANO
CRUCERO LA TRINIDAD
34 MI. 54 KM.
62 MI. 100 KM.
66 MI. 107 KM.
VALLE DE LAS PALMAS
EL DESCANSO
LA MISION
EL PORVENIR
FRANCISCO ZARCO
Rio Guadalupe
ENSENADA
EL SAUZAL
6 MI. 9 KM.
Bahia de Todos Santos
Punta Banda
MANEADERO
OJOS NEGROS
PARQUE NACIONAL CONSTITUCION DE 1857
Laguna Hanson
SIERRA DE JUAREZ
Cerro Cohabuzo
SANTO TOMAS
76 MI. 123 KM.
SANTA CATARINA
EL ALAMO
Cerro Alamo
ERENDIRA
SAN VICENTE
125 MI. 201 KM.
VALLE DE TRINIDAD
Cerro Colorado
SAN MATIAS PASS
Cerro del Barrego
COLONET
Bahia Colonet
SAN TELMO
PARQUE NACIONAL SIERRA SAN PEDRO MARTIR
Picacho del Diablo
OBSERVATORY
SIERRA SAN PEDRO MARTIR
42 MI. 68 KM.
CAMALU
COLONIA VICENTE GUERRERO
SAN QUINTIN
LAZARO CARDENAS
Bahia de San Quintin
Cabo San Quintin
SIERRA SAN MIGUEL
Cerro San Miguel
Pico Alfonso
Pico Muesca
36 MI. 58 KM.
EL ROSARIO
Bahia Rosario
Punta Baja
77 MI. 124 KM.
32 MI. 51 KM.
SAN FELIPE
Bahia San Felipe
Punta Estrella
Punta Diggs
Cerro Juan
Cerro Kino
Cerro Corcovado
Cerro Ronaldo
Cerro Matomi
Cerro San Fermin
Punta San Fermin
PUERTECITOS
Cerro San Juan de Dios
EL HUERFANITO
TO MEXICALI
CALLE SAN JOSE GUL
ARCHWAY
CALZADA
N
E
S
W
SAN FELIPE
DIVIDED HIGHWAY
MAIN ROAD
SECONDARY ROAD
SCALE IN MILES 0 0.3
SCALE IN KILOMETERS 0 0.5
MAP 2751
TO EL CENTRO & SAN DIEGO
CALEXICO

Mexicali
Calexico
Algodones

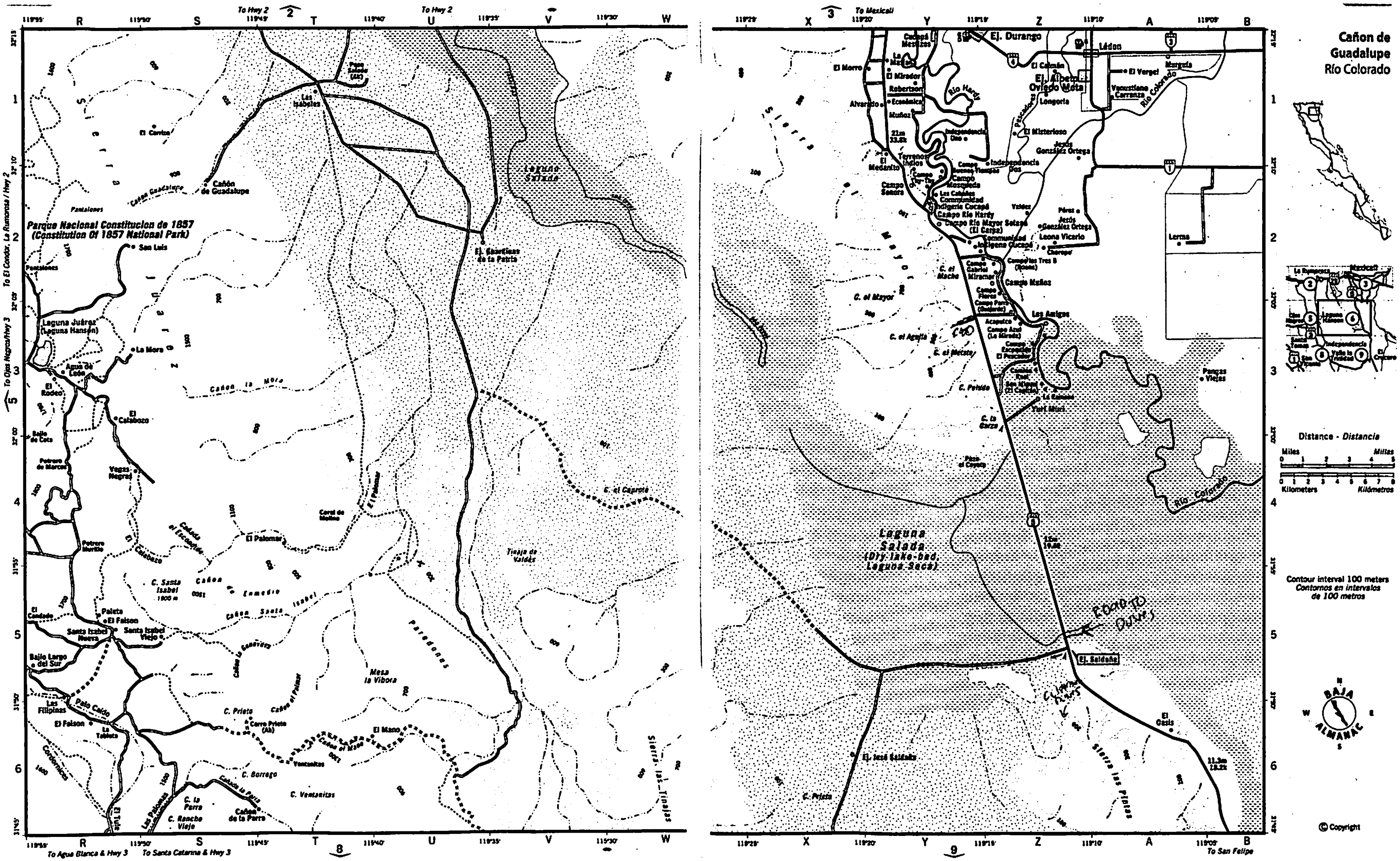




Contour interval 100 meters
Contornos en intervalos de 100 metros

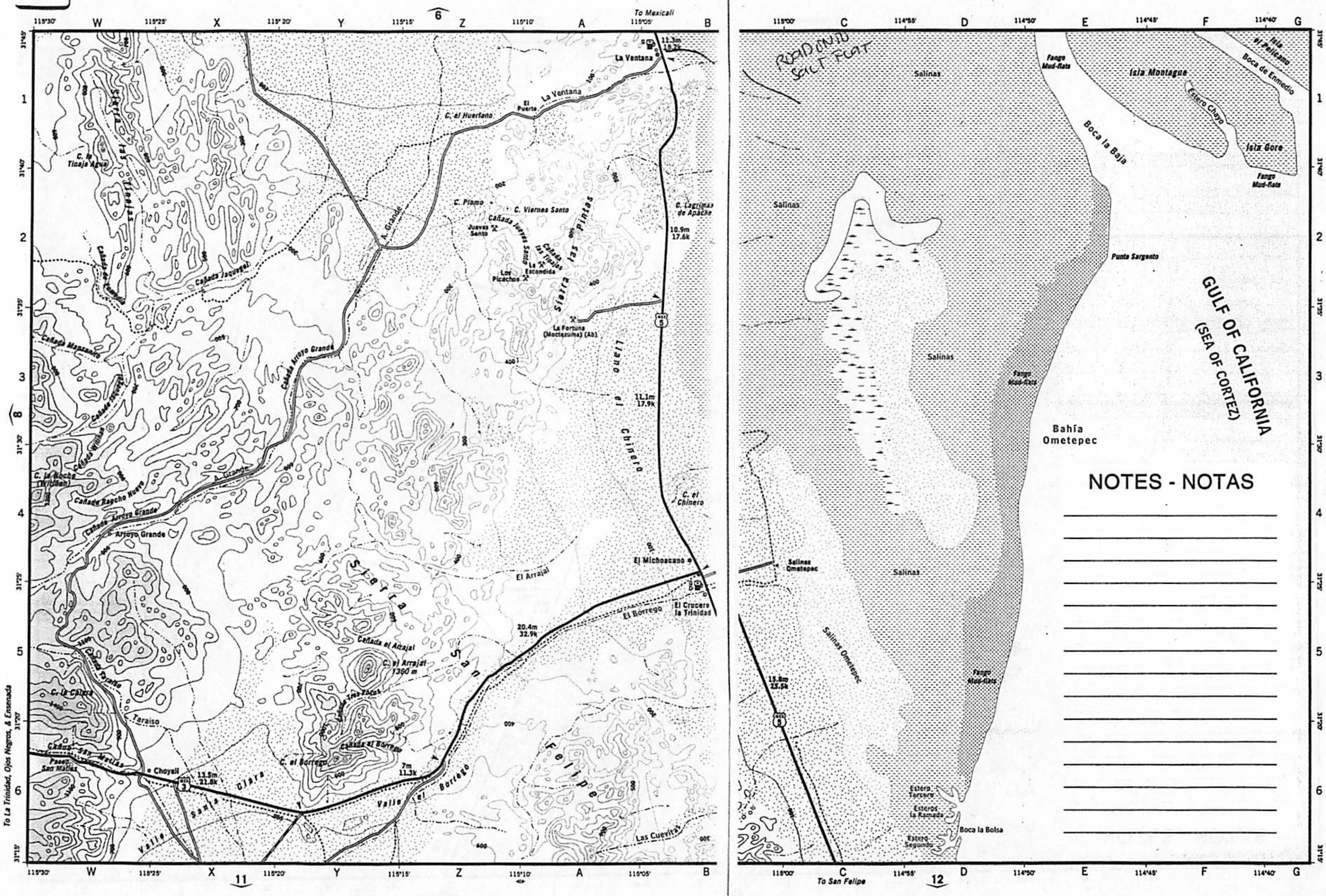
BAJA ALMANAC

Cañon de Guadalupe
Río Colorado



Contour interval 100 meters
Contornos en intervalos de 100 metros

© Copyright



ROAD UNTIL SALT FLAT

NOTES - NOTAS

____

____

____

____

____

____

____

____

____

____

____

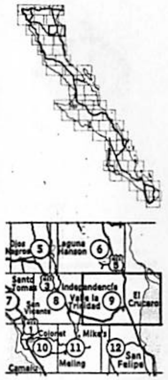
____

____

____

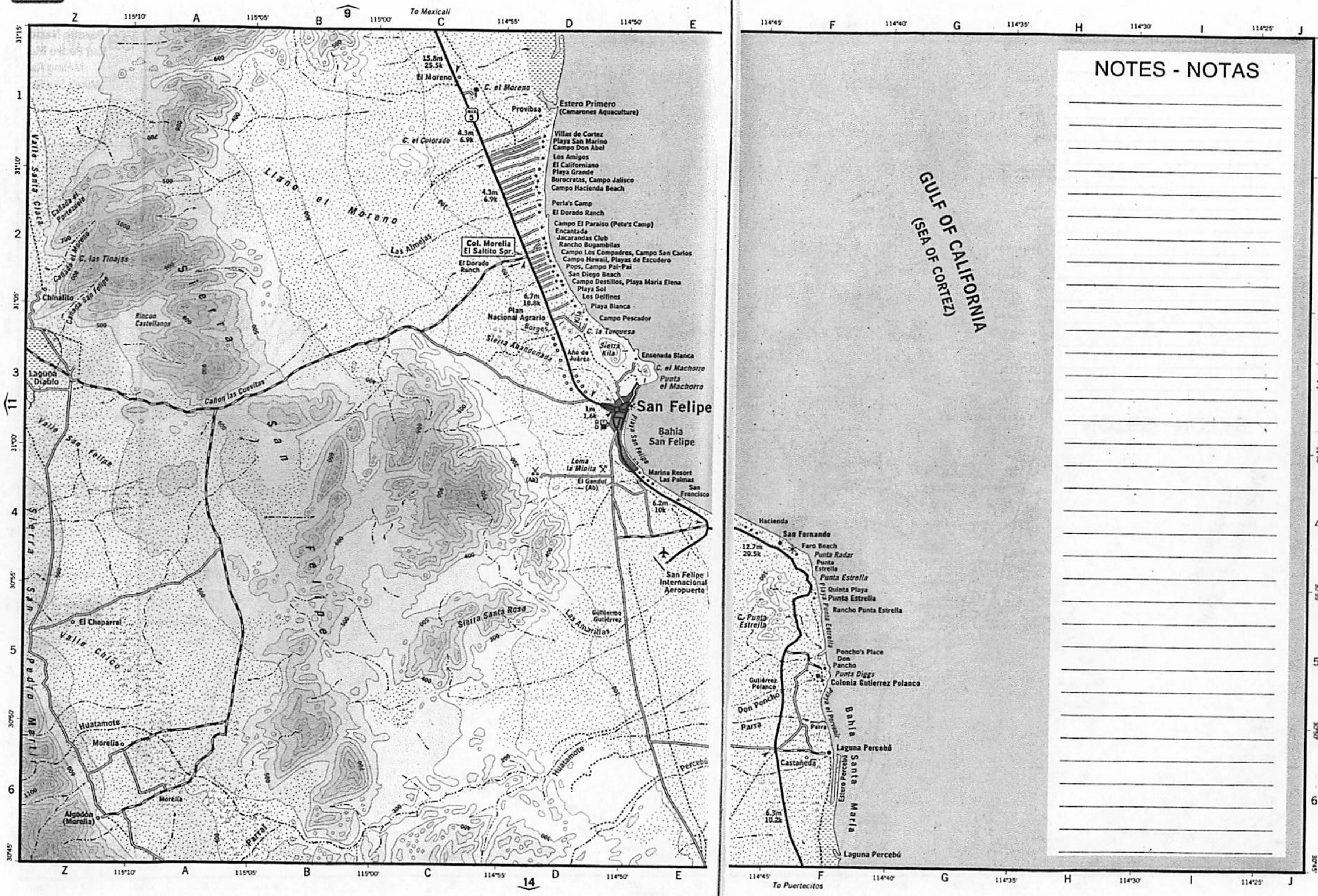
____

Llano el Chinero
La Ventana
Paseo San Matias



Distance - *Distancia*

Contour interval 100 meters
Contornos en intervalos de 100 metros



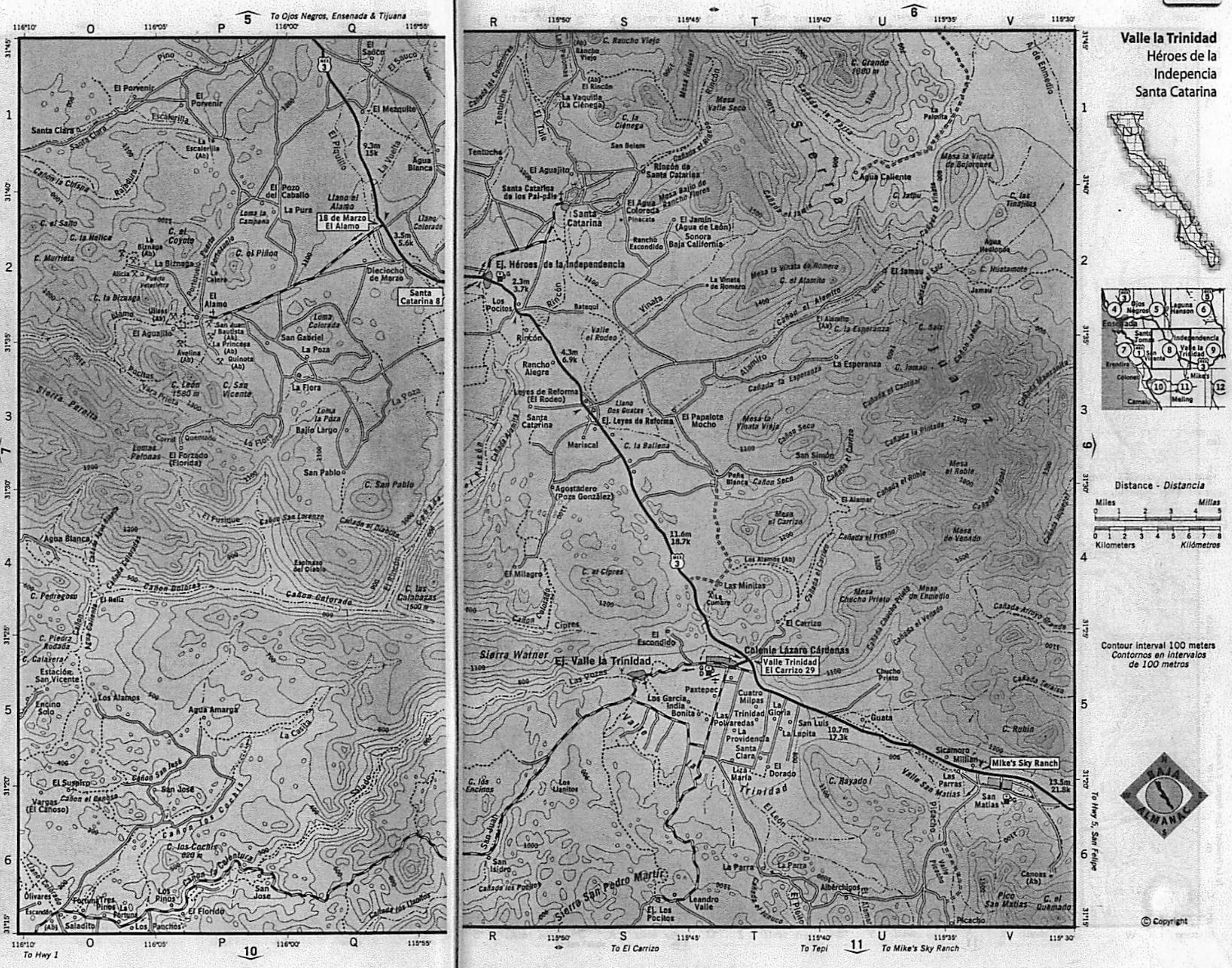
NOTES - NOTAS

San Felipe
Laguna Percebú
Morelia

Distance - *Distancia*

Contour interval 100 meters
Contornos en intervalos de 100 metros

NOTES - NOTAS



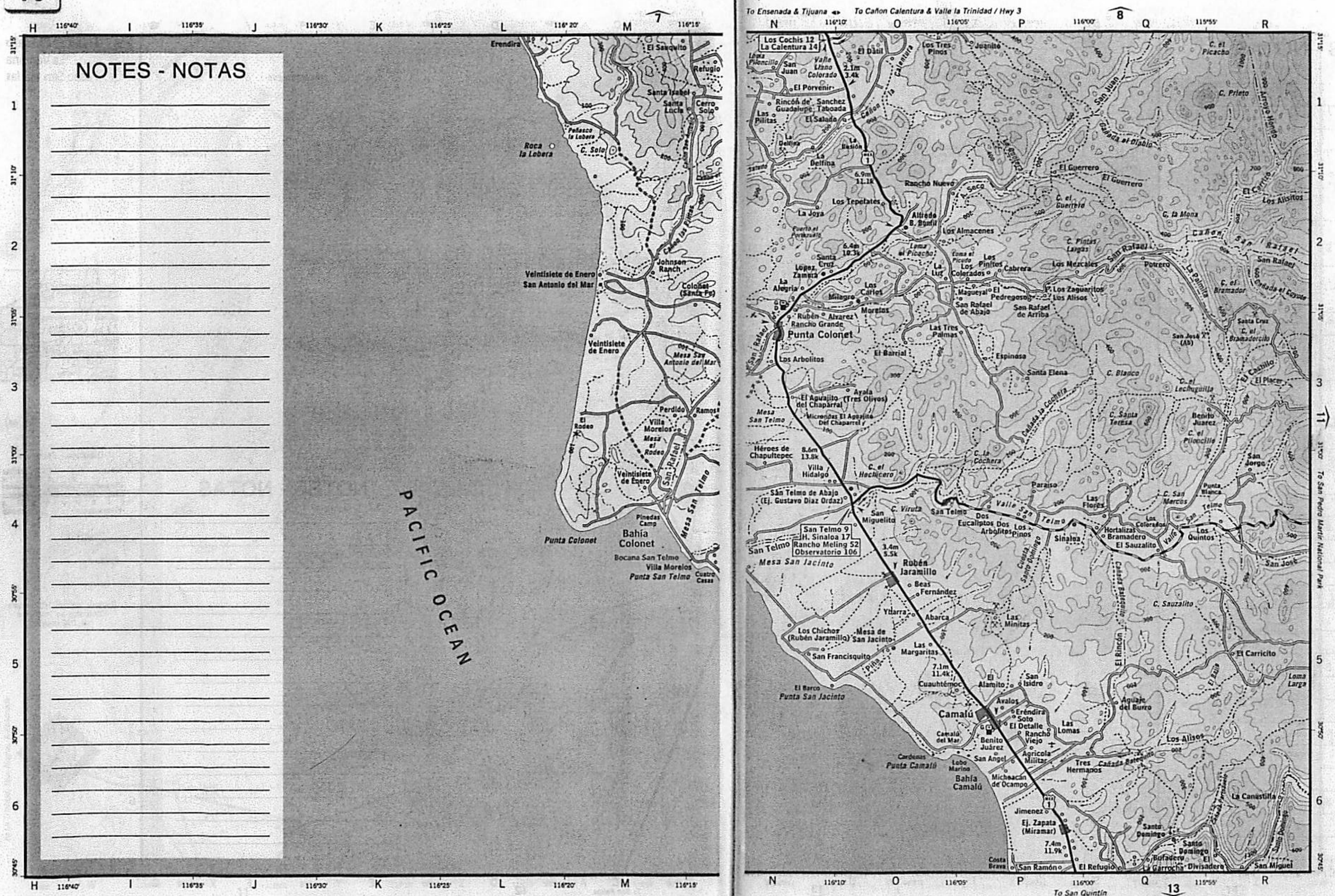
Valle la Trinidad
Héroes de la
Indepencia
Santa Catarina

Distance - *Distancia*

Miles *Millas*
Kilometers *Kilómetros*

Contour interval 100 meters
Contornos en intervalos de 100 metros

NOTES - NOTAS



Camalú
Colonet
San Telmo

Distance - *Distancia*

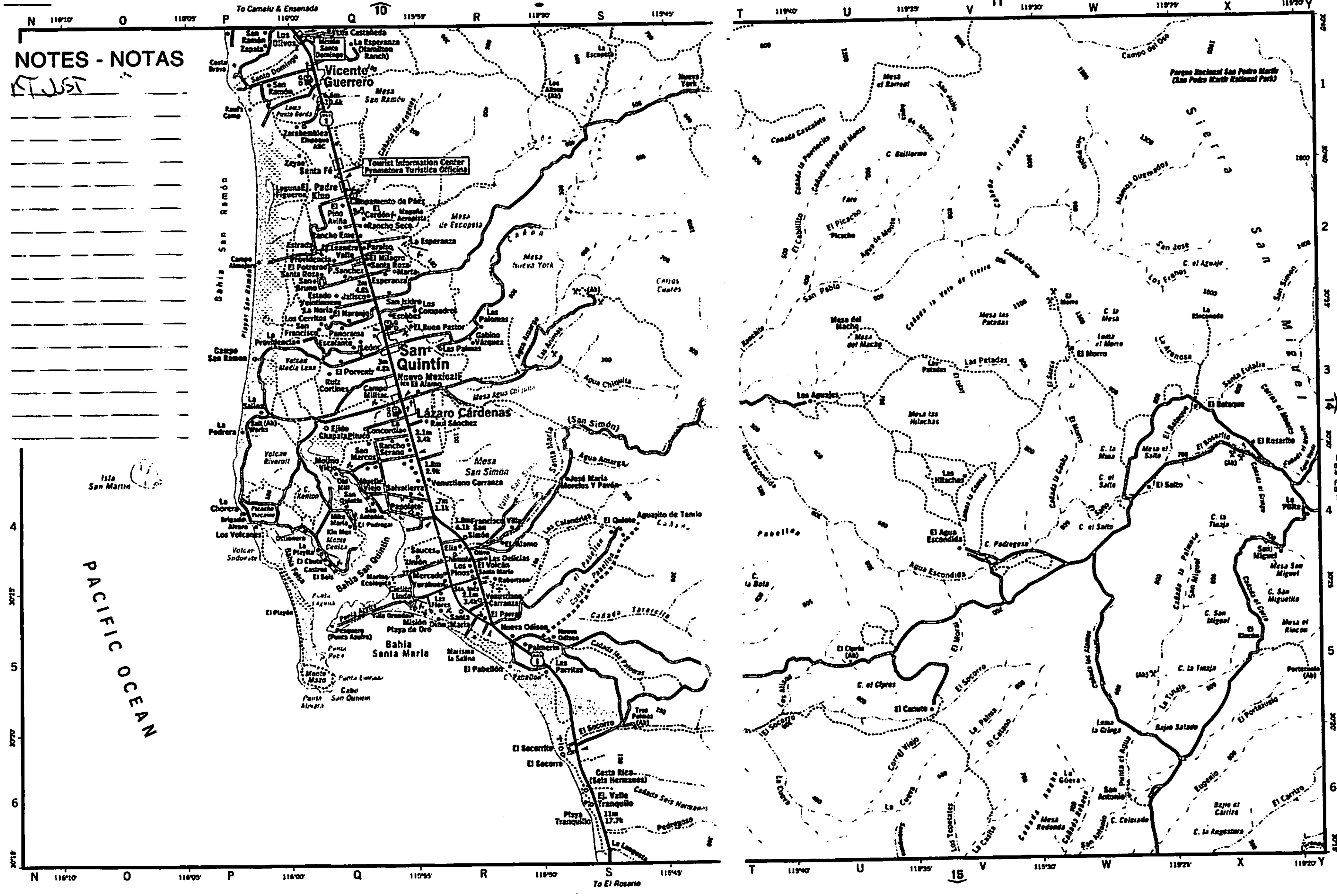
Miles 0 1 2 3 4 5 *Millas*
0 1 2 3 4 5 6 7 8
Kilometers *Kilómetros*

Contour interval 100 meters
Contornos en intervalos de 100 metros

BAJA ALMANAC
N E S W

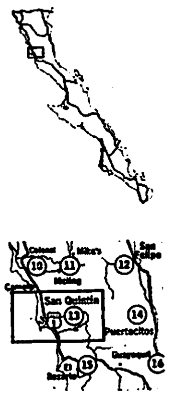
NOTES - NOTAS

KT JUST



13

San Quintín
Lázaro Cárdenas
Vicente Guerrero



Distance - Distancia

Miles 0 1 2 3 4 5 Millas

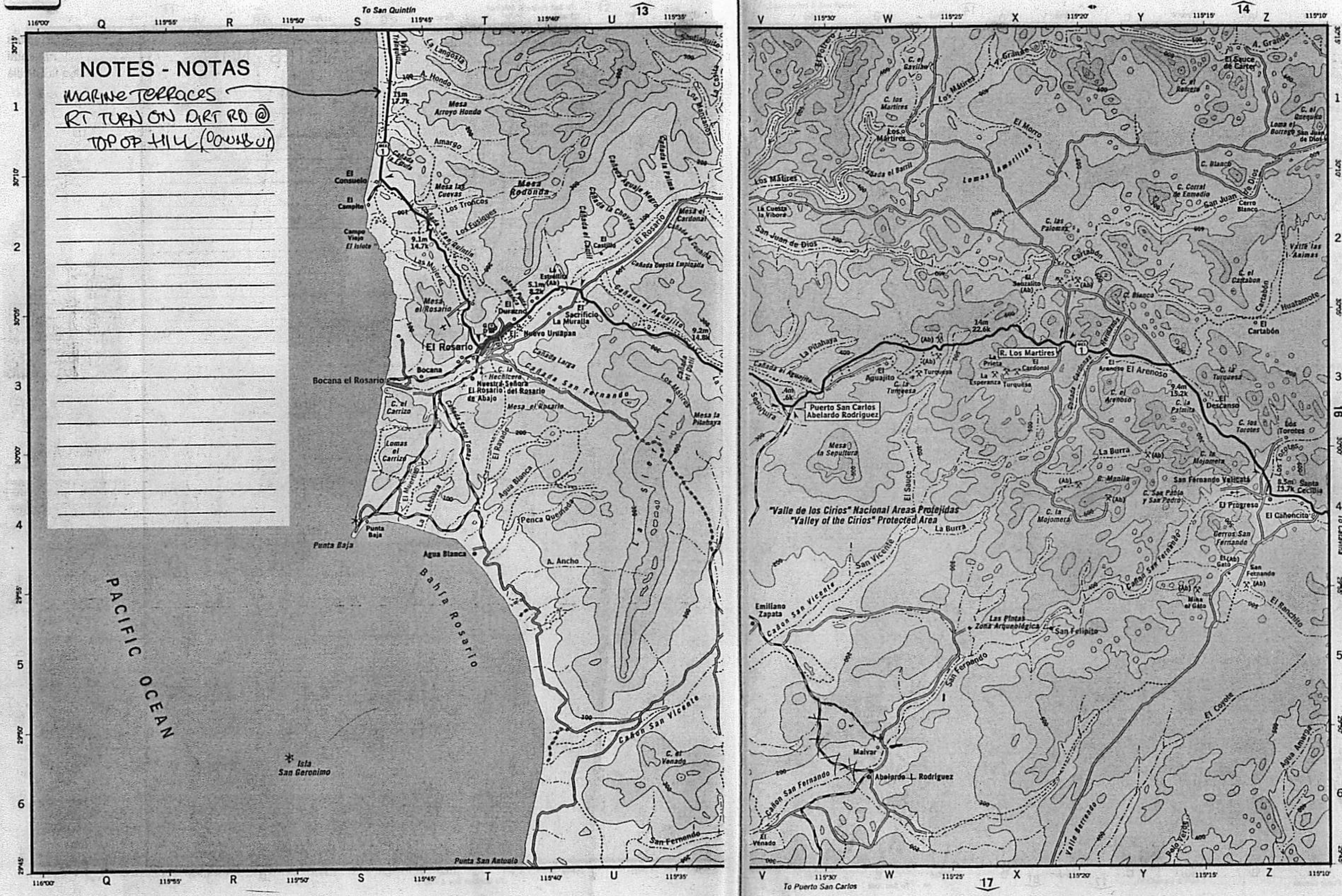
Kilometers 0 1 2 3 4 5 6 7 8 Kilómetros

Contour interval 100 meters
Contornos en intervalos de 100 metros

BAJA ALMANAC

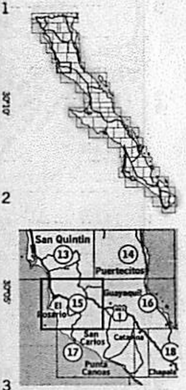
© Copyright

El Rosario
Punta Baja
San Juan de Dios

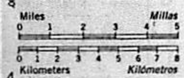


NOTES - NOTAS

MARINE TERRACES
RT TURN ON DIRT RD @
TOP OF HILL (DOWNBUI)

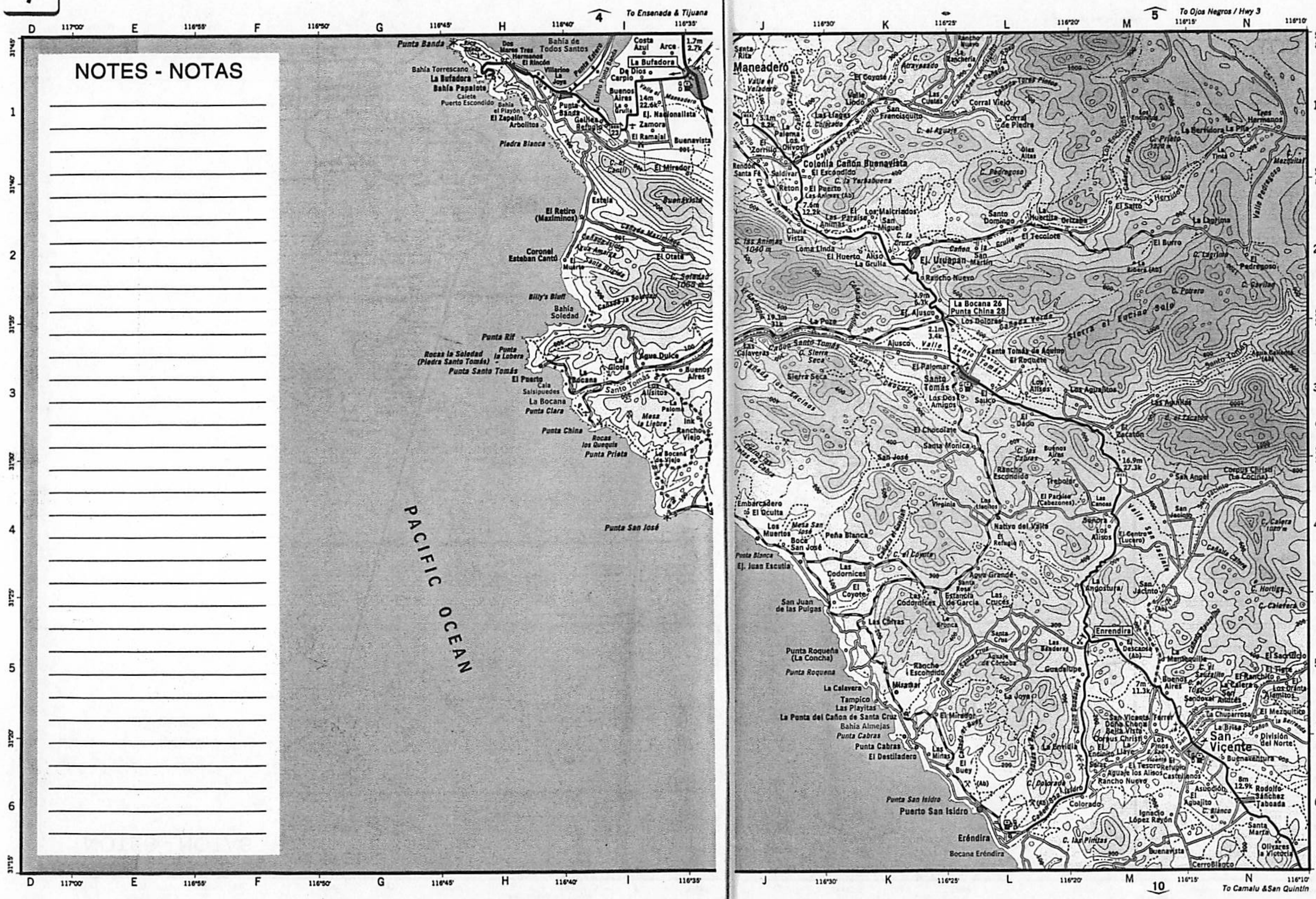


Distance - Distancia

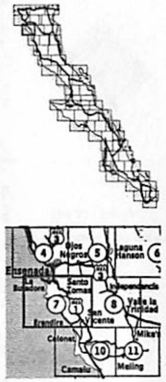


Contour interval 100 meters
Contornos en intervalos de 100 metros

NOTES - NOTAS



Santo Tomás
San Vicente
La Bufadora



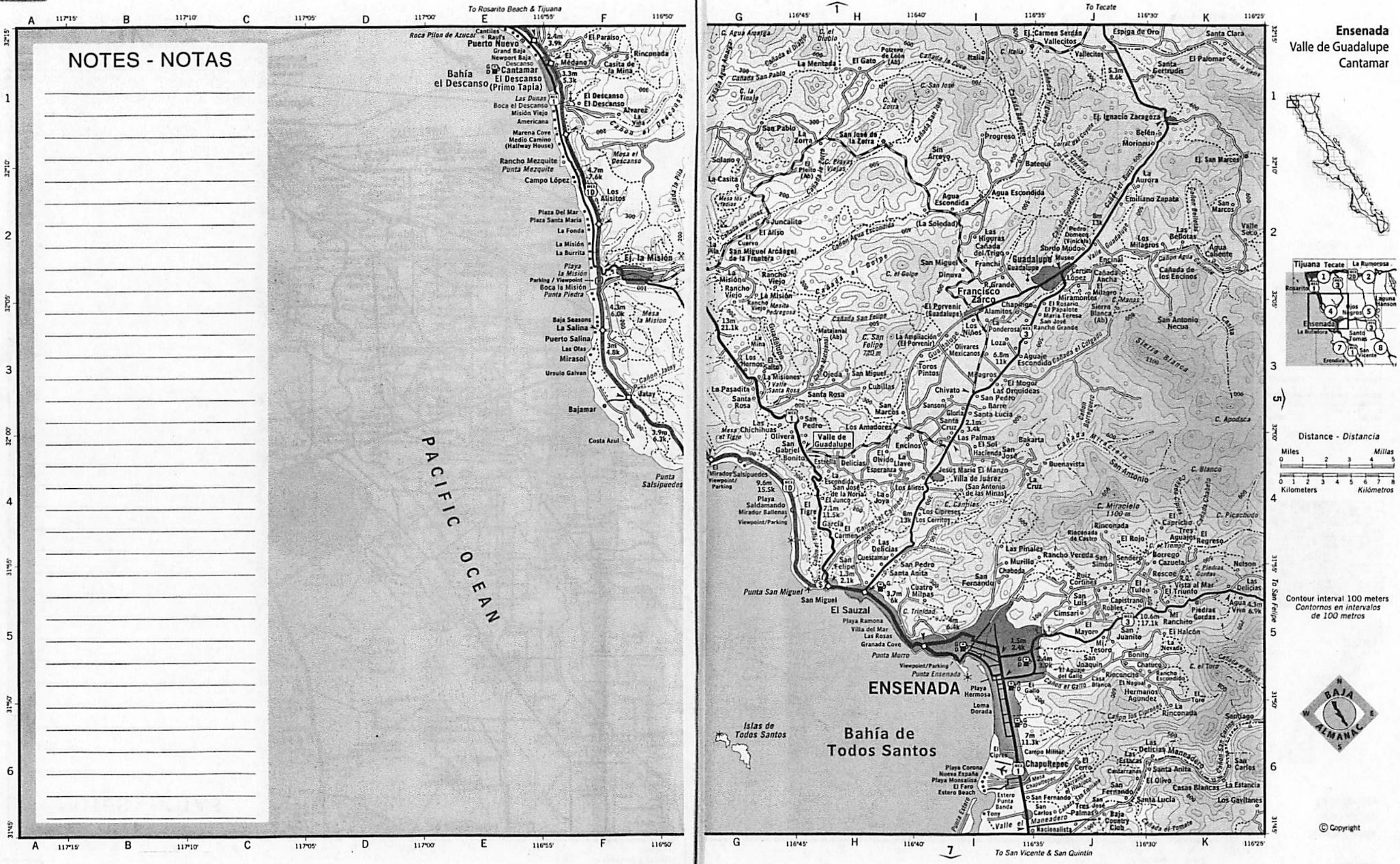
Distance - *Distancia*

Miles	*Millas*
0 1 2 3 4 5	
0 1 2 3 4 5 6 7 8	
Kilometers	*Kilómetros*

Contour interval 100 meters
Contornos en intervalos de 100 metros

Ensenada
Valle de Guadalupe
Cantamar

NOTES - NOTAS



Distance - Distancia

Miles 0 1 2 3 4 5 Millas

Kilometers 0 1 2 3 4 5 6 7 8 Kilómetros

Contour interval 100 meters
Contornos en intervalos de 100 metros

BAJA ALMANAC

Baja California Field Trip Mission Design

Jason W. Barnes
Jani Radebaugh, Joe Spitale, Colin Dundas, Elizabeth P. Turtle
Department of Planetary Sciences, University of Arizona, Tucson, AZ, 85721
`jason@barnesos.net`

ABSTRACT

The last Baja trip ran into trouble, nearly getting the field trips cancelled in perpetuity. In designing the trip this time, we took 3 measures to avoid a repeat: University vehicles, fall semester, and scouting. I have included in this document some driving directions as realized from the scouting trip. There is a lot of driving on this trip; tell me on Day 5 in the wrapup phase whether or not there was *too* much. At the end I have included a brief Spanish phrasebook for planetary gringos, tips for getting past the goons with M16s, and other possibly helpful comments.

Subject headings: field trip — driving directions — baja california — spanish-english dictionary

1. INTRODUCTION

Baja California is a remarkable place. At first blush it's like Arizona with beaches. The differences, cultural, ecological, and geological, are what make it interesting, unique, and worthy of study.

First a few boring words about words. The area we know of as Baja California was originally designated "California" by the Spanish in the 1500s, after a gold-filled island paradise in a then-popular book. It was decades before the European explorers came to realize that the real California wasn't an island at all, but rather a peninsula. The bottom line is that the term California originally referred to what is now Baja California, though shortly thereafter the term came to include the missions in Los Angeles and San Francisco as well. It's not all *that* big of a deal, but it is useful, especially when communicating with local Baja Californians, to acknowledge that the area gringos call "Baja" has as good, or better, a claim to the name California as the American state. The degeneracy might be best resolved by referring to Arnold Schwarzenegger's California as "Alta California" or "American California" and to "Baja" as "Baja California" when there is a chance of being misunderstood.

LPL's only previous trip to Baja California was in the spring of 1997. I wasn't on it. However, during my prospective dinner that was *all* the grads talked about. It was bad enough that Rachel Mastrapa figured I wouldn't even come to LPL, since all anybody did with their free time was sit around complaining. Since that's pretty much what I was used to at 'Tech, it didn't turn out to be a problem.

Anyway, the 1997 trip, as I understand it, was complicated by several vehicles getting bogged down in the mud on the dirt road out to the putative ammonite site at San Antonio del Mar. You can (and should) ask Joe Spitale and Peter Lanagan about the specifics, since they're old enough to have been around back then. The poor bedraggled field-trippers spent around 8 hours with shovels, firewood, and excess baggage trying to extricate the stuck vehicles. During this time some people hiked ahead to try to find the ammonites. They were unable to do so. Trip leader Jay Melosh let everyone sleep in the next morning and the San Felipe arm of the trip was cut in order to get everyone back to Tucson on time.

The complications set in when you realize that the trip vehicles in this particular instance weren't from the U of A Motor Pool, but rather were rented from Thrifty. As such they were totally plush Eddie Bauer edition Jeep Cherokees, or something else equivalently inappropriate for and incapable of real offroad driving. Without tow points, the front axle of Andy Rivkin's truck (the "USS Imperturbable") got bent during extraction. On the way home a semi kindly noted that the Imperturbable's tires were sparking – the misalignment had run down his tires' tread, leaving him to drive on the steel belts below. Every 300 miles or so the tires had to be swapped with the spares, which had been reconfigured onto the vehicle rooves by the students to better utilize storage space.

Thrifty then supposedly (this is all n-th hand – I'm just writing out the conventional wisdom here, future trippers should not use this as a primary account) brought a claim against the University for the damage caused. Ironically their best exhibit of the damage was an undamaged vehicle that was covered with mud except for the clean parts on the tail where duct tape had been removed. The clean areas spelled "Joe Schmoe and the Burning Butts". Thrifty claimed that because the muddy windows had been rolled down, they were ruined and had to be replaced. They said that it looked like people were dancing on the roof of some of the vehicles (actually they were managing spare tires). The bent axle was probably legitimate, if the result of their candy-assed supposed SUVs.

As for the political fallout, for a concise and lyrical description that you can dance to I refer you to Andy Rivkin's hit single "Imperturbable", which can be downloaded at: `http://c3po.barnesos.net:8888/andy/The Red Album/`.

The emergency boxes and associated equipment were purchased that fall to improve future vehicle recoveries. Their existence, along with Moses Milazzo's auto knowledge, surely saved us on the 2004 Canyonlands trip.

To avoid having to use the boxes on this trip, we have devised a three-pronged strategy. Firstly, we planned the trip and the dates for the trip sufficiently far in advance so as to be able to reserve University vehicles. Future trips should be sure to plan early as well, seeing as the basketball team might really need those 4WDs to be able to get to the ASU game in style that weekend.

Secondly, we scheduled the trip for the fall instead of the spring. This may not seem like such a big deal, but on the Pacific side of the Peninsular Ranges the rains come in the winter, same as in southern California. Because it rained on my graduation at Caltech (only the 2nd time ever, supposedly) that year, I remember that winter as being a rainy one, associated with an El Niño event. In March, then, even dry-looking areas had a lot of mud just undernearth the surface. The summer is dry and superhot, so by going in early fall the mud should be minimized. This change does add complications to the trip, though. In particular, the later after fall equinox that we go, the less daylight we will have. For this trip the day length will be particularly poor. The ideal tine frame to run the trip is probably in early October. We did the scouting mission then this year, and can confirm that the weather was good and the roads dry (despite a hurricane moving through the week before). In fact, since the mission design only includes a minimal amount of time on the Gulf of California side in the hot mid-afternoon Sun, the trip could be run even earlier. You have to balance the trade-off between baking in the hot sun on Laguna Diablo during day 2 and freezing at night and in the early morning on the Pacific coast night 2 and night 4. Also, in March the water's way to cold to do the in-situ ocean stuff, whereas it should be warm enough (at least on the Gulf of California side) in the fall.

Thirdly, we scouted the trip. Joe Spitale, Jani Radebaugh, Colin Dundas, and I drove the trip 2005 October 6-9. Note for future trip scouters: don't try to scout a 5-day trip in 4 days thinking that it will be faster. It won't. Just FYI. The scouting allowed us to verify that the 2WD SUVs that are all the motor pool could provide (for two of the vehicles anyway) will be able to get through the planned route. It also allowed us to find turnoffs. This turns out to be especially critical in Mexico where they don't seem to have any street signs. The locals must just know. In the next Section, I discuss the driving directions with particular attention to the tricky, unsigned parts. Tragically for Eric Palmer, there are no GPS coordinates. Please take that as a challenge to obtain such coordinates, writing them down in a place that will be accessible to future field trippers if you think they will want them.

The 1997 trip that this 2005 trip is based on was itself based on a trip run out of Caltech by Joe Kirschvink. So we have heritage. I think that is why the 1997 trip was structured as it was, stopping in Anza Borrego, starting on the west coast, and heading east. I thought that it was more appropriate to go clockwise instead, chopping out Anza Borrego, and doing the Gulf of California side first. This means that we don't have to camp in Anza Borrego, splicing out that part of the trip.

The 1997 trip was 4 days long. However, due to the aforementioned Issues the San Felipe portion had to get cut in order to get home in time. Accounting for actual travel time on Mexican roads (longer than you might think), we changed the trip to 5 days. A big feature of this is that it gives us time to go see the K/T landslide deposits in Cañon San Francisco, which I think will be cool.

An intrepid future Baja California trip planner could cut the trip over the Peninsular Range on Mexican Route 3 and instead continue south on the 5, meeting up with Route 1 just south of the Catavina boulder field (which would be a great spheroidal weathering stop). The 5 down there is pretty slow going, but it would turn the trip into more of a loop while allowing us to see some different sights (such as the volcanics in Cañon Matomi just north of Puertecitos and travertine deposits further south at El Marmol) at the expense of the peninsular ranges and associated dike swarm.

2. Driving Directions

2.1. Day 1

I estimate about 8.5 total hours of driving for this day.

⊕ Head west on the 10 for 4 hours (231 milesish) to Yuma.

⊕ Exit the 10 at the east end of Yuma on Fortuna Rd., exit 12. Turn north 1 block to the Chevron to gas up.

⊕ Head for lunch stop.

⊕ West on 10 again, cross the Colorado River into Alta California, and exit on to Califorina state route 166 about 3 miles past the river. The sign says, "Mexico".

⊕ Getting into Mexico is easy. It's getting back that's hard. When we scouted it, and on all of my other personal trips to Mexico, there is no checkpoint on the way in. Sometimes there is a guy there that may wave you on. Do be prepared to stop should he indicate that he wants to you do so.

⊕ When we cross the border, you will be in the Baja California town of Algodones. It's a cramped commercial area — please drive slowly and be wary of pedestrians. **Very shortly after crossing the border we will need to turn right for 4 blocks, and then left onto Baja California route 2, known in town as Calle 6ta (6th street).** We will do this as soon as possible after crossing the border, thereby avoiding the embarassing 22-point U-turn (not an exaggeration) on a residential dirt road that Colin Dundas and I had to pull.

⊕ Follow the signs (there are some here) to stay on Baja California Norte route 2, sometimes shown as BCN 2. Continue about 18 miles until BCN 2 hits a 'T' junction with Mexican Route 2 (don't get two confused, now). **Turn right on Mexican Route 2 for only about 150 feet, and then make an immediate left onto the west bank of the canal.**

⊕ It's a real maze inside the agricultural area here, until we hit the 5. Follow the BCN 2 signs if they're there. Be mindful of the frequent small villages, and slow down so as not to run over anybody. Another 20-25 miles in you will encounter the entrance to the Cerro Prieto visitors' center on the right shortly past Ejido Nuevo Leon.

⊕ Turn right (?) out of the Visitors' Center onto BCN 2 for about 2 or 3 miles. **Right after you cross the railroad tracks and the canal, make a sharp left (about $3\pi/4$ radians)** onto an unmarked BCN 2C (maybe — I can't really read my written-while-driving writing). **BCN2C jogs to the left just inside Estacion Delta, try to stay with it.**

⊕ **Turn right on BCN1 when BCN2C tees in the town of Oaxaca just a few 100m past the jog to the left.** Continue on BCN1 for about another 8 miles until it tees with BCN4. Then **Turn right on BCN4** for 10 miles until you reach Mexican Route 5.

⊕ **Turn left on Mexican route 5.** Take this all the way to San Felipe. Some good roads to the right toward some alluvial fans. Road to the left at the south end of the Laguna Salada (salt pan from a huge dry lake bed) just before the road to Ejido Saldana is a good turnoff to talk about the climbing dunes.

⊕ **San Felipe:** about a 1 hr drive S of the climbing dune field is the fishing and tourism town of San Felipe. On the way in you'll see the big symbol of San Felipe, El Arco. 0.6 miles or so past El Arco is a big traffic circle. Circling around to the right, 90 degrees around is the continuation of Mexican Route 5 toward the south. This is the direction of the campsite. To get fish tacos head straight in 180 degrees around the circle and continue for about a third of a mile. This part is a little hairy, but there's essentially a 1/4 mile (circumference) long rectangular loop that you have to take to park right in front of the beachfront food establishments from here. We'll go right when this road (Calzada Chetumal) ends, then left, and left again along the beach. There we'll scatter to find parking, and then separate to obtain the necessary fish taco fix. The places along here are used to seeing clueless gringo visitors like you, so you should be able to find your way to food without too much trouble. Everywhere that I've found takes US Dollars as if they were local currency. I don't know what the official exchange rate is precisely, but the Baja Californians take \$1 = 10 pesos straight up. Leaving San Felipe we'll continue N along the beachfront and then curve around to the left at the end of the beach, make another left, and hopefully meet back up with Calzada Chetumal where we'll make a right and head back for the central traffic circle.

⊕ Heading south from the traffic circle it's not entirely obvious that you're on Mex 5, but you are. Zero your odometer, especially since you're probably going to be turning in to get to the campsite in the dark. It is 26.7 miles from the traffic circle to the campsite turnoff. The sign on your left says, "Camp Mayma"; turn left there. When we were there the campsite was abandoned, and so was free. Therefore, continue through the gate on your left where it says \$10/car or whatever. If there's actually somebody there running the campground, then we'll pay. Otherwise we camp on the beach for free. Please park inside the campground, and **do not attempt to drive on to the beach.** We tried it. It's possible, but it requires airing down your tires to like 10 or 15 PSI, whereby you'll run out of gas driving back to San Felipe and we don't want to wait for hours while one of those little 12V pumps slowly refills your tires to 70 PSI.

2.2. Day 2

⊕ Leave the campsite the way that you came in, and make a right onto Mexican Route 5. Just as you arrive into San Felipe, $1\frac{1}{2}$ miles south of the traffic circle, stop at the PeMex with an AM/PM next door. There might be only 1 bathroom (problem), so don't dawdle, is all.

⊕ Turn left (270°) at the traffic circle and head back out past El Arco. Drive for half an hour, then make a left onto Mexican Route 3, heading across the peninsula toward Ensenada. We took a short cut along unmarked dirt roads on the scouting trip that we had to cut out due to time, so we didn't scout this turn, but it's the big turn that tourists heading back to Los Angeles take so I expect it to be well-signed.

⊕ Drive 27.4 miles until you crest a mountainous pass and turn at the big-looking dirt road off to your left. Proceed 4-5 miles to Laguna Diablo.

⊕ Retrace your dirt road steps, making a left to get back onto Mexican 3 in the same direction you were heading before: west.

⊕ After 24.2 miles or so, make a left inside Colonia Lazaro Cardenas (there may or may not be a sign there that says, "Valle Trinidad / El Carrizo"). Continue straight until the road tees (0.7 miles through town — go slow). Make a right. When *that* road tees, make a left, and zero your odometer. About 3.1 miles down, make a right on any road that looks kind of big. They all look the same, but they're all gridded such that if you're off by a few it isn't too hard to find your way to where your going, which is to the dirt road that heads west over the mountains.

⊕ 2.5-3 miles later is a good example of spheroidal weathering that we'll stop at. Another 6.4 miles on (20 minutes) is a good place to talk about alluvial fans. Lunch is hopefully at the spheroidal stop, depending. Another 5 minutes (1.7 miles) on from that is a roadcut the dikes, and a place to see them, too. There's no good place to stop the vehicles, unfortunately. But when we were on this road scouting we passed a grand total of 0 oncoming cars so we'll just pull over as far as we can and adjust later if someone else comes along.

⊕ Watch the bump heading downhill 10 miles past the dikes. 16.7 miles past the dikes on the left is where we camped on the scouting trip, and we could camp there if we're running behind. Otherwise continue another 8 miles to the intersection with Mexican Route 1.

⊕ Turn left on Mexican Route 1. It's The Main Road in Baja California, and you can drive it from North of Vancouver all the way down to Cabo San Lucas if you include US 1 and Canadian roads. As such there is quite a bit of truck traffic on it, so be careful. It is also pretty narrow and has no shoulders. We will do everything that we can to avoid driving on it at night, as that can get hairy. You have to be attentive, though, is what I'm saying, because the 1 isn't very forgiving of error. It is well-paved and without potholes, though, and all in all I think that it's a fine road.

⊕ 45 miles down the 1, 1 mile past the town of Vicente Guerrero and just headed down after cresting a hill, there's a small but demarcated turn to "Ejido Zarahemblea". Turn to the right there. Go 0.6 miles until the road ends, and turn right. Go slowly 0.4 miles, and make a left just after the 2 meter diameter, 2 meter high gray concrete cylinder. Drive for a few miles on until the 5-6 meter high hills extending north and south along the coast, and park below the hill. You can't make it over this hill onto the beach without seriously airing down either. We tried. Park at the bottom, and camp.

2.3. Day 3

⊕ Return, retracing last night's steps, to Mexican Route 1. Turn right. Drive for 34 miles or so, and right at the top of a hill (so go slow), between the km 36 and km 37 signs, turn right again onto a small dirt road. Park 1/2 mile down and listen to talks.

⊕ Retrace back to the 1 again, and turn right heading south again. Another 34 miles down the 1, through El Rosario, and up at the top of a hill near km 80, you'll see a road to the right next to a big sign that's so totally rusted out you can't even tell what it might have said at any point in the past. Turn right there.

⊕ This dirt road has numerous branching side paths. They all go to the same place, so take whichever one suits your fancy at the time. About 18 miles down this dirt road there's an unmarked left turn onto the road heading up Cañon San Fernando and to the K/T landslide deposits as outlined in Busby et al. (2002). They're located mostly on the east side of the canyon starting maybe 3 miles up and continuing for 5 or so miles past that.

2.4. Day 4

⊕ Return to the 1, retracing steps. It's about 1 hr back. Then drive N on the 1 way back up north past Laguna Figueroa, and past the dirt road to Lazaro Cardenas that we came across on and a few more miles on into San Vicente. San Vicente will be a gas, taco stand, and ice stop.

⊕ Continue north 23.9 miles from San Vicente, through the town of Santo Tomas at the end of which there is a turn to the southwest that we'll be taking to head to Punta San Jose. This portion of the trip was not scouted, part of my brilliant scout-the-5-day-trip-in-4-days brain wave (in addition to Other Factors including, but not limited to, the brake bolts falling off of our truck). The road is 30 miles of unscouted dirt. We pretty much head through the mountains and then make a break for the Pacific, and head up north 10 miles or so paralleling the beach. That's the best that I can give you.

2.5. Day 5

⊕ Welcome to The Suck. 9.5 hours of driving home. Please take this moment to switch into a vehicle full of people at whom you have not gotten stranglepissed over the course of the previous 4 days. We appreciate your cooperation in this matter, and may be able to provide a whacking stop to release tension if necessary. Drive back out to the 1 and turn left toward Ensenada.

⊕ **Ensenada:** the front passengers in all vehicles should now have a map in front of them and be devoting their full attention to not letting the driver get lost in the middle of a large foreign city. If you are unable or unwilling to provide this function, please take one of the rear seats that require less responsibility. We will make two 90o turns within the city of Ensenada: one at the south end, and one at the north end. At the south end, a few miles into the city, we will make a turn to the left to stay on route 1. Stay in the left lane in anticipation of this turn, as there is little prospect for getting an 8-SUV caravan over in the brief distance alotted by the signage. At least there are signs. After winding through the stop-and-go for about 6 miles the 1 will start to turn into the 'big' toll freeway that connects Ensenada and Tijuana, and on your right there will be an exit onto Mexican Route 3. You will probably also see signs for Route 3 at the south end of Ensenada. That road goes to San Felipe. We are headed to the border crossing in Tecate.

⊕ **Tecate / International Border:** They totally pretzeled this crossing post-9/11, so pay attention. Coming in on the 3 we will pass the first signs for Mexican Route 2D, a toll portion of the 2, and continue on to Avenida Juarez, the non-toll Mexican 2, about 4 blocks south of the border.

Turn right. Go "straight" (180°) through the roundabout, and then get in the left lane, from which you will turn left at the sign pointing you to the international border.

⊕ Once safely back into the United States, our first turn is to the right onto Schwarzeneggerian California Route 94 for 45 minutes to an hour or so. It's a pleasant, if windy, road at a high enough altitude to provide for a cool lunch spot, should we find a suitable spot. After that it's 5.5 hours of 10 home.

3. Dealing with Mexican Army Checkpoints and other Cultural Issues

3.1. Don't be a Complete Idiot

Possession of guns and/or drugs is illegal in Mexico. If you get caught with them, we will laugh at you, and then leave you there to rot in a Mexican jail cell while writing up your dissertation in pencil on rolls of toilet paper. It might still be less painful than doing it in Microsoft Word. You will then continue to be laughed at for decades to come by future field trippers.

3.2. Mexican Army Checkpoints

The Mexican Army is nearly the opposite of the American Army in the following sense: the American Army is forbidden from acting within the United States, the Mexican Army is used exclusively for internal security. In another sense it is the same: both armies are primarily composed of 19-year-olds with powerful automatic weapons.

There are several army checkpoints that we will encounter in Baja California. They are looking for guns and drugs, trying to intercept them during shipment to the US. Hence while travelling south you will likely be waved through most checkpoints, but while travelling north the vehicle is much more likely to get the full cavity search. The vehicle! The vehicle. Do not get alarmed.

When you see a checkpoint off in the distance, prepare. Turn off your CB radio, as it will avoid problems such as a very embarassing comment's transmission at a culturally inopportune moment. Take valubles like cameras and GPS units onto your person, either carrying them or having them in your pockets, to prevent them from becoming a donation. Drive very slowly up to the dude that will be standing there (I've only ever seen men in the Mexican Army, though this might just be a statistical anomaly). Roll down the window. You may then be asked to get out of the car in a brusque manner — they're not being rude necessarily, it's more likely that they just don't know English and so, like British tourists, they just say it louder.

Get out of the vehicle slowly, keeping your arms and hands visible at all times. If you speak no Spanish and someone keeps speaking it to you anyway, say "no hablo espanol" (no ah-low ess-pahn-yol) and point to someone who does (at least me and Jani Radebaugh — if you speak Spanish, too, let us know at the start of the trip so that we can use you).

When you are through the checkpoint, drive away, turn on your CB, and then look for the rest of us. We will probably be stopped waiting for you a mile or two out of range of the gunners.

On the 1997 trip, at an army checkpoint, Peter Lanagan's van was asked whether or not they had any drugs. After answering no, he was asked, "why not?". To this day I haven't figured out a good way to answer that question. If you come up with one, let us all know :)

3.3. And You Think Tucson Drivers are Bad

Mexican drivers tend to leave smaller margins around your vehicle when passing (they cut you off). They also park in unusual and obviously unsafe places, so please be careful when leaving parking lots. The speed limit on Mexican Route 1 is 80 km/hr, about 50 miles/hr. It's a good limit for the conditions.

When a driver in front of you that you've been tailing for awhile puts on his left blinker, he's telling you to pass him. This may or may not indicate that the driver of that vehicle thinks that it is safe to pass at that precise moment. Use your judgement, and look for yourself.

3.4. Gassing Up

You can buy gas anywhere that you want to in Mexico, as long as it's at the Nationalized oil company Pemex. The upside to this are subsidies for keeping gas prices the same in small, out-of-the-way stations like those in Baja California, the competent and professional attendants that pump your gas for you (it's all full serve), and the copious and clean restrooms. The downside is the lack of the competition that provides redundancy here in the US: there's usually just one Pemex in town, and if it's out of service you're SOL. We'll be in the more inhabited part of Baja California, so this is less of a problem than if you're driving all the way to Cabo San Lucas.

As you pull up, tell the attendant, "llena, por favor" (fill 'er up, please — pronounced yay-nahh). Hopefully I'll have already told him that one person will be paying for it all, but if you run into issues tell them "el va a pagar" (he will be paying — ell bah ah pah-gar) and point at me (or Zibi, or whomever — use "ella" (eh-yahh) if it's Zibi). Worst case we'll give you some money, give it to the attendant and then ask for "un recibo, por favor" (a recipt please — oon ray-see-bow).

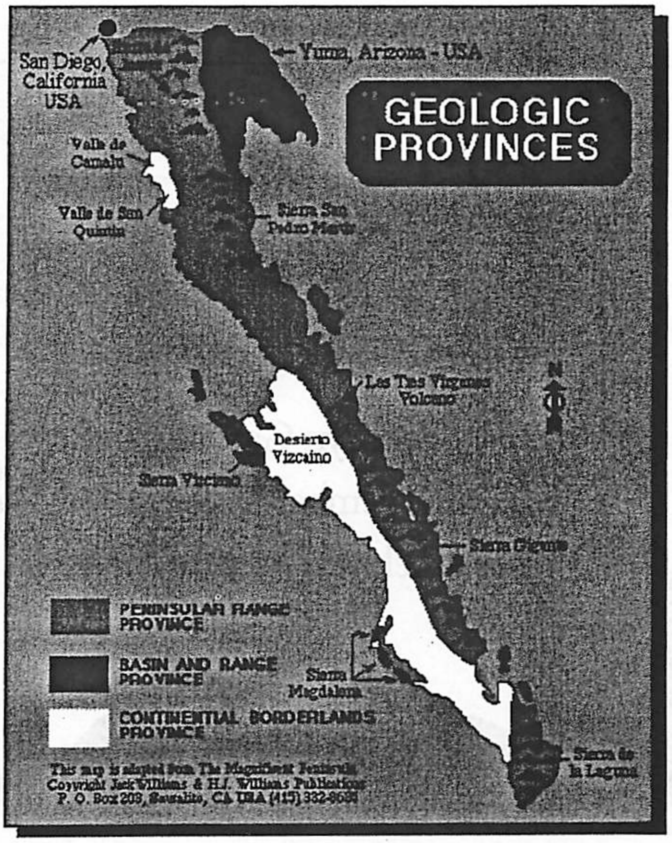
3.5. Ejidos

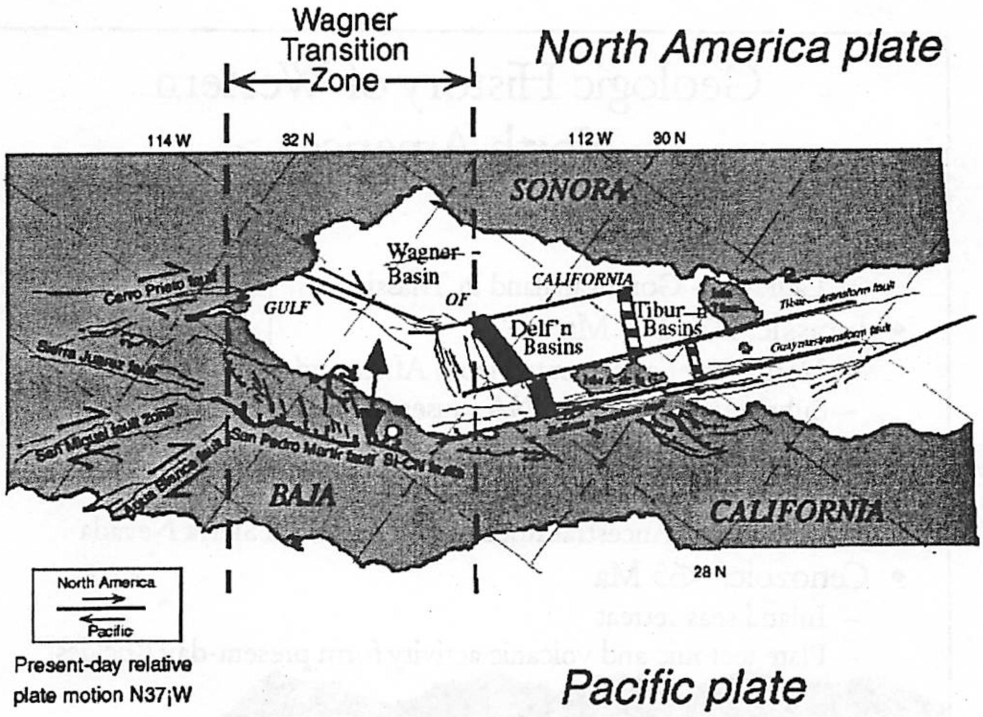
You'll see the word Ejido (ay-hee-doe) preceding some small town names in rural Baja California. It refers to a sort of reservation — an area set aside for the formerly landless poor to work and make money off of. It's a reservation in the sense that while these people have full use of the land, they don't own it because they can't sell it. The results of this experiment have been mixed: the land ownership is not concentrated into the hands of the primogenitured few, but these areas are the least productive farmlands in all of Mexico by a lot, and thus the economy suffers.

4. Spanish Phrasebook for Planetary Explorers

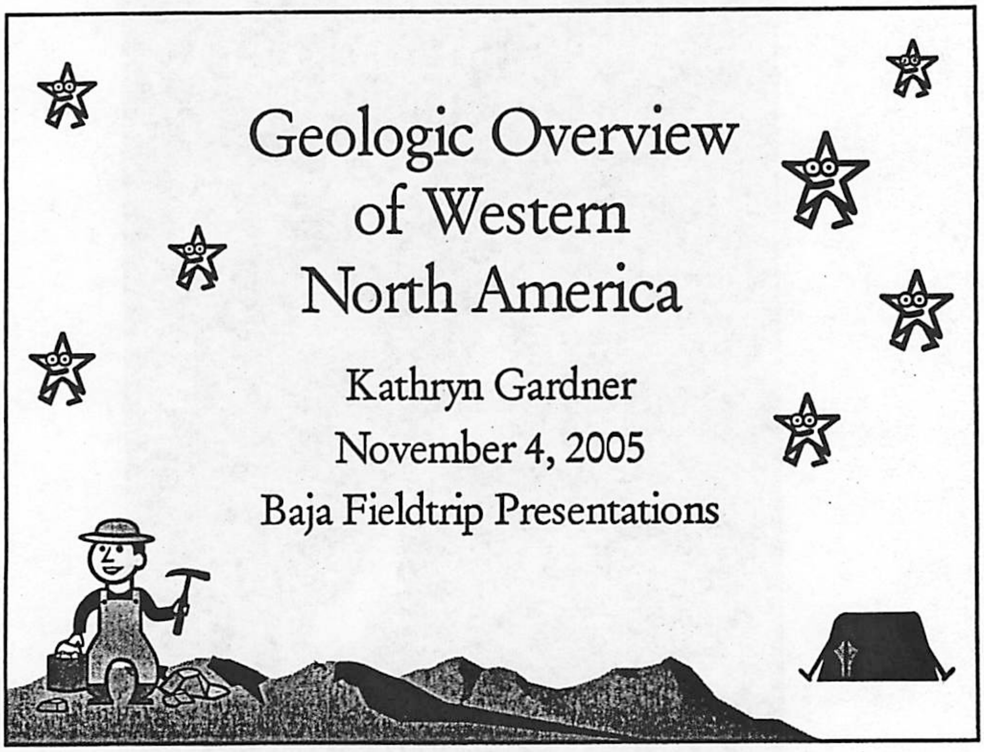
A brief set of potentially useful or interesting translations:

- alta (al-tah) — stop
- ayuda (ah-yoo-dah) — help
- basura (bah-sue-rah) — trash can
- cajero automatico (cah-hair-oh ought-tow-mah-tee-co) — ATM machine
- camino (cah-me-no) — way; street
- cerveza (sair-vay-sah) — beer
- cruce de escolares (croo-say day ess-co-lah-rays) — school crossing. You should slow down
- cruce de peatones (croo-say day pay-ahh-tone-ays) — pedestrian crossing. You should slow down
- curva peligrosa (coor-vah pay-lee-gross-ah) — dangerous curve. You should slow down
- despacio (des-pah-see-oh) — slow down. Not the name of the town you're driving into, as Jay Melosh reportly thought once on the last trip.
- geologia (hay-ah-low-hee-ah) — geology
- hielo (ee-ay-low) — ice
- llanteria (yan-teh-ree-uh) — tire shop
- llena (yay-nah) — full
- mariscos (mah-ree-scose) — seafood
- mercado (mair-cah-doh) — market
- piedras (pee-ay-drahs) — rocks
- playa (plah-yah) — beach
- pescado (pes-cah-doh) — fish. Usage: Quiero dos tacos de pescado, por favor to ask for two fish tacos (key-arrow is the first word)
- propiedad privada (pro-pee-ay-dahd pree-vah-dah) — private property
- que les vaya bien (kay lace bah-yah bee-en, spoken *really* fast) — have a nice trip; literally: that you would go well
- recibo (ray-see-bow) — recipt
- Rentería (Ren-tah-ree-uh) — sellout shortstop for the Boston Red Sox
- se vende (say ven-day) — for sale
- topes (tow-pays) — speed bumps. Often seen near cruces, see above





Top: http://www.bajaquest.com/maps/geology.html
Bottom: http://oro.ess.ucla.edu/labdata/jvgr/santa_isabel.html (Figure 7)

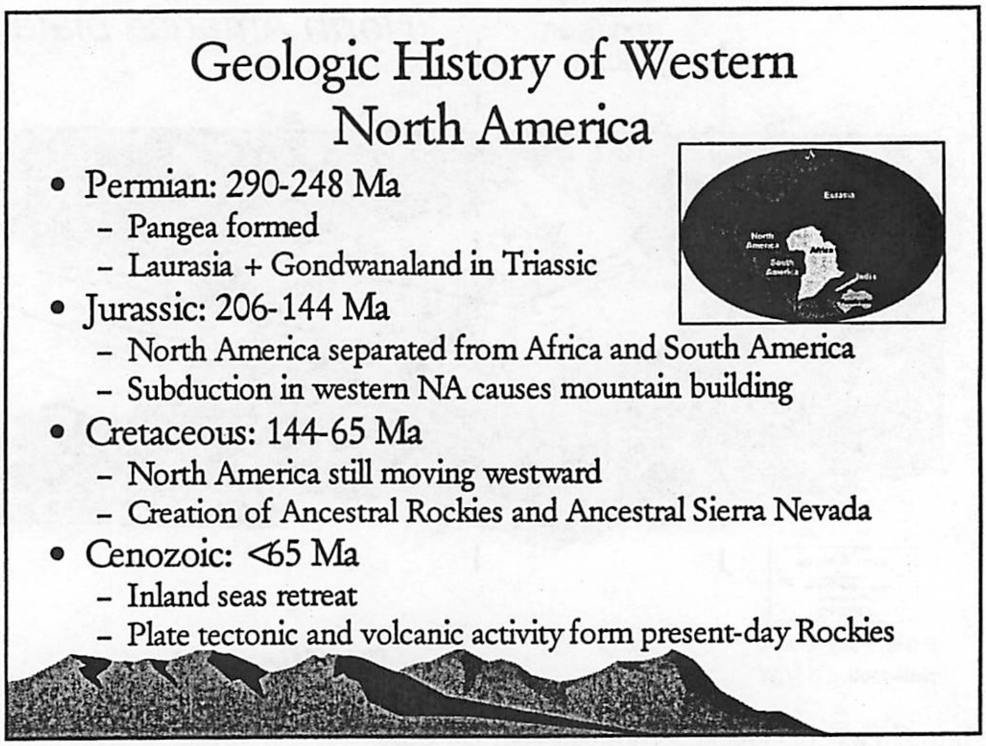


Geologic Overview of Western North America

Kathryn Gardner

November 4, 2005

Baja Fieldtrip Presentations



Geologic History of Western North America

- Permian: 290-248 Ma
  - Pangea formed
  - Laurasia + Gondwanaland in Triassic
- Jurassic: 206-144 Ma
  - North America separated from Africa and South America
  - Subduction in western NA causes mountain building
- Cretaceous: 144-65 Ma
  - North America still moving westward
  - Creation of Ancestral Rockies and Ancestral Sierra Nevada
- Cenozoic: <65 Ma
  - Inland seas retreat
  - Plate tectonic and volcanic activity form present-day Rockies

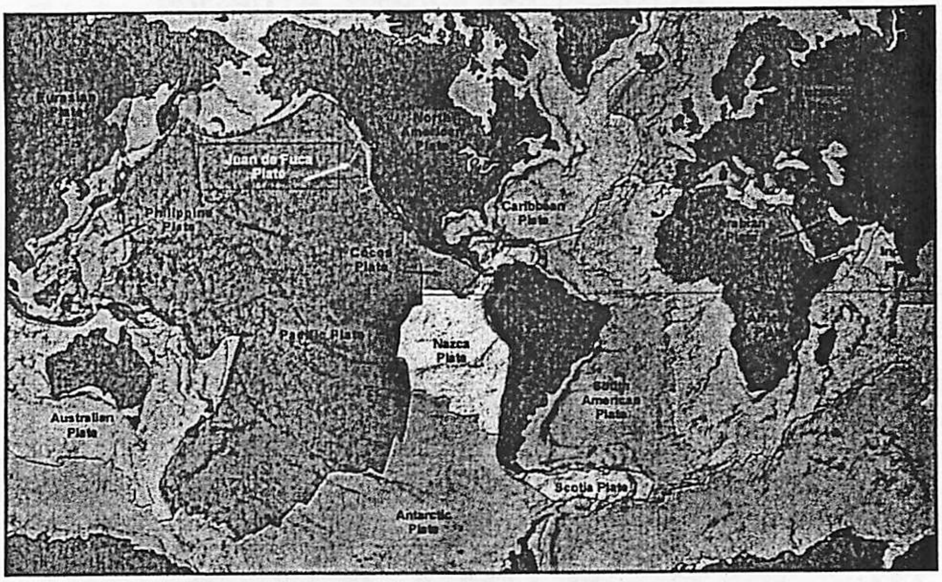
Major Geologic Provinces in Western North America

- **Rocky Mt. System:** Colorado, Wyoming, New Mexico, Montana, Idaho
  - 3 major tectonic episodes between 170-40 Ma, ending with Laramide Orogeny (70-40 Ma) which raised Rockies to today's height
- **Colorado Plateau:** Utah, Colorado, New Mexico, Arizona
  - Plateaus, mesas, deep canyons that expose preCambrian rocks
  - Example = Grand Canyon!
- **Basin and Range:**
  - *CB talk during trip... I won't step on toes!*

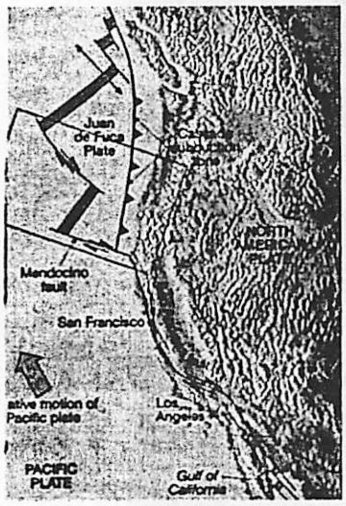
- **Columbia Plateau:** Washington, Oregon, Idaho
  - Huge accumulation of basalt that erupted 17-6 Ma
- **Pacific Mt. System:** California, Washington, Oregon
  - Cascade Mountains: Volcanic arc, Mt. St. Helens
  - Sierra Nevada: Granite, Mesozoic age, Yosemite

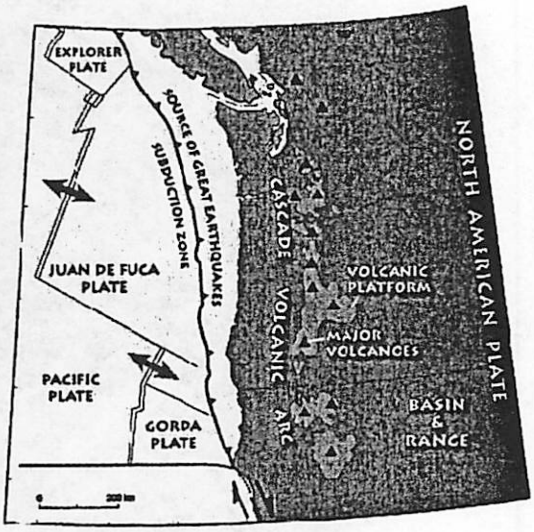
http://www2.nature.nps.gov/geology/usgsnps/province/province.htm

Global Tectonic Plates

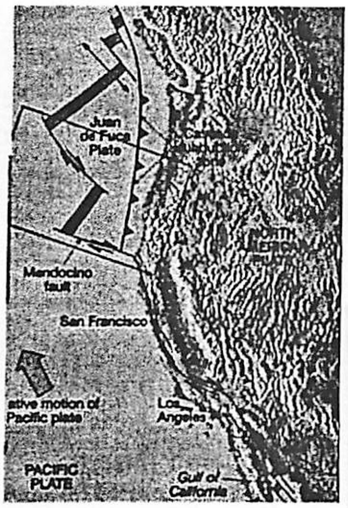


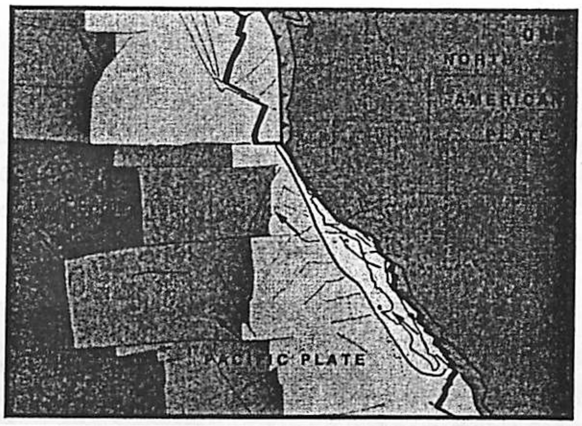
Subduction on Western North America





Subduction on Western North America

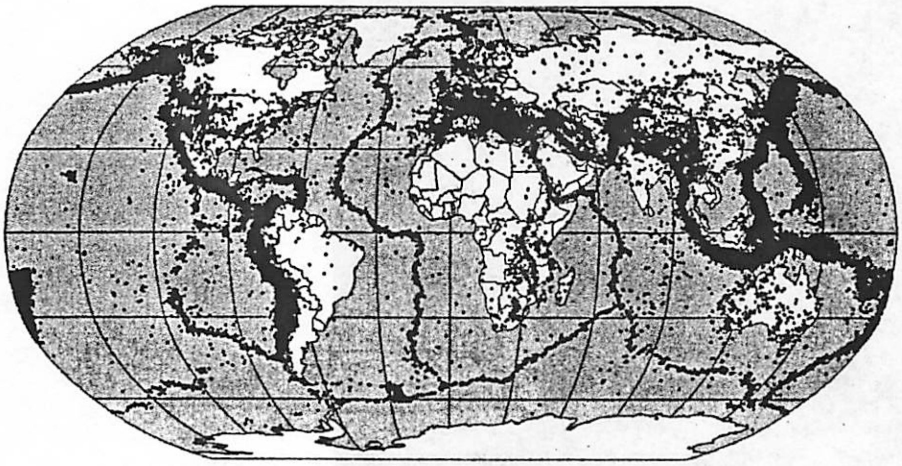




Note: Right-lateral strike-slip fault series across entire western North America!

Global Earthquake Epicenters

Preliminary Determination of Epicenters
358,214 Events, 1963 - 1998



Geologic Overview of Baja California, a region shaped by plate tectonics.

By Celinda A. Marsh

Until 15 million years ago, the region we call Baja California was a part of the North American plate. Now it is a small piece of continental crust attached to the mostly oceanic Pacific plate. This radical change occurred because of a plate that no longer exists – an oceanic plate that geologists have named the Farallon plate.

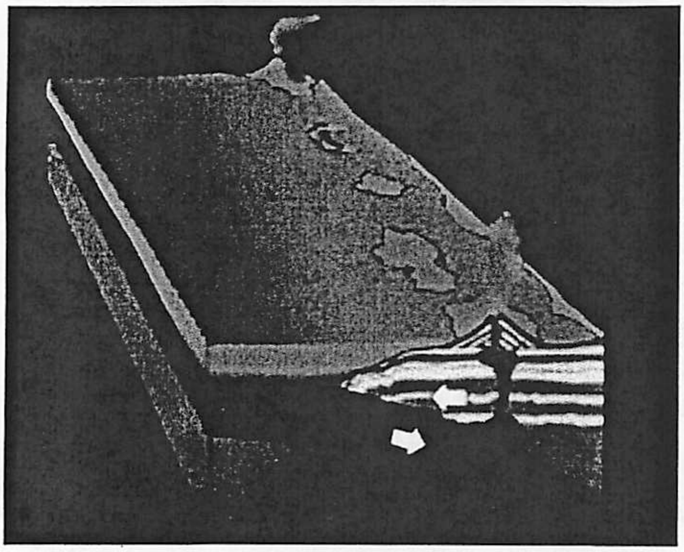


Figure 1.

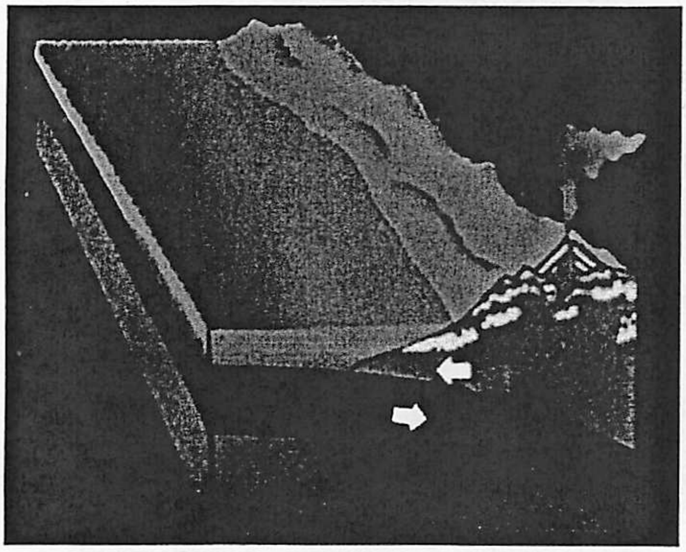


Figure 2.

Figures 1 & 2 show the Farallon plate subducting under the North American plate. This occurred from Triassic time until about 20 million years ago. The morphology of this subduction zone changed over this time range of more than 150 million years. At times the subduction rate was moderate and island arc ranges, like those currently found in the Southeast Pacific, were formed (see Figure 1). These produced basaltic eruptive deposits and characteristic back-arc sedimentary units. At other times, subduction was rapid and Andean style mountains erupted and built large rhyolitic ranges (see Figure 2). As subduction subsequently trailed off, the magma chambers of these ranges were able to slowly cool, producing large batholiths, that have been brought to the surface by erosional processes in some areas of Baja (see Giganormous Maps). Many of these unique rock sequences (or terranes), can be found in both Baja and across the Gulf in Sonora.

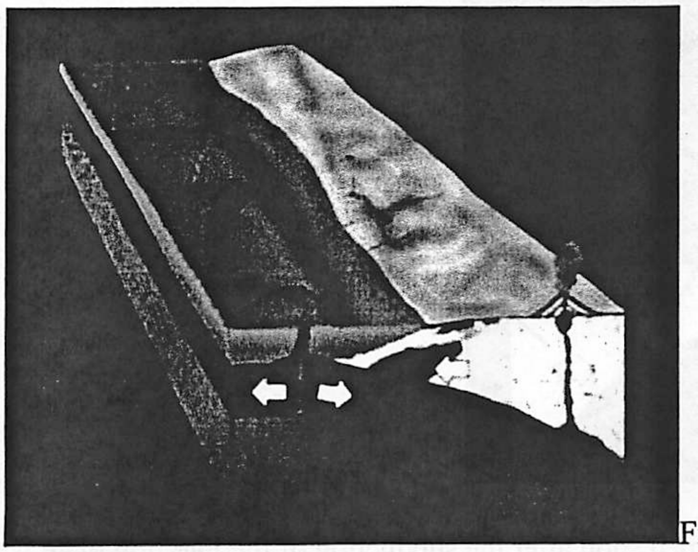


Figure 3.

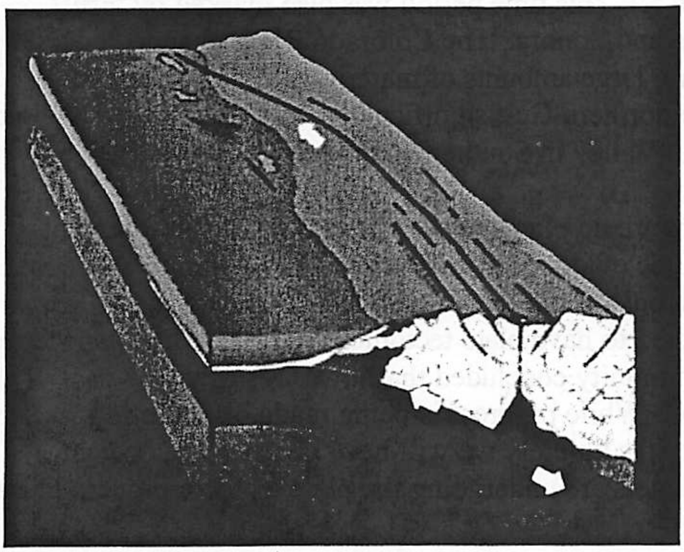


Figure 4.

In the long run, production of the Farallon plate at the Eastern Pacific Rise was insufficient to keep up with the subduction rate at the North American trench. The Rise itself was subducted (Figures 3 &4). This process also dragged the Pacific plate under a portion of the North American crustal material (Figure 4.) However, once the Farallon plate detached (15-13 million years ago, in the Miocene), the Pacific plate was not subducted further. This may all be related to the fact that the Pacific plate had changed direction about 30 million years earlier. (As demonstrated by the change in direction of the seamounts trailing out from the hotspot that is currently forming Hawaii island.) This in turn may be due to the end of the collision of India and Asia.

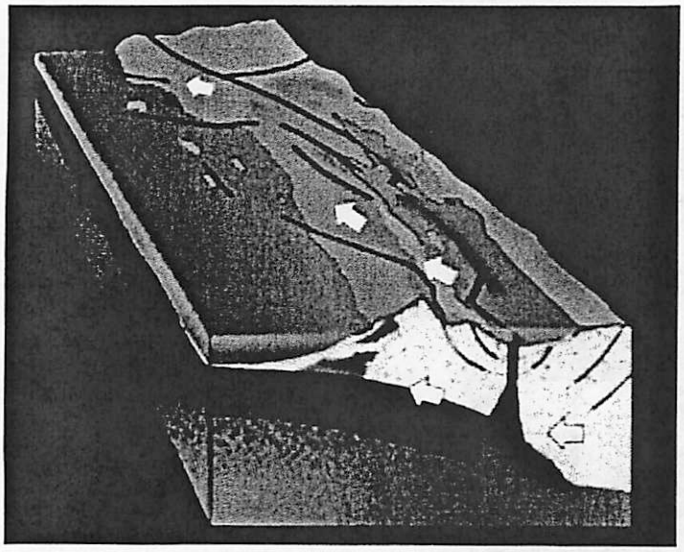


Figure 5.

The Gulf of California formed soon after the subduction of the Farallon plate was completed, however it didn't begin forming small amounts of oceanic crust at its bottom until 5 million years ago (see Figure 5.) This time period was also marked by thrust faults uplifting material in both Baja and Sonora. The Colorado River changed course around this time, and began emptying large amounts of material into the Gulf (20,000 feet in depth). This has filled in the northern Gulf significantly, as it used to extend up to the far northern end of the Coachella Valley in Southern California.

Planetary connection: There are no planetary bodies in our solar system that exhibit plate tectonics. Some magnetic evidence from Mars has been used to argue that it might have once had plate tectonics, but the interpretation of magetic data can be very model dependent. Venus was expected to have plate tectonics, but once Magellan started sending back data, the scientific community concluded that it was resurfaced approximately 200 million years ago. While progress is being made on detecting terrestrial planets around other stars, it is unlikely we will have images of sufficient quality to determine wether those planets are undergoing the plate tectonic process in our lifetime.

References: http://pubs.usgs.gov/publications/text/Hawaiian.html, a USGS publication summary

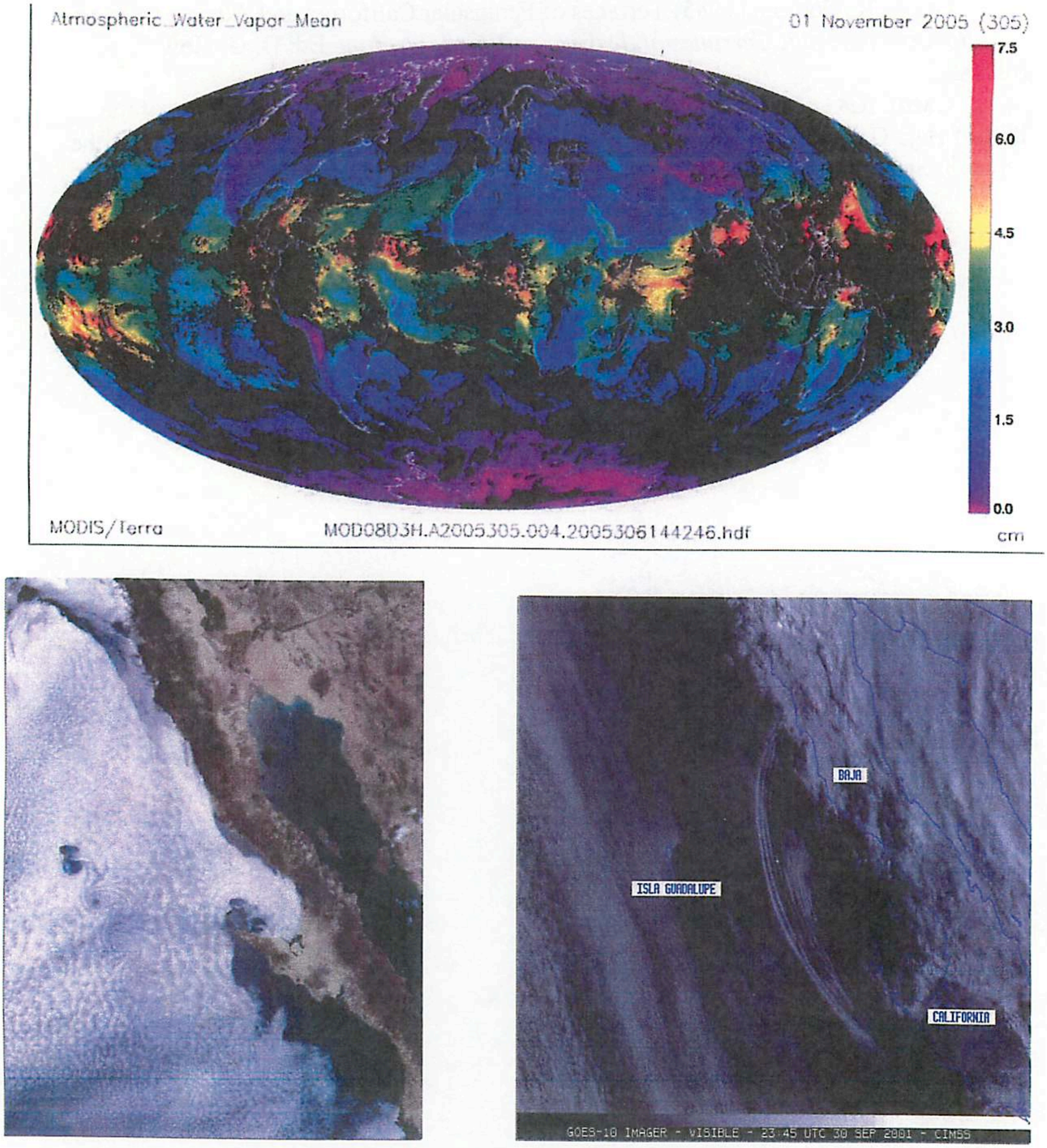
http://www.oceanoasis.org/fieldguide/geology3.html, an outreach site produced by the San Diego Natural History Museum, with text by Brad Riney.

Gastil, R. Gordon. (1985) Terranes of Peninsular California and Adjacent Sonora. In *Tectonostratigraphic Terranes of the Circum-Pacific Region.* Ed: D. G. Howell, p. 273-283.

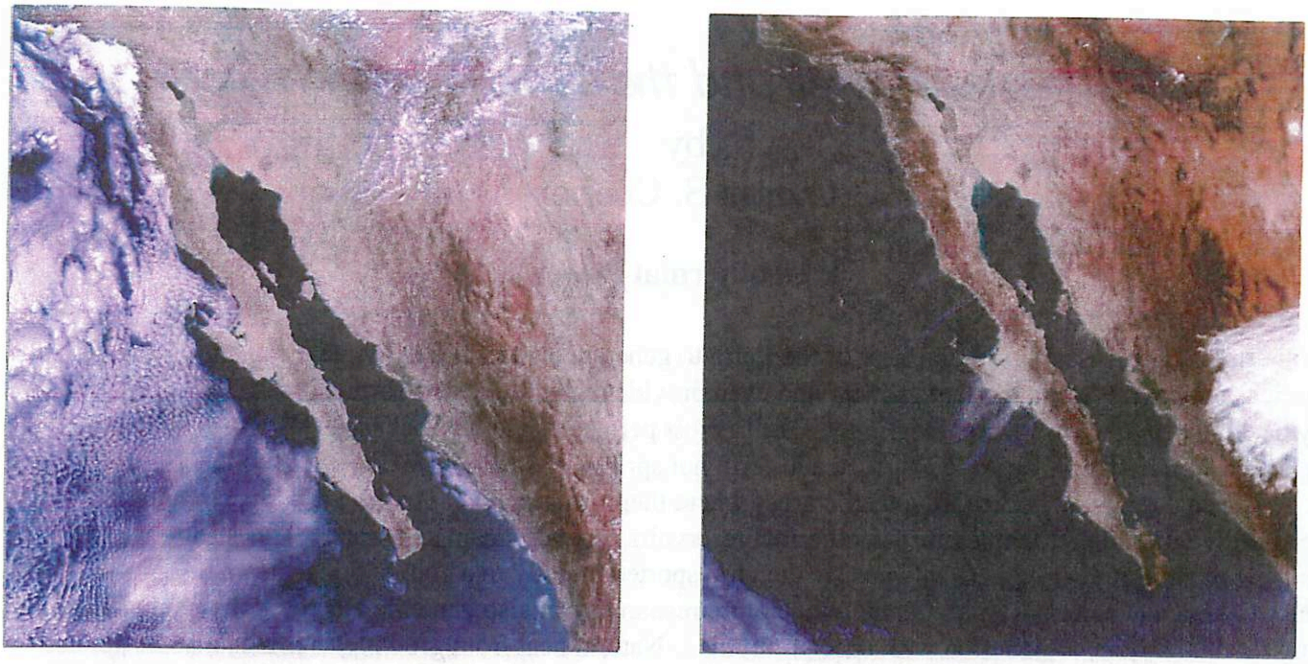
Gastil, R. G., Phillips, and Allison (1971) Reconnaisance Geologic Map of the State of Baja California (plates A, B, & C). AKA Giganormous Maps. Published by the Geologic Society of America

Baja, Mexico--Remote Sensing Overview

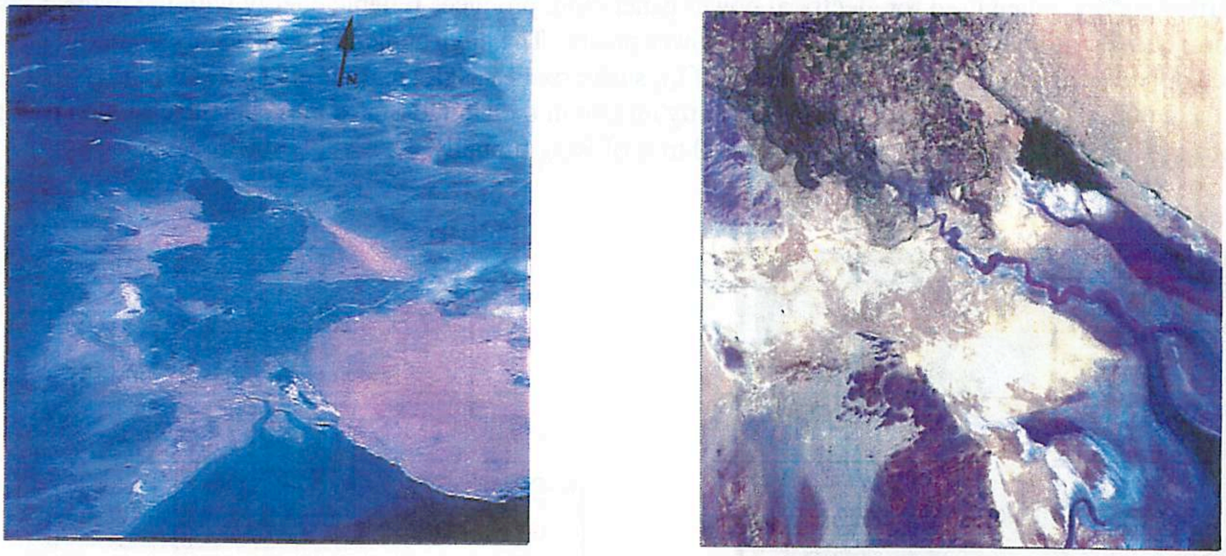
Nicole Baugh

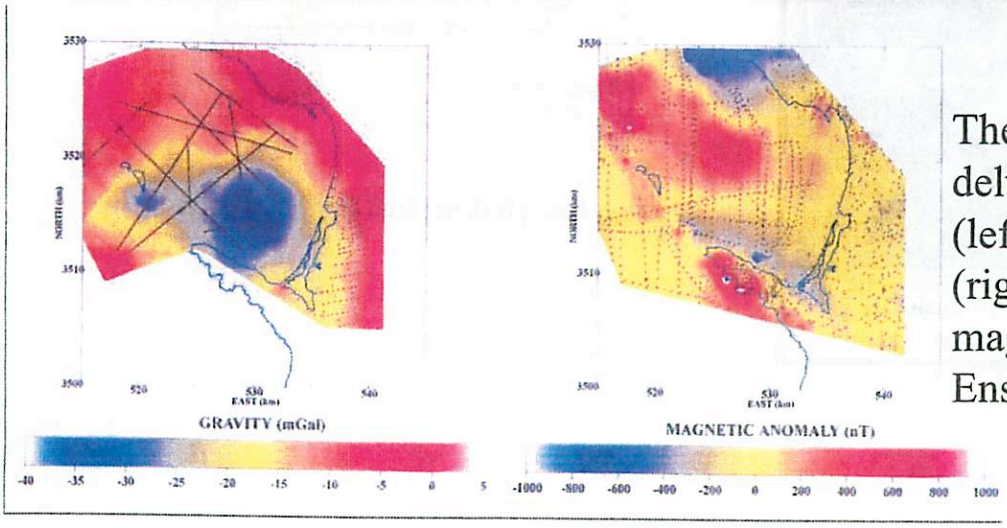


Atmospheric data from Terra MODIS (top, bottom left) and GOES (bottom right). Note the 'vortex street' in the bottom left image and the gravity waves to the right.



Satellite images from the Sea WiFS imager. Note the pytoplankton (bright green) in the left image. Several dust plumes are present in the right image.





The Colorado River delta from the shuttle (left) and from Terra (right) Gravity and magnetic data from Ensenada Bay.

Geothermal Power and the Cerro Prieto Project

by

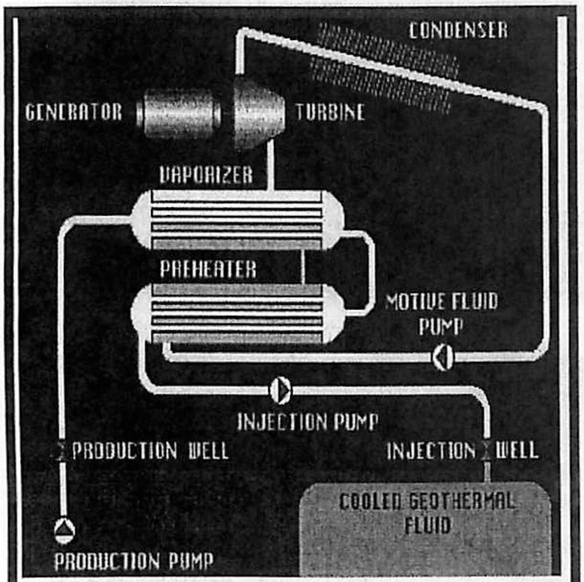
Curtis S. Cooper

I. Geothermal Power

Geothermal energy uses the natural heat of the Earth to generate electrical energy, heat residential and commerical buildings, facilitate plant growth, and even provide recreation in the form of spas. This form of energy occurs when the water contained in the Earth's crust permeates the hot rocks near the Earth's surface. These heated waters often flow to the surface and form hot springs or steam vents known as fumaroles. In most cases, geothermal reservoirs occur in volcanic areas where there is natural heat in the Earth's surface.

Wells drilled into higher temperature geothermal reservoirs produce steam and water. This steam, which results from the boiling of geothermal water, is then transported directly to a conventional steam turbine generator to generate electricity. Moderate temperature resources can also generate electricity by using heat exchange technology in conjunction with special turbines. Natural heat from ground water may also be applied directly to facilitate industrial processes, as well as heat buildings, greenhouses, and aquaculture. The currently installed capacity of direct-use systems is enough to meet the annual heating needs of 40,000 averaged-sized houses.

Geothermal energy, when used for electrical power generation, produces reliable energy with life cycle costs that are competitive with those of natural gas-fired power plants. The environmental benefits of geothermal energy include lower emissions of carbon dioxide (CO_2), sulfur oxides (SO_X) and nitrogen oxides (NO_X). For example, the 2,600 MW of geothermal energy currently on line in the United States prevents the emission of 22 million tons of CO_2, 200,000 tons of SO_X, and 80,000 tons of NO_X annually.



ORMAT® Energy Converter for sustainable geothermal power generation

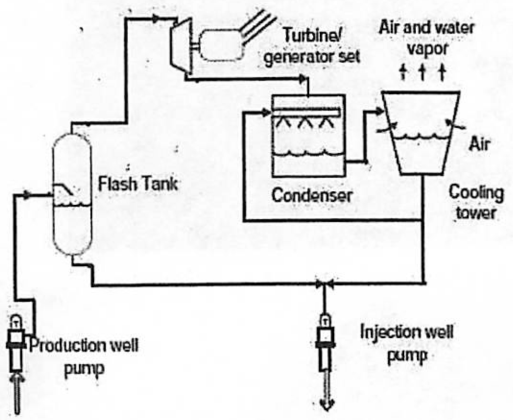


Fig. 1: Example flash-steam geothermal power plant.

The diagrams above show schematics of typical geothermal plant configurations. When the temperature of the hydrothermal fluids is over 177°C, flash-steam technology is generally employed. This is by far the most common type of geothermal plant. In these systems, most of the liquid is flashed to steam. The steam is separated from the remaining liquid and used to drive a turbine generator. While the water is returned to the geothermal reservoir, the economics of most hydrothermal flash plants are improved using a dual-flash cycle, which separates the steam at two different pressures. The dual-flash cycle produces 20-30% more power than a single-flash system at the same fluid flow.

II. The Cerro Prieto Project

Mexico's first geothermal power unit was the Cerro Prieto Geothermal Field in northern Baja. It started operation in April, 1973. Cerro Prieto ("black-mount" in English) is the name of a volcano northwest of the Cerro Prieto Geothermal Field. The volcano rises 260 m above sea level. Owing to its prominence, the name is given to the whole area, although the volcano itself has nothing to do with the geothermal field.

The field lies at only 6-7 m above sea level in the alluvial plain of the Mexicali Valley, an arid region with extreme ambient temperatures ranging from -2°C in winter to 47°C during the summer. The geothermal field covers an area of approximately 15 km^2. From a tectonic viewpoint, it lies in a "pull-apart" basin of the San Andreas Fault system, limited by two important right strike-slip faults, the Imperial and the Cierro Prieto. These NW-SE oriented faults are interspersed with several NE-SW faults that act as collectors of geothermal fluids. The heat source is a regional anomaly resulting from the thinning of the continental crust at the bottom of the basin. The heat—along with hydrothermal fluids—is transferred through Late Cretaceous, granitic basement rocks to deep aquifers within Tertiary sandstones and shales.

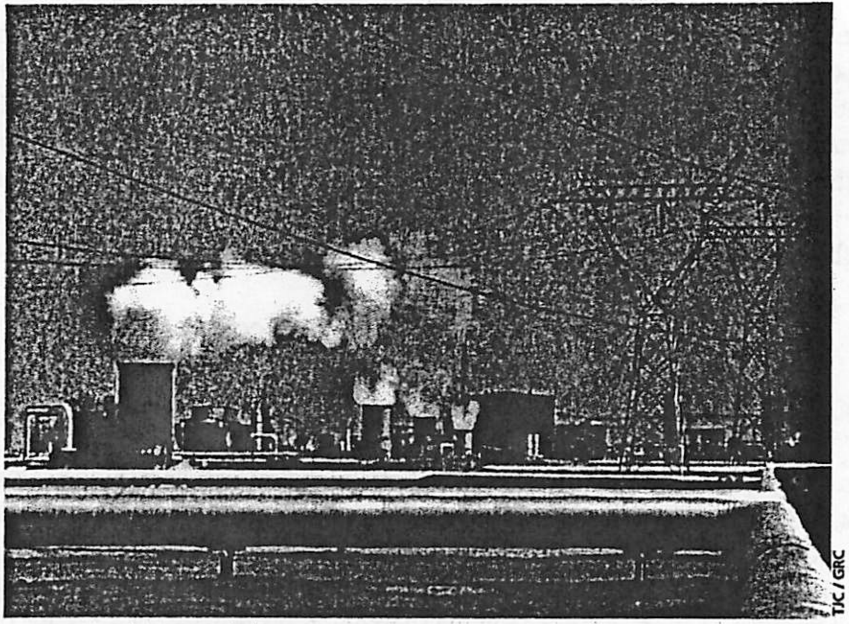
Presently, there are 13 power units in operation, grouped into four powerhouses (CPI through IV) with a total installed capacity of 720 MW. The power units have distinct capacities, ranging between 25 and 110 MW. The last four 25-MW units at CPIV were commissioned in July, 2000. The geothermal field has more than 120 km of steam pipe; 40 km of pipe and 60 km of channels to channel brine, and 10 km of pipe to conduct non-separating fluids (mixing).

During 2002, there were 180 production and 13 injection wells in operation at Cerro Prieto. The wells produced 47.6 million metric tons of steam at an annual average rate of 5,430 metric tons per hour. In addition, 72.3 million metric tons of geothermal brine were produced and disposed of by injection and evaporation. Evaporation takes place in a solar pond with a surface area of 18 km^2.

Total electricity generated at Cerro Prieto in 2002 was 4,934 GWh. This electrical generation supplied more than 50 percent of total demand for all of Baja California, which has a power transmission system that is isolated from the national electric grid.

During the last three decades, more than 870 million metric tons of steam and 1,300 million metric tons of brine have been extracted from the Cerro Prieto geothermal system, totaling approximately 2.5 km^3 of fluids. The volume is greater than the total of geothermal fluids (>250°C) estimated in the reservoir by some older and more conservative studies (1.6 km^3). More than 90,000 GWh of electricity had been generated at the Cerro Prieto Geothermal Field through the end of 2002.

Geothermal-electric generation during 2002 was 5,398 GWh, constituting 3 percent of total public service power generation in Mexico (178,510 GWh). Though this figure may seem small compared to total electricity generation in Mexico, it must be remembered that geothermal power development plays an important local role for the country. For instance, power produced at Cerro Prieto during the last three decades has supplied an average of 65 percent of regional demand in Baja California. During 10 of those 30 years, approximately 30 percent of the geothermal power produced at Cerro Prieto was exported to California through a long-term contract.



TK / GRC

Cerro Prieto Geothermal Field.

III. A Planetary Connection? Maybe.

Establishing human colonies on other planets is a long-term dream of the space program in this country and others. Is the use of geothermal power to support human settlements a possibility on Mars? Maybe. Hartmann (2001) suggests that localized geothermal activity may have played a role in Mars' geology. I don't think it is known for certain whether usable geothermal fields exist on Mars today. It is possible perhaps also that in the very distant future ways to harness the heat energy of Io will be discovered?! For more near-future applications, though, it doesn't seem likely based on our current understanding of the rapid cooling of low-mass bodies that geothermal resources will be available to facilitate mining or habitation of the Moon, asteroids, comets, etc.

References

CFE of Mexico, "Geothermal power": http://www.cfe.gob.mx/en/LaEmpresa/generacionelectricidad/termoelectrica/geotermoelectrica/
Darling, David, "Flash-steam geothermal plant:" http://www.daviddarling.info/encyclopedia/F/AE_flash-steam_geothermal_plant.html
DiPippo, R. (1999), "Small Geothermal Power Plants: Design, Performance, and Economics," *GHC Bulletin*
Hartmann, William K. (2001), "Martian Seeps and their Relation to Youthful Geothermal Activity," *Space Science Reviews*,,**96**, 405H
Hiriart, G. and Andaluz, J.I. (2000), "Strategies and Economics of Geothermal Power Development in Mexico," *Proceedings World Geothermal Congress*
Kutscher, Charles F., "The Status and Future of Geothermal Electric Power," Proceedings of the American Solar Energy Society Annual Conference, June 2000
Lund, J.W., "The Basics of Geothermal Power Conversion:" http://www.bgr.de/veransta/renewables_2004/presentations_DGP/Block1Introduction_pdf/3_Lund.pdf
Serrano, J.M.E. Vaca (1998), "Mexican Geothermal Development and the Future," *Energy Sources*, **20**, 743-751
Quijano-Leon, Jose L. and Gutierrez-Negrin, Luis C.A., "30 Years of Geothermal-Electric Generation in Mexico," GRC Bulletin.Sept./Oct. (2003)
World Energy Council, "Geothermal Energy": http://www.worldenergy.org/wec-geis/publications/reports/ser/geo/geo.asp

Mudpots, Fumaroles, and Geysers
by David "The Editor" Choi

PTYS 594A: Baja California Field Trip, 9-13 November 2005

Abstract

Mudpots, fumaroles, and geysers are surface features that form as a result of a planetary body's interior heating. This interior heating is mainly left over from the formation of the Earth (gravitational binding energy) or from radioactive decay (on Earth: uranium, thorium, and potassium ... estimated to contribute 45-85% of the overall heating). These features are simply another mechanism for the Earth's inherent heat to escape from the interior. These features are quite similar to one another and essentially differ in the degree to which water is involved.

Fumaroles

Fumaroles are simply vents and openings in the crust of Earth that emit steam and other volcanic gases. Fumaroles are (not surprisingly) often found near volcanoes.

Examples On Earth:
-Valley of Ten Thousand Smokes, Alaska (extinct)
-Yellowstone National Park, Wyoming
-Cerro Prieto Geothermal Field: i.e. the thing we're passing through in our travels.

On Io: theorized to exist from spectral data, where sulfur compounds detected are suggested to be of fumarolic origin (yes, apparently "fumarolic" is a word).

Mudpots (or "solfatare")

Mudpots are areas of hydrothermal activity where a minimal amount of water heated at depth comes into contact with the soil and dirt at the surface, forming a viscous mud slurry. Often the mud boils over the vent and can form a structure that resembles a volcano. These are often named "mud volcanoes" but actual mud volcanoes are a different beast altogether.

Earth examples:
-Yellowstone
-Cerro Prieto

Planetary connection:
-Early in Martian history, perhaps? Otherwise, unlikely.

Geysers

Geysers are vents where hot water and steam erupt periodically. This feature is relatively rare because they require an abundant water supply, a heating source, and unique "plumbing" underground. It is usually the latter condition that limits the number of geysers. About 1000 exist worldwide, with nearly half in Yellowstone National Park. Rhyolite and similar silica-laden rocks have been identified as conducive to forming geysers due to their ability to form a water-tight seal in the underground plumbing.

Physics / Mechanism:

-Groundwater trickles down where it meets rock heated by magma, so the water temperature begins to rise. Typically this water collects in a deep underground reservoir. The water is trying to convect, but the narrowness of the reservoir/channel means that it cannot do so effectively. A cold water layer at the top means that pressure builds, which leads to superheating of the water.

-Eventually the pressures and temperatures build up to a point where steam and water flow out of the vent. As the superheated water reaches the surface, this leads to a release of pressure and a chain reaction where the superheated water can turn into steam, violently spraying out through the vent (along with hot water)

-Hot water and steam flow until the geyser cools back below the boiling point, the eruption ends, and the cycle begins again.

Planetary Connection:

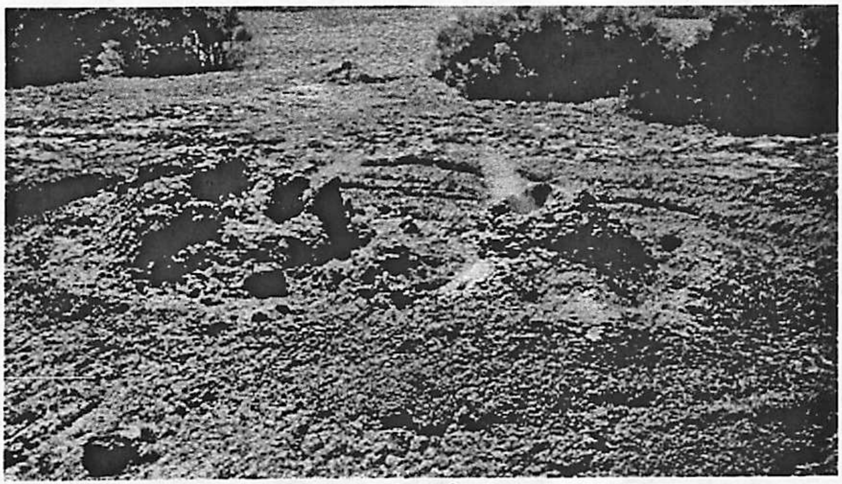
-There are "geysers" on Triton, except that these are erupting columns of gaseous nitrogen. Also, these features on Triton are driven mainly by solar heating (as most were located between 40 and 60 degrees South, corresponding to the subsolar point), but internal heating through tidal forces from Triton's retrograde motion may play a role.

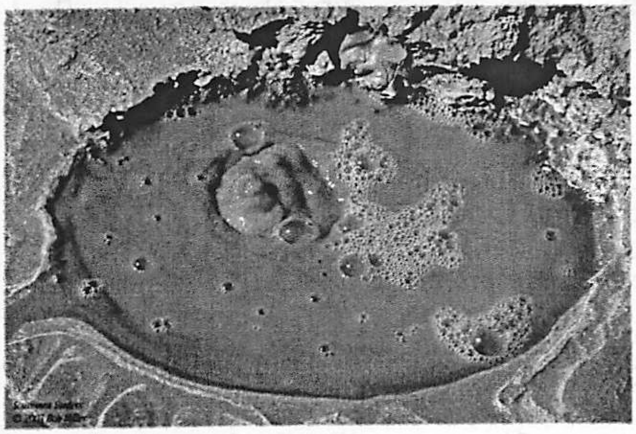
-The solar heating process involves a subsurface greenhouse environment, where the heating of nitrogen ices can lead to an explosive venting of nitrogen gas, forming a geyser-like feature. Only a 4 K temperature increase is necessary to acheive the required eruption parameters. The erupting column can reach 8 km high and deposit material almost 150 km downstream.

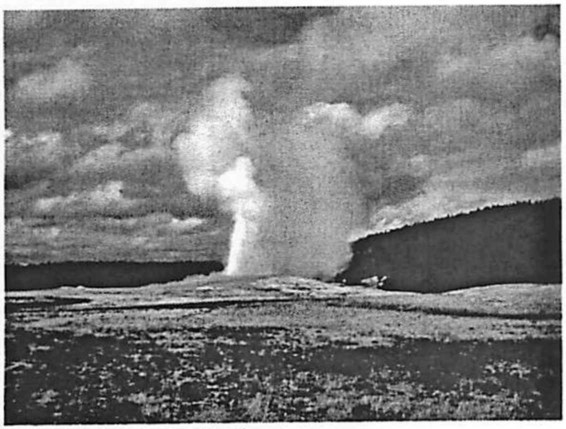
-Geyser-like jets on comets: Observations of Comet 19/P Borrelly reveal "several highly collimated dust jets emanating from the nucleus". Geyser flow is theorized to be supersonic. Essentially, a subsurface cavity contains gas which builds up in pressure and escapes through a narrow orifice on the surface.

-Geysers as strictly defined to be like the ones are Earth are most likely certainly unique to our home planet. The wild speculation regarding geysers on other planets early in their history is left as an exercise for the reader.

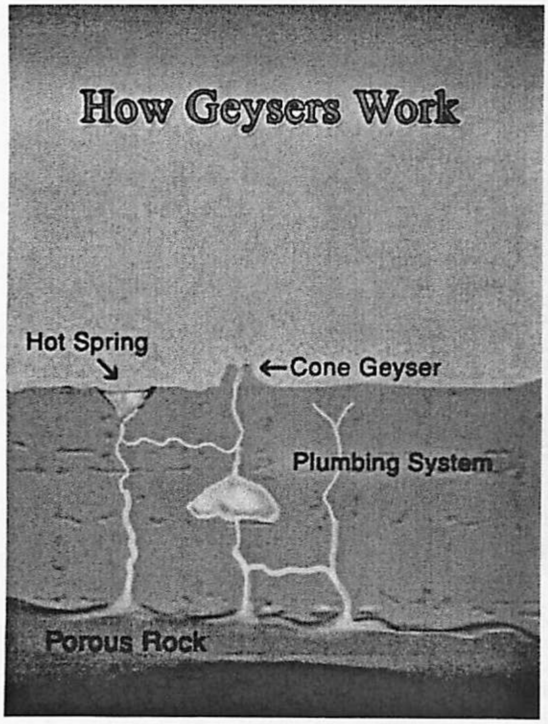
Pictures

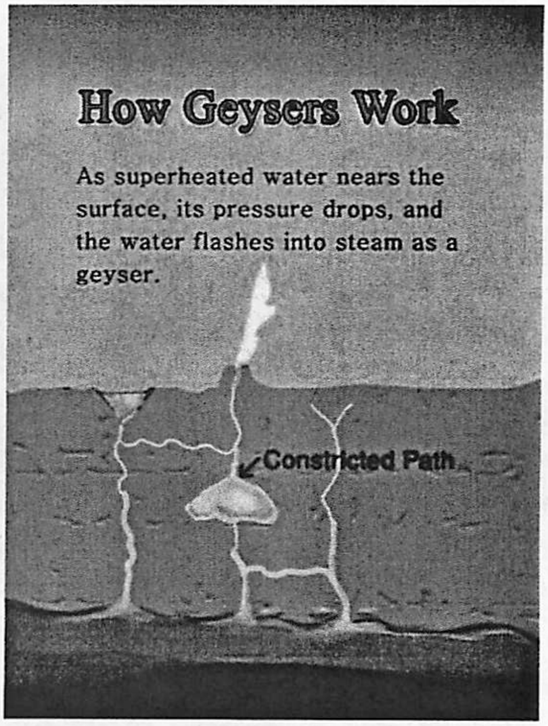

A fumarole (from Cerro Prieto)


A mudpot


Old Faithful, Yellowstone


Triton "geysers"





As superheated water nears the surface, its pressure drops, and the water flashes into steam as a geyser.

Sources

http://en.wikipedia.org/wiki/[Insert Topic from above here]
http://www.sandiegogeologists.org/Geothermal3.html
http://www.uweb.ucsb.edu/~glennon/geysers/
http://www.nps.gov/yell/nature/geothermal/geysers.htm

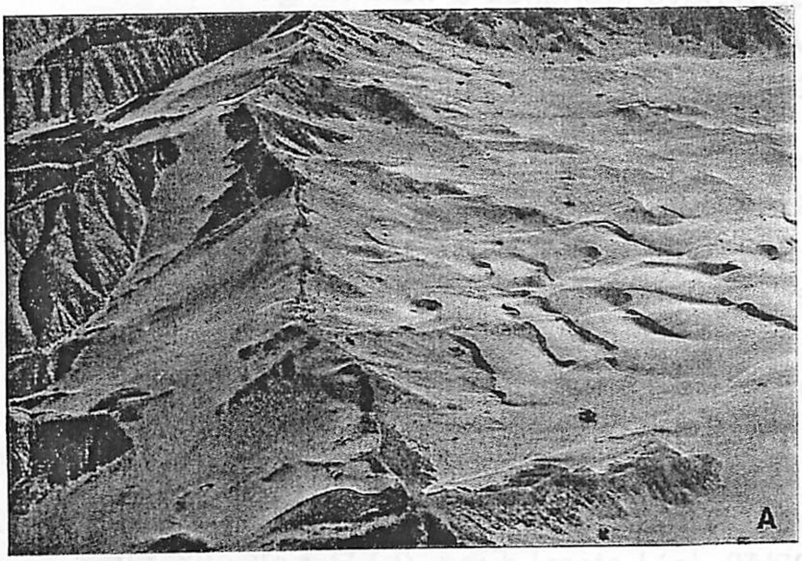
Greeley, Theilig, and Christensen. The Mauna Loa sulfur flow as an analogue to secondary sulfur flows on Io. *Icarus* (**60**) 189-199, 1984.

Soderblom, et al. Triton's geyser-like plumes - Discovery and basic characterization. *Science*. (**250**) 410-415, 1990.

Yelle, Soderblom, and Jokipii. Formation of jets in Comet 19P/Borrelly by subsurface geysers. *Icarus*. (**167**) 30-36, 2004.

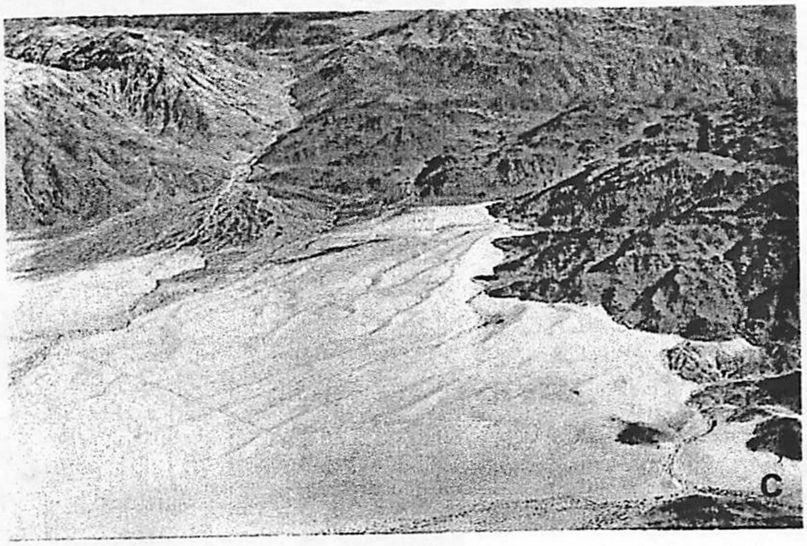
Climbing Dunes

Serina Diniega



Description:

- accumulations of loose, well-sorted, very fine to medium sand (about 0.06-0.5 mm)
- piled up against a rock face (cliff or steep hill) and are encroaching on its summit
- range in size from a meter or two to hundreds of meters in height and breadth
- oncoming dunes are usually barchan
- occur on slopes of about 30-50°
- have well-packed steep upwind slopes
- commonly have an uncrossable moat between the leading dune and the cliff face
- winds are strong and virtually unidirectional

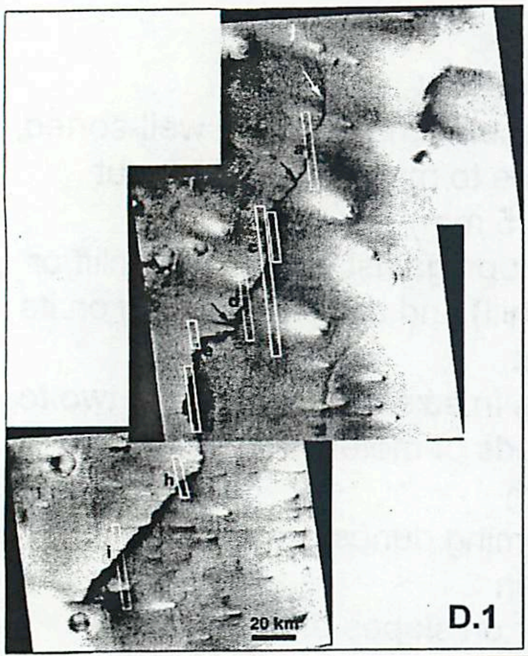


A – falling dunes on left; climbing dunes on right; aerial-oblique photo; north of Lima, Peru
B – climbing dunes; ground photo; north of Lima, Peru
C – climbing dunes; aerial-oblique photo; Mojave Desert, CA

http://www.tec.army.mil/research/products/desert_guide/lsmsheet/lsclimb.htm

On Mars:

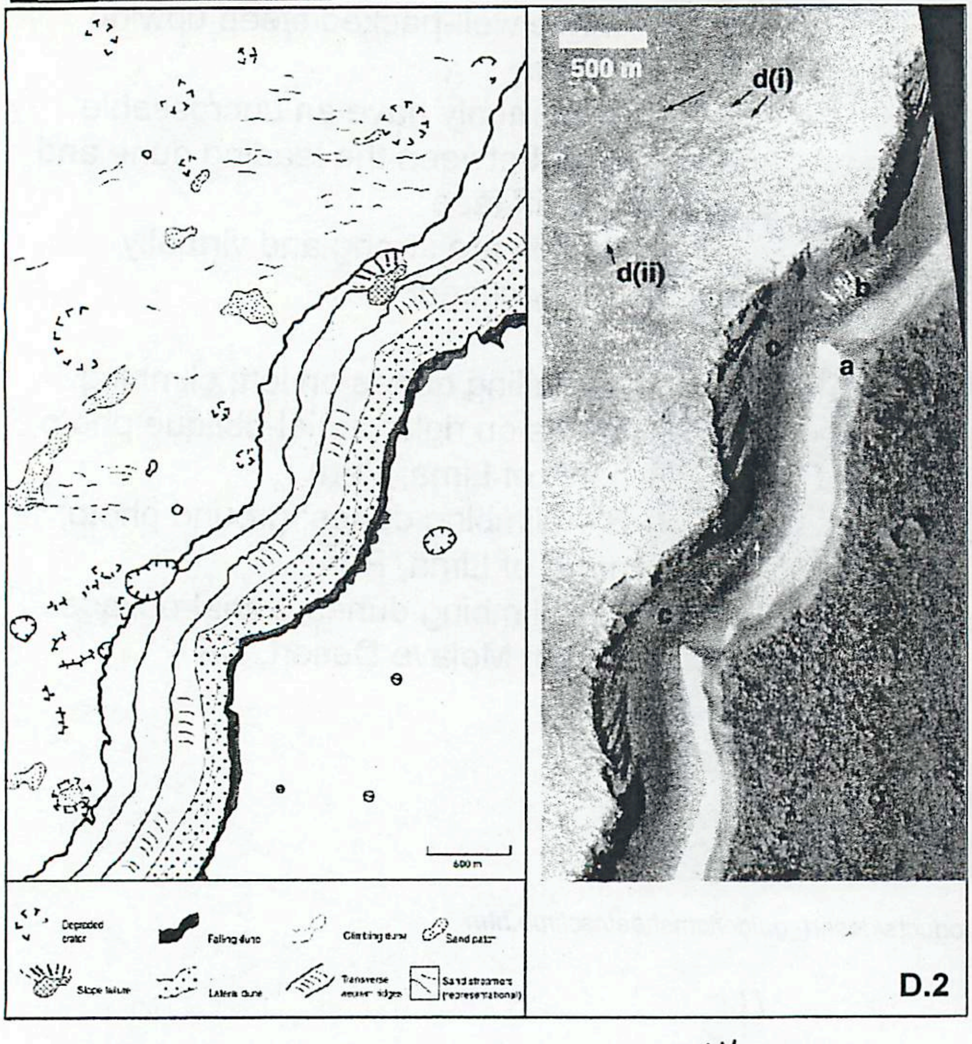
Bourke, et al. (2004, *Aeolian sediment transport pathways and aerodynamics at troughs on Mars*, **JGR**, vol. 109, E07005) have identified a wide range of aeolian sediment deposit type landforms on Mars, including climbing dunes. These link dunes inside of the trough with sand transport landforms on the downwind surface.



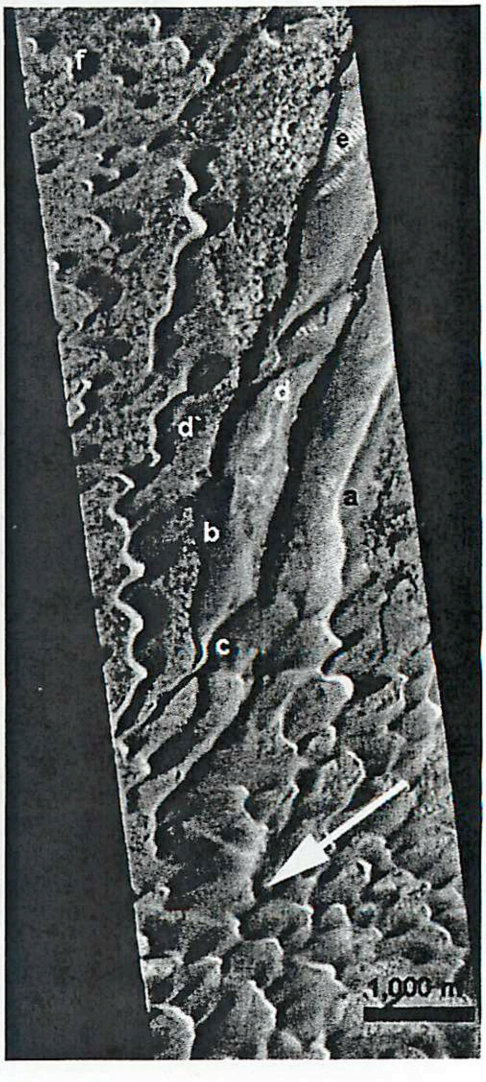
D.1

D.1 – mosaic of MOC wide-angle images of Arnus Vallis (12.3-15.28°N, 290.12-288.75°W). (e) is D.2. D.2 – (a) A large lateral dune extends along the eastern trough wall. (b) Transverse aeolian ridges are aligned along the trough floor, and **(c) hypothesized sand ramps** climb up the western trough wall. (d) Drift deposits: (i) sand streamers and (ii) sand patches.

E - Trough and dunes in Nili Patera Caldera (8.99N, 293.29W). (a) Lateral dune. **(b) Broad climbing dune**. (c) Linear extension from a transverse dune. Linear dune (d) supplies sediment to barchanoid ridge (d') on the downwind surface.



D.2

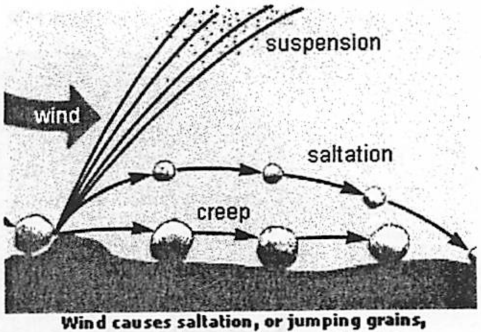


Some Background Information about Dunes:

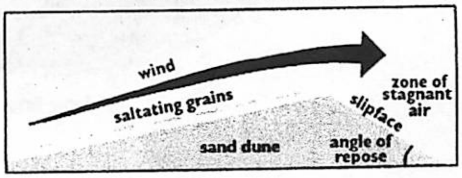
Dune formation requires sand, wind, and an obstacle (to cause initial accumulation). Dune motion and shape depends mostly on sand availability and wind direction.

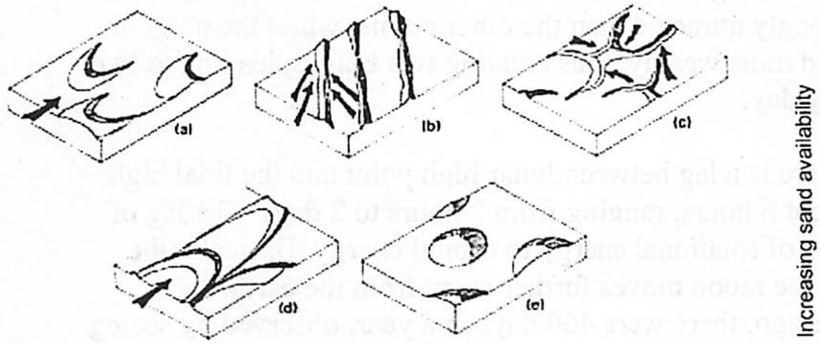
Typically dunes have a low slope face, called the windward face, that faces the wind direction and a steeper face, called the slip face, which points downwind, as shown below. Dunes move by wind eroding sand from the windward face by pushing it and bouncing the sand (saltation) along the windward face until it reaches the top of the dune. It is deposited along the slip face, which in effect moves the slip face forward in the direction of the wind.

http://www.nasaexplores.com/show2_articlea.php?id=04-201
http://pubs.usgs.gov/gip/deserts/eolian/

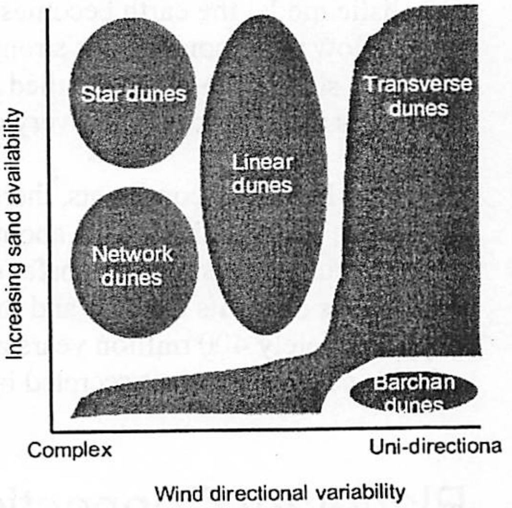


Wind causes saltation, or jumping grains, on the windward side of sand dunes.





Major types of sand dunes: (a) **barchan** or **crescent dune**; (b) **linear** or **longitudinal dune**; (c) **star dune**; (d) **parabolic** or **blownout** or **transverse dune**; (e) **dome dune**



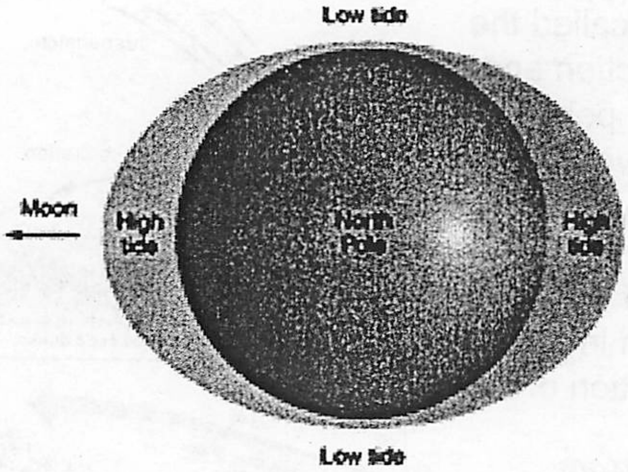
http://rst.gsfc.nasa.gov/Sect17/Sect17_5.html; http://www.geog.ucl.ac.uk/~hmomiji/environ.htm

Coastal Sand Dunes (based on location, motion):
bay dune: where sand is trapped between two headlands
spit dune: forming as a sandy promontory at the mouth of an estuary
hindshore dune: where sand is blown some distance inland over low-lying ground
ness dune: building out from the coast
tombolo: where sand is deposited in a narrow connection between the mainland and an island, or between two islands
climbing dune: where sand is piled against and moving onto a cliff or high ground
offshore island dune: where a small island has become the base for sand deposition

http://www-biol.paisley.ac.uk/bioref/Habitats/Dunes1.html

Tides

Maki Hattori



Differential gravitational forces across a body cause tides. As seen above, in the most simplistic model the earth becomes elongated in the direction of the lunar axis. The point right below the moon is more strongly attracted than the other points, while the point on the other side of the earth is pulled most weakly, thus creating two bulges, leading to two high tides and two low tides every day.

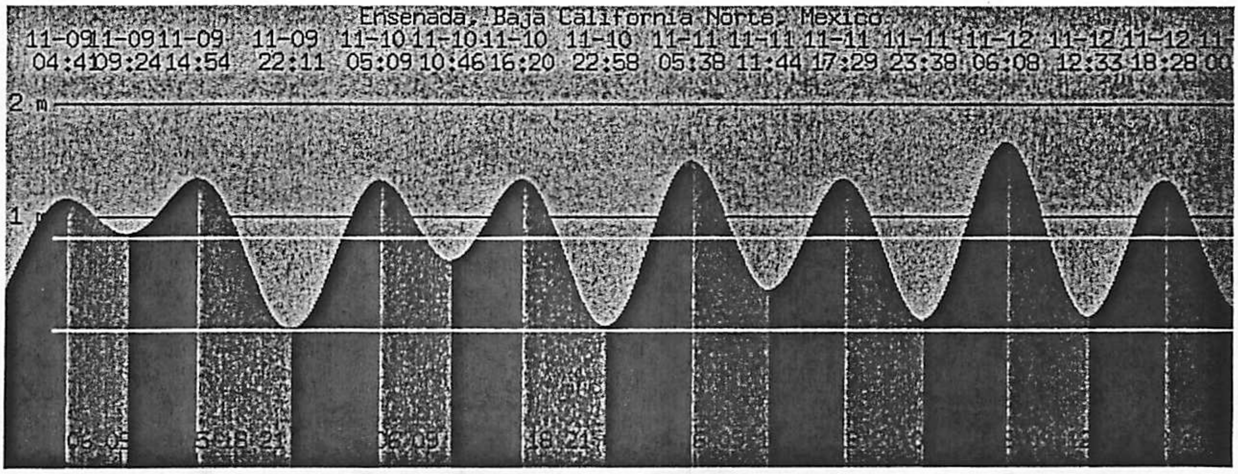
Since the Earth has continents, there is a lag between lunar high point and the tidal high point. The average tidal lag is about 6 hours, ranging from 2 hours to 2 days. The lag of the tidal bulge leads to the transfer of rotational energy to orbital energy. Basically the earth slows down its rotation and the moon moves further away from the earth. (Approximately 400 million years ago, there were 400 days in a year, observed by seeing calcium carbonate layers secreted by corals.)

Planetary Connection:

Tidal heating: Ex. Io:

Tidal locking of systems: Orbital and Rotational motion of 2 objects are locked causing one side of the orbiting object to always face the same side of the rotating object. The moon is tidally locked to the earth which is why we see only half of the moon.

Roche Limit: The distance from a body inside which the differential gravitational force is so large that an object held together only by gravitational forces is broken up. Ex. Rings of Saturn.

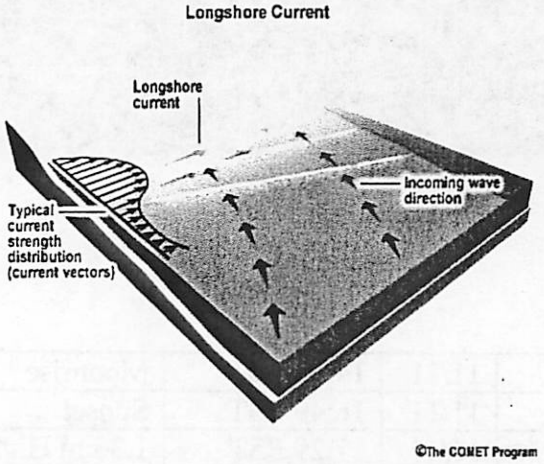


11/09	13:17 PST	Moonrise	11/11	14:20 PST	Moonrise
11/09	14:54 PST	1.34 m High Tide	11/11	16:49 PST	Sunset
11/09	16:50 PST	Sunset	11/11	17:29 PST	1.33 m High Tide
11/09	22:11 PST	-0.00 m Low Tide	11/11	23:38 PST	0.08 m Low Tide
11/10	00:26 PST	Moonset	11/12	02:38 PST	Moonset
11/10	05:09 PST	1.32 m High Tide	11/12	06:08 PST	1.66 m High Tide
11/10	06:10 PST	Sunrise	11/12	06:12 PST	Sunrise
11/10	10:46 PST	0.61 m Low Tide	11/12	12:33 PST	0.11 m Low Tide
11/10	13:50 PST	Moonrise	11/12	14:49 PST	Moonrise
11/10	16:20 PST	1.33 m High Tide	11/12	16:48 PST	Sunset
11/10	16:49 PST	Sunset	11/12	18:28 PST	1.32 m High Tide
11/10	22:58 PST	0.02 m Low Tide	11/13	00:14 PST	0.17 m Low tide
11/11	01:32 PST	Moonset	11/13	03:43 PST	Moonset
11/11	05:38 PST	1.49 m High Tide	11/13	06:13 PST	Sunrise
11/11	06:11 PST	Sunrise	11/13	06:38 PST	1.79 m High Tide
11/11	11:44 PST	0.35 m Low Tide	11/13	13:18 PST	-0.09 m Low Tide

From Tide/Current Predictor: http://tbone.biol.sc.edu/tide/

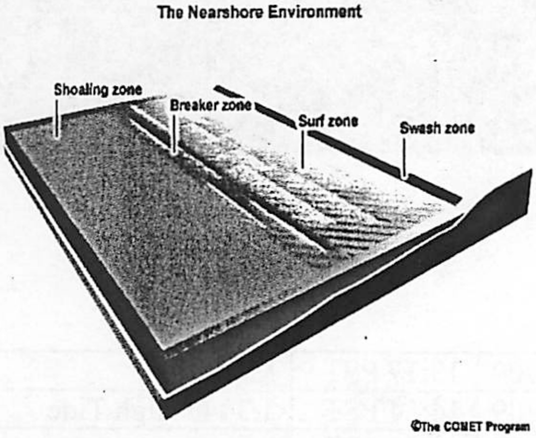
Longshore Currents
Kerri Donaldson Hanna

Definition: Waves that approach a shoreline at an oblique angle and then break in the surf zone will produce a longshore current and drift. Longshore currents are more prevalent along lengthy, straight coastlines.



©The COMET Program

Figure 1. Longshore Current Diagram



©The COMET Program

Figure 2. Nearshore Environment diagram

Shoaling Zone – This region marks the transition from deep to shallow water. In this zone the depth of the water is less than half of its wavelength and the vertical orientation of the wave changes as it begins to feel the effect of the ocean bottom.

Breaker Zone – The region where waves arriving from offshore continue to increase in steepness until they become unstable and break. Not all waves break in the same location due to wave height variation.

Surf Zone – As the waves begin to break they enter the surf zone where water is transported to the beach in the form of smaller, broken waves known as bores. A bore can be thought of as a continuously breaking wave.

Swash Zone – As bores reach the beach, water particles are pushed onshore and then retreat seaward. This area of run-up of wave swash and backwash is the swash zone.

Longshore Current Generation:

As a wave front enters shallow water, the leading edge of the waves hits the shallow water sooner than the rest of the wave front and slows down, bending the wave as it moves ashore. When these waves break, the water continues to rush up the beach at the same angle as the waves (known as swash), but when it stops it runs back down the beach along the greatest slope as backwash. This swash/backwash motion will result in a zigzag movement of the water with a net direction that is the same as the approaching waves and will produce a longshore current.

The speed of the longshore current increases by:

(1) increasing the wave height
(2) decreasing the wave period
(3) increasing the angle of the wave front to the beach
(4) increasing the beach slope.

Peak currents occur when the wave approaches from 45 degrees. Higher or lower angles produce slower currents. Waves breaking parallel to the shoreline will have no longshore current generated by the wave angle. Once established the current moves at a speed of about one knot in the same direction as the advancing wave train. Longshore currents are subtle but can be seen or felt while standing in the surf zone.

Longshore currents span the entire width of the surf zone and reach their maximum strength in the middle of the surf zone. The strength of the current diminishes as it moves farther offshore (Figure 1).

Large-scale currents moving at slower speeds in the nearshore can also be generated from persistent synoptic-scale winds as opposed to locally-breaking waves, but the dominant reason for longshore currents is the motion of the wave hitting the beach at an oblique angle.

Longshore Drift:

Breaking waves disintegrate into churning sheets of water called swash that carry sediments up onto the beach at the oblique angle that the wave is moving at. Backwash carries the sediment away from the beach at 90 degrees perpendicular to the shore. The sediment moves downcoast in a zigzag path with the net transport of the sediment in the direction of the longshore current. The sediments are later deposited along the coastal shoreline. A sand spit is where sediments are deposited from a point of land along the direction of the longshore drift. A bay mouth bar or barrier is where the spit extends across a bay. A tombolo is where a spit extends between an island offshore and the land. A barrier island is when sediments are deposited parallel with the shoreline.

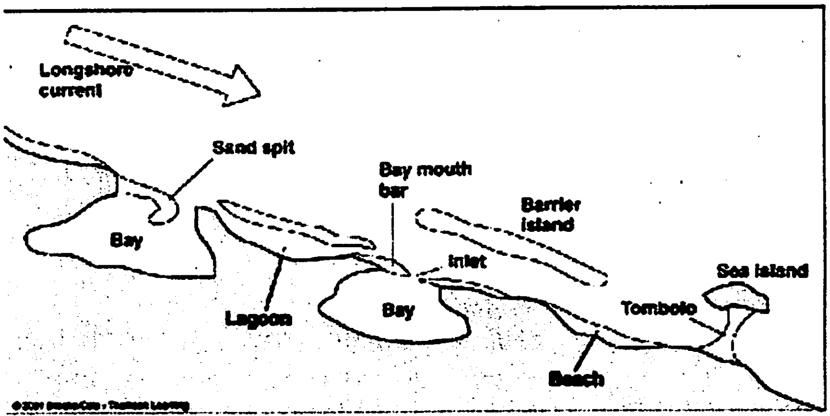


Figure 3. Examples of marine deposits from longshore drift.

Many of these deposits can be observed along the Baja California coastline.


Figure 5. Sand spits


Figure 6. Bay mouth bar and lagoons

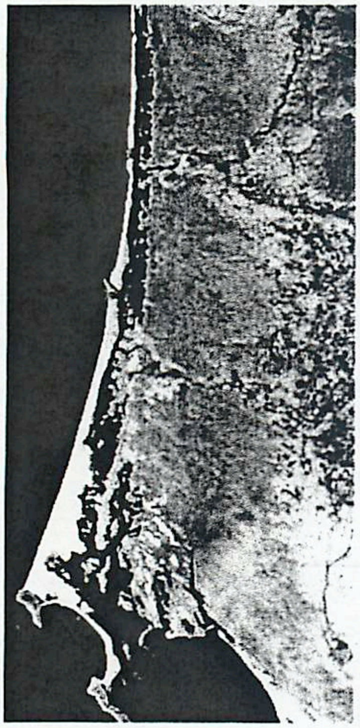
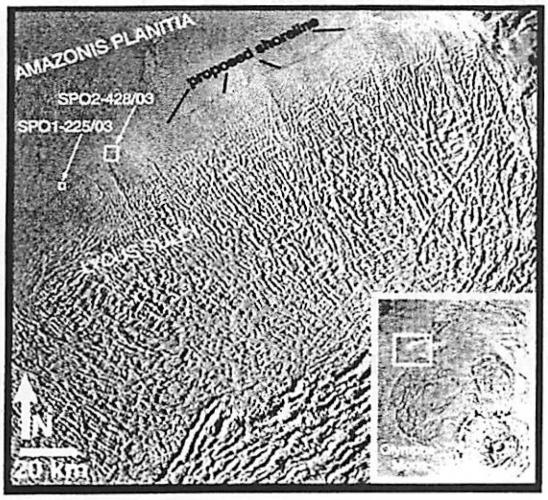


Figure 7. Island barriers, sand spit and beaches

Longshore Currents on Other Planets:
Since longshore currents are created by oblique wave action along a shoreline it would be necessary for a planet to have an ocean to observe this phenomenon on other planets. Currently it is under debate if the Martian surface once contained an ancient ocean. In particular a region in the Amazonis Planitia is being analyzed for a possible shoreline (Figure 8). A high resolution MOC image of the proposed shoreline indicates no visible

evidence of a shoreline (Figure 9). Using high resolution images such as MOC the proposed shorelines of the ancient oceans could be imaged and analyzed for deposits similar in nature to those of longshore drift.



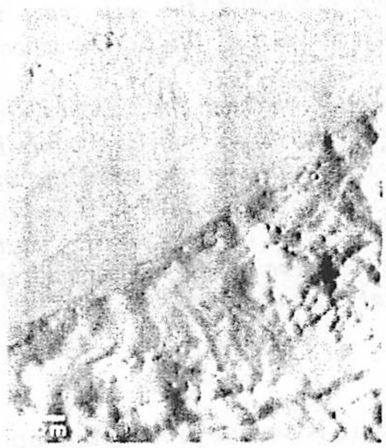


Figure 8. Proposed shoreline of ancient ocean

Figure 9. MOC image SPO2-428/03 of shoreline

Both images courtesy of NASA/JPL/Malin Space Sciences System

References:

Fisher, J.S and Dolan, R., Beach Processes and Coastal Hydrodynamics. 1997

Knowles, E., The Shore, Coastal Waters & Marginal Seas. http://www4.ncsu/edu/eos/users/c/ceknowles/public/chapter12/part1.html

Komar, P.D., Beach Processed and Sedimentation, 2nd edition. 1998.

MetEd, Rip Currents: Nearshore Environment Home. http://meted.ucar.edu/marine/ripcurrents/NSF/print.htm

Adventures in Boredom

Ralph D Lorenz

Britain is almost devoid of spectacular natural phenomena of the active sort, and, on balance is the pleasanter for it. An odd glacier or geyser here and there might not be unwelcome, but who wants volcanos, earthquakes, typhoons, cyclones and the like?.......But we have the bore - that relentless moonchild, the eerie wave that glides, sweeps and crashes its way upstream through the lower reaches of the Severn when tides are high...' Rowbotham, 1964

Shortly after the after the tide had stopped running out they saw something coming toward them from the ocean in a long white line, which grew bigger and whiter as it approached. Then there was a sound like the rumbling of thunder which grew louder and louder as the white line came nearer until it seemed as if the whole ocean had risen up, and was coming churning and thundering down on them, boiling over the edge of this pile of water like an endless cataract, from four to seven metres high, shat spread out across the whole Eastern horizon. This was the pororoca! Branner, 1884

A tidal bore is a wave propagating up a river estuary, heralding the turn of the tide. The bore, unlike regular seaside waves, is essentially solitary (although is often followed by some smaller waves) and the water level continues to rise after it.

A tidal bore is a direct analog in hydrology of a shock wave in aerothermodynamics: a disturbance (the rising tide/Concorde) is being forced through a medium (the estuary/the air) faster than the medium can allow a perturbation (a gravity wave/a sound wave) to propagate. As a result, there is a sharp boundary (bore/sonic boom) across which the state properties of the medium (depth/P,T) have a discontinuity.

The requirements for a bore are a high amplitude tide (thus typically in a resonant basin, like the Bay of Fundy) and a shallow-sloped estuary, such that the projected high-water mark can propagate rapidly. Some shallow seashores, e.g. that at Mont Saint-Michel in France, and the Solway Firth in Scotland, have wall-like tides that, since they are not confined in a river, are not strictly bores.

Some Tidal Bores with Cool Names

Chau Dau	Tsientang, China
Pororoca	Amazon, Brazil
Burro	Colorado, Mexico
Mascaret	Seine, France
Aegir/Eagre	Trent, England

Bores in Literature

The bore-like tide in the Solway Firth is mentioned in Sir Walter Scott's Redgauntlet
The Trent Aegir is mentioned in 'The Mill on the Floss'
Victor Hugo's daughter was killed by the Mascaret.

Things to do at Bores

- Fish - Arrival of the Pororoca was heralded by Cranes, presumably drawn to the fish brought to the surface by the bore's turbulence. Baby Eels, similarly exposed to predation by the bores brought on in spring tides, are a traditional Good Friday meal in the Severn estuary in England.
- Tube Rafting - see web pages below
- Surf - the Severn Bore propagates some 10 miles. At least one surfboard has been broken.
- Get a free ride upstream. In the Tsientang river, fishermen tie their boats into protected piers to shelter against the bore; after it has passed, they release and are carrier upriver (remember the tide continues to rise after the passage of the bore)

Where do Tides Come From?

Tidal forces are due to the radial differential in gravitational field strength. Simplistically, the equilibrium shape of the equipotential surface on a spherical earth is ellipsoidal, with a bulge towards and away from the Moon, with a height of 18cm or so (Isaac Newton took the first stab at this, and obtained a figure of 9 inches).

NB the equilibrium tide essentially equates the horizontal component of (gravity-centrifugal force) to the pressure gradient caused by the change in water level.

The Earth rotates under this bulge, so an observer fixed on the Earth's surface would see the tide rise and fall twice a day (approx), and tides at low latitudes would be highest. In reality, water motions cannot keep up with the motion of the sublunar point, and dynamic effects come into play - including the resonance of basins and coriolis forces. These effects conspire to give some places two tides a day ('semidiurnal tide, M_2', as in England) and others one (the diurnal tide, e.g. Vietnam), while most places have a mix (e.g. San Francisco)

The Sun's tidal effect (proportional to Mass divided by the cube of distance) is about one third of the Moon's.

Large Tides

Maximum tides occur in spring and fall (where the Sun is over the equator, and therefore the track of the sublunar point and the subsolar point are near-parallel and close) at New and Full Moon (syzygy, where the Sun and Moon are pulling together), and when the Earth-Sun and Earth-Moon distances are smallest.

Tides of large amplitude occur in basins which resonate at a harmonic of the tidal excitation frequency (~12 hours). Notable examples are the Severn Estuary in the UK, the Bay of Fundy in Canada, and the Gulf of California. The resonance is due to the propagation time of a wave (+ the tide) up and down the basin [for the Bay of Fundy, 270km long , depth D~60m, a shallow water wave travelling at $\sqrt{gD} = 24\ ms^{-1}$, gets to the end and back in 2.2e4s, or 6.1 hours - a convenient multiple of the 12.2 hour lunar semidiurnal period]

Most of the Gulf of California is too deep for shallow water waves like this to work, but it does behave similarly in that the northern part of the Gulf behaves as a tuned oscillator; with the tide covering it in one quarter of a tidal cycle (Filloux, 1973). At the mouth of the Gulf, for example, the M_2 component has an amplitude of 30cm; this falls to about one third in the middle of the Gulf, but builds to 165cm at the head of the Gulf.

Planetary Connection

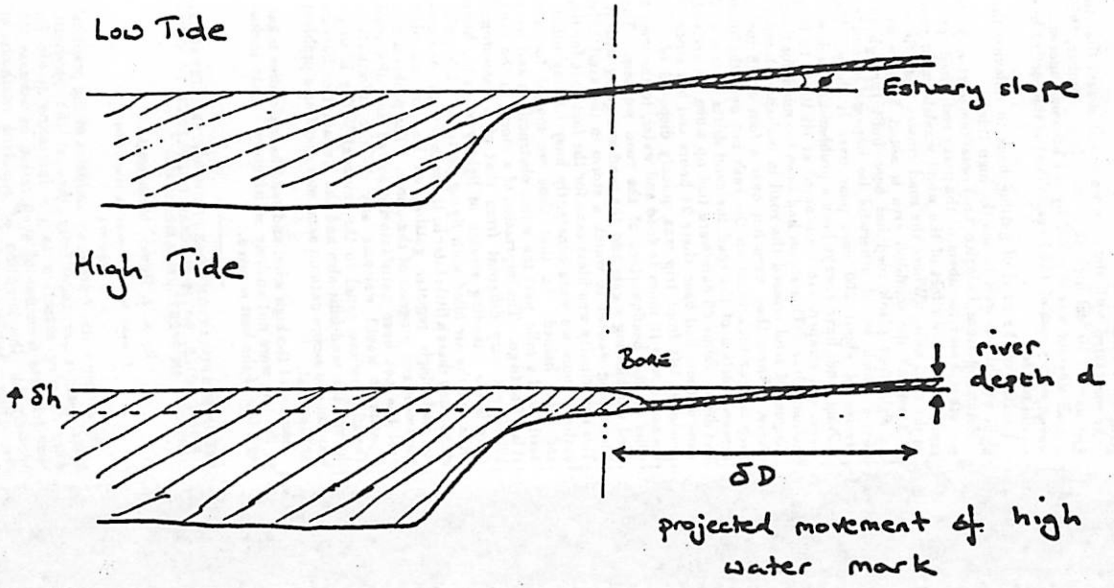
Tides are perhaps the most familiar connection between the heavens and human affairs - tides themselves are a planetary connection. More generally, ask Dave Trilling about how tides can push giant planets about....

Titan, which may have seas of liquid hydrocarbons, is subject to an equilibrium tide from Saturn some 400x larger than that on the Earth from the Moon. However, Titan rotates synchronously, so the ~100m tidal bulge stays nearly in the same place. Its orbit is slightly (e=0.029) eccentric, so the tide would go up and down by 9m (=3e, as the tidal potential is proportional to the cube of distance), and oscillates by 3° of longitude. Global oceans seem ruled out, and seas are likely to be confined to crater basins, with steep walls. Tidal bores, and other cool stuff, cannot be ruled out, however.

Annotated Bibliography

- Tricker, R. A. R. Bores, Breakers, Waves and Wakes - An Introduction to the Study of Waves on Water, Elsevier New York, 1965 [551.46 T823] *(Marvellous book - nice photographs, descriptions; even straightforward equations and water tank experiments)*
- Waves, Tides and Shallow Water Processes, The Open University, 1989. [GC 211.2 W38] *(A Modern and well-illustrated introduction, with mathematics)*
- D K Lynch, Tidal Bores, *Scientific American* , vol.247, no.4 146-156, 1982 *(good readable account)*
- S Bartsch-Winkler and D K Lynch, Catalog of Worldwide Bore Occurrences and Characteristics, US Geological Survey Circular 1022, 1988 [QE75.C5] *(a comprehensive list of known bores, and a superb bibliography)*
- Rowbotham, F. The Severn Bore [GC 376.R69 - need to get on Interlibrary loan] *(very parochial account, complete with the name of Pubs as landmarks for bore-viewing. Some excellent photographs too)*
- E. P. Clancy - Tides, The Pulse of The Earth, [GC301.C55] *(Good historical background, but not much else)*
- Branner, J. C. The 'pororoca' or Bore of the Amazon, *Science*, v.4 488-490, 1888 *(good old-fashioned - 'I went here and saw this' science)*
- Sykes, G. G. A Westerly Trend, U. of Arizona Press, 1945 [CT 275. S9877.A3] *(Interesting account of an Englishman's wanderings in the Southwest; as well as seeing the bore on the Colorado Delta, he was a member of the Carnegie Desert Laboratory in Tucson, and helped build the dome at Lowell Observatory, etc.)*
- Filloux, A. Tidal Patterns and Energy Balance in the Gulf of California, *Nature*, v.243, 217-221, 1973

Web
Severn Bore Predictions:
http://www.severn-trent.com/rec_cons/severnbore.htm
Tube-Rafting on Rivers in the Bay of Fundy
http://www.nsis.com/~webmagic/truro/bore.html



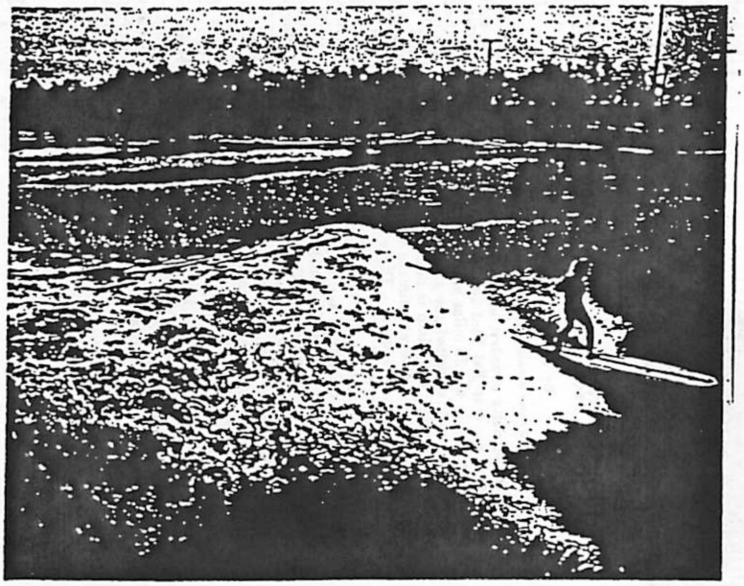
Bore occurs (approx) when $\frac{\delta D}{\delta t} > \sqrt{gd}$

or $\sim \frac{\delta h}{\delta t} > \phi \sqrt{gd}$

10m in 3.5 hrs $\sim 10^{-3}\ ms^{-1}$

$\sim 10^{-3}$

$\sim 3\ ms^{-1}$ for 1m depth



BORE ON THE SEVERN is the largest in Britain. It is a powerful breaking bore with a crest large enough for surfers to ride upstream for miles. The bore forms near the Severn bridge above Sharpness and extends to Gloucester. Two conditions must be met for a bore to form. First, there must be a broad estuary that narrows toward the river mouth and has a shallow, gently sloping bottom. Such a configuration funnels the incoming tide, increasing its height. The Severn estuary from Cardiff to Bristol has the required narrowing shape. Second, the tides in the adjoining tidal basin must be very high. A difference of more than 30 feet between high water and low water at Sharpness is generally necessary for the Severn bore to form.

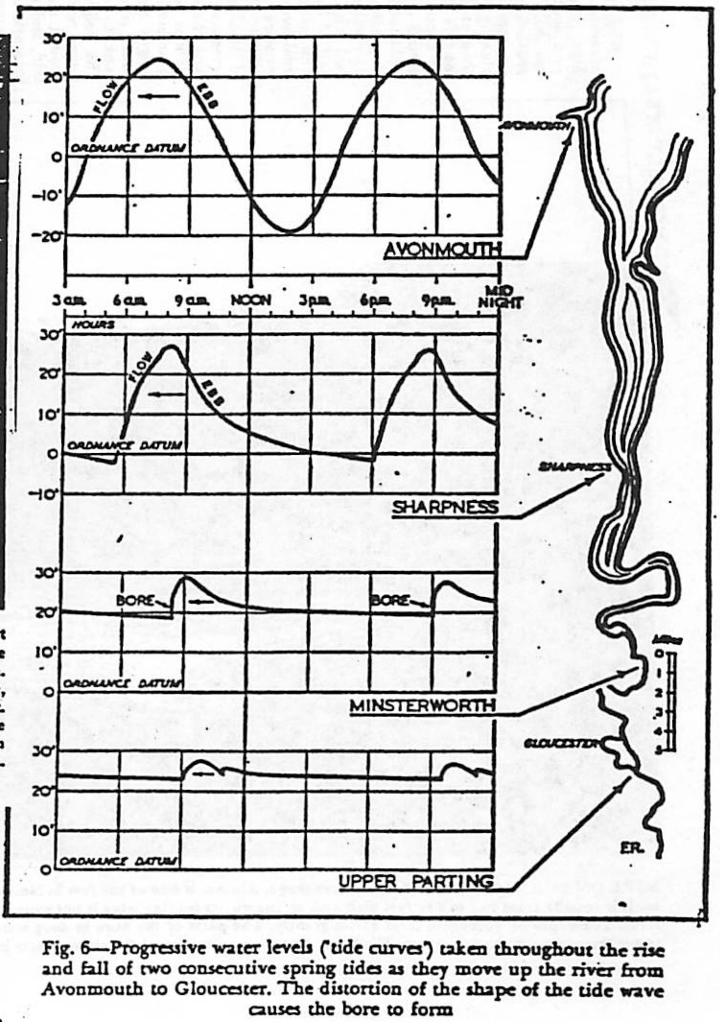
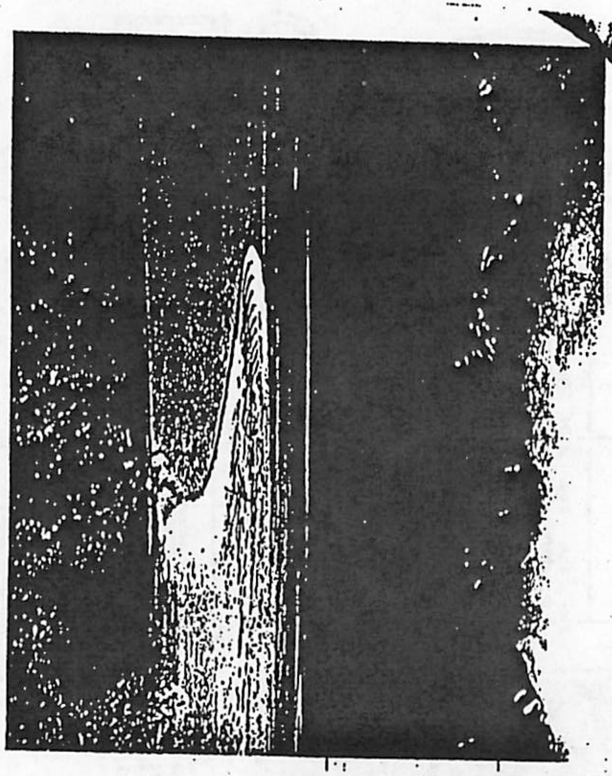


Fig. 6—Progressive water levels ('tide curves') taken throughout the rise and fall of two consecutive spring tides as they move up the river from Avonmouth to Gloucester. The distortion of the shape of the tide wave causes the bore to form



BORE ON TURNAGAIN ARM, near Anchorage, Alaska, is one of the few in North America. It is usually from two to five feet high and, as shown, its leading edge is not straight or uniform. The depth of Turnagain Arm varies greatly. The parts of the bore in deep water move faster than those in shallow water. The faster parts are undular and the slower parts breaking.

TIDAL BORE AT MOUTH OF COLORADO RIVER DECEMBER 8 TO 10, 1923

By James H. Gordon

[Weather Bureau, Yuma, Ariz., December 1923]

The lower delta country, as observed on this trip, is a great level plain so flat that the elevation probably did not vary a foot in the 25 miles crossed. The ruts which formed the road furnished the greatest variation in elevation observed. The plain is almost entirely destitute of plant growth. A liberal estimate would be one small bush to every hundred acres. There was a strong wind blowing. My hat went off. One of the men sprang after it, but was distanced. Because of recent rains it was unsafe to leave the road and follow "cross country." We did not follow the road which trended southeast while the hat went straight south. The hat was kept in sight for more than 3 miles and in that distance there had not been so much as a bush to check it in its mad flight. This to illustrate the character of the country. There are no recognizable channels across it except occasional drainage lines a few inches deep. Water from the Colorado at flood times and from overflow tides must cross this plain to reach Laguna Salada, which they are supposed to feed. The elevation of the plain is given as 8 feet at the northern end and 7 a little distance south of La Bomba.

While crossing this open country Pinto Mountain w observed. It is an isolated peak 1,500 to 1,800 f high, rising abruptly from the western edge of the pla just south of the entrance to Laguna Salada. It normally dark in color with its steep slopes grotesqu spotted with big patches of sand, some probably ha an acre in extent. Apparently the high north win blowing down the Laguna Salada Valley pick up near their maximum load of sand. Eddies and swirls on th lee side of the mountain check the wind velocity enoug to cause a dropping of the sand load. Time did no permit a close study of the mountain.

About 3 miles from La Bomba the road ran into wat It was shallow but extensive, so we left the cars and wad The water was nowhere more than 6 inches deep, und laid with a very adhesive mud, and covered perhap half of the distance. A few "islands" were fairly dr The rest of the way was mud. The water came from tidal overflow of two nights previous and would requir we were told, two more days to drain off.

The "city" of La Bomba, the "seaport" of this sectio of Mexico with two small steamers a week, consists o seven small buildings, including a radio station, and at th time of our visit boasted five inhabitants and seven automobiles and trucks. The "port" is a slushy, crumblin river bank. I did not witness the method of unloading freight but with a normal tidal range of fully 12 fee strong river and tidal currents and only a crumbling mud bank to work from it must present many difficultie The freight brought in is mostly liquor for the borde towns while fish are shipped south. The "city" i flooded about 6 inches deep every new moon, we wer told, and at times of high water in the river it is cut o for weeks at a time. It is soon to be linked with Mexical by Government-built railroad, much of the grading ha been done, but it can never be much of a port. A present it seems to be the only point which may b reached by automobile from which the bore may b observed.

We reached La Bomba at 11.30 a. m. December A strong, cold north wind was blowing and having take the lay of the land, measured the height of the bank and set stakes by which to judge the bore we took shelter in the lee of one of the houses. A mountain chain o many interlocking ranges lies some 8 miles to the wes and was remarkably impressive and beautiful in th sandstorm haze. From our shelter it was possible t see some distance down the river.

The coming of the bore was first called to our attentio by the disturbance among a big flock of white pelicans fully 6 miles away. Fish always follow the bore in, we were told. The brown line of the bore itself was visible wit the glass at perhaps 3 miles. Its speed appeared to b nearly 8 miles an hour. As a spectacle it was disappointing. This was doubtless due in some measure the strong north wind that had been fighting the tid all the way up the Gulf. Up to the moment that th bore, or first wave, arrived the current was runnin strongly seaward. In an instant it was reversed an racing up the river. The bore was not over 3 feet high a racing wave fully a mile long, foam crested and perhaps a foot higher over the shallows and sand bars. In dee water it was like a ground swell apparently running ov the outgoing tide and river current. The *lack of turmo between the two opposite currents was surprising.* The le of the river rose 3 feet in the first minute and 5 feet 15 minutes. The bank was 15 feet high at low tid The high tide of two nights previous had filled the channel and overflowed the surrounding country 6 inche

deep. Probably a full half mile behind the first wave something similar to a tide rip appeared, waves 3 to 4 feet high probably not over 20 feet from crest to crest racing up the river. They would have made very rough going for a small boat.

As contrasted with the bore we saw it is said that the first wave is 10 feet high at times. In September, 1922, a small steamer was wrecked by the bore and succeeding waves, with a loss of 130 lives. That is the sort of bore we did not see.

Because of the need of getting back to Calexico that night we did not wait to see the high tide.

Returning from Calexico to Yuma the next day the two other Yuma members of the party and I had opportunity to see the effect of the worst windstorm in years on the sand hills. Where the road crosses this "Sahara of America" the sand-hill area is about 5 miles wide. An eight foot plank road has been built through this section which would otherwise be impassable and an average of about 200 cars pass over it daily. The shifting sands have always been a problem and men with teams and scrapers are maintained at all times to keep the road clear. This storm had been too much for them. Tongues of sand crossed the road in perhaps a hundred places. Where they were not over a foot or 18 inches deep the car took them on the rush but over the most exposed portion of the road the sand drifts were 4 or 5 feet deep. Some 60 cars were tied up when we arrived, some of them had been there 24 hours and our stock of provisions left from trip was quickly disposed of. To the east it was 10 miles to food and water, to the west 5 miles to the headquarters of the road workers. The wind was blowing a gale and the sand was going with it. I have long wanted to watch a storm in the sand hills. This opportunity was ideal save for the fact that for the next six hours we were constantly busy helping others and being helped. In that time we moved forward nearly half a mile, past the worst obstructions and were at last free to go. The impression of a storm in the sand hills is not very different from that of a snowstorm; there is the unending stretch of light grey sand, huge drifts and the air filled with flying particles. I hope to spend a day there a little later in the season with anemometer and single register getting an idea of the wind movement and progress of the dunes. The problem of a road has not been satisfactorily solved and the road department would welcome any definite information. The all-American canal to the Imperial Valley is to go through the sand hills also and the Reclamation Service is anxious to secure data on sand movement as a problem for the canal.

Because of the high wind and sand haze pictures taken on the trip were not entirely satisfactory. I am inclosing a few of the best secured.

LEE ON EVAPORATION LOSS FROM WATER SURFACES: MOIST SOILS, WITH SPECIAL REFERENCE TO CONDITIONS IN WESTERN AMERICA

By A. J. Henry, Meteorologist

[Weather Bureau, Washington, March, 1924]

[Abstract]

The author writes from the standpoint of the practical hydrologist rather than from that of the physicist. After directing attention to the increasing needs for more accurate measures of evaporation he stresses the necessity for the adoption of standard methods of observation, a subject to which further reference will be made later.

pp98-99 Vol. 52 1924

Playas – Laguna Diablo

Ingrid Daubar

Playas on Earth

Definition

A *playa* (misleadingly, Spanish for "beach") is a closed basin in an arid environment, which may sometimes be temporarily covered by water, but is dry the majority of the time. A **dry lake bed**. Also *salar, sabkha, vloer, faydah, takir, bahi* or *kavir* in various parts of the world.

Occurrence

Playas are common in the **basin and range provinces** of southwestern North America – basins are often bowl-shaped and have no drainage. **Alluvial slopes** surround the mountain ranges, extending from the mountain bedrock to the more gently sloping **desert flats.** (Figure 1) Desert flats may be covered with gravel and vegetation, unlike the desolate playas they surround. Playas themselves occupy the lowest-elevation areas of desert valleys.

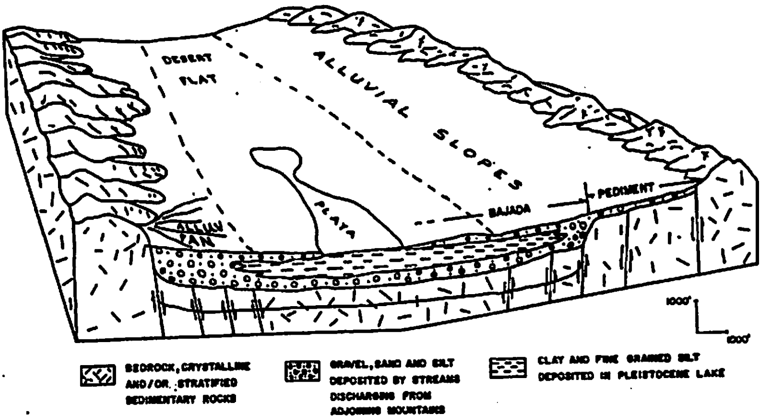


Figure 1: Schematic diagram of playa and surrounding areas. (Source: Motts 1970)

Formation

Water flows into the playa via streams that cross the alluvial slopes and desert flats. Because the basin is closed, the water cannot escape. Water trapped within the playa evaporates, leaving behind the material it carried into the playa. (Infiltration rates must be low, or the water sinks through the surface, into the groundwater. In this case, a playa does not form.) **Lakes** may form within playas, but they are not regular occurences, and do not last.

As the water evaporates, the remaining brine becomes more and more concentrated. Dissolved minerals such as salts, calcite, and gympsum come out of solution and form **evaporites** (see Eric Palmer's presentation for more on evaporites).

Types

There many ways to classify playas. This scheme is based on overall sediment texture through the depth of the playa, which controls the hydrology and resultant surface morphology.

Fine-grained.

- Medium silt to fine clay sediments.
- Low discharge, or none at all.
- Smooth, dry, hard crust with lower evaporite content.

Coarse-grained.

- Sand, silt, and other evaporites.
- High level of discharge by capillary action ⇒ evaporites form in sediments near the surface ⇒ soft, friable "puffy ground."
- More groundwater discharge ⇒ thicker evaporite crusts.

Surface Features

- Contraction cracking – as sediments dessicate, can form **polygons** of various sizes. Also cracks in the form of stripes and rings.

  Giant dessication polygons (Figure 2):
  - More common in fine-grained, clay-rich playas than in salt-rich ones.
  - Usually the result of drought or ground water levels falling.
  - Require a minimum of 5 meters of sediments.
- Drainage channels – radial pattern towards center (topographic low)
- Other playa morphologies:
  - Karst topography – thick salt crust collapses when underlying deposits dissolved away.
  - Mounds – depositional or erosional
  - Deflation pits
  - Erosional buttes
  - Sand ripples
  - Evaporite encrustations

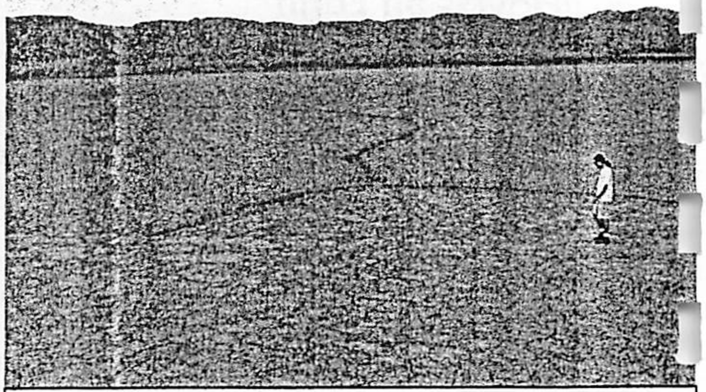


Figure 2: Dave O'Brien explores giant dessication polygons on the Red Lake Playa, 2000. (Photo source: Jason Barnes.)

Remote Sensing

- **Visible (color, albedo):** (Figure 3)
  - Evaporites such as salt show up as distinct high-albedo features.
  - Sediments are often zoned in color.
  - Karst depressions can be seen in aerial photography (indicator of salt content).
- **Topography:** Very flat! Flattest places on Earth.
- **RADAR:** (Figure 4) Very low backscatter (smooth!).
  - Can de differentiated from smooth lava flows.

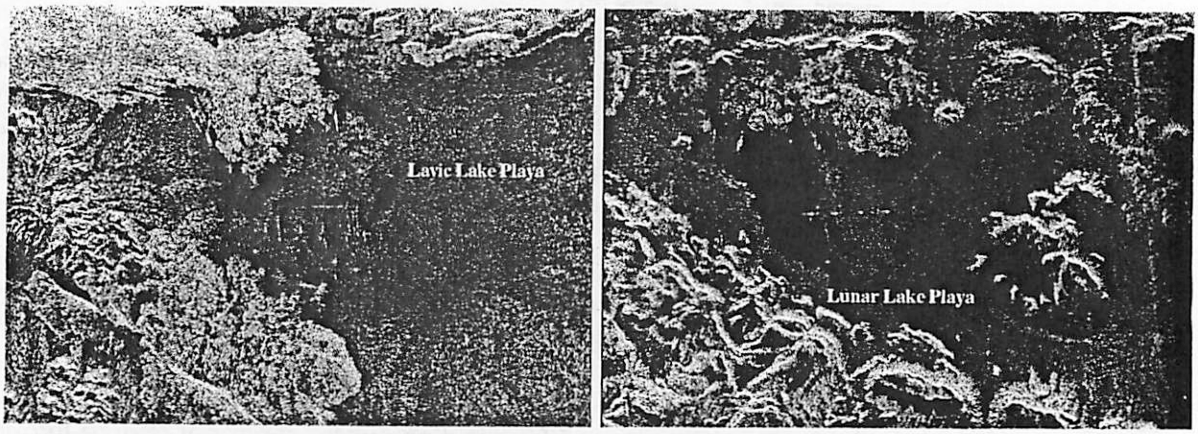


Figure 6.9. AIRSAR L-band (24 cm wavelength) HH-polarization radar images of the Lavic Lake and Lunar Lake playas. The image width is 12.4 km, range projection. The image has not been geometrically rectified for the change in horizontal spatial resolution with radar range. The lower end of the image stretch corresponds to a brightness of −40 dB, so the playas are exceedingly smooth at this wavelength. (Courtesy of NASA/JPL.)

Figure 3: Radar images of terrestrial playas. (Source: Campbell 2002)

- **IR:** (Figure 5) Can differentiate types of playas listed above.
  - Different heat capacities (densities) and emissivities (salt content).

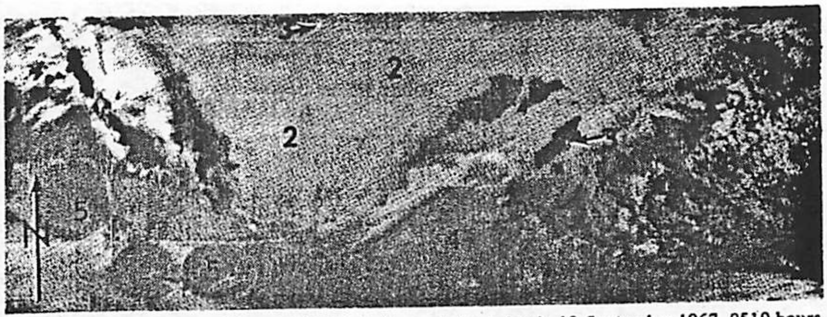


Fig. 11. Nighttime infrared image (4.5-5.5 μ), Harper Lake (playa), 12 September 1967, 0510 hours. Comparison of surface features on this image with Figure 12 (daytime image) shows thermal discrimination of soft, dry, friable surfaces (1) and hard, dry, clay crusts (2) (see Figs. 1 and 3) and contrast (thermal) reversal between day and night images. Other features of interest are (3) bonfires, (4) alluvial sand and gravel, (5) cultivated fields, (6) standing water, (7) moist playa clays, and (8) area of vegetated dunes and channels at east edge of playa.

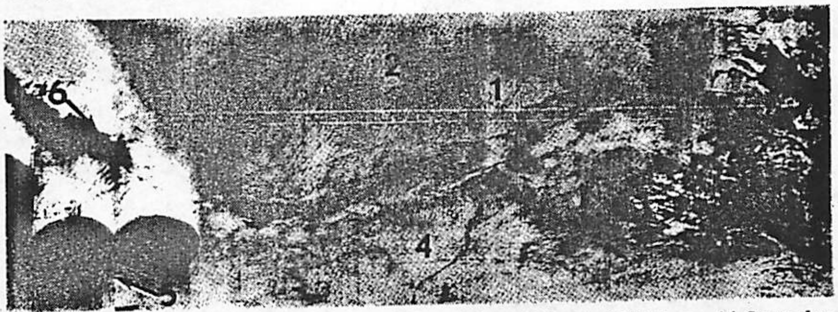


Fig. 12. Daytime infrared image (4.5-5.5 μ), Harper Lake, California, 1014 hours, 14 September 1967. Compare features shown here with those on Figure 11 (nighttime image). Scale is distorted on each image.

Figure 4: Day and night infrared images of a playa. (Source: Neal 1975)

Laguna Diablo: "Devil's Lake"

Laguna Diablo is a 15-mile long playa located in the Parque Nacional Sierra San Pedro Martir, a national park in northern Baja, Mexico. Directly to the west of to the playa, and 10,000 feet above, is the Pichacha del Diablo, or Devil's Peak. This mountain is a popular destination for hikers and climbers, as well as home of the San Pedro Martir Observatory.

Figure 5: Dessication cracks on Laguna Diablo. (Photo Source: http://www.oz.net/~geoffsi/baja20012002.htm)

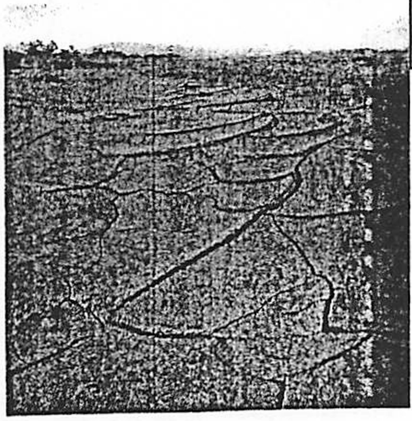


Figure 6: Salt at the surface of Laguna Diablo. (Photo Source: J.V. Luna)

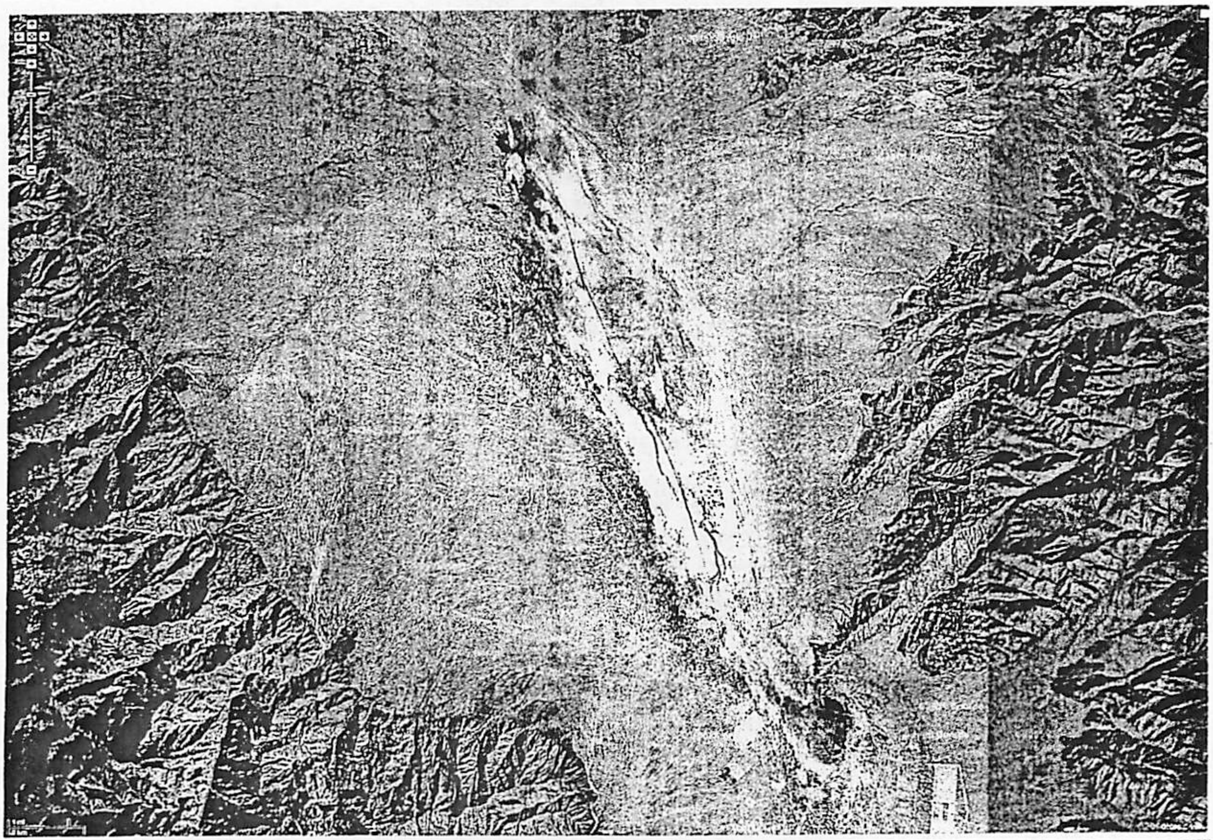


Figure 7: Satellite imagery of Laguna Diablo. (Source: Google maps)

Playas on Mars

"Follow the water" – Identifying a surface feature as a playa would indicate that standing water once stood there. Important to studies of climate change, life, mineralogy, etc. Terrestrial playas give ground truth to remote sensing data of Mars.

Polygons – this is another whole topic. See Spitale 2000 and Ekholm 2000. Highlights:

- Polygonal fractures recognized on Mars since Viking.
- Associated with ends of large outflow channels in Northern plains.
- Martian polygons seen by Viking (3-20 km across) are 1-2 orders of magnitude larger than terrestrial polygons.
- MGS found polygons at same scale as terrestrial "giant" polygons.
- Horizontal scale ~ depth of wetting, so giant polygons require wetting & drying a very deep sediment layer.
- Other formation mechanisms proposed: ice wedges, tectonic stresses, cooling & contracting volcanics...
- Controversial.

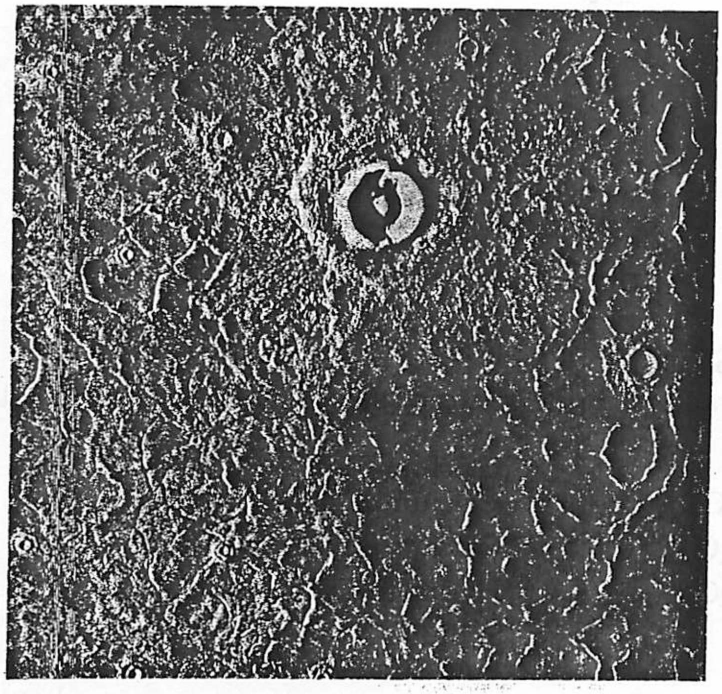


Figure 3-14. Polygonally fractured ground at 38°N, 258°W. Similarly fractured ground is generally found at the ends of outflow channels. The picture is 176 km across (Viking Orbiter frame 573A08).

Figure 8: Polygonal fractures on Mars. (Source: Carr 1996)

Crater Lakes – could also be an entire topic…

- Sedimentary structures such as lacrustine deltas, terraces, shorelines, & mounds are evidence for standing bodies of water in many Martian craters.
- Evidence for evaporites within crater basins (see Eric Palmer's presentation).
- Ice-covered lakes could survive under present conditions for thousands of years, possibly up to hundreds of millions of years (?).
- Depending on infiltration rates, might leave behind… a playa!

REFERENCES

Alden, A. "A Look at the Playa." About.com, New York Times Company. 2005. http://geology.about.com/library/weekly/aa082601a.htm

Banerdt W.B. et al. "Stress and Tectonics on Mars." *Mars.* Ed. H.H. Keiffer et al. Tucson: University of Arizona Press, 1992. 249-197.

Cabrol, N.A. and E.A. Grin. "Distribution, Classification, and Ages of Martian Impact Crater Lakes." Icarus 142 (1999): 160-172.

Campbell, B. *Radar Remote Sensing of Planetary Surfaces*, Cambridge: Cambridge University Press, 2002.

Carr, M. *Water on Mars*. New York: Oxford University Press, 1996.

Ekholm, A. "Playas on Mars." *Death Valley Planetary Field Geology Practicum*. Tucson: University of Arizona, 2000. 35-38.

Holliday, V.T., S.D. Hovorka and T.C. Gustavson. "Lithostratigraphy and geochronology of fills in small playa basins on the Southern High Plains, United States. " *GSA Bulletin* 108 (1996): 953–965.

Luna, J.V. "A Baja Geological/Cultural Road Log." http://www.elchineroconcepts.com/BAJA ROAD LOG.htm

Motts, W.S. (ed.) *Geology and Hydrology of Selected Playas in Western United States*. Amherst, MA: University of Massachusetts, 1970.

Neal, J.T. (ed.) "Playa Surface Features as Indicators of Environment." *Playas and Dried Lakes.* Ed. J.T. Neal. Stroudsburg, PA: Dowden, Hutchingon & Ross, Inc., 1975. 363-388.

Newsom, H.E. et al. "Impact crater lakes on Mars." *Journal of Geophysical Research* 101 (1996): 14951-14956.

Parker G.G. and C.G. Higgins. "Piping and pseudokarst in drylands." *Groundwater Geomorphology*. Ed. C.G. Higgins & D.R. Coates. Boulder, CO: The Geological Society of America, 1990. 77-110.

Radebaugh, J. "Playa Lakes." *Death Valley Planetary Field Geology Practicum*. Tucson: University of Arizona, 2000. 16-17.

Spitale, J. "Giant Dessication Polygons." *Death Valley Planetary Field* Geology Practicum. Tucson: University of Arizona, 2000. 18-21.

Evaporates

by Eric E. Palmer

MINERAL PRECIPITATION SEQUENCE

Progressive water loss causes concentration in brine to exceed solubility for each mineral in sequence:

Calcite	$CaCO3$	Calcium Carbonate
Dolomite	$Ca Mg (CaCO_3)_2$	Calcium Magnesium Carbonate
Anhydrite	$CaSO_4.2H_2O$	Calcium Sulfate
Gypsum	$CaSO_4.6H_2O$	Hydrated Calcium Sulfate
Halite	$NaCl$	Sodium Chloride
Sylvite	KCl	Potassium Chloride

Mixed salts of K+, $Mg^{2}+$, SO4- and Cl- (very soluble)

Complete evaporation will create a layered sequence, with calcitic and dolomitic limestones overlain by sulfates, halite, etc.

CALCITE

Calcite, which gets its name from "*chalix*" the Greek word for lime, is a most amazing and yet, most common mineral. It is one of the most common minerals on the face of the Earth, comprising about 4% by weight of the Earth's crust and is formed in many different geological environments. Calcite can form rocks of considerable mass and constitutes a significant part of all three major rock classification types. It forms oolitic, fossiliferous and massive limestones in sedimentary environments and even serves as the cements for many sandstones and shales. Limestone becomes marble from the heat and pressure of metamorphic events.

Uses: In cements and mortars, production of lime, limestone is used in the steel industry; glass industry, ornamental stone, chemical and optical uses and as mineral specimens.

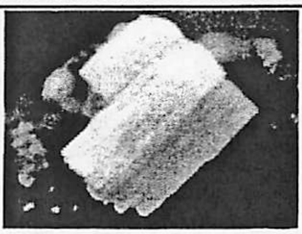
Best Field Indicators are crystal habit, reaction to acid, abundance, hardness, double refraction and especially cleavage.

ANHYDRITE or ANGELITE

Anhydrite is a relatively common sedimentary mineral that forms massive rock layers. Anhydrite does not form directly, but is the result of the dewatering of the rock forming mineral Gypsum ($CaSO4-2H2O$). This loss of water produces a reduction in volume of the rock layer and can cause the formation of caverns as the rock shrinks.

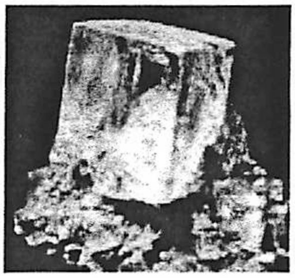
Uses: in the manufacture of some cement, a source of sulfate for sulfuric acid.

Best Field Indicators are crystal habit, rectangular and non-uniform cleavage and low density.



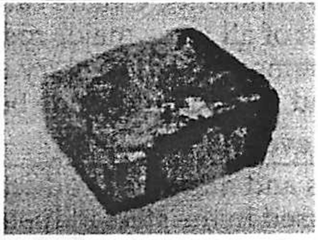
HALITE

Halite, better known as rock salt, can easily be distinguished by its taste. Since taste is an important property of salt, there is a right way to taste a specimen of halite (or an unknown mineral that is similar to halite) and a wrong way. The right way is to first lick your index finger, rub it against the specimen and then taste the finger. This limits the amount of the mineral that actually gets in your mouth, an important consideration when you consider that there are poisonous minerals that resemble halite.

Uses: Major source of salt and as mineral specimens. Best Field Indicators are taste, cleavage and crystal habit.	 

DOLOMITE

Dolomite is a common sedimentary rock-forming mineral that can be found in massive beds several hundred feet thick. Dolomite differs from calcite, CaCO3, in the addition of magnesium ions to make the formula, $CaMg(CO_3)_2$. The magnesium ions are not the same size as calcium and the two ions seem incompatible in the same layer. In calcite the structure is composed of alternating layers of carbonate ions, CO3, and calcium ions.

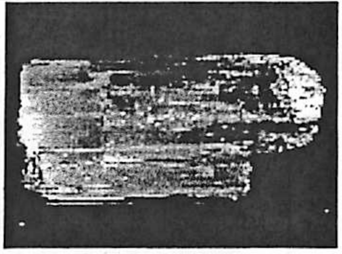
Uses: in some cements, as a source of magnesium and as mineral specimens. Best Field Indicators are typical pink color, crystal habit, hardness, slow reaction to acid, density and luster.	

ULEXITE

Chemistry: $NaCaB_5O_6(OH)6\text{-}5H_2O$, Hydrated Sodium Calcium Borate Hydroxide

Ulexite, like other borates, is a structurally complex mineral. The basic structure of ulexite contains chains of sodium, water and hydroxide octahedrons linked in endless chains. The chains are linked together by calcium, water, hydroxide and oxygen polyhedra and massive boron units.

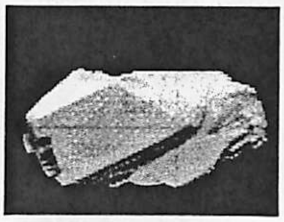
Ulexite is also found in a vein-like bedding habit composed of closely-packed fibrous crystals. This variety is called *"TV Rock."* The fibers will behave like optical fibers and transmit an image from one side of the specimen to the other.

Uses: an ore of boron and as mineral specimens. Best Field Indicators are crystal habit, associations, locality, density, unique optical property, and hardness.	 

BORAX

Chemistry: Na2B4O7 -10H2O, Hydrated sodium borate.

Borax is a complex borate mineral that is found in playa lakes and other evaporite deposits. The basic structure of borax contains chains of interlocking $BO_2(OH)$ triangles and $BO_3(OH)$ tetrahedrons bonded to chains of sodium and water octahedrons.

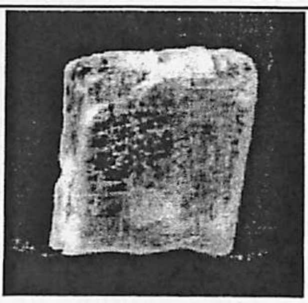
Uses: an ore of boron and as a source of borax (a cleaning agent and useful industrial chemical) Best Field Indicators are crystal habit, color, associations, locality, density and hardness.	 

GYPSUM

Gypsum is one of the more common minerals in sedimentary environments. It is a major rock forming mineral that produces massive beds, usually from precipitation out of highly saline waters. Since it forms easily from saline water, gypsum can have many inclusions of other minerals and even trapped bubbles of air and water.

Gypsum has several variety names that are widely used in the mineral trade.

- "Selenite" - colorless and transparent variety that shows a pearl like luster and has been described as having a moon like glow.
- Satin Spar - a compact fiberous aggregat, which has a very satin like look that gives a play of light up and down.
- Alabaster - a fine grained massive rock is called "alabaster" used in carvings for centuries.

Uses: plaster, wall board, some cements, fertilizer, paint filler, ornamental stone, etc.. Best Field Indicators are crystal habit, flexible crystals, cleavage and hardness.	 

SYLVITE

Sylvite, also called sylvine, is a major source of potassium or potash used in fertilizer products. So great is the need for potassium that sylvite deposits are considered very valuable economically. The crystals can be well formed and are often reddish due to inclusions of hematite. Sylvite is closely related to the more common halite. Tests include a taste test in which halite, salt, will taste salty and sylvite tastes bitter.

Best Field Indicators are bitter taste, associations and crystal habit. Uses: As a major source of potash and as mineral specimens.	 

Mineral Identification Matrix

Mineral	Color	Luster	Cleavage	Fracture	Hardness
Calcite	white, colorless or light yellow, orange, blue, pink, red, brown, green, black & gray	Vitreous to dull	Perfect, forming rhomobohedrons	conchoidal	2.5 to 3
Dolomite	pink, white, yellow, gray	Pearly to vitreous to dull	Perfect, forming rhombohedrons	conchoidal	3.5 to 4
Anhydrite or Angelite	white, gray or colorles	vitreous	Form rectangles, perfect in 1, good in 2	conchoidal	3.5
Gypsum	white, colors or gray	vitreous to pearly	Good in 1 directions, distinct in 2	uneven and rare	2 (fingernail)
Halite	clear or white, sometimes blue, purple, pink, yellow, gray	vitreous	Perfect in 3 directions, forming cubes	conchoidal	2 (fingernail)
Sylvite	colorless or white somtimes tinted red, blue or yellow	vitreous	Good in 3 directions, forming cubes	uneven	2 to 2.5
Borax	white to clear	vitreous	Perfect in 1 direction	conchoidal	2 to 2.5
Ulexite	white, gray to colorless	silky	Perfect in 1 direction	fibrous	2 (fingernail)

Table 3-4

Mohs Scale of Hardness

Mineral	Scale number	Common objects
Talc	1	
Gypsum	2	Fingernail
Calcite	3	Copper coin
Fluorite	4	
Apatite	5	Knife blade
Orthoclase	6	Window glass Steel file
Quartz	7	
Topaz	8	
Corundum	9	
Diamond	10	

References

http://mineral.galleries.com/minerals/by-name.htm
Press, F. and Siever, R, Earth, 4th Edition. W. H. Freeman and Company, New York, New

Alluvial Fans

By Shawn Wheelock
Department of Hydrology and Water Resources *and* Lunar and Planetary Laboratory
University of Arizona

One of the first things we learn as children is that water flows downhill. Then we get to college and learn that it flows down gradient; be it a thermal, pressure, chemical or gravitational gradient. As a hydrology student here at the U of A, what I have learned is that there is a major anomaly in the west: water actually flows uphill; uphill towards power and money that is[1]. Since there is no money and power to speak of in Baja, I think water can be safely be assumed to obey normal laws.

I. Hydrologic Underpinnings

In order to explain the morphology of alluvial fans, I will start with a *very* brief overview of river morphologies, in case some don't have a geology background to lean on. There are three basic types of rivers: meandering, braided, and anastomosing. For purposes of this discussion, we will ignore the last one (it occurs in extremely low energy environments, like river deltas). Figures (1) and (2) show the respective morphologies.

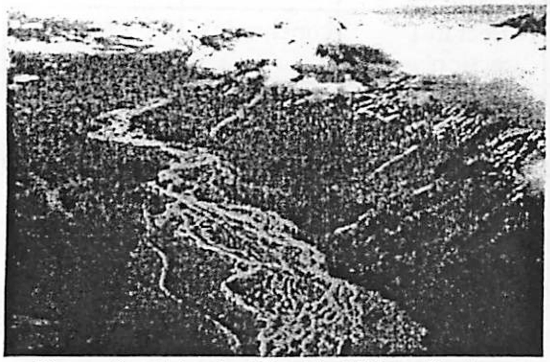


Figure 1 – A typical Braided River System.

Figure 2 – A typical Meandering River System

So when do you get one or the other, and what has this to do with alluvial fans? The answer to the latter question is that these are how these magnificent fans are created. On their surface, you will find water flowing in both of these morphologies, but primarily in a braided fashion. In answering the first: whether a river braids or meanders is based on Equation (1), where ε is the ratio of work to available energy (potential and kinetic).[2]

$$(1)\qquad \varepsilon(m)=\frac{\tau_0\left(\dfrac{B}{m\pi}\right)}{\sqrt{\rho U^2 d_0}\sqrt{\rho g d_0^2}}$$

Equation 1 – The parameters are: ε = braiding parameter, m = braiding index, U = velocity, B = channel width, d0 = flow depth, g = gravitational accel., τ0 = bed shear stress, ρ = water density.

What this all means in practical terms is:

- $\varepsilon \ll 1$, extreme meandering
- $\varepsilon < 1$, meandering
- $\varepsilon > 1$, braiding
- $\varepsilon \gg 1$, extreme braiding.

An alternative perspective that is useful when considering braided rivers is to think of ε as a measure of "the ratio of the work that must be done to maintain a mode of oscillation [for] m braids"[3]

The braids can remain in place for decades[2, 4], or change in the matter of hours of competent flow[5, 6]. This has to do with their stability, which will not be discussed further. The *geologic* factors that contribute to a channel's braiding are: a steep gradient, excess energy, and in many cases, sediment load of the water. In the first two cases, a high velocity area forms in the channel, and that causes low velocity areas to form, which will, of course, be the places where the sediment is deposited Additionally, these high velocity areas will divide if there is enough sediment.[7]

The last thing that will be mentioned is that, curiously, the braiding pattern of a stream is a fractal[8-10], as defined by Mandelbrot[11, 12].

II. The Alluvial Fan

An alluvial fan is basically just a junk pile, geologically speaking. Desert soils (Aridisols) usually have some sort of Fragipan if they have had time to evolve[13]. Often this is a carbonate hardpan, and the net effect is to turn the soil into a no flow boundary, at least in short time scales (one of the reasons we have flash floods here in Tucson). These flood events will scour sediment from their mountainous canyons, and incite mass wasting events. If you look at Figure (3), you will see that there are many active and abandoned channels on it. These flood events are one of the primary ways in which channels on it are abandoned and reformed. However, even in their absence, the river channels will migrate all over the surface each time the equilibrium of the channel is disrupted.

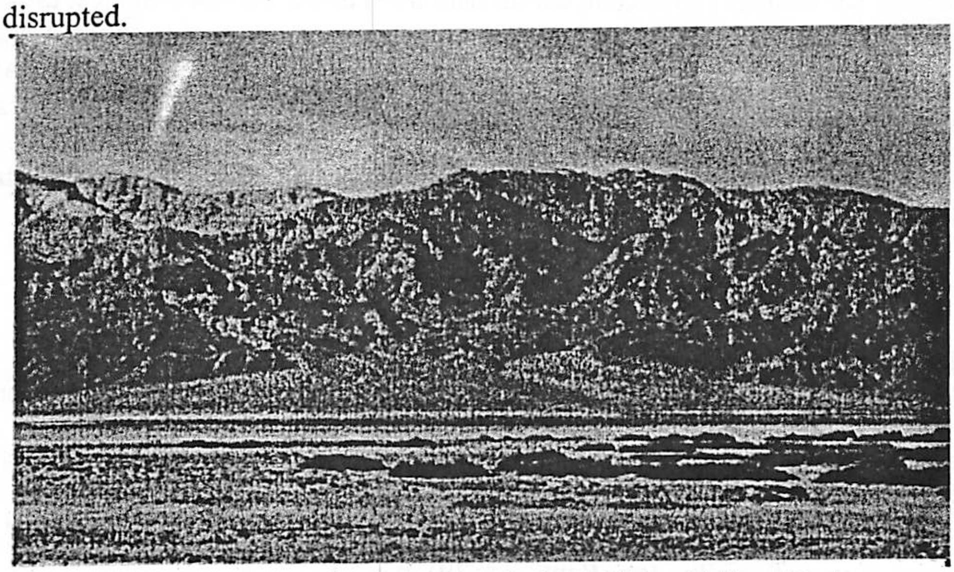


Figure 3 – The Furnace Creek Fan, in Death Valley National Park.

If you look very closely, you can see some areas where algae may be growing.

They are found in all climates, but are particularly apparent in the desert (none of those evil plants covering the geology!) For each fan, there is an apex point where it leaves the confines of the canyon in which it was traveling. Once the water is no longer confined, it spreads out, slows down, and drops the entire sediment load it was carrying (with the exception of the dissolved load – salts and such). It is like the opposite of taking a garden hose and pinching it so that only some of the water can get out, thus causing an increase in pressure and velocity.

They can classified as either dry fans (there is only ephemeral flow), or wet fans (year round flow). They are also broken down into fluvial fans (mostly from water as I described above), or debris fans, which formed primarily from mass wasting processes (such as land slides). As is often the case in geomorphology, what you see will likely fall in the middle of the extreme labels. Even in a debris fan, there almost always has to be water present to decrease friction and soften the material in order for flow to be initiated.

They are also of vital importance to the hydrology of the valley. Their permeability tends to be higher than the valley floor (they are just piles of sediments from the size of clay all the way to boulders, all mixed up). So this is where the rain and snow melt that occurs in the mountains are able to soak in and eventually recharge the aquifer. This is called 'mountain front recharge', and is not very well understood at the present time. Remember, that most of the rest of the valley floor will have its fragipans, preventing water from infiltrating into the ground. They will instead form short lived lakes and fill some arroyos (a river with only ephemeral flow). Unfortunately, the vast of this majority of this water is lost to evaporation rather than being stored in the ground.

They are often on top of faults, they subside, and can sometimes be a useful record of seismic activity[14]. Once abandoned and buried (and then exhumed), paleo-climatologists and sedimentologists can extract significant, useful data from them. In wet climates, they tend not to be very long lived[15], but in a dry, desert environment, the preservation times increase drastically. The Atacama desert is a place often used as a analog for mars (in addition to Antartica[16]). Atacama cobles have been found to have been laying on the fans for nine million years.[17] As planetary scientists, it is very important to understand them, and get a greater understanding of geomorphology in general as the advances in our field continue to bring us surface data of unprecedented quality.

References:

1. M. Reisner, *Cadillac Desert* (Penguin Books, 1993).
2. L. B. Leopold, and M. G. Wolman, "River Channel Patterns: Braided, Meandering and Straight," (USGS Professional Paper 282-B, 1957), pp. 39-103.
3. G. Parker, "On the cause and characteristic scales of meandering and braiding in rivers," Journal of Fluid mechanics 76, 457-480 (1976).
4. A. C. Peale, "Report on the geology of the Green River district in Hayden, F.V.,," in *U.S. Geol. and Geog. Survey Terr. 9th Ann. Rept.*, (1879), p. 720.

5. R. I. Ferguson, "Understanding braiding processes in gravel-bed rivers: progress and unsolved problems.," in *Braided Rivers*, J. L. Best, ed. (Geological Society of London, Special Publication 75, 1993), pp. 73-88.
6. R. I. Ferguson, P. E. Ashmore, P. J. Ashworth, C. Paola, and K. L. Prestegaard, "Measurements in a Braided River Chute and Lobe 1. Flow Pattern, Sediment Transport, and Channel Change," Water Resources Research **28**, 1877-1886 (1992).
7. W. R. Richardson, and C. R. Thorne, "Multiple thread flow and channel bifurcation in a braided river: Brahmaputra-Jamuna River, Bangladesh," Geomorphology **38**, 185-196 (2001).
8. V. I. Nikora, "Fractal Structures of River Plan Forms," Water Resources Research **27**, 1327-1333 (1991).
9. V. B. Sapozhnikov, and E. Foufoula-Georgiou, "Self affinity in braided rivers," Water Resources Research **32**, 1429-1439 (1996).
10. V. B. Sapozhnikov, and E. Foufoula-Georgiou, "Experimental evidence of dynamic scaling and indications of self-organized criticality in braided rivers," Water Resources Research **33**, 1983-1991 (1997).
11. B. B. Mandelbrot, *Fractals:Form, Chance and Dimension* (W.H. Freeman, New York, 1977).
12. B. B. Mandelbrot, *The Fractal Geometry of Nature* (W. H. Freeman, New York, 1982).
13. S. W. Buol, R. J. Southard, R. C. Graham, and P. A. McDaniel, *Soil Genesis and Classification* (Iowa University Press, 2003).
14. R. J. Dorsey, P. J. Umhoefer, and P. R. Renne, "Rapid Subsidence and Stacked Gilbert-Type Fan Deltas, Pliocene Loreto Basin, Baja-California-Sur, Mexico," Sedimentary Geology **98**, 181-204 (1995).
15. K. Saito, and T. Oguchi, "Slope of alluvial fans in humid regions of Japan, Taiwan and the Philippines," Geomorphology **70**, 147-162 (2005).
16. W. C. Mahaney, J. M. Dohm, V. R. Baker, H. E. Newsom, D. Malloch, R. G. V. Hancock, I. Campbell, D. Sheppard, and M. W. Milner, "Morphogenesis of antarctic paleosols: Martian analogue," Icarus **154**, 113-130 (2001).
17. K. Nishiizumi, M. W. Caffee, R. C. Finkel, G. Brimhall, and T. Mote, "Remnants of a fossil alluvial fan landscape of Miocene age in the Atacama Desert of northern Chile using cosmogenic nuclide exposure age dating," Earth and Planetary Science Letters **237**, 499-507 (2005).

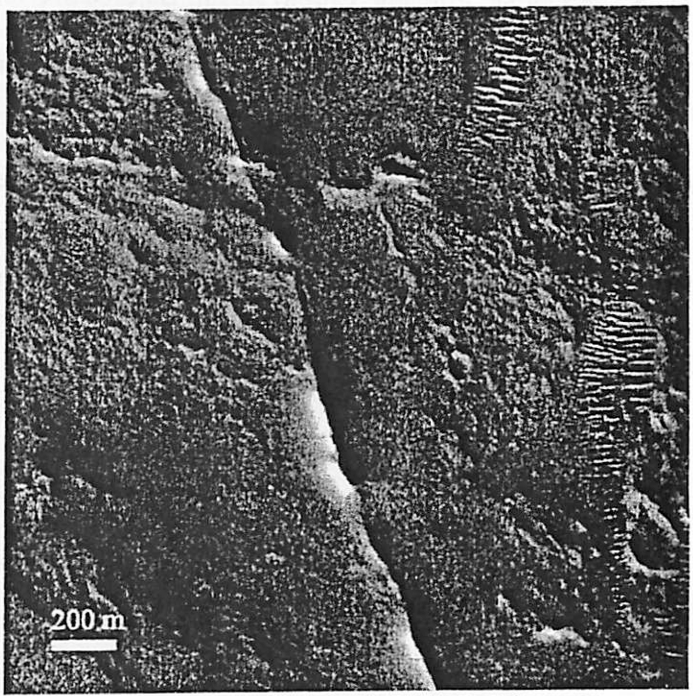
The San Marcos Dike Swarm

Colin Dundas

Dikes are a common way for magma to ascend through the lithosphere. The magma rises in a self-propagating crack. Stress at the tip of the crack causes it to extend upward, and the magma rises due to pressure differences. They are approximately planar, and generally near vertical. Directions are determined by the stresses on the rock. (Rubin, 1995) The dikes are often exposed very well because the remaining magma is often harder than the surrounding rock, so when the rock is eroded the dikes stick out. A chilled margin can sometimes be observed since the edges cool first.

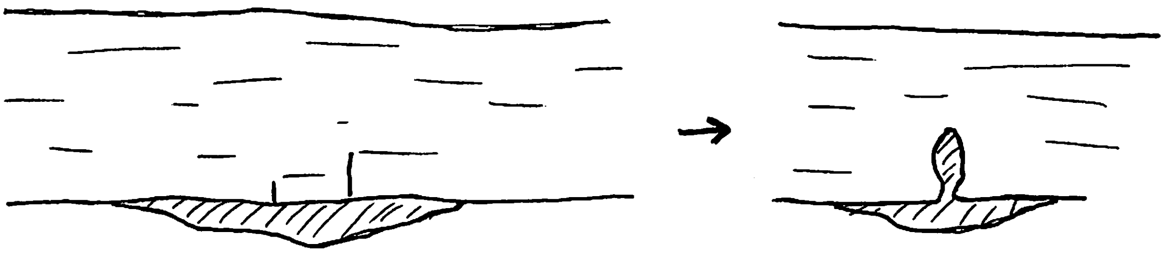
The San Marcos dike swarm is ~120 Myr old, exposed over approximately 100 km in Baja California. The swarm has an average 320° strike and 79° NE dip, indicating a small amount of tilting when combined with paleomagnetic data. The dikes intrude both metamorphic rocks and granites, and mostly have an intermediate composition (not very mafic or felsic). The dikes are typically 1-10 m across. (Bohnel et al., 2002)

Dikes are expected to be an important mechanism for magma transport on other planets, as well as on Earth. Stevenson (1982) argued that on bodies with smaller g, dikes will be larger but rarer, so individual eruptions should be larger. This appears to fit the large scale of Martian volcanic flows.

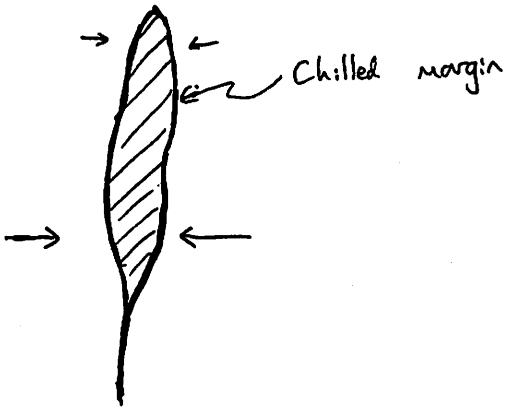


MSSS suggests that this is a dike on Mars, exposed by erosion (MOC image M0201249)

Schematic sketch of dike formation and propagation (based on Weertman, 1971):



Low-density melt forms below the lithosphere and rises into a crack.



The crack propagates towards the surface due to pressure differences.

Bohnel, H., Delgado-Argote, L. A., Kimbrough, D. L. Discordant paleomagnetic data for middle-Cretaceous intrusive rocks from northern Baja California: Latitude displacement, tilt, or vertical axis rotation? Tectonics 21 (5), 2002.
Rubin, A. M. Propagation of magma-filled cracks. Ann. Rev. Earth Planet. Sci., 23, 287-336, 1995.
Stevenson, D. J. Migration of fluid-filled cracks: Applications to terrestrial and icy bodies. LPSC XIII, abstract 768, 1982.
Weertman, J. Theory of water-filled crevasses in glaciers applied to vertical magma transport beneath oceanic ridges. Journal of Geophysical Research, 76, 1971.

The Peninsular Range Batholith: an oversimplified overview of orogenesis

And other tales

Michael Bland

Definitions:

Batholith: *n.* a large, discordant plutonic mass more than 100 km^2 in area with no visible or clearly inferred floor… Batholiths are formed of a cluster of **plutons** and are associated with orogenic belts. – *Collins Dictionary of Geology*

Pluton: *n.* any massive body of igneous rock formed beneath the surface of the Earth by the consolidation of magma. – *Collins Dictionary of Geology*

Granite: *n.* a medium to course-grained plutonic igneous rock composed principally of quartz and feldspar, with biotite and/or hornblende as the commonest mafic minerals. – *Collins Dictionary of Geology*

Peninsular Ranges batholith:

Location:

The Peninsular Ranges batholith of Baja California extends from southern California, down the length of the peninsula to the border of Baja California Sur (Fig 1B). It is inferred that the batholith continues below the surface to outcrop again in the Sierra Laguna mountins near San Cabo in B.C.S. This batholith is part of a larger chain of batholiths that extend from the Yukon Territory of Canada, through British Columbia and into California (Fig. 1A).

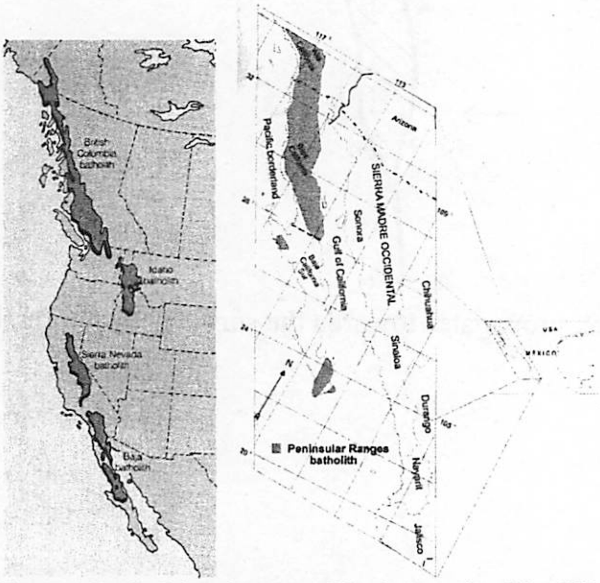


Fig 1. a) Batholiths of western North America (Hamblin and Christiansen, 1998). b) Details of extent of Peninsular Ranges batholith (Ortega-Rivera, 2003).

Geology:

The PRB of Baja California has a complex geology and is subdivided into several different regions. In particular there is a strong compositional difference between the western batholith, whose plutons consist mostly of gabbroic rocks, and the eastern batholith, where the plutons are granitic. There are also more subtle distinctions in the PRB's mineralogy and oxygen isotopes from west to east (see Fig 2. A and B). Finally, the PRB north of the Agua Blanca Fault (Fig. 3) seems to have had a different geologic history than the rest of the PRB. This evidence suggests that the PRB of Baja has had a complex geologic history.

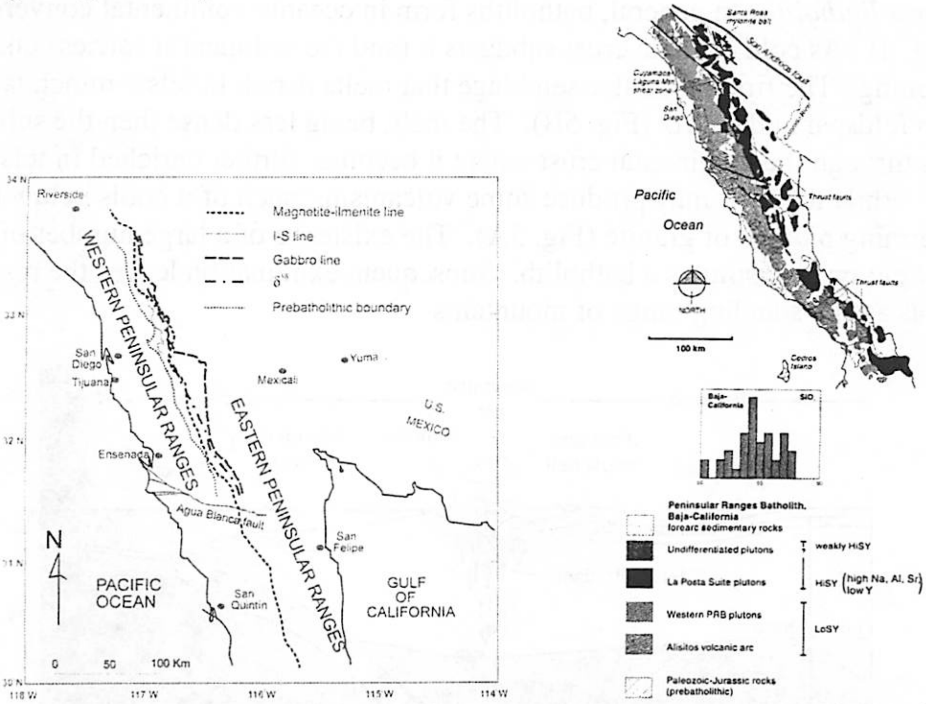


Fig 2.: a) Compositional divisions between the western gabbroic PRB and eastern granitic PRB follow more subtle mineralogic and isotope differences between the two regions (Ortega-Rivera, 2003). These trends are made obvious in b) where black plutons (La Posta) represent granitic rocks and grey plutons represent gabbroic rocks (Tulloch and Kimbrough, 2003).

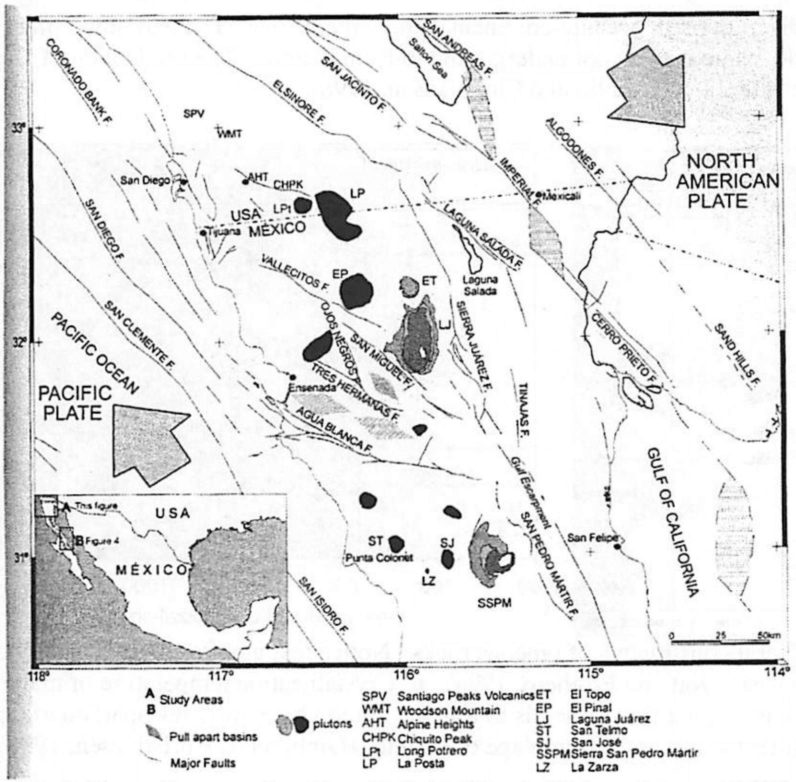


Fig 3: Tectonic map of northern Baja California (Ortega-Rivera, 2003)

Geologic History and Formation:

Recipe for a Batholith: In general, batholiths form in oceanic-continental convergent zones (Fig. 4). As cold oceanic crust subducts it (and the sediment it carries) undergoes partial melting. The first mineral assemblage that melts is rich in felsic minerals like potassium feldspar and quartz (Fig. 5B). The melt, being less dense then the subducting slab, rises through the continental crust where it becomes further enriched in felsic minerals. While the melt may produce some volcanism, much of it cools below the surface forming plutons of granite (Fig. 5A). The existence of a large number of these individual plutons constitutes a batholith. Subsequent exhumation leaves the resistant batholith as a high standing range of mountains

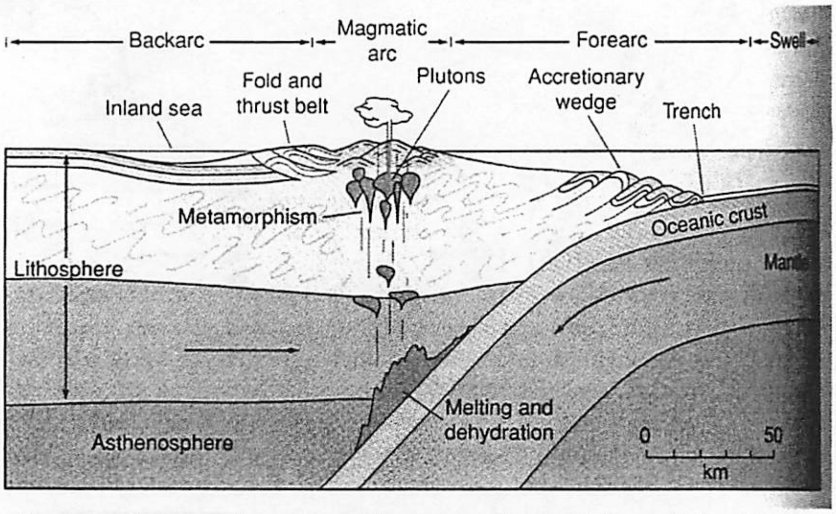


Fig 4: Schematic diagram of an oceanic-continental convergent zone. The partial melting of the subducting slab generates felsic magmas that cool underground to form plutons. The production of large numbers of plutons creates the batholith (Hamblin and Christiansen, 1998).

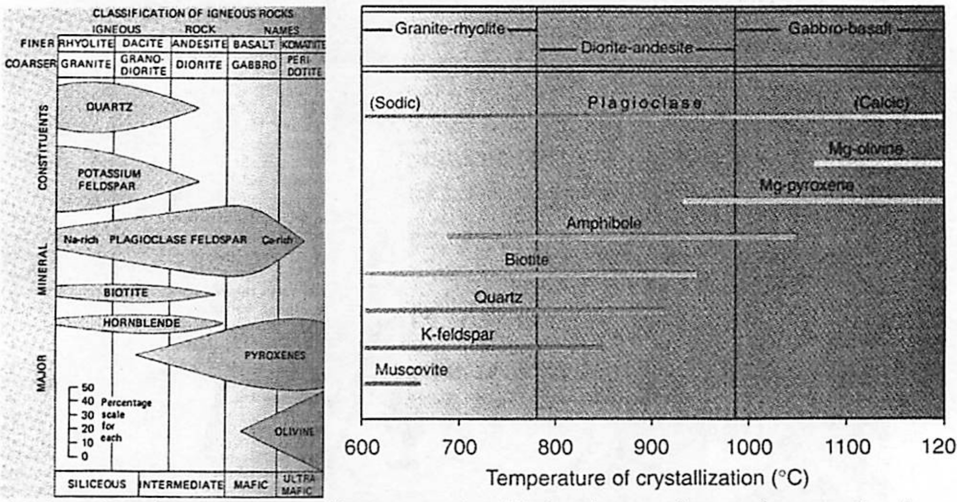


Fig. 5. a) Major mineral constituents of igneous rocks. Notice that granite consists mostly of quartz, k-feldspar and plagioclase (Dott and Prothero, 1994). b) Crystallization temperature of major rock forming minerals. As a rock melts, the first minerals to join the liquid phase are k-feldspar, quartz, plagioclase, muscovite, and biotite: the mineral assemblage of granite (Hamblin and Christiansen, 1998).

Details of the Peninsular Ranges batholith: Aside from the petrologic and mineralogical trends discussed above, age dating of the plutons has suggested that:

1. the plutons formed in the Mesozoic era (~120 to 80 Ma), during the mid-Cretaceous.
2. the plutons become younger as you move eastward suggesting an eastward migration of the focus of magmatism.
3. uplift and exhumation occurred rapidly (within a few million years of emplacement).

(Ortega-Rivera, 2003). A number of hypotheses exist to explain the formation of this complicated region. However, none of them successfully explain all the mineralogical, petrologic and temporal trends seen the rocks. Sedlock [2003] breaks these hypotheses down into three basic types:

1. **A single arc**: The batholith formed above a single subduction zone, much as in Fig. 4 above. Over time the subduction angle shallowed (as evidenced by the wave of volcanism that swept across CA, AZ and NM), causing the plutonic activity to migrate to the east. This migration crossed a pre-existing plate boundary (probably Jurassic in age) that creates the differences in the western and eastern PRB.
2. **Composite with Fringing Arc**: Similar to the single arc model, this is the most popular hypothesis. This proposes that the western-eastern division represents a suture zone formed by the accretion of a fringing arc to the western edge of North America in the early Cretaceous. The differences in the geologic history between the northern and southern PRB is the result of the arc accretion occurring at different geologic periods in the north and south.
3. **Composite with Exotic Island Arc:** This model suggests that the southwestern-eastern boundary in the PRB is the result of the accretion of a pre-existing island arc to western North America. Such exotic terrain is found up and down the west coast of North America. The accretion of terrain helps to explain the north-south dichotomy in the western PRB.
4. **Hybrid model:** While none of the above models reconciles all of the data a combination of them provides a complex but sufficient history of the region that includes subduction that shallows over time, the existence of a fringing arc to the south, and the accretion of an exotic island arc in the north. Clearly these models suggest a complex history for the PRB!

References:

Dott, R. H. and D. R. Prothero (1994). "Evolution of the Earth 5th Ed." McGraw-Hill, New York, USA.

Hamblin, W. K. and E. H. Christiansen (1998). "Earth's Dynamic Systems, 8th Ed." Printice-Hall, Inc. New Jersey, USA.

Lapidus, D. F. (1990). "Collins Dictionary of Geology." HarperCollins, Glasgow, U.K.

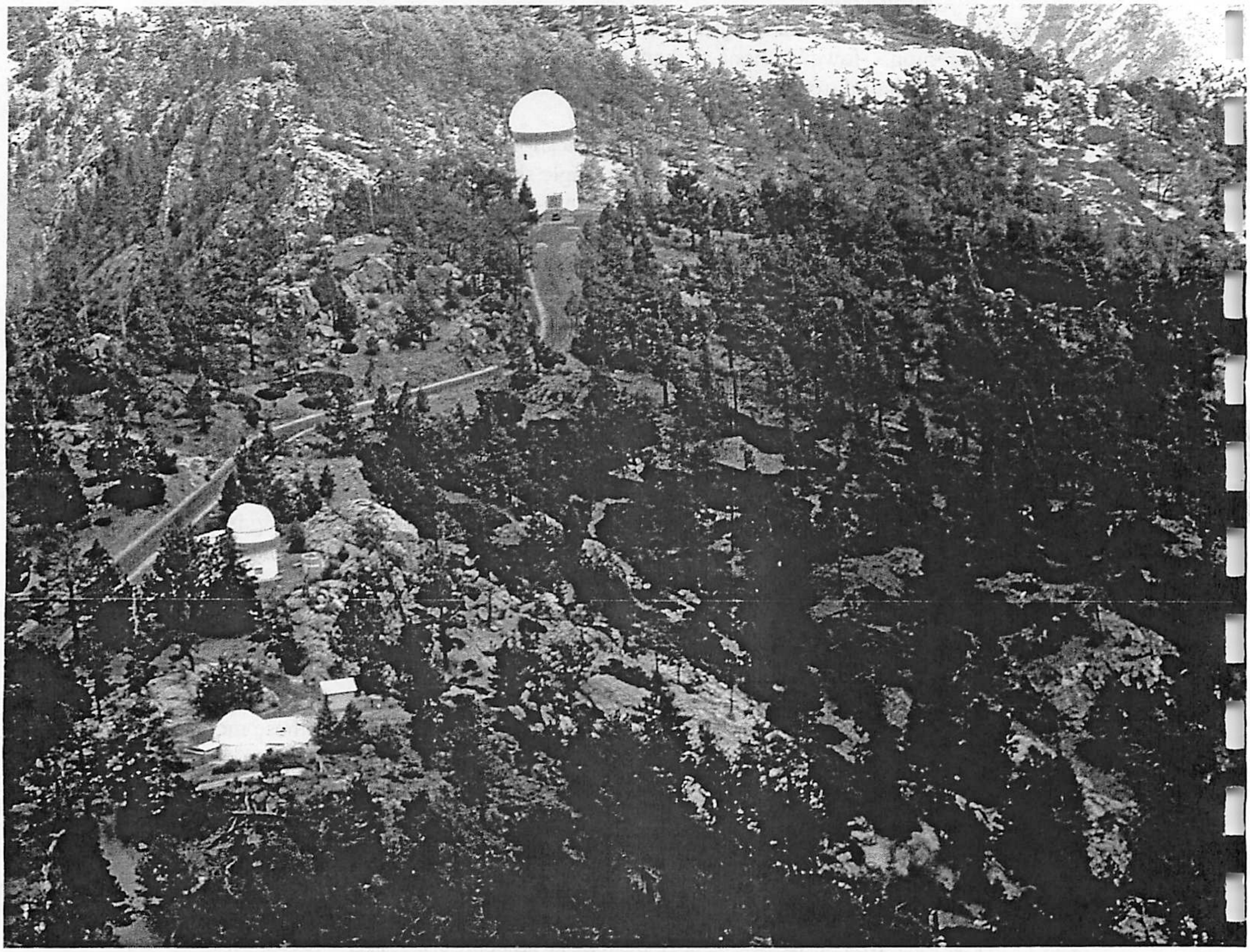
Ortega-Rivera, A. (2003). "Geochronological constraints on the tectonic history of the Peninsular Ranges batholith." *In* Tectonic Evolution of Northwestern Mexico and the Southwestern USA, S. E. Johnson, *et. al.* Ed. GSA, Special Paper 374.

Sedlock, R. L. (2003). "Geology and tectonics of the Baja California peninsula and adjacent areas." *In* Tectonic Evolution of Northwestern Mexico and the Southwestern USA, S. E. Johnson, *et. al.* Ed. GSA, Special Paper 374.

Tulloch, A. J. and D. L. Kimbrough. (2003). "Paired plutonic belts in convergent margins and the development of high Sr/Y magmatism: Peninsular Ranges batholith of Baja-California and Median batholith of New Zealand." *In* Tectonic Evolution of Northwestern Mexico and the Southwestern USA, S. E. Johnson, *et. al.* Ed. GSA, Special Paper 374.

Naydene Hays

Observatory Site Selection
And
San Pedro Martir Observatory



San Pedro Martir Observatory. Picture from http://atst.nso.edu/site/sites/spm.html

I. Criteria For Observatory Site Selection

- A. Location
  - i. Feasibility of building at the site
    - 1. Available space
    - 2. Cost
  - ii. Nearby hydrological/geological features
    - 1. Presence of nearby water
    - 2. Elevation
  - iii. Local/Federal governing agents

- B. Weather
  - i. Temperature gradients; humidity
    - 1. Smaller differences in temperature over a single night lead to better observation conditions
  - ii. Average number or percentage of photometric/spectroscopic nights
  - iii. Wind patterns
    - 1. Laminar wind flow at ground level is necessary. Site must not be at a location of wind turbulence due to geographic features
  - iv. Wind speed
    - 1. High-altitude wind speed as factor for adaptive optics and site potential for very large telescopes

- C. Seeing
  - i. Average seeing values
  - ii. Seasonal variations
  - iii. Meteorological variations

II. Specifics on San Pedro Martir Observatory

- A. Location
  - i. N 31° 02.65' W 115°27.82'.
  - ii. Elevation: 9186 feet
  - iii. 61 km east of the Pacific Ocean, 61 km west of the Gulf of California
  - iv. Located on the peninsular divide
  - v. Governing agencies: UNAM (Universidad Nacional Autonoma de Mexico) and San Pedro National Park
- B. Weather
  - i. Estimated Sunshine: 2600 hours/ year
  - ii. Average annual temperature: 6o C
  - iii. Average rainfall 500 mm

- iv. From **Ten Years of Weather and Observing Statistics in San Pedro Martir, Baja California, Mexico** (Tapia, M 1992)
    1. Average nightly temperature variation is less than 3.5 K on 89% of nights (from 1985-1991).
    2. Humidity can exceed 90% but average humidity is 64%.
    3. Observatory site has monsoon season from late July to early September
    4. 27.4 nights of scheduled observations lost due to weather issues (average value of all 10 years)
    5. Percentage of scheduled nights that were photometric: 57.6 and spectroscopic: 80.4 (again averaged over the 10 years). Greatest percentages occur from May to October.

- v. Wind data
    1. Average wind range in relation to atmosphere elevation
        - a. At 16200 m: 5 - 23 m/s
        - b. At 11800 m: 12 -34 m/s
        - c. At 3000 m: 3 – 8 m/s
    2. Greatest wind speeds occur from Jan – Apr, regardless of altitude
    3. Wind conditions thought to be excellent for extremely large telescopes-Turbulence above 9 km was relatively calm.

C. Seeing

- i. From **Site Testing At Observatorio Astronómico Nacional In San Pedro Mártir** (Echevarria, J et al).
    1. Observations made during a three-year period from Steward Observatory indicate a median seeing of 0.61 arcsec
    2. Seeing is effected by seasonal changes. Seeing in spring and summer: 0.59 arcsec. Seeing in fall and winter: 0.69 arcsec
    3. Seeing does not appear to depend strongly on meteorological variations such as wind direction, humidity or external temperature.
- ii. From **Contribution Of The Surface Layer To The Seeing At San Pedro Mártir: Simultaneous Microthermal And DIMM Measurements** (Sanchez, L.J. et al)
    1. The surface layer (2.3 – 15 m) contributes a mean value of 16% to the total optical turbulence of the site
    2. This contribution equates to a 10% degradation of the seeing.
    3. Value consistent with other observatories

D. Projects at San Pedro Martir
   i. Was a candidate for ATST (Advanced Technology Solar Telescope) – decided to pass on San Pedro Martir
   ii. Search for Extra solar Planets in the Old Metal-rich Open Cluster NGC 6971- included with Hawaii (CFH telescope) and Loiano-Bologna in Italy as part of a multi-site investigation.

III. References

Avila, R., et al. Optical-Turbulence and Wind Profiles at San Pedro Martir. *RevMexAA* **19**, 11-22.

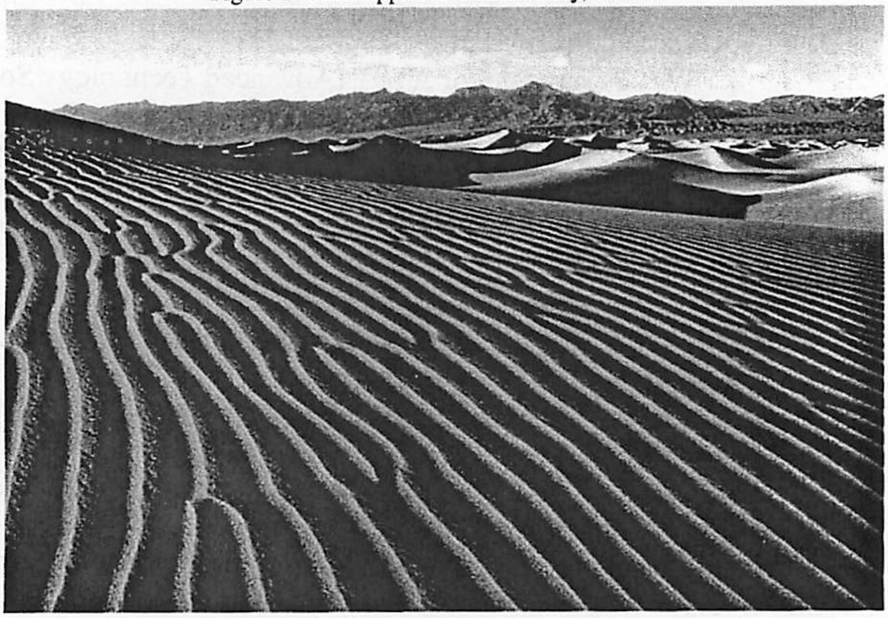
Diaz, G. et al. Geotechnical Study of the OAN/SPM. *RevMexAA*, **19**, 109-117.

Echevarria, J, et al. Site Testing at Observatorio Astronomico Nacional in San Pedro Martir , *RevMexAA* **34**, 47-60.

Sanchez, L.J. et al. Contribution of the Surface Layer to the Seeing at San Pedro Martir: Simultaneous Microthermal and DIMM Measurements. *RevMexAA*, **19**, 23-30.

Tapia, M. 1992, Ten Years of Weather Observing Statistics in San Pedro Martir, Baja California, Mexico, *MexAA*. **24**, 179-186.

Figure 1: Sand ripples in Death Valley, CA.



Sand Ripples and Their Formation

by Gwendolyn D. Bart
November 4, 2005

1 Ripple Observations

Ripples are commonly observed in dry, sandy, windy environments (deserts) and also under shallow water. Figure 1 shows ripples formed on sand dunes at Mesquite Flat in Death Valley, CA [1]. The ripples form perpendicular to the direction of the prevailing wind. An example of ripples formed under shallow water is shown in Fig. 2. The image was taken at Grant Park on the Lake Michigan Shoreline [2]. The ripples form perpendicular to the direction of water flow.

Sometimes ripples are preserved in sedimentary rock. Figure 3 shows an example of fossilized ripples exposed in sedimentary rock.

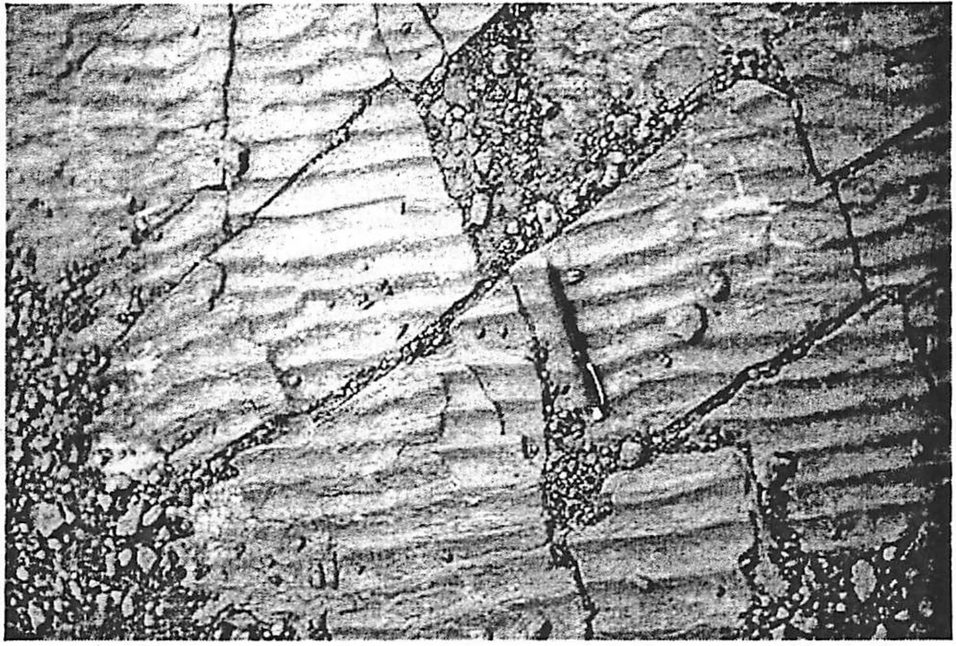
2 Ripple Formation

Ripples form because of the movement of individual sand grains. The primary mechanism by which grains move is known as saltation. Figure 4 shows how saltation occurs in both aeolian and aqueous (under water) environments [3, 4]. When wind speed reaches 4.5 m/s, it will begin to move the grains along the surface (called *surface creep*). As the wind speed increases, the wind becomes turbulent and picks up sand grains. The grains follow an arcuate path, landing a short distance away. That impact may launch subsequent grains into arcuate paths as well. This process is called *saltation*. Saltation can also occur in aqueous environments. Three effects that must be considered in a theory of saltation are: (1) retardation of the wind by drag on the particles, (2) the acceleration of the particles by the wind, and (3) the injection of particles from the surface into the saltation layer by grain impacts [5].

In 1941, Bagnold [6] suggested that ripple wavelength was determined by the path length of saltating particles. The rhythmic barrage of trajectories of length equal to the ripple spacing forms the ripples. This view was challenged [7] because early in their formation ripples have a short wavelength, and the wavelength grows over time to a steady state wavelength. The path length of saltating particles is determined by the wind speed, which is likely constant or irregular with time.

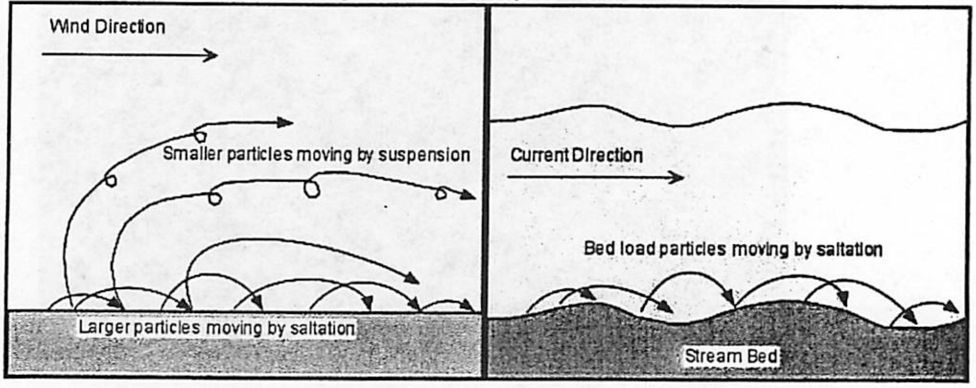
Figure 2: Underwater sand ripples, Lake Michigan.

Figure 3: ripples preserved in sedimentary rock



Anderson [8] constructs an analytical model which indicates that ripple wavelength depends on a pattern of divergence and convergence of mass flux dominated by reptating grains with a probability distribution of reptation lengths. While saltation is initiated by particles picked up by the wind, the bulk of saltation responsible for producing the ridges is initiated by sand thrown up by the impact of another sand grain. Wind causes grains to land with more energy than they were ejected with, leading to increasing grain movement with time. Grains ejected into the wind by grain impacts he refers to as *reptation*, instead of saltation. He determines that it is the reptation wavelength which determines ripple length, and it is not a simple 1:1 relation. The resulting fastest-growing ripple wavelength should be roughly 6 times the mean reptation distance. Wind tunnel experimental results support this view.

Figure 4: grain movement by saltation



3 Ripples on Mars

Ripples are also observed on Mars at a variety of scales. The Mars Exploration Rover *Oppertunity* drove over martian ripples (Fig. 5).

4 Bibilography

[1] Miller, Marli Bryant (2004) Sand Dunes `http://darkwing.uoregon.edu/ millerm/sanddunes.html` Univ. of Oregon, Dept. of Geological Sciences. [2] A Virtual Field Trip: Lake Michigan Shoreline Erosion and Deposition. Grant Park. `http://www.uwm.edu/ caberg/mtp5/virft/beaches/grant.shtml` [3] Nelson, Stephen A (2003) Wind Action and Deserts `http://www.tulane.edu/ sanelson/geol111/deserts.htm` Tulane University, Geol 111. [4] Nelson, Stephen A. (2004) River Systems and Causes of Flooding `http://www.tulane.edu/ sanelson/geol204/riversystems.htm` Tulane University, Geol 204. [5] Ungar, J. E., and P. K. Haff (1987) Steady state saltation in air. *Sedimentology* **34**, 289-299. [6] Bagnold, R. A. (1941) *The Physics of Blown Sand and Desert Dunes*. Methuen & Company, London, 265 pp. [7] Sharp, R. P. (1963) Wind Ripples. *J. Geol.*, **71**, 617-636. [8] Anderson, R. S. (1987) A theoretical model for aeolian impact ripples. *Sedimentology* **34**, 943-956.

Figure 5: ripples on Meridiani Planum, Mars

Fog & Marine Layer

Fall 2005 LPL Field Trip

Mark Szwast

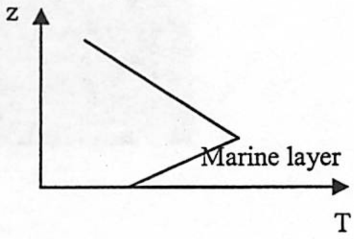
FOG

- A cloud in contact with the ground
- Forms when relative humidity reaches 100% (air temperature falls below dew point).
- Forms in a number of ways depending on how cooling occurred, including:
    - Radiation fog – cooling of ground after sunset
    - Advection fog – moist air flows over cool ground
    - Upslope fog – air blows up a slope, adiabatically cooling it

MARINE LAYER

- Cool, moist, sometimes fog-laden layer of air
- Typically several hundred to as much as 2,000 feet thick
- Chilly oceans (Pacific off California) cool the air just above it, creating the marine layer
- Warmer air above the layer acts like a lid, keeping it from mixing and dispersing
- A steady west wind often piles the marine layer ashore, especially overnight, locking coastal communities in a cool, thick fog
- Lasts usually until midday when the sun is strong enough to break the inversion and mix out the layer

Atmospheric Causes of Marine Layer



- Ocean is cold
- Air above is cooled
- At night, surface radiates heat, so temperature increases with height close to surface → inversion
    - Air cannot mix vertically through inversion
- In morning, ground heats more rapidly than the water, creating convection (warmer air over ground rises, cooler air from over ocean flows onshore)
    - Reinforces inversion
- If physical barriers prevent horizontal transport (such as mountains), then air is trapped

Sources

- http://en.wikipedia.org/wiki/Fog
- http://www.usatoday.com/weather/resources/askjack/archives-clouds-precip.htm

Stromatolites

Implications for Astrobiology

David Minton

Stromatolites represent some of the earliest macrofossil evidence for life, however less than 1% of fossil stromatolites contain the fossilized remains of the microorganisms that created them (Groztinger & Knoll, 1999). Although in general the biological origin of stromatolites is indisuputed, for some very early Archean and possible martian stromatolites it may be harder to argue for a biological origin.

There are several reasons to suspect that if microbial life had ever taken hold on the surface of Mars that it would probably have formed stromatolites. One definition for a stromatolite is an "attached, laminated, lithified sedimentary growth structure, accretionary away from a point or limited surface of initiation" (Semikhatov, et. al., 1979). This definition makes no reference to the origin of the stromatolite, whether by a particular mat-building microbial organism or even an abiologic process.

Illustration 1: 1 Stromatolite growth simulation using a diffusion-limited aggregation model (from Groztinger & Knoll, 1999)

Indeed, Chan & Grotzinger were able to model basic morphology (columnar and branching) of a type of stromatolite without making any reference to specific biological processes, but instead using a diffusion-limited aggregation and episodic sedimentation model, as seen in Figure 1 (Groztinger & Knoll, 1999). They also argue that these types of structures will only occur under specific conditions relating to the chemistry of the water, for instance calcium carbonate seems to be an important precipitate for the initiation of stromatolite forms over other types of minerals.

This implies that even native martian biota, evolved completely independently of Earth, may still build stromatolites under appropriate conditions. However, it also allows for an abiological origin for stromatolites, meaning that if laminated sedimentary growth structures resembling stromatolites are ever discovered on Mars, some other line of evidence must be used to establish their biological origin. It also means that even if stromatolite fossils are discovered on Mars, their morphology may not be enough to indicate whether they are the result of native biogenesis, or are the descendants of organisms from Earth that have been seeded on Mars due to impacts.


Illustration 2: 2 Fossil columnar stromatolites from the early Proterozoic. Wildbread Formation, East Arm Great Slave Lake, NW Territories, Canada (photo P. Hoffman).

Impact seeding seems to be a possible mechansim for cross-contamination of the terrestrial planets, especially during the period of Late Heavy Bombardment (Gladman, et. al., 2005). It is also probable that life evolved under the high UV flux, high CO_2 atmosphere Archean Earth could survive on the surface of an earlier, wetter Mars. Studies of modern strains of cyanobacteria, related to organisms that create stromatolites, show that they can grow in 100% CO_2 (Thomas, et. al., 2005) and Mars-level UV flux (Cockell, et., al., 2005).

The discovery of stromatolite fossils on Mars would be an exciting find, however by themselves they may be only marginally useful in unraveling some of the deeper questions in astrobiology, particularly the universality of life in the Universe.

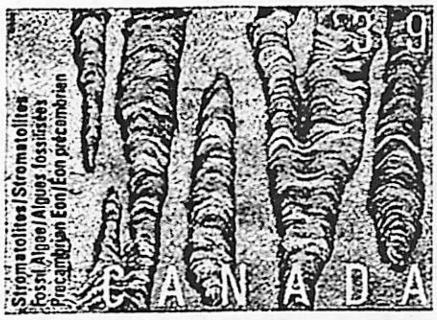
References

Cockell, CS, Schuerger, AC, Billi, D, Friedmann, EI, and Panitz, C. "Effects of a Simulated Martian UV Flux on the Cyanobacterium, *Chroococcidiopsis* sp. 029." *Astrobiology*, 2005, 5:127-40.

Gladman, B., Dones, L., Levison, HF, and Burns, JA. "Impact Seeding and Reseeding in the Inner Solar System." *Astrobiology*, 2005. 5:483-96.

Grotzinger, JP and Knoll, AH. "Stromatolites in Precambrian Carbonates: Evolutionary Mileposts or Environmental Dipsticks?" *Annu. Rev. Earth Planet. Sci.*, 1999. 27:313-58

Thomas, DJ, Sullivan, SL, Price, AL, and Zimmerman, SM. "Common Freshwater Cyanobacteria Grow in 100% CO_2." *Astrobiology*, 2005. 5:66-74.



Stromatolites

Then and now

Catherine Neish
Baja Field Trip (Nov. 9-13, 2005)

Stromatolites: What are they?

Stromatolites are layered structures that are formed by communities of microscopic organisms (Figure 1). They appear both in the fossil record and alive in several localities around the world.

Ancient stromatolites were likely formed as they are today, by prokaryotic cyanobacteria in shallow sea-water. Cyanobacteria are photosynthetic organisms, and thus require good light conditions to grow. To maximize their light intake, they large form mats on the sea floor. Through photosynthesis, cyanobacteria deplete carbon dioxide in the surrounding waters, causing calcium carbonate to precipitate over the mat. These minerals, along with sediments in the water, get trapped in the sticky mucilage that surrounds the bacterial colonies. To get the sunlight they need to survive, the cyanobacteria migrate upwards and form a new mat. Over time, a distinctive layered structure is built up. Most stromatolites appear as arches, spheres, or domes. The layers within these structures are known as "laminae."

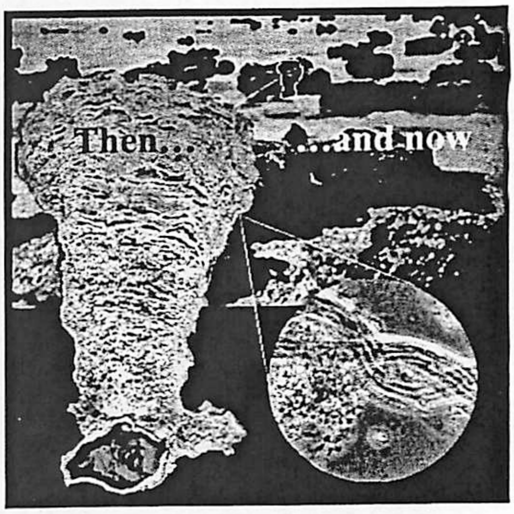


Figure 1: An example of a fossilized stromatolite superimposed on a modern community of stromatolites. Inset is an example of the organisms living in a stromatolite.

Fossil stromatolites

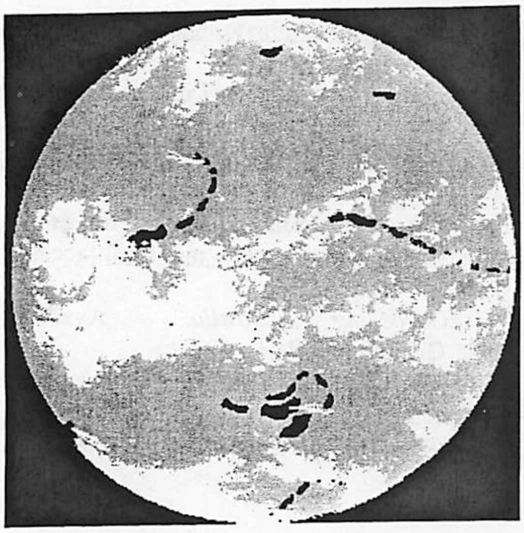
Stromatolites fossils are evidence of some of the earliest life on Earth (Figure 2). The oldest stromatolites date to the Early Archaean (~3.5 billion years ago), but stromatolites did not become widespread until the Proterozoic (2.5 – 0.57 billion years ago). Over this period of Earth's history, stromatolites were the main reef building organisms, constructing large masses of calcium carbonate. Stromatolites also helped to change the Earth's atmosphere during this time, converting the original CO_2 rich atmosphere into the current oxygen rich atmosphere. By the close of the Proterozoic, the abundance of stromatolites decreased markedly, as animals evolved that consumed cyanobacteria (Figure 3).

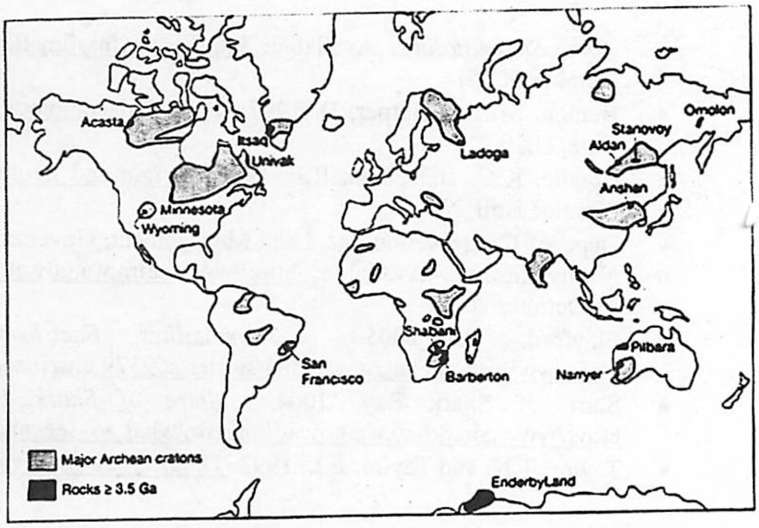
The best stromatolite fossils are found in Western Australia. In some cases, the cyanobacteria are fossilized along with the layers, but more often only the layers are preserved.

References

- *About Stromatolites*. Available: http://www.fossilmall.com/Science/About_Stromatolite.htm [accessed 31 October 2005]
- Benton, M. and Harper, D. 1997. Basic Palaeontology. Addison Wesley Longman Limited, Edinburgh Gate, UK.
- Condie, K.C. and Sloan, R.E. 1997. Origin and Evolution of Earth: Principles of Historical Geology. Prentice Hall, NY.
- Dept. of Conservation and Land Management, Government of Western Australia. *Hamelin Pool Marine Nature Reserve*. Available: http://www.calm.wa.gov.au/national_parks/hamelin_pool_mnr.html [accessed 31 October 2005]
- Playford, P. 2005. *Stromatolites Factsheet – Gardening Australia.* Available: http://www.abc.net.au/gardening/stories/s69379.htm [accessed 31 October 2005]
- Shire of Shark Bay, 2004. *Shire of Shark Bay – What to See and Do.* Available: http://www.sharkbay.wa.gov.au/tourism/what_to_see_and_do/ [accessed 25 October 2005]
- Taylor, T.N. and Taylor, E.L. 1993. The Biology and Evolution of Fossil Plants. Prentice Hall, New Jersey.

ARCHEAN EARTH & EARLY LIFE



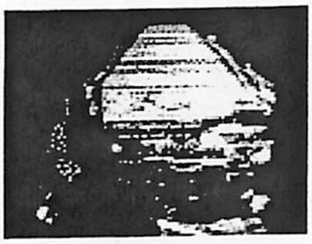


http://www.geo.msu.edu/geo333/Precambrian.html

- 3.8 -2.5 Ga
- Deposition and metamorphism of some of the oldest crustal rocks.
- Formation of ancient continental crust from the cratons of the modern continents.
- Condensation of water vapor leads to the formation of a global ocean.

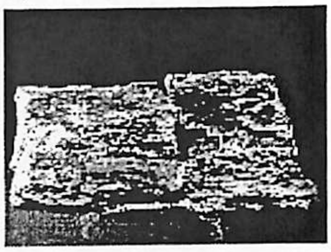
- Plate tectonics - the Earth's interior was ~3X hotter than today - greater concentration of radioactive isotopes and residual heat from the accretion process.
- More fluid mantle, much thinner crust, rapid production and recycling of oceanic crust. Volcanic Islands and Arcs in great abundance.

- Cratons probably consisted of light colored felsic rocks and greenstones.
- Archean rocks originated as deep water clastic deposits (mudstone, greywacke), with high concentrations of eroded volcanic material. Sediments appear to have been deposited in basins and subduction zones, shallow water shelf deposits are absent.
- First large continent formed in the middle Archean - preserved in South Africa. Broad stream channels with detrital accumulations of gold are evidence for an extensive landmass.



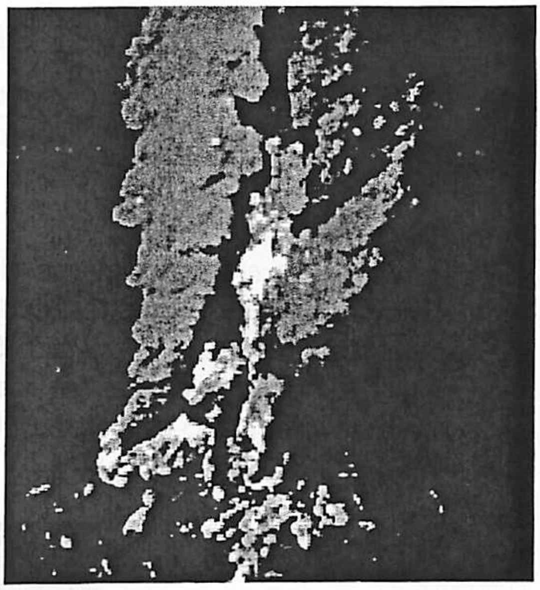
http://mineral.galleries.com/

- The Archean atmosphere was nitrogen rich with less than 1/1000 of the oxygen levels of today. Most CO_2 was sequestered in limestone at the bottom of the ocean. Evidence: abundance of pyrite and uraninite and a lack of hematite in the Archean sediments The oxygen levels presumably rose upon the advent of cyanobacteria.



http://mineral.galleries.com/

- Oldest known fossils date to the Archean:
    - Stromatolites: 3.5Ga Warrawoona Group of the Pilbara Shield of Western Australia & the Onverwacht Group of South Africa
    - Preserved organic matter: 1. 'cyanobacteria-like' filamentous structures in ultra-fine grained cherts: 3.5Ga, Australia. 2. Cells in various stages of division: 3.0Ga, Fig Tree Group, South Africa
- Life would have required spontaneous organization of self replicating molecules with energy capturing capabilities.



http://www.seasky.org/monsters/sea7a6.html

- Where did life originate? Shallow pools, as proposed by Darwin, or deep sea vents? Shallow water is the more popular theory, but it has been suggested that UV radiation could damage organic material. Alternative - if the earliest organisms were hyperthermophiles and chemoautotrophs, they could have survived the hot temperatures of the volcanic vents that were abundant along the rifting zones of the ocean floor. They would have been provided chemical and heat energy, chemical and mineral compounds, including sulfur, as well as protection from the UV radiation.
- UV radiation on Mars is much more damaging - lack of ozone shield - but this does not preclude the "biogeographically widespread colonization of land." There are microhabitats on that Earth provide a refuge from the UV radiation (salt, rocks). Similar niches could exist on Mars. (Cockell & Raven, 2004)
- Sulfate rich sediments on Mars - chemoautotrophs?

http://www-atdp.berkeley.edu/9931/jbutler/attitude2.gif

•Amethyst Galleries' Mineral Gallery. http://mineral.galleries.com/ (November 2005).
•Barley, M., Bekker, A., Krapez, B. (2005) Late Archean to Early Paleoproterozoic global tectonic, environmental change and the rise of atmospheric oxygen. Earth and Planetary Science Letters 238, 156-171.
•Bennington, J. Hofstra University, Department of Geology "The Archean Eon." http://people.hofstra.edu/faculty/j_b_bennington/2cnotes/archean.html (November 2005).
•Cockell, C., Raven, J. Zones of Photosynthetic potential on Mars and the early Earth. Icarus 169, 300-310.
•Jia, Y., Kerrich R. (2004) A reinterpretation of the crustal N-isotope record: evidence for a ^{15}N-enriched Archean atmosphere? Terra Nova 16 (3), 102-108.
•Michigan State University, Department of Geology "The Precambrian Era." http://www.geo.msu.edu/geo333/Precambrian.html (November 2005).
•Prepared by E. L. Berger

A wet bar with NO alcohol: Coastal Spits & Bars

By Jade Bond.

What are they?

Spits and bars are linear marine depositional features, commonly composed of sand and/or gravel. Bars are ridge-like depositional features that can be either exposed or submerged under shallow water. Spits are a sea-ward extension of a beach i.e. the beach extends out to sea but remains joined to the mainland at one end. Spits are sometimes referred to as a type of bar. One well-known example of a spit is Cape Cod, MA (Figure 1).

Figure 1: Aerial image of Cape Cod, showing the spit structure. Image from: http://www.terc.edu/handsonIssues/s97/capeaerial.html

How do they form?

Bars form where the current conditions promote deposition. So essentially they form wherever the current slows to a point where it can no longer carry the sediment load resulting in deposition occurring. As such, bars can form in any marine environment – lakes, rivers and seas. This also means that bars come in a variety of sizes, ranging from the meter size up to several hundreds of kilometers.

Spits, however, are produced by longshore drift (see Figure 2 for a description) meaning that they form along embayed coastlines where there are plentiful beaches and a prevailing wind. Under such conditions, beach material migrates along the beach until it is eventually deposited in deeper water, usually located behind a headland, where the longshore current velocity decreases. This thus extends the beach out beyond its normal location, producing a spit. Spit ends will often be curved towards the coastline due to refraction of waves in the newly created bay and possibly also a different wind direction. Marshes often develop behind a spit due to the sheltered conditions present there. See Figures 3 & 4 for diagrams of both spit and bar formation.

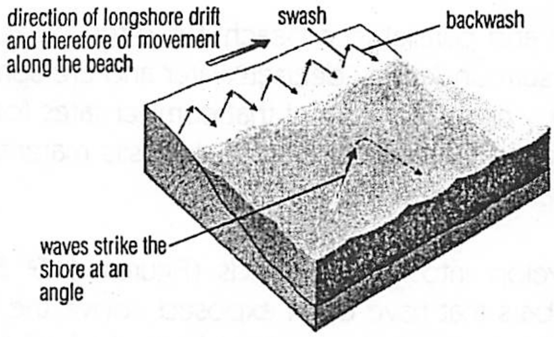


Figure 2: Diagram of longshore drift. Image from: http://www.acleanerenvironment.com/Beacherosionnotes.html

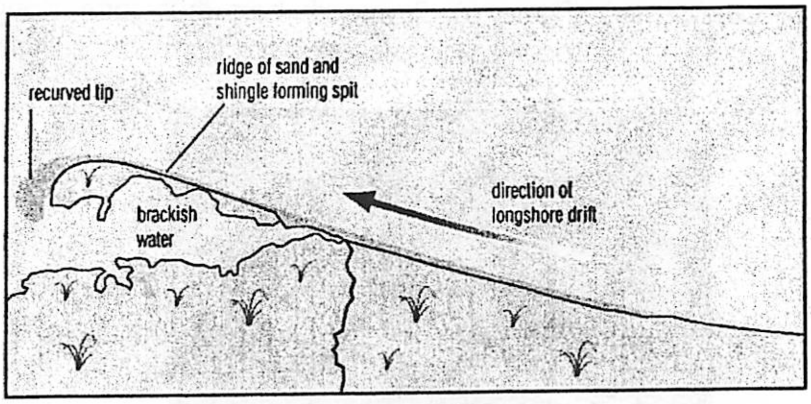


Figure 3: Diagram of spit formation. Image from: http://www.acleanerenvironment.com/Beacherosionnotes.html

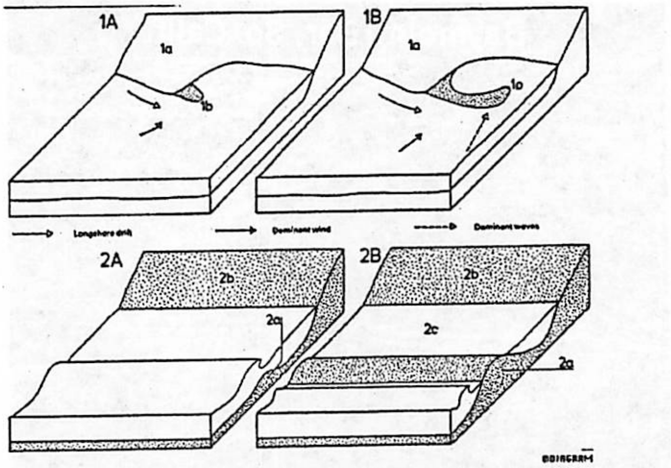


Figure 4: Diagram of (1) spit formation and (2) bar formation. Image from: http://www.fofweb.com/Subscription/Science/Science-Detail.asp?SID=1&iPin=E0346

Are there different types?

When a bar forms at sea and parallel to a beach it is often called longshore bar (or a sandbar). These bars are surrounded by deeper water and are sometimes visible at low tide. They are produced by the under-current that compensates for the wave-produced current on the water surface. This counter current deposits material at the waves' break point, thus producing a bar parallel to the beach.

Longshore bars can develop into barrier islands (Figures 4 & 5). These islands are essentially just longshore bars that have been exposed above the water level and now trap a lagoon between the coast and the island itself. Barrier islands are common in coastal areas such as that of Florida with one well known example being Coney Island, NY.

When a spit extends from one headland to another, it forms a feature known as a baymouth bar (or bay barrier) (Figure 6). Baymouth bars thus form along embayed coastlines where the currents are too weak to prevent a spit from continuing to expand.

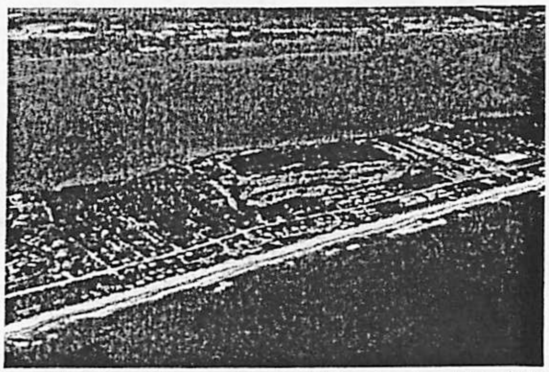


Figure 5: Aerial image of Bogue Banks, NC, a barrier island. Image from:
http://www.geosci.unc.edu/faculty/glazner/Images/Coastlines/BarrierIslands/BogueBanks.jpg

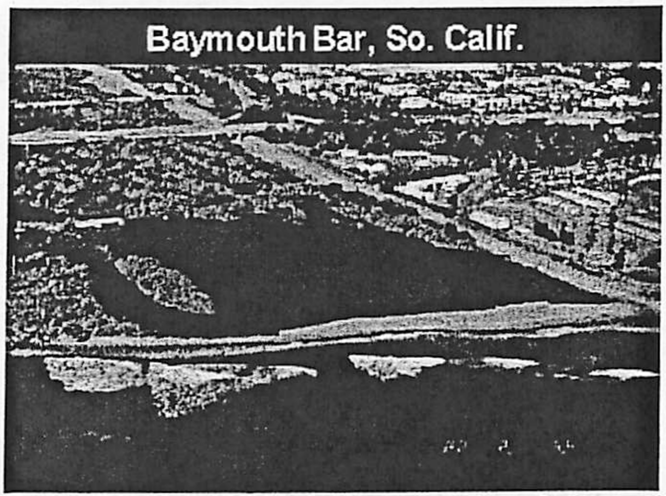


Figure 6: Aerial image of a baymouth bar in Southern CA. Image from:
http://www.geo.wvu.edu/~kite/Geol221_2001Lect23Coastal/sld061.htm

Is there a planetary connection?

The processes that form spits and bars are universal so we would expect to see these features along any shoreline with both liquid (water or any other substance) and beach material (sand or gravel) present. As such, we could expect to find ancient spits and bars on Mars and possibly also on Titan (such as in Figure 7).

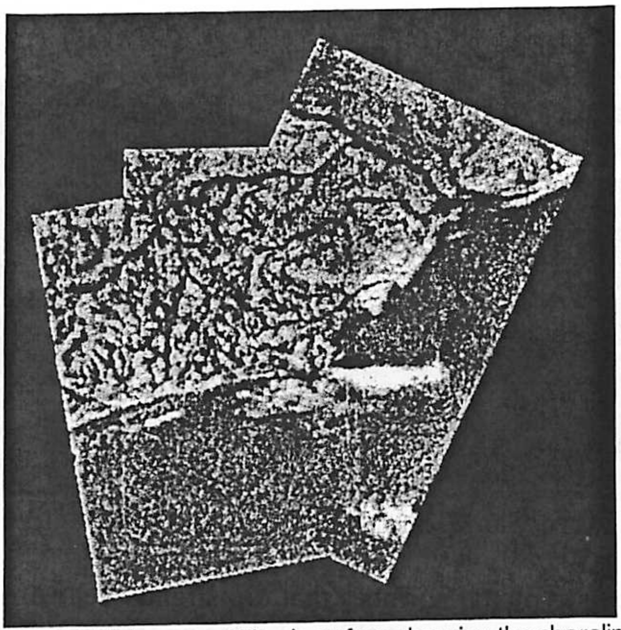


Figure 7: Mosaic of 3 DISR images of Titan's surface showing the shoreline. Image from: http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=36397

References:

While no specific references were given, the general information for this handout was compiled from a variety of sources including the following:

Bascom, W. 1980. *Waves and Beaches*. Double Day, New York, USA.

Hamblin, W. K. & Christiansen, E. H. 1998. *Earth's Dynamic Systems*, 8th Edition. Prentice Hall, New Jersey, USA.

Skinner, B. J. & Porter, S. C. 2000. *The Dynamic Earth: an introduction to physical geology*, 4th Edition. John Wiley & Sons Inc., New York, USA.

Marine terraces

Chris Okubo

1. What they look like

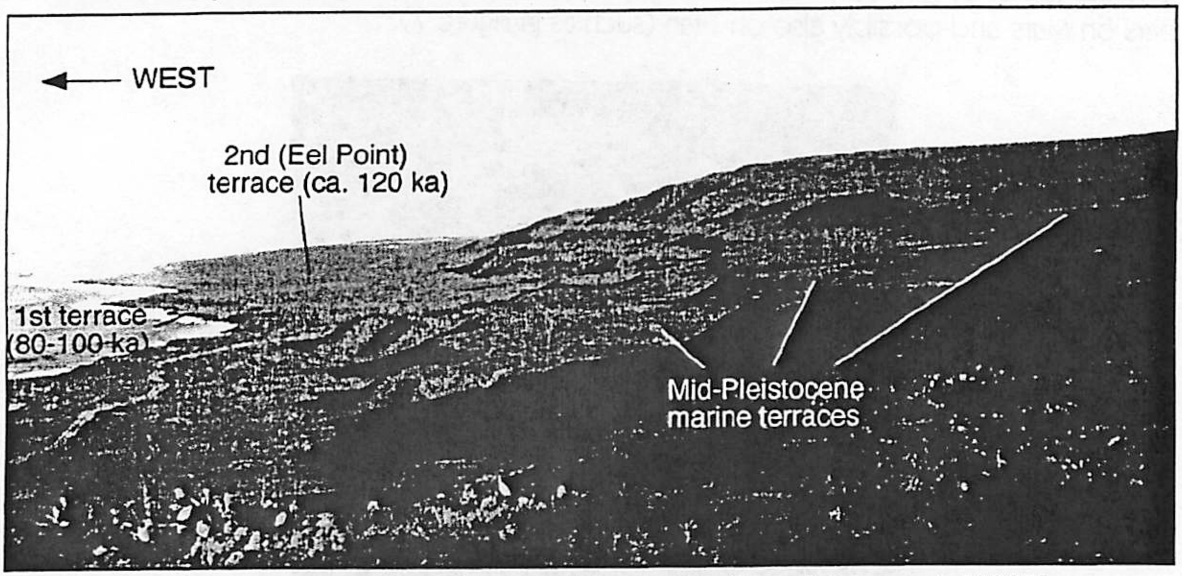


Figure 1. Marine terraces on San Clemente Island, CA. From Muhs et al. [2002].

Marine terraces are planar surfaces that dip slightly seaward and are bounded on the seaward side by a steep escarpment (Fig. 1). Marine terraces are commonly observed forming stair–stepped morphologies along present day or paleo–shorelines. Marine terraces are also present below sea level.

2. How they form

Marine terraces form within the intertidal range through wave erosion of geomaterials along the coast (Fig. 2). In mechanically weak materials, such as sandstone, wave erosion can undercut the shoreline materials, forming an intertidal notch. In mechanically strong materials, the intertidal notch can be negligible and wave erosion is generally manifest as cliff retreat. Persistent growth of the intertidal notch leads to the collapse of overhanging material and landward growth of the platform. The platform of an actively forming terrace (or 'intertidal bench') is located below mean sea level, but above mean lowest low water ('mllw').

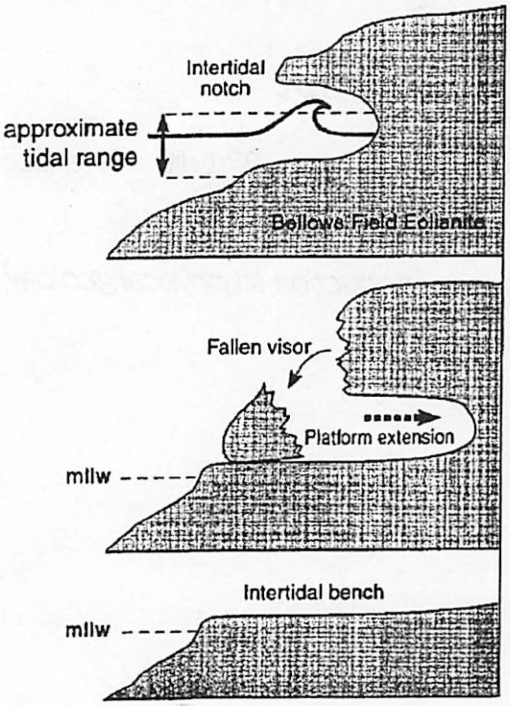


Figure 2. Conceptual model of marine terrace formation. From Fletcher and Jones [1996].

Since the elevation of an actively forming marine terrace is a function of mean sea level and intertidal range, changes in these two parameters leads to changes in the elevation of the actively forming terrace. This means that changes in sea level relative to an actively forming terrace will impede the growth of that terrace and lead to the growth of a new terrace.

Relative changes in sea level are commonly achieved through a combination of: 1) changes in the elevation of the landmass due to crustal deformation, and 2) global changes in ocean volume.

A relative drop in sea level leads to the formation of 'emergent' terraces that are stranded above sea level (Figs. 3, 4). A relative increase in sea level leads to the formation of 'submerged' terraces.

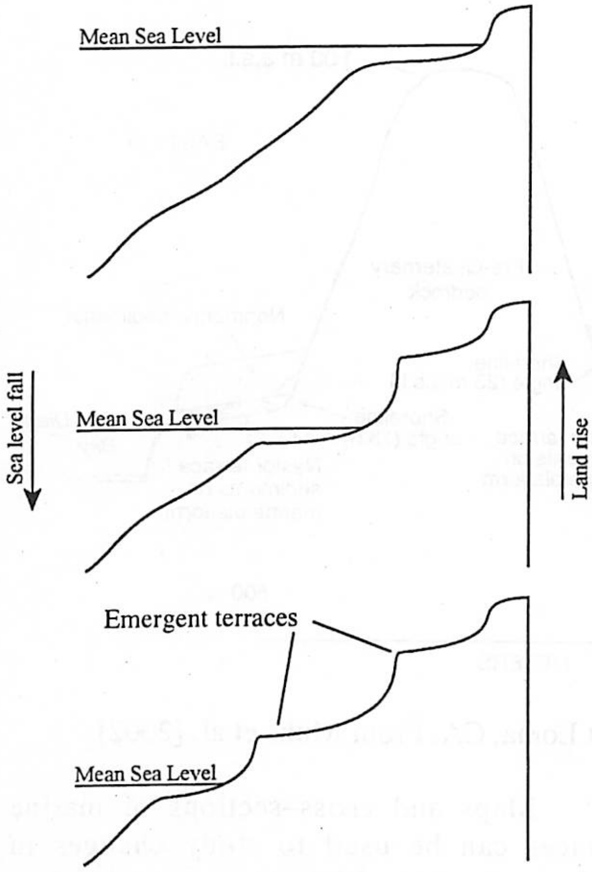


Figure 3. (above) Processes that commonly generate emergent marine terraces.

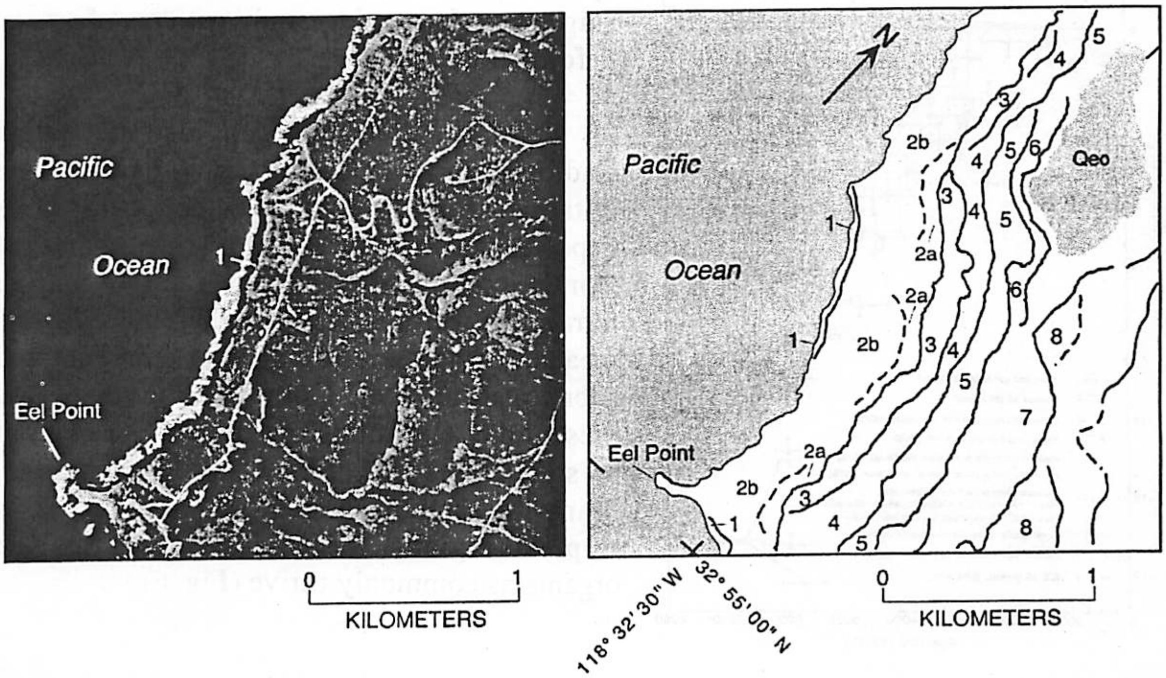


Figure 4. Map view patterns of emergent marine terraces on San Clemente Island, CA. From Muhs et al. [2002].

3. What they tell you

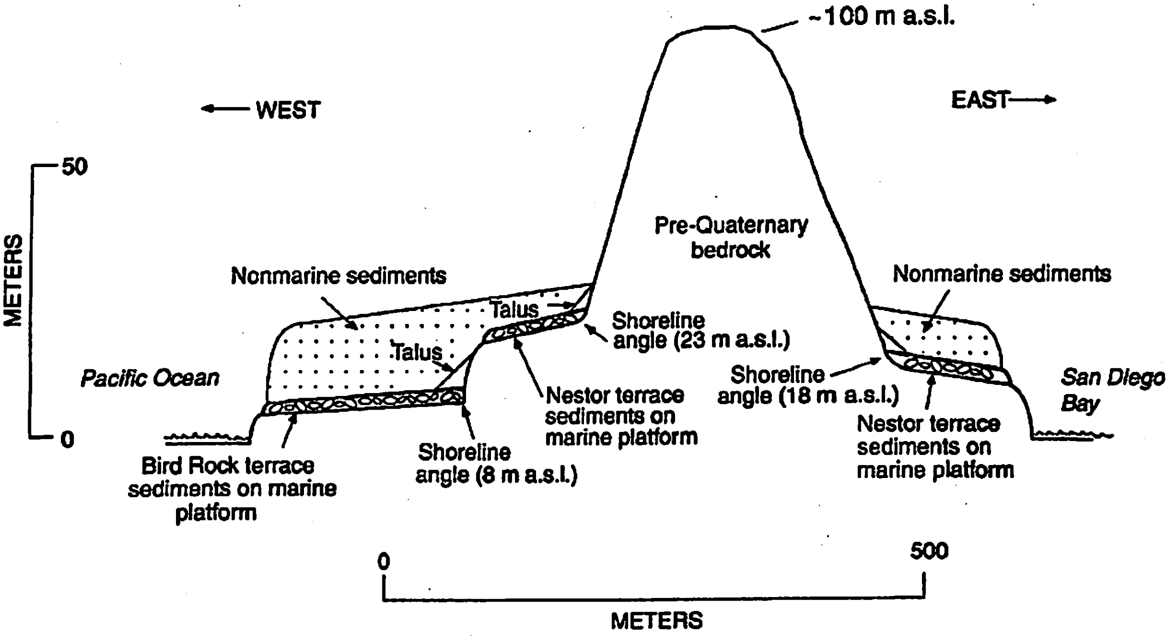
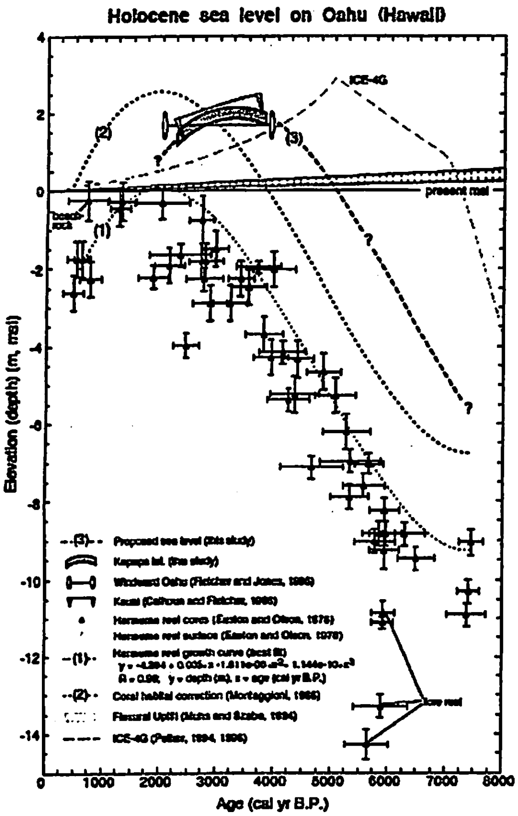


Figure 5. (above) Cross–section through Point Loma, CA. From Muhs et al. [2002].



Maps and cross–sections of marine terraces can be used to study changes in surface elevation. Since mean sea level is regionally constant at any given point in time, spatial variability in the elevation of a terrace (Fig. 5) can be used to study patterns of crustal deformation.

Marine terraces can also be dated. Radiocarbon and other isotopic ages can be obtained for corals and other calcareous deposits generated by living marine organisms. Corals commonly grow on active marine terraces in warm waters and thereby provide a means to determine the ages of emergent and submerged terraces. Comparing the ages and present day elevations of terraces can be used to study rates of relative sea level change. Many such studies have been conducted in tropical regions where calcareous marine organisms commonly thrive (Fig. 6).

Figure 6. Holocene sea level change as recorded, in part, by calcareous fossils in marine terraces on the island of Oahu, Hawai'i. From Grossman and Fletcher [1998]

4. Local significance

Emergent marine terraces are prominent along the Pacific coast of Baja California, west of the Peninsular Ranges. Ages and elevations of these terraces suggest persistent coastal uplift during the late Quaternary of about 0.13 mm/yr. Uplift rates are maximum toward the north (0.13–0.14 mm/yr), in the San Joaquin Hills–Ensenada region of California, where maximum cumulative uplift of 155 m has been observed along the Rifle Range terrace [Kern and Rockwell, 1992]. Uplift decreases to zero toward the south and is negligible at 28.6° latitude. This coastal uplift is interpreted to be the result of both regional faulting and lithospheric flexure along the Pacific plate boundary. Local faulting is driven by regional right–lateral strike–slip displacements, and lithospheric flexure occurs in response to rifting within the Gulf of California [Mueller, 2001].

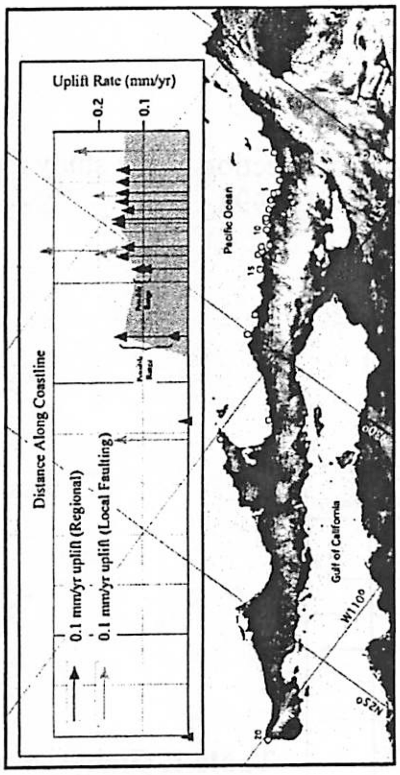


Figure 7. (left) Uplift rates along the Pacific coast determined by age dates and present day elevations of emergent marine terraces. From Mueller [2001].

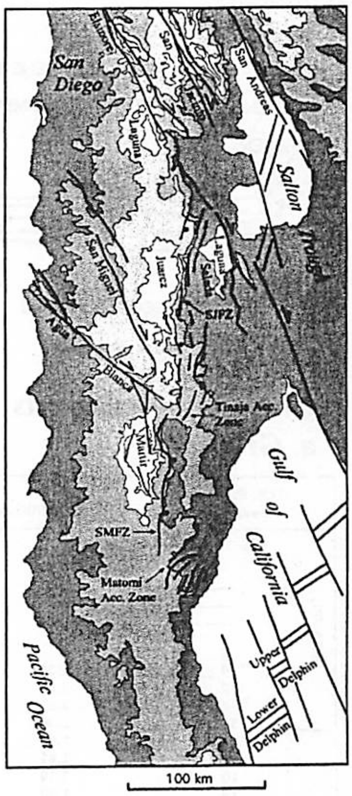


Figure 8. (right) Generalized regional fault traces. Arrows show the sense of displacement along strike–slip faults. Filled circles are on the down–thrown sides of normal faults. From Mueller [2001].

References

Fletcher, C.H., Jones, A.T., 1996. Sea–level highstand recorded in Holocene shoreline deposits on Oahu, Hawai'i. Journal of Sedimentary Research, 66(3), 632–641.

Grossman, E.E., Fletcher, C.H., 1998. Sea level 3500 years ago on the Northern Main Hawaiian Islands. Geology 26(4), 363–366

Kern, J.P., Rockwell, T.K., 1992. Chronology and deformation of marine shorelines, San Diego County, in Quaternary Coasts of the United States: Marine Lacustrine Systems, SEPM Special Publication 48, p. 377–382.

Mueller, K., 2001. Origins of Coastal Uplift in San Diego and Orange Counties: Huge Blind Thrusts or Aseismic Rift Shoulder? Final technical report to the U. S. Geological Survey External Research Support program. Award 01HQGR0031.

Muhs, D.R, Simmons, K.R., Kennedy, G.L., Rockwell, T.K. The last interglacial period on the Pacific Coast of North America; timing and paleoclimate. Geological Society of America Bulletin, 114(5), 569–592

Sedimentary Deposition and Conglomerates

by Oleg Abramov

1. General description of the study area

A cross-section of the area we'll be visiting is shown in Fig 1. Note that there is an upper and a lower terrace. During the Cretaceous period, the shoreline was at the level of the upper terrace, and a thick layer of Cretaceous sediments was deposited in this shallow marine environment. A subsequent uplift episode raised the upper terrace, with the newly cut lower terrace was submerged to the point labeled "Pleistocene shoreline and sea cliff." The streams originating from the hills to the east delivered sediments that were deposited on the submerged shelf. Finally, as a result of another uplift episode, the ocean receded, forming a new marine terrace. Further sediments were then deposited on top of it. The lower terrace is now dry and cut by gullies draining into the sea, giving us a good look at the cross-section of these Pleistocene sediments.

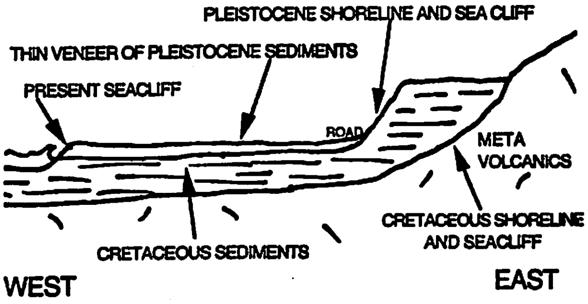


Figure 1. A cross-section of the study area. From *Minch et al.*, 1998.

2. Classifying sediments

a. Grain size

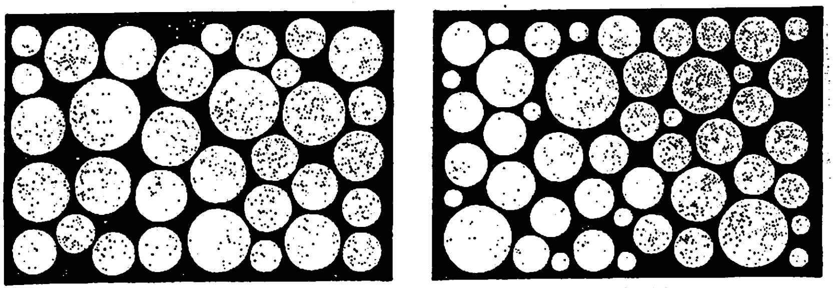
		U.S. Standard sieve mesh	Millimeters		Phi (ϕ) units	Wentworth size class
GRAVEL			4096		-12	Boulder
			1024		-10	
			256	256	-8	
			64	64	-6	Cobble
			16		-4	Pebble
		5	4	4	-2	
		6	3.36		-1.75	Granule
		7	2.83		-1.5	
		8	2.38		-1.25	
		10	2.00	2	-1.0	
SAND		12	1.68		-0.75	Very coarse sand
		14	1.41		-0.5	
		16	1.19		-0.25	
		18	1.00	1	0.0	
		20	0.84		0.25	Coarse sand
		25	0.71		0.5	
		30	0.59		0.75	
		35	0.50	½	1.0	
		40	0.42		1.25	Medium sand
		45	0.35		1.5	
		50	0.30		1.75	
		60	0.25	¼	2.0	
		70	0.210		2.25	Fine sand
		80	0.177		2.5	
		100	0.149		2.75	
		120	0.125	⅛	3.0	
		140	0.105		3.25	Very fine sand
		170	0.088		3.5	
		200	0.074		3.75	
		230	0.0625	1/16	4.0	
MUD	SILT	270	0.053		4.25	Coarse silt
		325	0.044		4.5	
			0.037		4.75	
			0.031	1/32	5.0	
			0.0156	1/64	6.0	Medium silt
			0.0078	1/128	7.0	Fine silt
			0.0039	1/256	8.0	Very fine silt
	CLAY		0.0020		9.0	Clay
			0.00098		10.0	
			0.00049		11.0	
			0.00024		12.0	
			0.00012		13.0	
			0.00006		14.0	

Table 1. Grain-size scale for sediments, showing Wentworth size classes, equivalent phi units, and sieve numbers of U.S. Standard Sieves. Modified from *Wentworth*, 1922.

The Wentworth grain-size scale is used almost universally by sedimentologists (Table 1). On the basis of grain size, clastic sedimentary rocks can be divided into mudstones, shales, siltstones, sandstones, and conglomerates. The grain size provides a big clue to the environment in which the rock was originally formed. Rocks with small particle sizes, like shales, are generally deposited in low-energy type of environments, such as the ocean floor, while rocks with large grain sizes, like conglomerates, are deposited in high-energy environments, such as turbulent streams. For rocks deposited in flowing water, grain size is also a good indicator of water velocity.

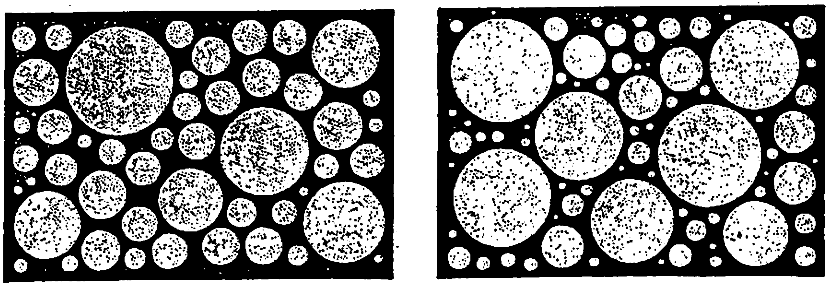
b. Sorting

Sorting in a sedimentary rock refers to the range of grain sizes present and the magnitude of scatter of these sizes around the mean. Sorting can be calculated mathematically using the standard deviation of grain sizes. A graphical illustration of sorting in shown in Fig 2. Geologically, sorting can hint at the depositional environment, with good sorting suggesting a low-viscosity fluid such as air, and poor sorting implying a high-viscosity fluid such as ice. Poor sorting can also indicate rapid deposition or an inconsistent-energy environment. Another sorting mechanism that may be important for this particular location is reworking by waves.



VERY WELL SORTED

WELL SORTED



MODERATELY SORTED

POORLY SORTED

Figure 2. Grain-sorting diagrams for sediments with different degrees of sorting. From *Anstey and Chase*, 1974.

c. Shape

Particle shape is characterized by *sphericity*, which describes how close a particle is to a perfect sphere, and *roundness*, which is a measure of the smoothness of particle corners. This is illustrated in Fig 3. The roundness of particles in a sediment is a function of particle size, material properties, type of transport process, and distance of transport. Typically, rounder particles were in the fluid for a longer time and were transported a greater distance. The significance of sphericity is harder to interpret, because of two competing effects. Non-spherical particles have a lower settling velocity and therefore tend to stay in suspension longer, while spherical particles are more easily rolled along the bed.

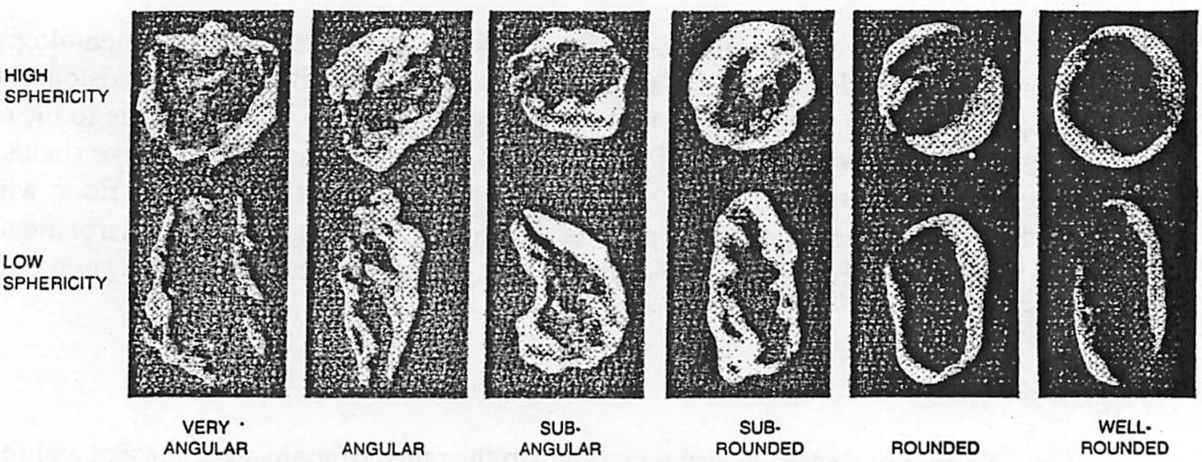


Figure 3. Grain images for estimating the roundness and sphericity of sedimentary particles (*Powers*, 1953).

d. Bedding (from *http://www.earthsci.org/*):

Rhythmic Layering - Alternating parallel layers having different properties. Sometimes caused by seasonal changes in deposition (Varves). i.e. lake deposits wherein coarse sediment is deposited in summer months and fine sediment is deposited in the winter when the surface of the lake is frozen.

Cross Bedding - Sets of beds that are inclined relative to one another. The beds are inclined in the direction that the wind or water was moving at the time of deposition. Boundaries between sets of cross beds usually represent an erosional surface. Very common in beach deposits, sand dunes, and river deposited sediment.

Graded Bedding - As current velocity decreases, first the larger or more dense particles are deposited followed by smaller particles. This results in bedding showing a decrease in grain size from the bottom of the bed to the top of the bed.

e. Consolidation

In order to become rocks, clastic sediments need to be cemented by natural minerals such as calcite or quartz. This usually happens by percolation of groundwater through sediments that have been buried and compacted. This process is called lithification. Loose, unconsolidated sediments indicate a recent deposition, with insufficient time for lithification.

3. Classifying conglomerates

At this field stop we should encounter a lot of conglomerate, which is simply a rock consisting of large clasts cemented together. While this definition technically includes volcanic and impact breccias, the term conglomerate is usually reserved for rocks formed by sedimentation, which have subangular to well-rounded clasts. In order for a rock to be classified as a conglomerate, the largest clasts have to be > 2 mm in diameter. If more than 85% of the rock consists of large grains (> 2 mm), it is called an *orthoconglomerate*, as opposed to a *paraconglomerate*. Orthoconglamerates indicate a more energetic transport process than paraconglamerates. The clasts can be metamorphic, sedimentary, or igneous (Fig 4), and a conglomerate can have only one type of clasts, in which case it's called a *monomict* conglomerate, or more than one type of clast, making it a *polymict* conglomerate.

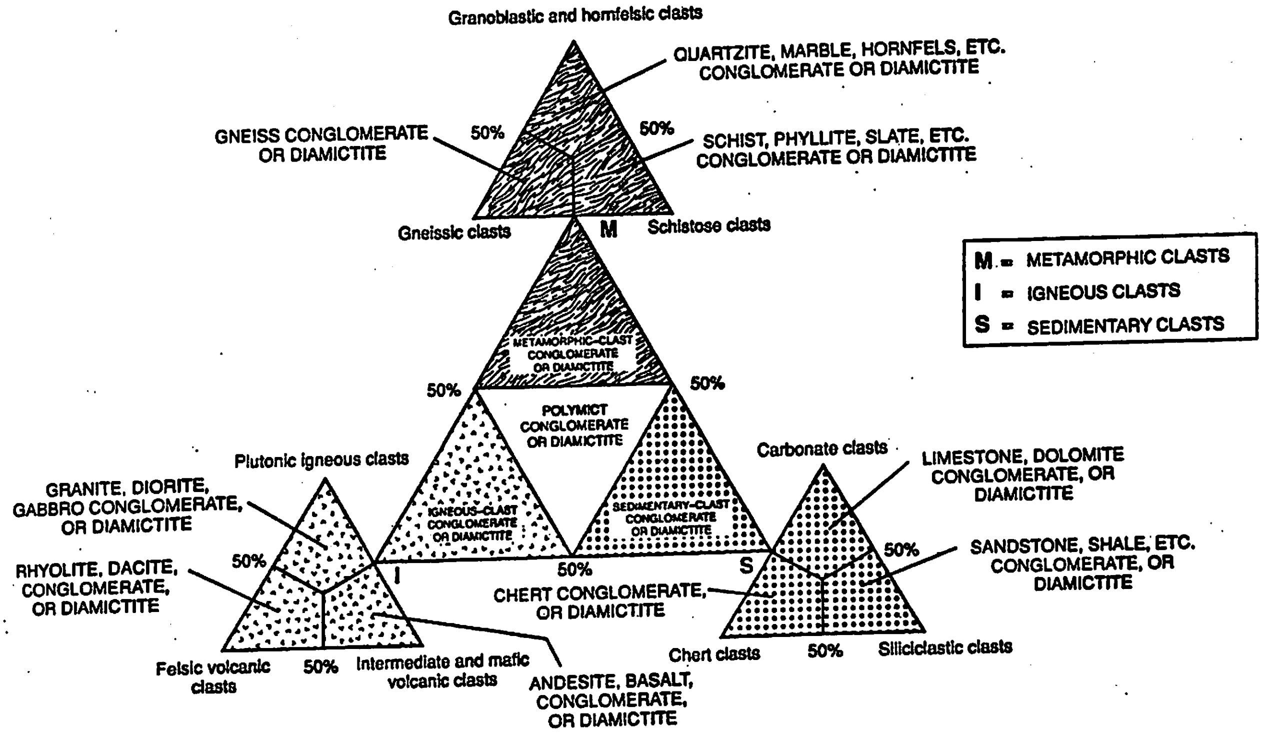


Figure 4. Classification of conglomerates on the basis of clast lithology and type of fabric support. From *Boggs*, 1995.

4. Things to consider at this site

- What is composition of the clasts in the conglomerate?
- Where did these clasts originate?
- How were these sediments deposited (flash floods, streams, etc.)?
- Was this site flooded when these sediments were deposited? How can we tell?

5. References

Anstey, R. L. and T. L. Chase (1974) *Environments Through Time: A Laboratory Manual in the Interpretation of Ancient Sediments and Organisms*, Burgess Publishing, Minneapolis, MN.

Boggs, S. (1995) *Principles of Sedimentology and Stratigraphy*, 2nd ed., Prentice Hall, Upper Saddle River, NJ.

Minch, J., E. Minch, J Minch. (1998) *Roadside Geology and Biology of Baja California*, Mission Viejo, John Minch and Associates.

Powers, M. C. (1953) A new roundness scale for sedimentary particles, *J. Sediment. Petrol.*, *23*, 117-119.

Wentworth, C.K. (1922) A scale of grade and class terms for clastic sediments, *J. Geol.*, *30*, 377-392.

Chicxulub Impact and Distal Effects (Baja)

Diana Smith

Highlights:

- [1]Ancient impact crater buried underneath the Yucatan peninsula of approximately 300 km wide.
- Center located approximately underneath the town of Chicxulub, Yucatán, Mexico
- Dated from the late Cretaceous (about 65 Ma)
- Meteorite's estimated size approx 10 km in diameter and released 4.3e23 Joules (equivalent to 191,793 Gtons of TNT) in the impact
- Caused giant tsunamis and emission of dust and particles caused drastic environmental changes in which the Earth's surface is totally covered by a cloud of dust for several years. (Pope, et al., 1997)
- Timing in good agreement with extinction of dinosaurs (K-T boundary)
- The main evidence is a widespread, thin layer of iridium present in this geological boundary across the world. Iridium is a rare metal on Earth, but abundant in meteorites.
- It is thought that this impact event may have been partially or wholly responsible for the Cretaceous-Tertiary extinction event.

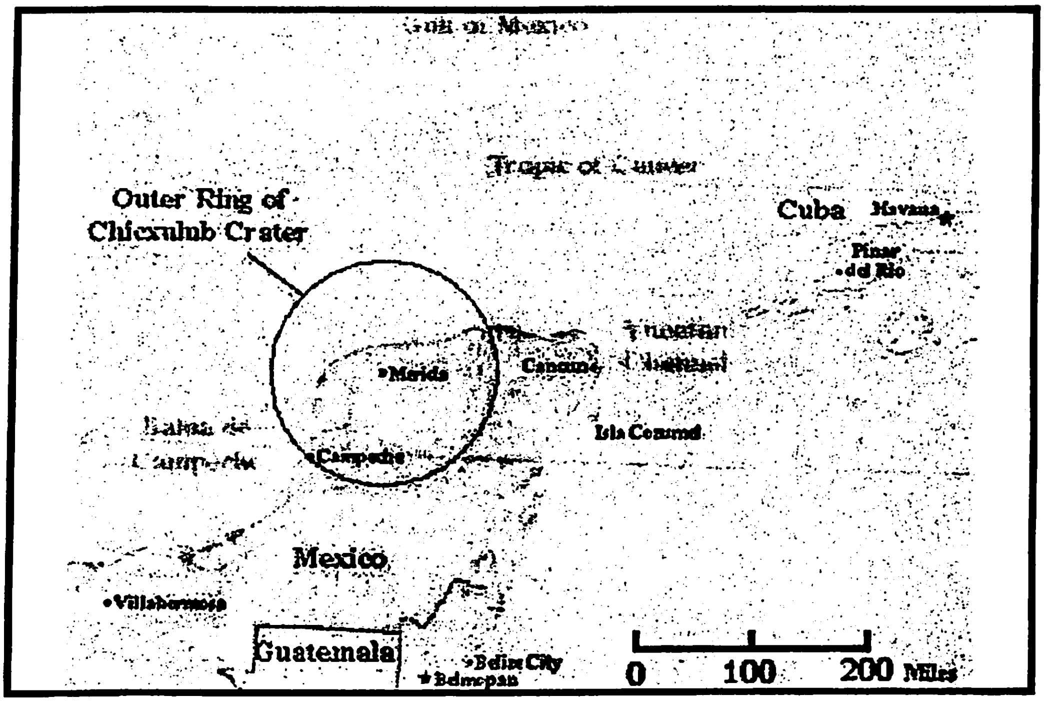


Figure 1. Map of the location of Chicxulub crater. Image borrowed from http://www.space.com/php/multimedia/imagedisplay/img_display.php?pic=h_chicxulub_map_02a.jpg

---

[1] The coordinates of the crater are 21°24′ N 89°31′ W

Discovery:

- In 1990, a graduate student from the University of Arizona named Alan K. Hildebrand was investigating K-T deposits of jumbled coarse rock fragments that were scoured up from one location and redeposited by giant tsunamis km's high that could have resulted from an Earth impact.
- Many of these deposits are located in the Caribbean basin, hence the reason for his being there.
- He found an excess of iridium, shocked quartz grains and tektites in some clay samples. He and William V. Boynton published these findings and suggested the existence of a buried impact crater and that this impact may have caused the K-T extinctions.
- A geophysicist named Glen Penfield had discovered a possible impact crater buried under the northern Yucatan Peninsula back in 1978.
- Hildebrand was able to contact Penfield and perform an analysis of samples from wells drilled by PEMEX in 1951. These clearly showed shock-metamorphic materials.
- Research really took off when Kevin O. Pope, Adriana C. Ocampo, and Charles E. Duller surveyed satellite images of the region and found an almost perfect ring of sinkholes that matched the ring in Penfield's data. (Pope, et al., 1996)

Some General Impact Characteristics:

- Iridium Anomaly: A high concentration of Ir indicates an impact event because during Earth's differentiation siderophile elements like Ir were carried down to the core and thus should be rare in the Earth's crust. An impact body would not have a depletion of these elements.
- Shocked Quartz: Only impact events and nuclear explosions have been shown to produce shocked quartz. Shocked quartz displays a set of planar shock features which could be fractures unfilled or filled with silica glass (lamellae).
- Impact Melt Spherules: In a large impact, the Earth's crust can melt and then these droplets can then be ejected from the crater and rain out as tektites. Usually have characteristic spheroidal shapes.

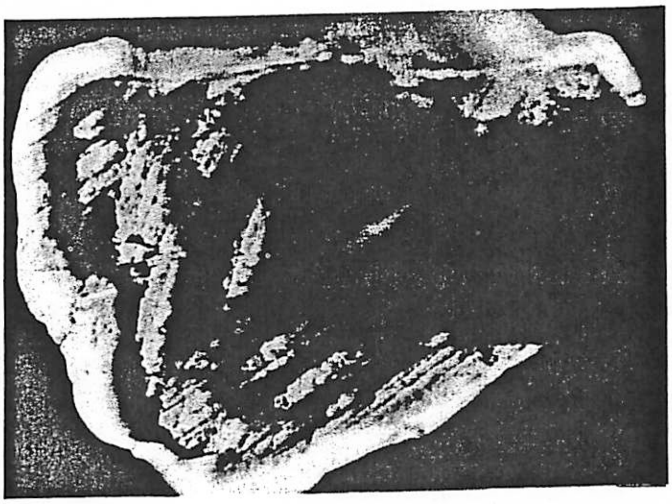


Figure 2. Cross-polarized view of shocked quartz showing planar deformation. Image borrowed from http://dsaing.uqac.uquebec.ca/~mhiggins/MIAC/chicxulub.htm

Baja and Distal Ejecta:

- Although most of the material ejected is deposited relatively close, a significant amount (10 vol%) may travel great distances to form deposits of distal ejecta.
- When an atmosphere is present transport of smaller ejecta particles (≤ 1 mm) to regional or global distances can take place.
- Deposits are usually less than a few cm's thick and may contain distinctive impact evidence, i.e. shocked rock/mineral fragments, chemical/isotopic signatures, and unusual glassy objects.
- The thin layer of material ejected from the Chicxulub forms the K-T boundary layer and is a perfect example of distal ejecta.
- In Baja, we are a few thousand km away from the Chicxulub crater so we will see (hopefully) the low and high energy layers of the K-T boundary. These correspond to low and high energy ejecta.
- The bottom layer is the low-energy ejecta, and the thickness should drop off as we move further and further away from the center of the crater.
- The upper layer is the high-energy ejecta and is composed of materials that were ejected high enough into the atmosphere to be distributed globally. This layer is much thinner.
- Two kinds of glassy material in distal ejecta:
    1. **1.** Spherules of fresh or altered glass—these are mm-sized glassy objects that were formed from shock-melted droplets of impact melt. (see Figure 6.11 from *Traces of Catastrophe*) Association with shocked quartz and an iridium anomaly establishes them as impact melts.
    2. **2.** Tektites and microtektites—typically black, but sometimes greenish, brownish or grayish. They are completely glassy with no microlites or phenocrysts like terrestrial volcanic glasses. Chemical composition close to shales or other sedimentary rocks (see Figure 3 below).

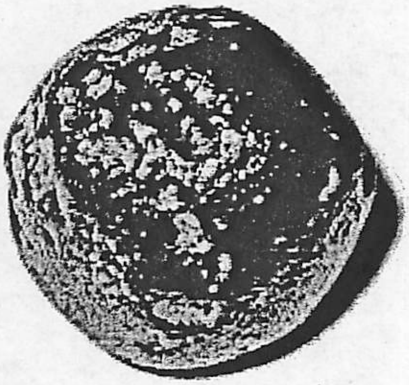


Figure 3. Image of a tektite borrowed from http://en.wikipedia.org/wiki/Image:Tektite.jpg

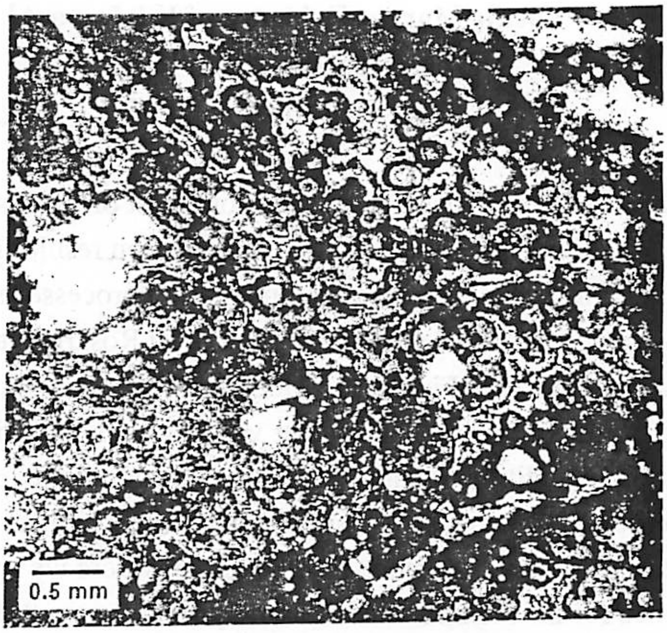


Fig. 6.11. Impact melt rock: spherulitic glass rim on rock fragment. Heterogenous mixture of recrystallized spherulitic glass and small rock and mineral fragments, forming a heterogeneous glassy rim on a larger rock fragment core. The composite inclusion occurs in a metamorphosed suevite breccia. The small rock fragments, chiefly quartz and feldspar, are generally angular and irregular in shape, and phenocryst textures typical of glassy volcanic rocks are not observed. Despite postimpact greenschist metamorphism, original heterogeneity of the glass is preserved by the distribution of secondary minerals, chiefly quartz, feldspar, chlorite, and amphibole. The small red-brown spherical bodies frequently contain a smaller central crystal fragment, suggesting that they were discrete droplets before being incorporated into the rim around the larger core fragment. If so, the texture may result from accretion of glass and rock fragments during ballistic ejection. (The texture may also represent subsequent in-place devitrification or recrystallization around the mineral fragment nucleus.) Granitic rock fragment from Onaping Formation "Black Member," type locality at Onaping Falls (Highway 144, Dowling Township), northwestern corner of Sudbury structure (Canada). Sample CSF-66-50-1-D (plane-polarized light).

References:

French, Bevan M., *Traces of Catastrophe: A Handbook of Shock-Metamorphic Effects in Terrestrial Meteorite Impact Structures*, Lunar and Planetary Institute, 1998.

Hildebrand et al. (1991), The Chicxulub Crater: A possible Cretaceous-Tertiary boundary impact crater on the Yucatan Peninsula, Mexico. *Geology*, 19:867-871.

Pope KO, Baines KH, Ocampo AC, Ivanov BA (1997). Energy, volatile production, and climatic effects of the Chicxulub Cretaceous/Tertiary impact *Journal of Geophysical Research* 102 (E9): 21645-64.

Pope KO, Ocampo AC, Kinsland GL, Smith R (1996). Surface expression of the Chicxulub crater *Geology* 24 (6): 527-30.

Sharpton VL, Marin LE (1997). The Cretaceous-Tertiary impact crater and the cosmic projectile that produced it. *Annals of the New York Academy of Sciences* 822: 353-80.

Pacific Margin Evidence of KT Impact?

Brian Jackson & John Keller

Baja Fieldtrip, Fall 2005

Busby et al. (2002) have proposed that a study area southeast of El Rosario, Mexico, shows evidence of coastal landsliding and catastrophic sedimentation resulting from the KT Chicxulub impact event. While significant evidence for sedimentation processes related to KT impact is found in the Gulf of Mexico and the Atlantic margin, the El Rosario site is the first reported evidence on the Pacific margin (see Figure 1). Modeling suggests the impact event may created a magnitude 13 earthquake with more that 1 meter vertical ground motion 7000 km away (Boslough et al., 1996). In addition to leading to a large tsunami, the impact is thought to have triggered a prolonged period of increased seismic activity and readjustment, with a great deal of landsliding and re-sedimentation. At Canon San Fernando where we will visit, Busby et al. (2002) suggest evidence for the formation of a 5-km by >15-km coastal paleovalley that was rapidly cut and filled by multiple mass wasting events.

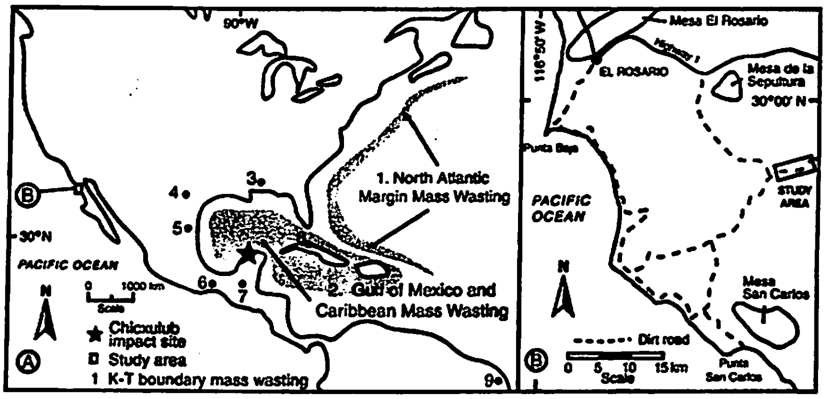


Figure 1. A: Sites of catastrophic sedimentation at Cretaceous-Tertiary (K-T) boundary in and around Gulf of Mexico, Caribbean Sea, and North Atlantic margin (numbered 1–8). Full documentation is available in GSA Data Repository (see text footnote 1). Site of our newly recognized Pacific margin example (labeled B) on Baja California Peninsula in Mexico is shown. B: Our study area (box; see Fig. 2) and other geographic features of El Rosario area (Baja California, Mexico) discussed in text.

Geometry of Paleovalley

Figure 2 provides a geologic map and cross-sections of the proposed paleovalley. The valley was cut into the marine Rosario Formation deposits and fluvial El Gallo Formation deposits that predate the KT impact. Northern and eastern walls of paleovalley are distinct; southern and western margins have not yet been accurately mapped. Transverse cross section (A-A') cuts across the width of the paleovalley; longitudinal cross section (B-B') cuts across the length of the valley. The paleovalley is asymmetric in cross-section, more consistent with a valley formed by catastrophic failure than by more gradual processes like river cutting.

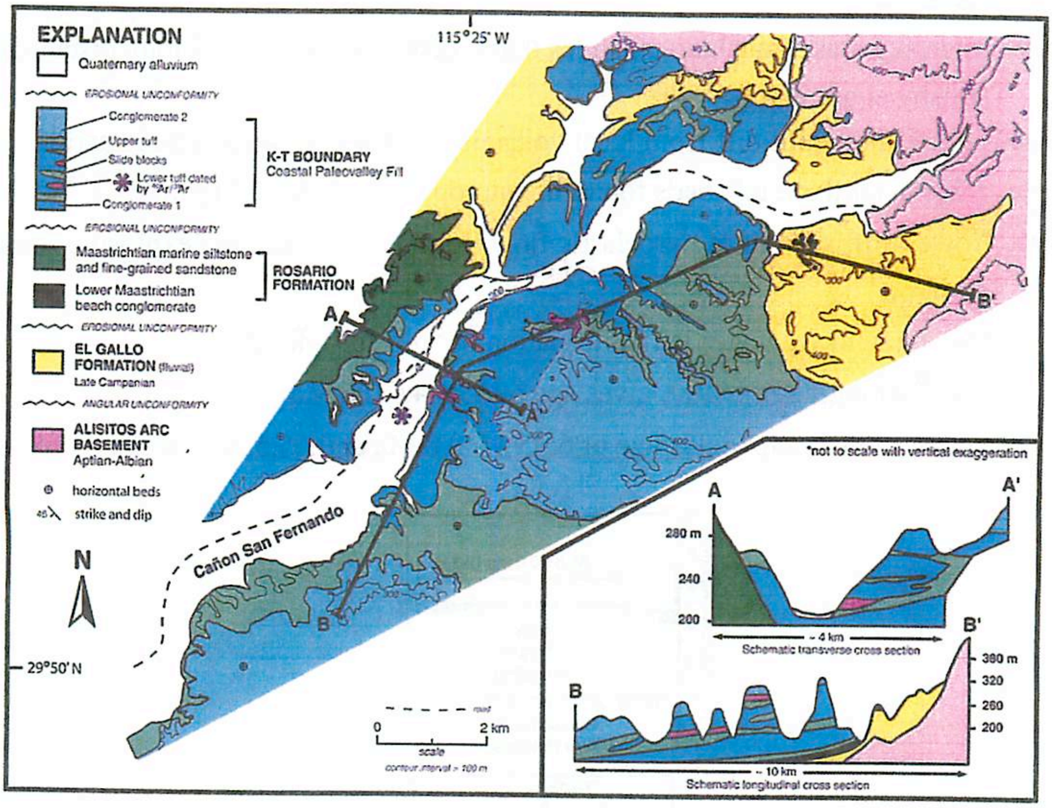


Figure 2. Preliminary geologic map of Cretaceous-Tertiary (K-T) coastal paleovalley in Cañon San Fernando area, Baja California (see locality in Fig. 1). K-T boundary is preserved in this coastal paleovalley, which is very well exposed along present-day Cañon San Fernando and its tributaries. Transverse cross section is ~9 km from head of coastal paleovalley, and schematic longitudinal section extends 15 km along length of paleovalley.

Paleovalley Sediments

- Conglomerate units with <10% sandstone
    - Lower Conglomerate 1: Interpreted as "sediment gravity flows deposited in a marine environment just below wave base on an uneven and unstable substrate of slide blocks" (Busby et al., 2002)
    - Upper Conglomerate 1: Interpreted as "traction flows in a very proximal mouth-bar setting, in water shallow enough for wave reworking to occur." (Busby et al., 2002)
    - Conglomerate 2 lacks slide blocks and marine fossils (deposited subareally after seismic activity decreased)

- Slide-block accumulations within and between conglomerate
  - Compositionally similar to Rosario Formation rocks
  - Range in size from outcrop scale (1-200 m across) to map scale (several hundred meters across).
  - Interpreted as "translational slides that probably did not travel long distances." (Busby et al., 2002)
- Lenses of tuff and lapilli tuff from local volcanism concurrent with sedimentation
  - 2 20-meter thick tuff beds found in outcrops near A-A' in Figure 2
  - Lower tuff is result of pyroclastic flow from nearby subaerial explosive silicic eruption
  - Mixing with sea water led to formation of "tuff turbidite."
  - ^{40}Ar/^{39}Ar dating of biotite gives age of 65.5 +/- 0.6 Ma
  - Fusion step dating yields age of 65.5 +/- 0.8 Ma and 65.5 +/- 2.8 Ma

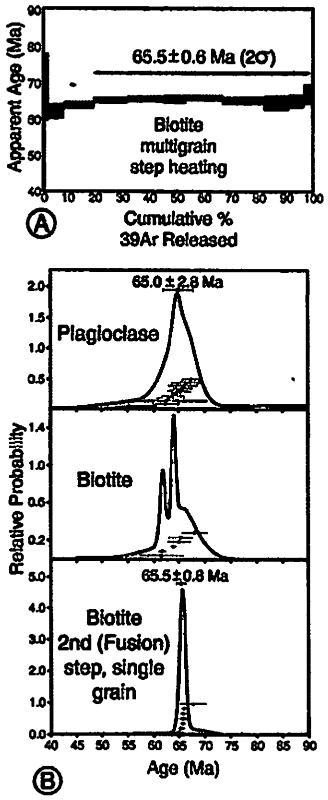


Figure 3. Multigrain (A) and single-crystal (B) Ar/Ar age data from pumices in dacite pumice lapilli tuff. This tuff occurs in lower part of coastal paleovalley fill (see Fig. 2) and yields ages similar to those of Haitian tektites dated in same laboratory (see text).

Planetary Connections

- Impact crater events on other planets and moons
- Landslides on other planets and moons

Figure 4: "The landslide in this VIS image is located inside an impact crater located south of the Isidis Planitia region of Mars. As with other crater landslide, this one formed due to slope failure of the inner crater rim. "
-- http://themis.asu.edu/theme-mass_wasting

- Ignimbrite deposits on other planets and moons

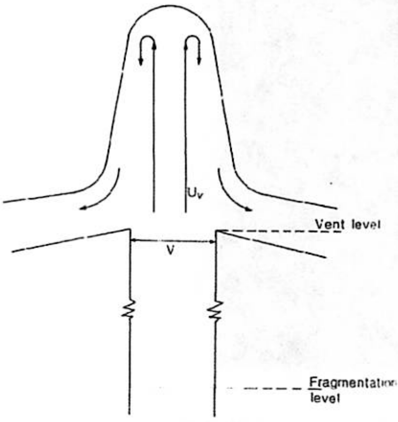


Fig. 1. Geometry of the fountain structure formed over a volcanic ve by an erupting stream of volcanic gas and pyroclastic particles whic fail to form a convecting eruption cloud and so generate a pyroclast flow. See Table 1 for definitions of symbols.

Figure 5: Taken from Wilson and Heslop (1990), illustrating geometry of volcanic vent and deposit formation for Earth and Mars.

- Subaerial sedimentation processes on other planets and moons

- Tectonic activity on other planets and moons

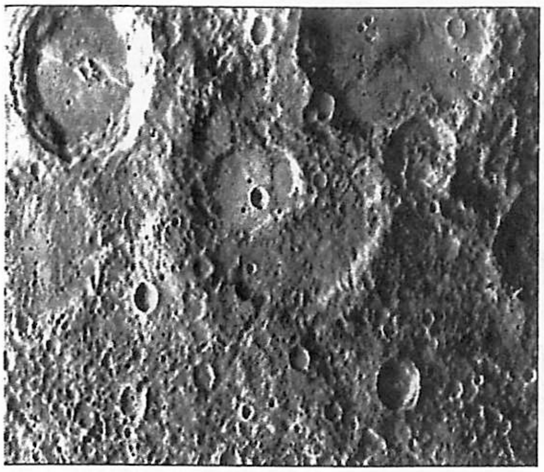


Figure 6: On Mercury: "The scarp in the crater at the upper left of the image has been diverted by the central peaks, suggesting it may be a flow front. However, a darkline on the interior eastern wall appears to join the floor scarp, and if they are related, the scarp probably has a tectonic origin."
--photojournal.jpl.nasa.gov

- Apollo 17 landed near bright mantled material to the north of South Massif within the 2-kilometer-deep Taurus-Littrow Valley on the eastern edge of Mare Serenitatis. The cause of this landslide is believed to be ejecta from Tycho Crater hitting the top of South Massif. See Figure 4.

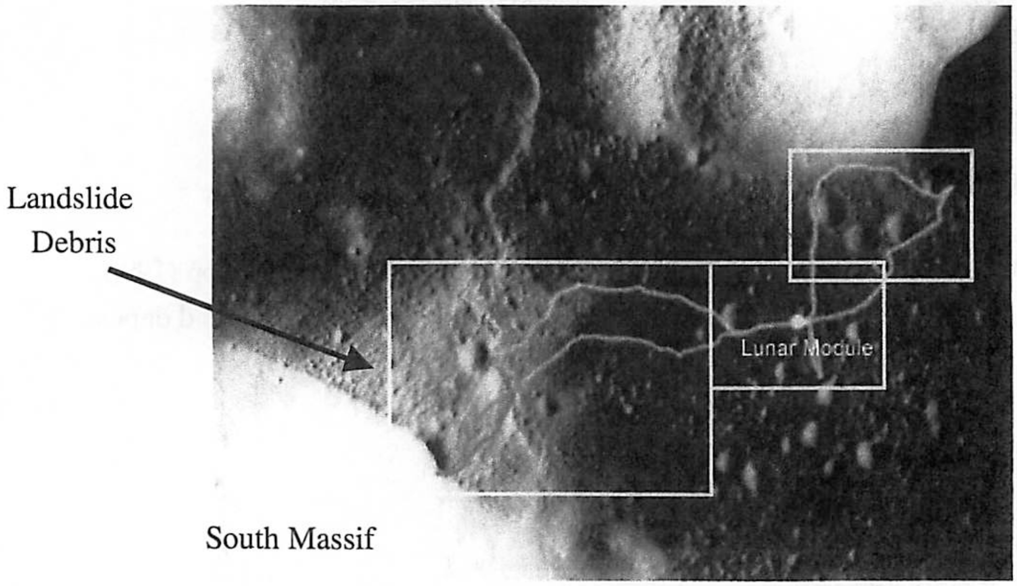


Figure 7. One interesting result of the Apollo 17 mission was the discovery that the bright landslide to the west of the landing site was probably caused by the impact of material launched from the crater Tycho when it was formed 109 million years ago.

http://www.boulder.swri.edu/~durda/Apollo/ls_17e.html

References

Boslough, M.E., Chael, E.P., Trucano, T.G., Crawford, D.A., and Campbell, D.L., 1996, Axial focusing of impact energy in the Earth's interior: A possible link to flood basalts and hotspots, *in* Ryder, G., et al., The Cretaceous-Tertiary event and other catastrophes in Earth history: Gological Society of America Special Paper 307, p. 541-550.

Busby, C.J., Smith, D.P., Morris, W.R., and Adams, B., 1998, Evolutionary model for convergent margins facing large ocean basins: Mesozoic Baja California (Mexico): Geology, v. 26, p. 227–230.

Busby, C.J., Yip, G., Blikra, L., & Renne, P., 2002, "Coastal landsliding and catastrophic sedimentation triggered by Cretaceous-Tertiary bolide impact: A Pacific margin example?" Geology, 30: 687-690.

Norris, R.D., Firth, J., Blusztajn, J.S., and Ravizza, G., 2000, Mass failure of the North Atlantic margin triggered by the Cretaceous-Paleogene bolide impact: Geology, v. 28, p. 1119–1122.

Wilson, L. and Sally Heslop. 1990. Clast Sizes in Terrestrial and Martian Ignimbrite Deposits. GRL. v. 95, 17309-17314.


File Edit View Add Tools Help
Lower Tuff Sample
Road Ends
Farm
29 50'N, 115 25'
Turn off to head up canon
N
W
E
S
Dirt Road Meets Canon San Fernando
Image © 2005 DigitalGlobe
© 2005
Google
Pointer 29 51'44.32" N 115 28'12.44" W elev 902 ft
Streaming |||||||| 100%
Eye alt 26576 ft

Coastal landsliding and catastrophic sedimentation triggered by Cretaceous-Tertiary bolide impact: A Pacific margin example?

Cathy J. Busby
Grant Yip } Department of Geological Sciences, University of California, Santa Barbara, California 93106, USA
Lars Blikra Geological Survey of Norway, N-7040 Trondheim, Norway
Paul Renne Berkeley Geochronology Center, 2453 Ridge Road, Berkeley, California 94709, USA

ABSTRACT

We report here the first-recognized Pacific margin stratigraphic sequence containing evidence for catastrophic landsliding attributed to bolide impact–related seismic shocking at the Cretaceous-Tertiary (K-T) boundary. The K-T boundary is not commonly preserved in stratigraphic sequences of the Pacific margin, but we have discovered it within a coastal paleovalley in Baja California, Mexico (near El Rosario). This 5-km-wide, >15-km-long, and 200-m-deep coastal paleovalley formed by massive gravitational collapses and rapidly filled with coastal (shallow marine and lesser fluvial) gravels and sands, as well as slide sheets of marine mudstone that range from meters to kilometers in length. We infer that seismic shocking caused liquefaction and extremely rapid sedimentation of the gravels and sands, simultaneous with unleashing of slide sheets. Laser-heating $^{40}Ar/^{39}Ar$ data for biotite, hornblende, and plagioclase (single crystal and bulk step heating) on a 20-m-thick pumice lapilli tuff in the middle of the valley fill give an age of 65.5 ± 0.6 Ma; this is indistinguishable from the age of Haitian tektites dated by the same laboratory. Our new Pacific margin sequence, like many K-T boundary sequences in the Gulf of Mexico–Caribbean region, provides evidence of giant landslides and catastrophic sedimentation >1800 km from the bolide impact site.

Keywords: Cretaceous-Tertiary, mass wasting, impacts, paleovalley.

INTRODUCTION

Recent years have seen a great deal of research on sedimentation related to the Chicxulub Cretaceous-Tertiary (K-T) bolide impact (Bourgeois et al., 1988; Bralower et al., 1998; Norris et al., 2000; Smit, 1999). Workers have described mass-wasting, sediment gravity-flow, or tsunamite deposits in the Gulf of Mexico, the Caribbean Sea, and along the length of the North Atlantic margin, from Puerto Rico to the Grand Banks (Fig. 1; see also Data Repository Fig. 1[1]). Earlier papers largely attributed the catastrophic sedimentation events to tsunami directly generated by the bolide impact, but more recent papers have shown that mass-wasting deposits generated from collapses were too deep seated and too laterally extensive to be attributed to tsunami activity and were instead seismically induced (see discussion in Norris et al., 2000). Computer modeling indicates that the initial impact generated an earthquake of magnitude 13 on the Richter Scale and that vertical ground motion was in excess of 1 m within 7000 km of the impact (Boslough et al., 1996). With an earthquake of this magnitude, one would expect adjustments on regional fault systems for some period of time after the impact, although the areal extent and length of time of these adjustments are not known. Yancey (1997) proposed that the tsunamites in southern Texas (Bourgeois et al., 1988) resulted from a series of seismic events triggered by and following the initial Chicxulub impact, rather than being the deposits of a single tsunami generated by the impact. We present evidence here that seismicity was protracted enough to trigger a series of collapse and resedimentation events.

We present a preliminary map, cross sections, and descriptions of a 5-km-wide and >15-km-long coastal paleovalley in Baja California, Mexico (Figs. 1 and 2). We present evidence that the paleovalley was rapidly cut and filled by a series of massive gravitational collapses. We also present age data that suggest that these collapses occurred at the K-T boundary (Fig. 3) and speculate that they were the result of a period of seismic activity initiated by the Chicxulub impact.

GEOLOGIC SETTING

The Rosario embayment of the Peninsular Ranges forearc basin complex is interpreted as a Late Cretaceous forearc strike-slip basin formed under a compressional convergent-margin strain regime (Busby et al., 1998). This forearc basin formed atop an accreted island-arc basement (Alisitos Group, Fig. 2) and filled with Campanian to Paleocene fluvial to deep-marine sedimentary rocks (see description and references in Busby et al., 1998). Around the time of the Cretaceous-Tertiary boundary, contraction of the forearc strike-slip basin produced a broad north-northwest–trending, gently southward-plunging syncline. Because of the southward plunge of the growing syncline, the basin gradually shoaled and became emergent in the north, while it remained deeply submerged in the south. In the northernmost part of the basin, at the present-

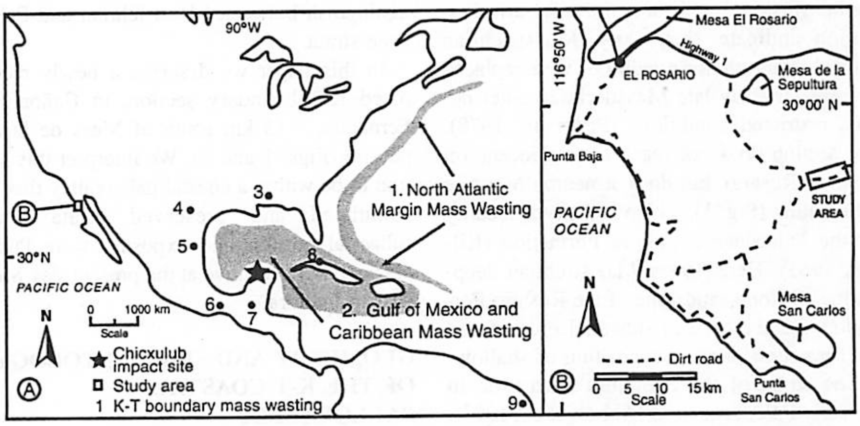


Figure 1. A: Sites of catastrophic sedimentation at Cretaceous-Tertiary (K-T) boundary in and around Gulf of Mexico, Caribbean Sea, and North Atlantic margin (numbered 1–8). Full documentation is available in GSA Data Repository (see text footnote 1). Site of our newly recognized Pacific margin example (labeled B) on Baja California Peninsula in Mexico is shown. B: Our study area (box; see Fig. 2) and other geographic features of El Rosario area (Baja California, Mexico) discussed in text.

---

[1] GSA Data Repository item 2002081, Figure 1, Full documentation for sites of catastrophic sedimentation at the Cretaceous-Tertiary boundary, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, editing@geosociety.org, or at www.geosociety.org/pubs.ft2002.htm.

Geology; August 2002; v. 30; no. 8; p. 687–690; 3 figures; Data Repository item 2002081.

119

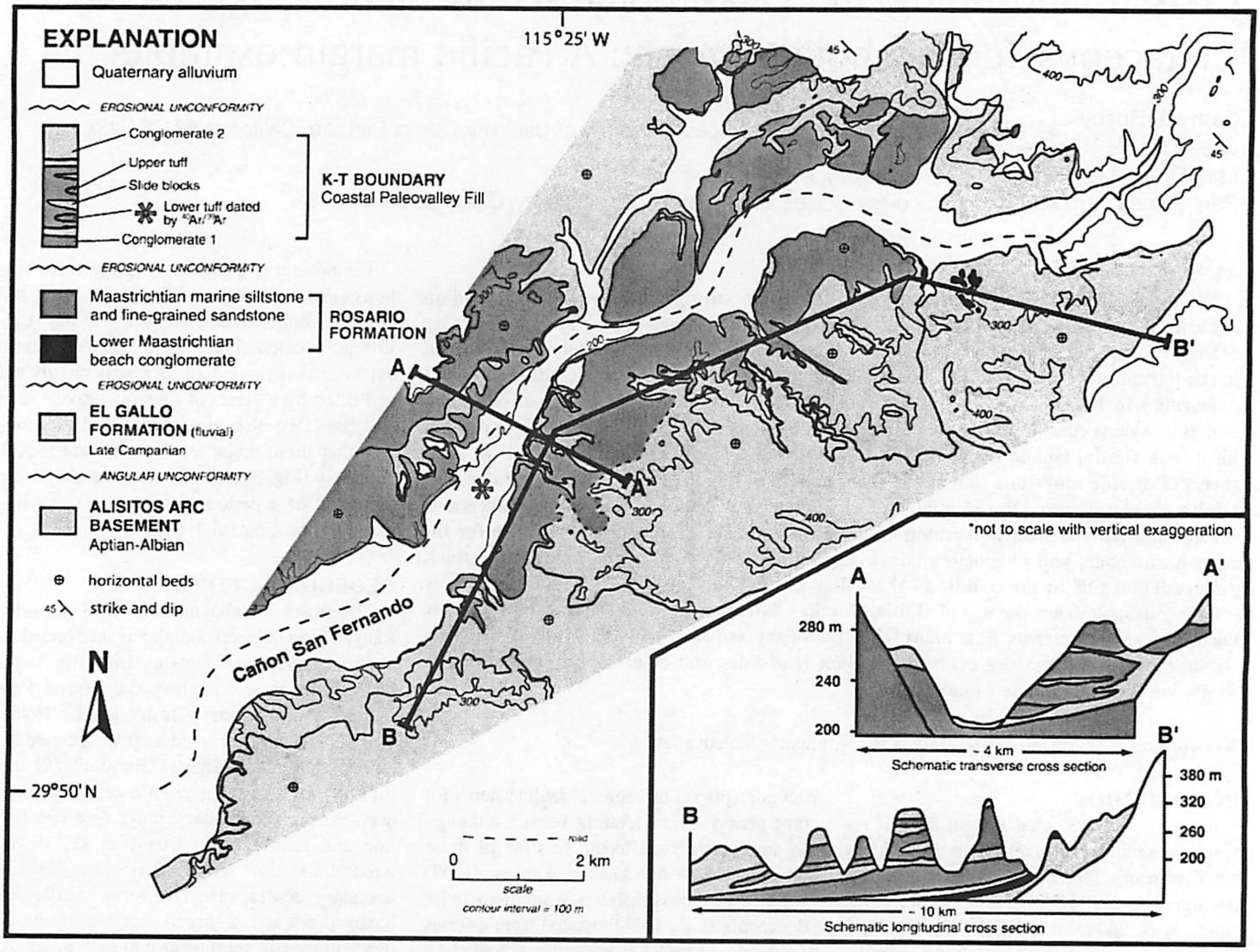


Figure 2. Preliminary geologic map of Cretaceous-Tertiary (K-T) coastal paleovalley in Cañon San Fernando area, Baja California (see locality in Fig. 1). K-T boundary is preserved in this coastal paleovalley, which is very well exposed along present-day Cañon San Fernando and its tributaries. Transverse cross section is ~9 km from head of coastal paleovalley, and schematic longitudinal section extends 15 km along length of paleovalley.

day Mesa El Rosario (Fig. 1), microfossils in marine siltstone-sandstone of the Rosario Formation indicate that early Maastrichtian bathyal, open-marine conditions were replaced by early or early late Maastrichtian outer neritic, restricted conditions (Patterson, 1978). The section does not reach the Paleocene on Mesa El Rosario, but does at nearby Mesa de la Sepultura (Fig. 1), which is the type locality for the Paleocene Sepultura Formation (Kilmer, 1963). Here, lower Maastrichtian deep-marine siltstone-sandstone of the Rosario Formation was exposed to subaerial erosion and soil formation prior to deposition of shallow-marine strata of the Sepultura Formation in late early Paleocene time (Abbott et al., 1993). In contrast, microfossil data from the south part of the basin, at Mesa San Carlos (Fig. 1), show that the Cretaceous-Tertiary boundary is preserved within a conformable, uniform, upper bathyal siltstone-sandstone section (Morris and Busby-Spera, 1988; Morris, 1992); here, one cannot use lithology or unconformities to distinguish between Maastrichtian and Paleocene strata.

In this paper we describe a newly recognized K-T boundary section, in Cañon San Fernando, ~15 km south of Mesa de la Sepultura (Figs. 1 and 2). We interpret this section to be within a coastal paleovalley that accumulated and preserved strata while subaerial erosion and exposure were taking place on the interfluve at the present-day Mesa de la Sepultura.

GEOMETRY AND SEDIMENTOLOGY OF THE K-T COASTAL PALEOVALLEY

We present here a preliminary geologic map and schematic transverse and longitudinal cross sections of our proposed K-T boundary coastal paleovalley (Fig. 2). Along much of its length, this coastal paleovalley fills an ~200-m-deep incision that is cut into lower Maastrichtian marine siltstone and fine-grained sandstone of the Rosario Formation. This relationship is best demonstrated at the steep northern wall of the paleovalley, where flat-bedded conglomerates and sandstones of the paleovalley fill onlap undisturbed, flat-bedded Maastrichtian siltstones in the paleovalley wall (see transverse cross section, Fig. 2). The south margin of the paleovalley has not yet been accurately mapped because the slide blocks of Maastrichtian siltstone become progressively larger in that direction, making it difficult to distinguish between allochthonous slide sheets and autochthonous paleovalley wall. The head of the coastal paleovalley is downcut through lower Maastrichtian beach conglomerate (also of the Rosario Formation) into Campanian fluvial deposits (El Gallo Formation) and locally into Aptian-Albian arc basement below (see longitudinal cross section, Fig. 2).

We infer that most of the sedimentary sec-

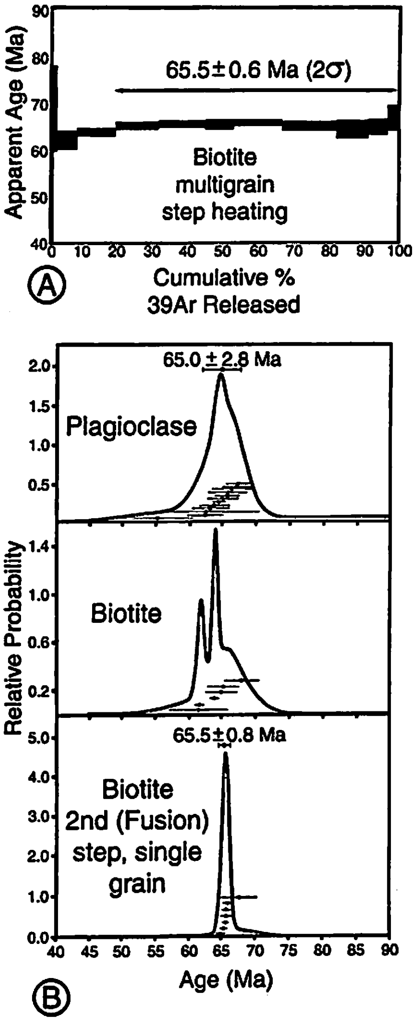


Figure 3. Multigrain (A) and single-crystal (B) Ar/Ar age data from pumices in dacite pumice lapilli tuff. This tuff occurs in lower part of coastal paleovalley fill (see Fig. 2) and yields ages similar to those of Haitian tektites dated in same laboratory (see text).

tion in Cañon San Fernando accumulated in a very short period of time at the K-T boundary, by catastrophic means. The valley fill is composed of three units (Fig. 2): (1) conglomerate units with <10% sandstone, (2) slide-block accumulations within and between the conglomerates, and (3) volumetrically minor lenses of tuff and lapilli tuff. We divide the conglomerate into two units (1 and 2, Fig. 2). Conglomerate 2 is mapped separately from conglomerate 1 because it lacks slide blocks and has no marine fossils.

A transverse cross section through the coastal paleovalley (Fig. 2) shows the steep northern wall where the valley is cut into Maastrichtian marine siltstones and fine-grained sandstones of the Rosario Formation. This material makes up the huge slide blocks interstratified with the valley-filling conglomerates. The transverse cross section also shows the lower of two tuff lenses within conglomerate 1, a pumice lapilli tuff up to 20 m thick, that we sampled for dating (Fig. 3).

A composite longitudinal section of the coastal paleovalley demonstrates the reactivated nature of the valley (Fig. 2). The first valley-cutting event is recorded by the unconformity between the El Gallo Formation and the arc basement, and the second is recorded by the buttress unconformity of the lower Maastrichtian beach conglomerates (Rosario Formation) against the El Gallo Formation. The erosional surface at the base of conglomerate 1 locally merges with the erosional surface below the lower Maastrichtian beach conglomerates. The longitudinal section also shows the overall progradational and aggradational character of the K-T boundary valley fill and the great size of some of the slide blocks. Further, it demonstrates that tuffs are at two different horizons.

The distribution of the coastal paleovalley fill demonstrates that the incision was highly asymmetrical (Fig. 2). This is an unusual shape for a valley cut by a river during a sea-level lowstand. An irregular shape would be expected, however, in a valley formed by catastrophic failure. The map relationships between conglomerate 1 and conglomerate 2 also demonstrate that the depositional system prograded down the valley with time (Fig. 2). Conglomerate 1 has shallow-marine fossils throughout and is interpreted to record a complex interplay of traction, density current, and wave-reworking processes. Conglomerate 2, in contrast, lacks marine fossils within the map area and appears to be entirely fluvial. The lack of slide sheets in conglomerate 2 could reflect cessation of seismicity during its deposition. The rest of this section focuses on conglomerate 1 because it contains the slide sheets as well as the dacite pumice lapilli tuff we dated.

Conglomerate 1

Conglomerate 1 is a cobble to boulder conglomerate, with lesser pebble conglomerate. Clasts are well rounded and were derived from volcanic, plutonic, and metasedimentary sources in the present-day Peninsular Ranges.

The lower half of conglomerate 1 is a crudely stratified to nonstratified, clast-supported, but only moderately well sorted conglomerate with soft-sediment slump structures, load structures, and abundant interstratified slide blocks. We interpret the lower half of conglomerate 1 to represent sediment gravity flows deposited in a marine environment just below wave base on an uneven and unstable substrate of slide blocks.

The upper half of conglomerate 1 is a well-stratified, clast-supported, and well-sorted conglomerate with planar horizontal or weakly inclined beds. The coarsest beds are on erosional surfaces and may represent channel lags on a proximal mouth bar. The inclined beds may represent low-relief mouth bars, which could develop under conditions of high-momentum (coarse sediment–charged) floods. Well-developed clast imbrication fabrics are highly variable, but all are within the western sector, ranging from southwestward to northwestward in transport direction; this variability may be the result of interaction with a very complex topography created by the giant slide blocks. The upper half of conglomerate 1 also contains scattered horizons with disc-shaped clasts and abundant shell fragments, which may record reworking by waves. We interpret the upper half of conglomerate 1 to record traction flows in a very proximal mouth-bar setting, in water shallow enough for wave reworking to occur.

Sandstones

Sandstones interstratified with conglomerate 1 are strikingly massive. They occur largely as lenticular beds to 1 m thick, filling scours or cut by scours. The beds are massive with scattered siltstone clasts, or contain stratification in the form of gravel trains. The presence of mollusk fragments throughout the sandstones indicates that they are marine. The overwhelming predominance of massive sandstones and the vertical aggradation indicated by the gravel trains suggest high sediment supply and deposition from steady, sustained, high-density turbidity currents (e.g., Kneller and Branney, 1995). We suggest that these were delivered to the shallow-marine environment by floods.

Slide Sheets

We have not identified any autochthonous siltstones or mudstones within conglomerate 1; all siltstone-mudstone sections appear to be present as slide sheets or blocks. The slide sheets and blocks are largely undisrupted internally and consist of laminated, thin-bedded, fine-grained sandstones and siltstones with graded beds and Bouma divisions, identical to the Maastrichtian marine mudstone in the coastal paleovalley walls (Fig. 2). The slide sheets and blocks have injection structures in the form of conglomeratic sills and less common conglomeratic dikes. The sizes of the slide sheets range from outcrop scale (1–200 m across) to map scale (several hundred meters across, although these may be composites of several blocks). Aspect ratios of the blocks and sheets range from 1:1 to as low as 1:30. Small slide blocks and sheets (<2 m thick) that are much rarer and are more disrupted than large ones pass gradationally into debris-flow deposits that fill local depressions. The low degree of internal deformation in the slide sheets and blocks, as well as the rarity of associated debris-flow deposits, indicates that they were translational slides that probably did not travel long distances.

Tuffs

We have mapped two tuffs in conglomerate 1 (Fig. 2), each to 20 m thick. The lower tuff consists of interstratified pumice lapilli tuff and medium-grained to coarse-grained crystal vitric tuff, and the upper tuff is a crystal vitric tuff. Both tuffs contain euhedral plagioclase, biotite, and lesser hornblende in a matrix of bubble-wall shards; lithic fragments are rare. We describe the lower pyroclastic lens in more detail here, because we sampled pumices from it for Ar/Ar dating, described in the next section.

We infer that the lower tuff represents a pyroclastic flow that was erupted from a not-too-distant subaerial source during an explosive silicic eruption and fed directly into the coastal paleovalley, where it mixed with seawater to form a "tuff turbidite." Petrified log fragments to 0.5 m in length indicate a subaerial eruptive source. A lack of abrasion of the delicate pyroclastic components and a lack of admixed nonpyroclastic components indicate that the lower tuff was fed by an eruption, but the sedimentary structures suggest deposition from cold, high-density turbidity currents (rather than hot, gas-supported flows). Grain-size fluctuations occur throughout the tuff, but it forms an overall upward-fining sequence of beds, dominated by poorly sorted, massive to crudely stratified, nongraded or graded thick beds and lesser planar-laminated or convolute-laminated medium to thin beds. The absence of traction structures and scour structures suggests high aggradation rates. The lower tuff occupies a low area between slide blocks, which appears to have channeled the turbidity flows. There is no recognized source of the appropriate age for the tuffs in eastern Baja California or in adjacent mainland Mexico, although tuffs of this age form an ignimbrite province in southern Mexico (Righter et al., 1995).

Ar/Ar GEOCHRONOLOGY

Procedures for the $^{40}Ar/^{39}Ar$ dating were as described by Renne (1995). Ages are reported relative to 28.02 Ma for the Fish Canyon sanidine standard (Renne et al., 1998), and uncertainties do not include systematic errors as enumerated by Renne et al. (1998). A five-grain sample of biotite was step heated with an Ar-ion laser in 12 steps and yielded a plateau age of 65.5 ± 0.6 Ma (2σ) for ~80% of the ^{39}Ar released (Fig. 3A). Six single grains of biotite were analyzed individually by fusion in two steps. The first steps were variably discordant, probably reflecting minor alteration, but the second (fusion) steps were tightly clustered (Fig. 3B) and yielded a weighted mean age of 65.5 ± 0.8 Ma. We analyzed 11 crystals of plagioclase by total fusion; they yielded mutually indistinguishable ages (Fig. 3B) with a weighted mean of 65.0 ± 2.8 Ma. All results are consistent with the biotite plateau age 65.5 ± 0.6 Ma, which we infer as the eruptive age of this tuff. This age is indistinguishable from the ages of Haitian tektites and the terrestrial K-T boundary when all are normalized to the same standard age, e.g., as discussed specifically by Renne et al. (1998).

CONCLUSIONS

Geologic mapping, sedimentologic studies, and field relationships of a coastal paleovalley exposed in Cañon San Fernando indicate rapid incision and filling at the K-T boundary. These processes are demonstrated by (1) the highly asymmetric cross-sectional profile of the paleovalley, (2) the dominantly massive, disorganized conglomerate with <10% sandstone composing the basal paleovalley fill, (3) the interbedded map- and outcrop-scale slide sheets of mudstone that are lithologically identical to Maastrichtian mudstone composing the K-T paleovalley wall, and (4) the 65.5 ± 0.6 Ma (Ar/Ar) crystal vitric tuff interbedded with massive, disorganized conglomerate at the base of the paleovalley fill. Our study represents the first Pacific margin example of giant landslides and catastrophic sedimentation at the K-T boundary and is consistent with observations reported from sites in the Gulf of Mexico and North Atlantic margin.

ACKNOWLEDGMENTS

Supported by the American Chemical Society (grant to Busby) and the Geological Society of America (grant to Yip).

REFERENCES CITED

Abbott, P., Hanson, A.D., Thomson, C.N., Loque, D.L., Bradshaw, K.E., Pollard, W.J., and Seeliger, T.E., 1993, Geología de la Formacion Sepultura del Paleoceno, en Mesa de la Sepultura, Baja California: Ciencias Marinas, v. 19, no. 1, p. 75–93.

Boslough, M.E., Chael, E.P., Trucano, T.G., Crawford, D.A., and Campbell, D.L., 1996, Axial focusing of impact energy in the Earth's interior: A possible link to flood basalts and hotspots, *in* Ryder, G., et al., eds., The Cretaceous-Tertiary event and other catastrophes in Earth history: Geological Society of America Special Paper 307, p. 541–550.

Bourgeois, J., Hansen, T.A., Wiberg, P.L., and Kauffman, E.G., 1988, A tsunami deposit at the Cretaceous-Tertiary boundary in Texas: Science, v. 241, p. 567–580.

Bralower, T.J., Paull, C.M., and Leckie, R.M., 1998, The Cretaceous-Tertiary boundary cocktail: Chicxulub impact triggers margin collapse and extensive sediment gravity flows: Geology, v. 26, p. 331–334.

Busby, C.J., Smith, D.P., Morris, W.R., and Adams, B., 1998, Evolutionary model for convergent margins facing large ocean basins: Mesozoic Baja California (Mexico): Geology, v. 26, p. 227–230.

Kilmer, F.H., 1963, Cretaceous and Cenozoic stratigraphy and paleontology, El Rosario area [Ph.D. thesis]: Berkeley, University of California Berkeley, 149 p.

Kneller, B.C., and Branney, M.J., 1995, Sustained high-density turbidity currents and the deposition of thick massive sands: Sedimentology, v. 42, p. 607–616.

Morris, W.R., 1992, The depositional framework, paleogeography and tectonic development of the Late Cretaceous through Paleocene Peninsular Range forearc basin in the Rosario Embayment, Baja California, Mexico [Ph.D. thesis]: Santa Barbara, University of California, 295 p.

Morris, W.R., and Busby-Spera, C.J., 1988, Sedimentologic evolution of a submarine canyon in a forearc basin, Late Cretaceous Rosario Formation, San Carlos, Mexico: American Association of Petroleum Geologists Bulletin, v. 72, p. 717–737.

Norris, R.D., Firth, J., Blusztajn, J.S., and Ravizza, G., 2000, Mass failure of the North Atlantic margin triggered by the Cretaceous-Paleogene bolide impact: Geology, v. 28, p. 1119–1122.

Patterson, D., 1978, The foraminiferal biostratigraphy and paleoecology of the type Rosario Formation, El Rosario, Baja California del Norte, Mexico [M.A. thesis]: Santa Barbara, University of California, 150 p.

Renne, P.R., 1995, Excess ^{40}Ar in biotite and hornblende from the Norils'k 1 intrusion: Implications for the age of the Siberian Traps: Earth and Planetary Science Letters, v. 131, p. 165–176.

Renne, P.R., Swisher, C.C., Deino, A.L., Karner, D.B., Owens, T., and DePaolo, D.J., 1998, Intercalibration of standards, absolute ages and uncertainties in $^{40}Ar/^{39}Ar$ dating: Chemical Geology, v. 145, p. 117–152.

Righter, K., Carmichael, I.S.E., Becker, T.A., and Renne, P.U., 1995, Pliocene-Quaternary volcanism and faulting at the intersection of the Gulf of California and the Mexican volcanic belt: Geological Society of America Bulletin, v. 107, p. 612–626.

Smit, J., 1999, The global stratigraphy of the Cretaceous-Tertiary boundary impact ejecta: Annual Review of Earth and Planetary Sciences, v. 27, p. 75–113.

Yancey, T.E., 1997, Tsunamites and bolide impact: Cretaceous-Tertiary boundary deposits, northern shelf of the Gulf of Mexico: Geological Society of America Abstracts with Programs, v. 29, no. 6, p. A142.

Manuscript received October 25, 2001
Revised manuscript received April 11, 2002
Manuscript accepted April 16, 2002

Printed in USA

Gullies: Pete Lanagan

Introduction

A fluid which flows downslope may erode the underlying surface and form gullies. Below, I discuss the geomorphology of gullies on Earth and other planets.

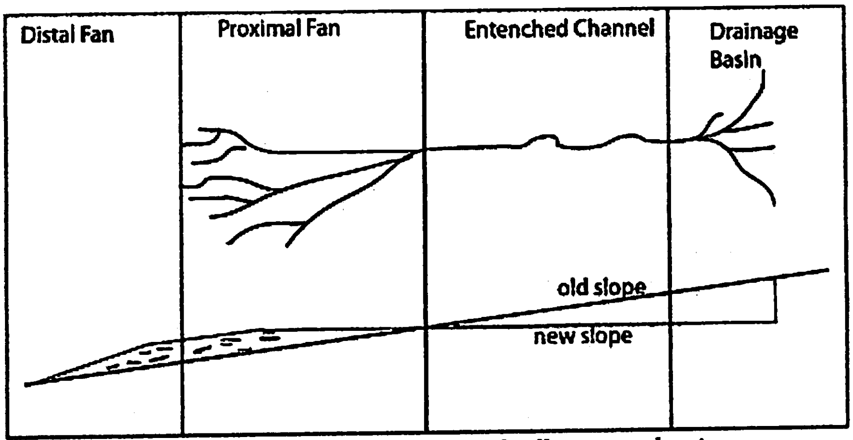


Figure 1: Plan view and cross-sectional view of gully system showing relationship between slope of surface and location of gully network features. (After Fig. 3.18 of Waters, 1992)

Geomorphology of Gullies

Terrestrial gullies are typically divided into three portions: the head, the channel, and the debris apron.

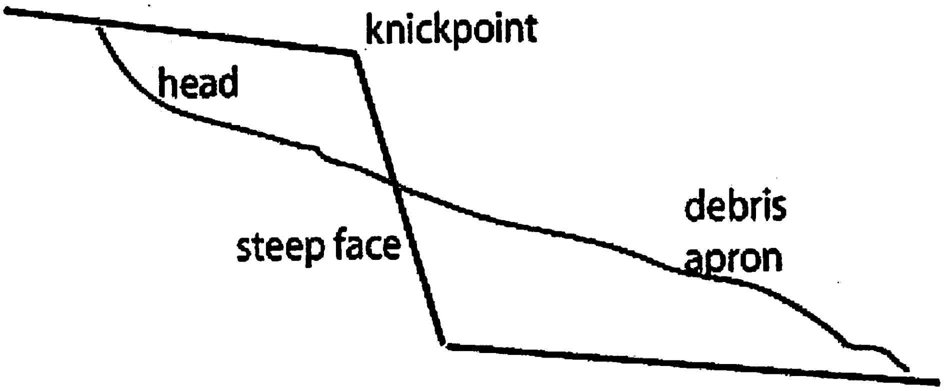


Figure 2: Longitudinal profile of gully. The black line represents the initial slope profile of the surface. The gray line represents the slope profile of the surface after gullying. (After Fig 4.33 of Leopold et al., 1992)

Heads

Gully heads generally form where water flowing downslope encounters a local abrupt change in slope (the *knickpoint*) (Leopold et al., 1992). At this point, the shear stress due to the flow on the substrate is the greatest, and mechanical weathering may occur at this point. Headward erosion of the scarp is initiated due to incision of the knickpoint and, in cases where a vertical headwall forms, undercutting due to the formation of a plunge pool. Consequently, gully heads migrate upslope towards the local source of the surface water.

Water for gullies may originate from:

- Overland sheet flows: A sheet flood (often caused by intense precipitation in the southwest) moving down a slope may cut a gully in a location where the sheet flood encounters a break in slope.
- Rills: Rills (small runoff channels) may form a gully head where it spills over a knickpoint
- Seepage/sapping: Groundwater flowing out of the ground may undercut the surface and form a gully head

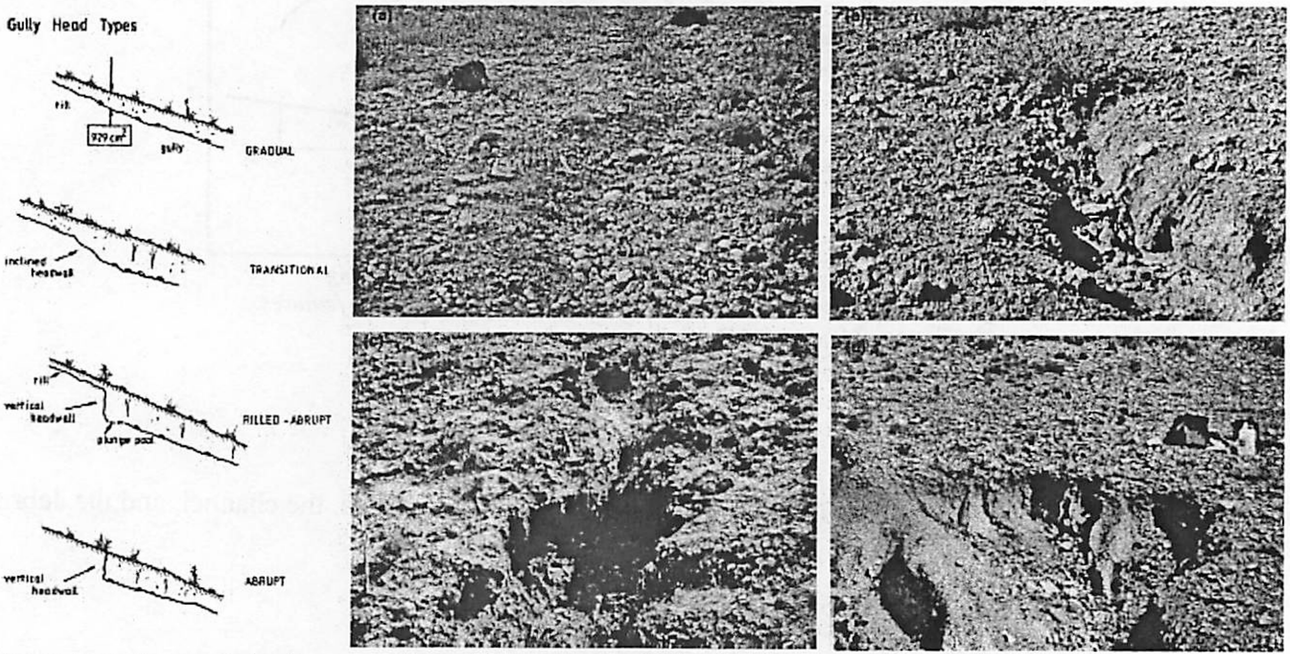


Figure 3.: Left: Longitudinal cross-sections of four types of gully heads. The upper surface in the drawing represents the original slope profile. Right: Photos of gully head types. A: gradual; b: transitional; c: rilled-abrupt; d: abrupt. (From Wijdenes et al., 1999)

Channels

In the upslope drainage basin, gully channels may coalesce and serve as tributaries for an entenched channel, which is primarily confined by its walls. Material eroded by the flow is deposited downslope at locations where either the flow encounters a shallower slope or where a critical fraction of water escapes the system (i.e., through infiltration for terrestrial examples). In many gully systems, this transition is located approximately where the old surface intersects the new surface.

Debris apron

The debris apron forms where material eroded from the upper reaches of the gully is deposited. The debris apron takes the form of a fan, and gully channels may divide to form distributary gully networks. This is a subaerial analog to river deltas (where sediment is deposited subaqueously). A distal fan of eroded debris may form downslope of the gullies' termini.

Gullies on Other Planets

Mars

Malin and Edgett (2000) identified small martian gullies with lengths from 100-1000 m on poleward-facing slopes. The gullies are similar to terrestrial gullies described above in that they have a defined head, main and secondary channels, and debris aprons with distributary channels. However, there is no evidence for overland flow feeding these gullies. Instead, the heads of the gully are generally located some distance below the surrounding surfaces. This has lead to the inference that these gullies are spring-fed (Malin and Edgett, 2000).

There is little agreement as to how liquid water could have carved these gullies. In general, liquid water is not currently thermodynamically stable on the martian surface (Haberle et al., 2001), so some workers have concluded that the gullies formed in periods of higher obliquities (e.g., Costard et al., 2002). Other workers have concluded that it is difficult to get liquid water at depth even during periods of high obliquity unless the water is briny (Mellon and Phillips, 2001). Heldmann et al. (2005) modeled the flow of liquid water flowing over the martian surface and concluded that water flows could have carved the gullies prior to the water subliming or freezing. Christensen (2003) argues that water for the gullies did not originate from a subsurface reservoir but instead rather from melting of near-surface snow deposited during periods of high obliquities.

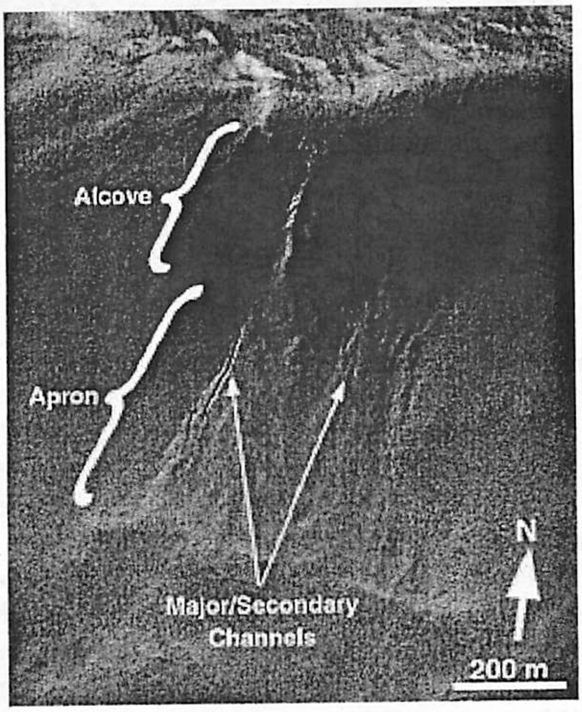


Figure 4: Portion of MOC image M03-00537 showing martian gullies. Note the alcove head, debris apron, and channels. Also note the lack of incised channels or other signs of overland flow at elevations above the gully heads.(Malin and Edgett, 2000).

Titan

DISR on board Huygens imaged features reminiscent of channel networks on Titan. These features are suggestive of fluvial erosion of the surface. However, debris fans expected from gullies are not observed. It is possible that the material making up debris fans were themselves transported elsewhere or that it is difficult to identify small debris fans in the images. Similarly, it may be difficult to identify features of small gully channels due to compression artifacts in the images.

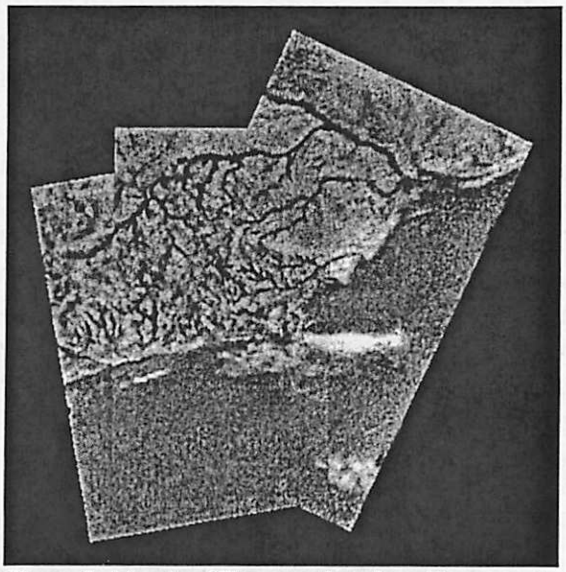


Figure 5.:Mosaic of Titans surface from Huygens. A channel network is visible, but there are no obvious depositional features.
*(*http://photojournal.jpl.nasa.gov/jpegMod/PIA07236_modest.jpg)

References

Christensen, P. R. Formation of recent martian gullies through melting of extensive water-rich snow deposits. *Nature*, **422**, 45-48, 2003.

Costard, F.; Forget, F.; Mangold, N.; Peulvast, J. P. Formation of Recent Martian Debris Flows by Melting of Near-Surface Ground Ice at High Obliquity. *Science*, **295**, 110- 113, 2002.

Haberle, R. M., McKay, C. P., Schaeffer, J., Cabrol, N. A., Grin, E. A., Zent, A. P., & Quinn, R. 2001, *Journal of Geophysical Research*, **106**, 23317-23326, 2001

Heldmann, J.~L., Toon, O. B., Pollard, W. H., Mellon, M. T., Pitlick, J., McKay, C. P., & Andersen, D. T. Formation of Martian gullies by the action of liquid water flowing under current Martian environmental conditions , *Journal of Geophysical Research (Planets)*, **110**, 5004, 2005.

Leopold, L. B, M. G. Wolman, and J. P. Miller. Fluvial Processes in Geomorphology. Dover Publications, Inc., 1992.

Malin, M. C. and K. S. Edgett. Evidence for Recent Groundwater Seepage and Surface Runoff on Mars, *Science,* **288**, 2330-2335, 2000.

Mellon, M. T. and R. J. Phillips. Recent gullies on Mars and the source of liquid water. *Journal of Geophysical Research*, **106**, 23165-23180, 2001.

Waters, M. R., Principles of Georchaeology, University of Arizona Press, Tucson. 1992.

Wijdenes, D. J., J. Poesen, L. Vandekerckhove, J. Nachtergaele, J. de Baerdmemaeker. Gully-head morphology and implications for gulkly development on abandoned fields in a semi-arid environment, Sierra de Gata, southeast Spain. *Earth Surf. Process. Landforms*, **24**, 585-603

Climate and Vegetation of Baja:

Michael Bland

Overview: The Baja Peninsula is composed of richly varying terrain. An east-west transect across the peninsula (a distance of ~45 mi) would take you from costal scrub and marshland, across chaparral covered hillsides to peaks covered in conifer forests and back down to the scrub deserts typical of Sonora. Each of these ecological zones maintains a unique set of vegetation, making Baja rich in ecological diversity.

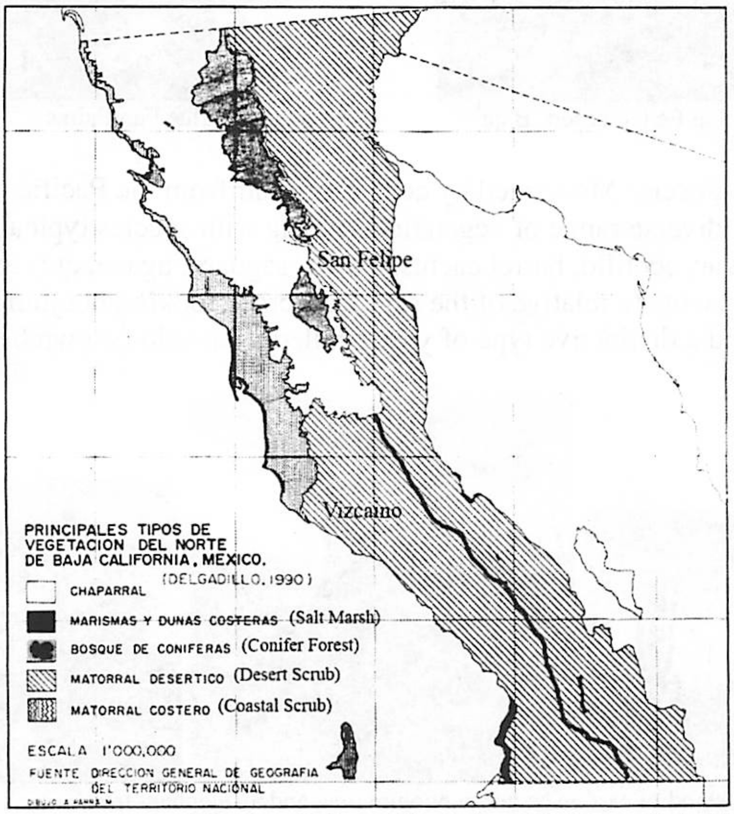


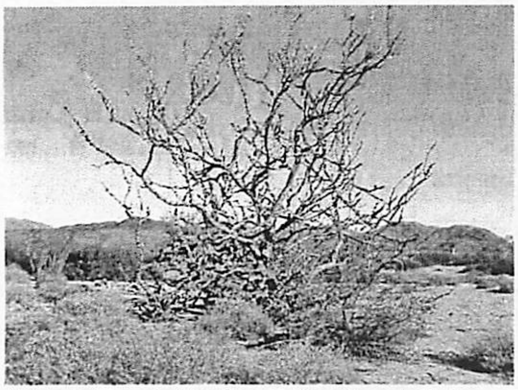
Fig 1. Vegetative Zones of Northern Baja California (modified from Delgadillo, 1955)

Ecological Zones:

Sonoran Desert:

The major vegetative zone in Baja is the Sonoran desert (Fig. 1). Like Tucson, this region's climate is dominated by relatively warm winters, and long, hot summers. The Sonoran desert in Baja can be divided into two distinct deserts: the San Felipe desert on the northeastern edge of the peninsula and the Vizcaino desert in the western and central portions of the peninsula.

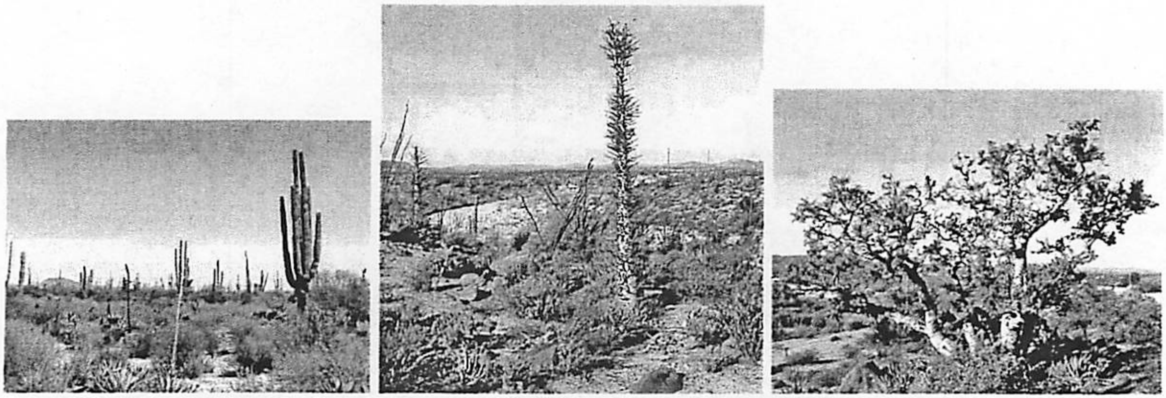
San Felipe desert: The San Felipe desert sits in the rain shadow of the Peninsular ranges. It is therefore more arid then typical Sonoran desert (~4 cm of precipitation per year!). The vegetation in this region is dominated by creosote and salt bush but also includes several species not found in the USA including the Adam's tree (a relative of the Ocotillo) and the Blue Fan Palm (both shown below).



Adam's Tree in the San Felipe desert, Baja

A stand of Blue Fan Palms

Vizcaino desert: Moderated by cool, moist, air from the Pacific the Vizcaino desert supports a diverse range of vegetation. Along with species typical of the Sonoran desert (prickly pear, ocotillo, barrel cactus, cholla, saguaro, agave, etc) species include the large cardon cactus (a relative of the saguaro), crazy looking boojum trees, thick elephant trees, and a distinctive type of yucca called a datilillo (shown below).



From left to right: A stand of cardon cactus, a boojum tree, and an elephant tree.

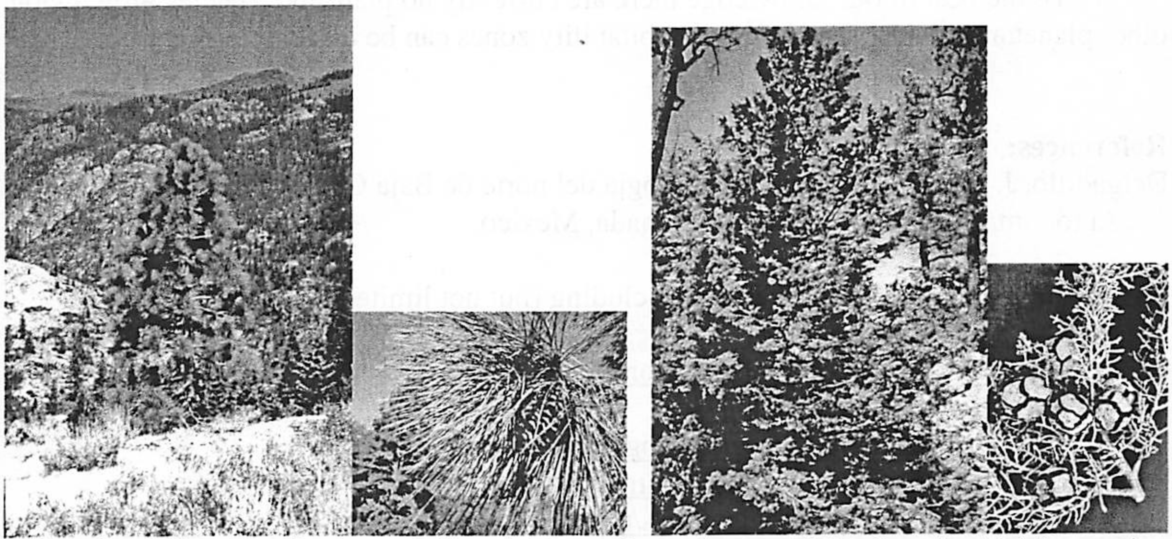
Chaparral:

Chaparral is the predominant vegetation of the mediterranean climatic zone of southern California and northern Baja. This zone has hot dry summers and cool wet winters, with almost all of the precipitation falling in the winter months. The plants of the chaparral zone are generally quite hardy. They must be resistant to both draughts and fires (which are common occurrences). Plants tend to be shrub sized to 2 or 3 m tall. The chaparral zone in Baja can be subdivided into 'coastal', 'desert/transition' and 'mountain' types, each with a slightly different species set. However, each type is dominated by chamise or greasewood (below), sumac, poison oak, and manzanita (below).

Chamise or greasewood (left) and manzanita (right) are typical of the chaparral zone

Conifer Forests:

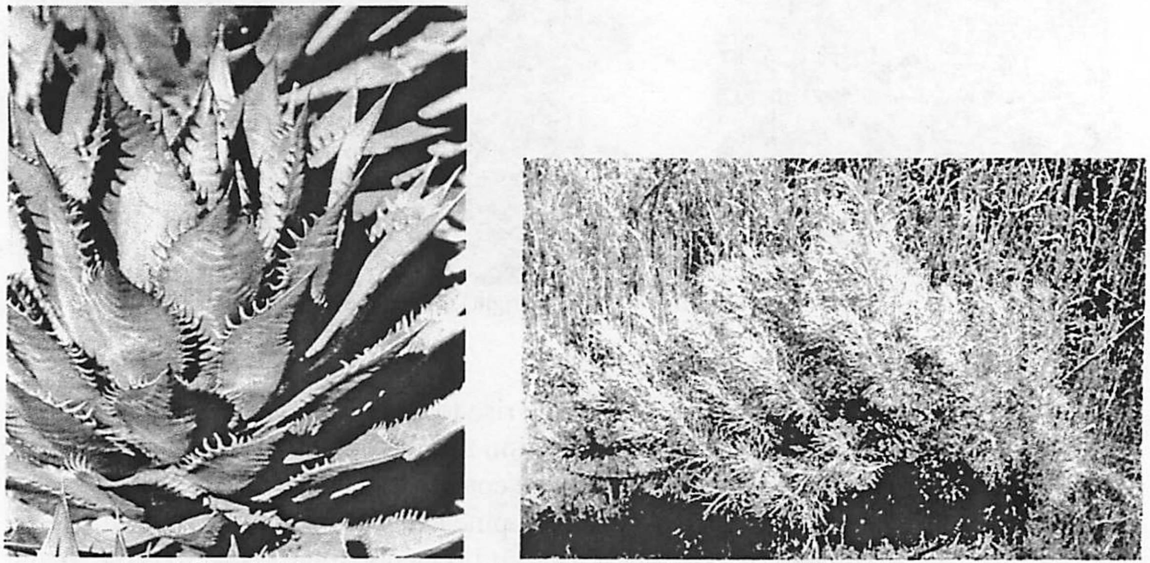
The peninsular ranges of Baja California rise to over 3000 m. Like the Catalinas and Rincons, these peaks produce a climatic region that is cool and wet year round providing ideal growing conditions for extensive conifer forests. The lower altitude regions of these forests are dominated by pinyon pine and California Juniper while the upper reaches are dominated by Jeffrey, Sugar and Lodgepole pine, as well as the White fir. The San Pedro Martir mountains are also home to three endemic species of Cyprus including the Arizona Montano Cyprus shown below (at right)



Jeffrey pine (left) and needles (center left); and Arizona Cyprus (center right) and needles (right), a species endemic to Baja California.

Coastal Sage Scrub:

The western coast of Baja contains a region of similar climate to the chaparral zone but at a lower elevation. The warmer temperatures associated with these lower elevations provides habitat for a coastal sage scrubland. The predominant species in this zone is the California Sage (shown below at right), but many other small shrubs and succulents make this region their home. These include century plants (Agave Shawii), several types of yucca, buckeye, and desert thorn.



Agave Shawii (also known as a century plant) at left and the California Sage at right.

Planetary Connection:

To the best of our knowledge there are currently no plant-like species growing on other planetary bodies. The issue of habitability zones can be discussed as a group…

References:

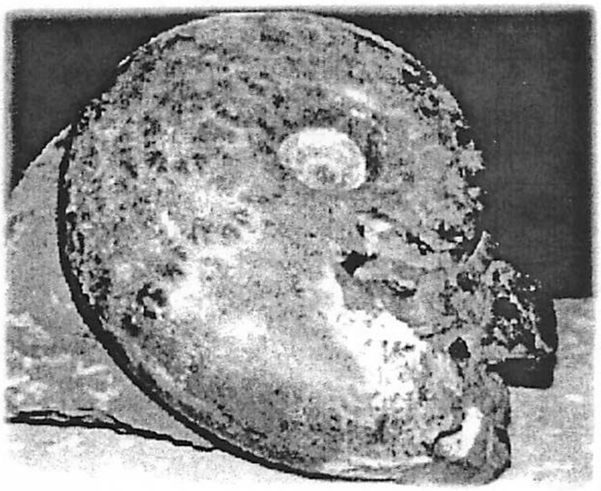
Delgadillo, J. (1955). "Floristica y ecologia del norte de Baja California." Universidad Autonoma de Baja California. Ensenada, Mexico.

Images are from a variety of websites including (but not limited to):
http://www.wikipedia.org
http://www.questconnect.org/baja_california.htm
http://www.oceanoasis.org/fieldguide/
http://helios.bto.ed.ac.uk/bto/desertecology/bajacali.htm
http://www.pinetum.org/PhotoJEFF21.htm
http://www.fs.fed.us/database/feis/plants/tree/

Ammonites

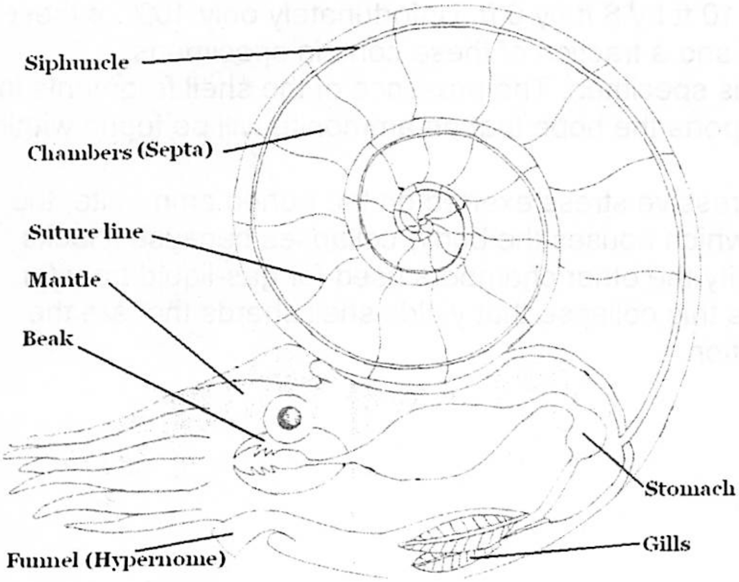
Oh, to be a cephalopod!

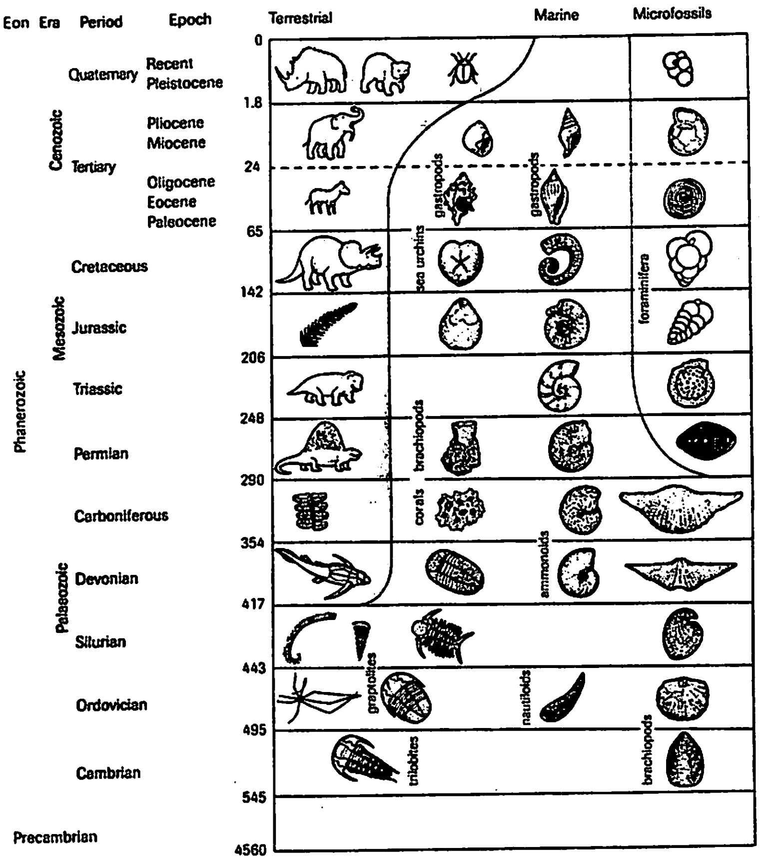
By Abby Sheffer



Name: Pachydiscus Catarinae
Locality: La Mision, Baja California, Mexico
Geologic Range:Late Cretaceous (100-60 million years ago)
Approximate Age of Specimen:
65 million years

Ammonites are a member of the class cephalopoda ('head-footed'). The shell is made of aragonite, $CaCO_3$ (called mother-of-pearl), and has a complex series of chambers that can be filled with water or gas to change buoyancy. They are very common, and so often used for biostratigraphy. In the fossils, the aragonite can be replaced by pyrite or calcite, but often it just dissolves to leave an imprint or cast.





Ammonites existed from the Devonian through the Cretaceous. They had a long, slow decline throughout the Cretaceous, but none are seen after the impact boundary. The closest surviving relative of the ammonite is the chambered nautilus.

Specimens occur in the narrow interval of the Rosario Formation of La Mision, Baja California. They are found in concretionary boulders that range in size from 4 ft. in diameter to 10 ft by 8 ft by 6 ft. Unfortunately only 10% of these boulders contain ammonites and a fraction of these contain specimens approaching the quality of this specimen. The presence of the shell fragments in the concretionary matrix supports the hope that an ammonite will be found within a concretion.

As a result of the compressive stress exerted on the buried ammonite, the outermost hollow chamber (which houses the body) collapses because it lacks the buttressing walls that fortify the other chambers used for gas-liquid transfer and buoyancy regulation. It is this collapse that yields shell shards that are the telltale guide for field excavation.

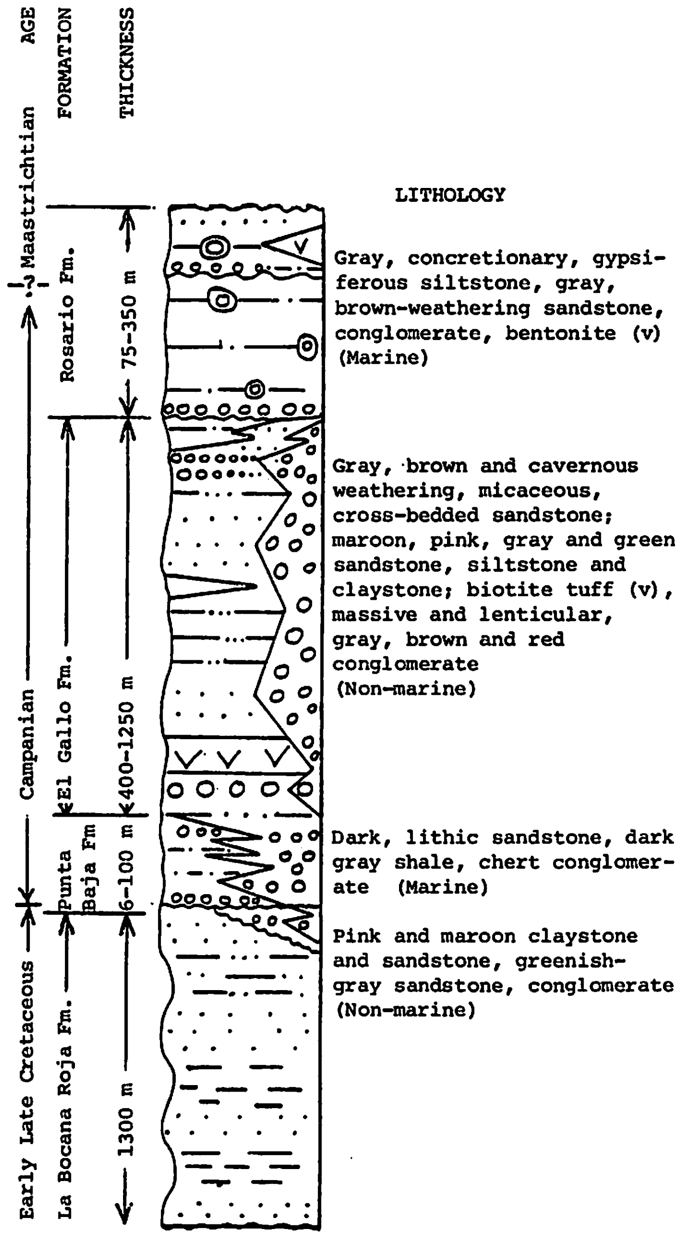


Figure 2. Upper Cretaceous stratigraphy in the El Rosario area. After Kilmer (1963).

Boehlke, J. and Abbott, P. (1986) Punta Baja Formation, A Campanian Submarine Canyon Fill, Baja California, Mexico. *Cretaceous Stratigraphy of Western North America*. Ed. P. Abbott. 91-101.

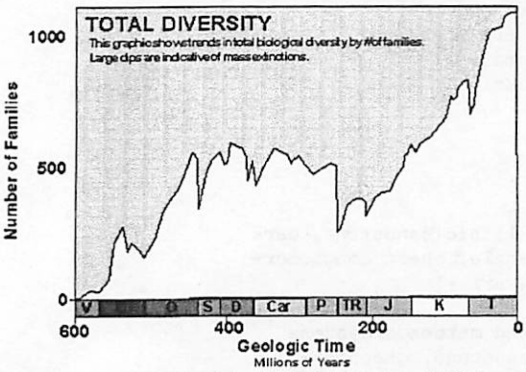
Eyden, P. (2003) Ammonites:A General Overview. http://www.tonmo.com/science/public/ammonites.php Accessed November 1, 2005

Monks, N. and Palmer, P.(2002) *Ammonites*. Smithsonian Institution Press, Washington, DC. 159 p.

http://libraries.ou.edu/etc/geology/ammonite.asp Accessed November 1, 2005

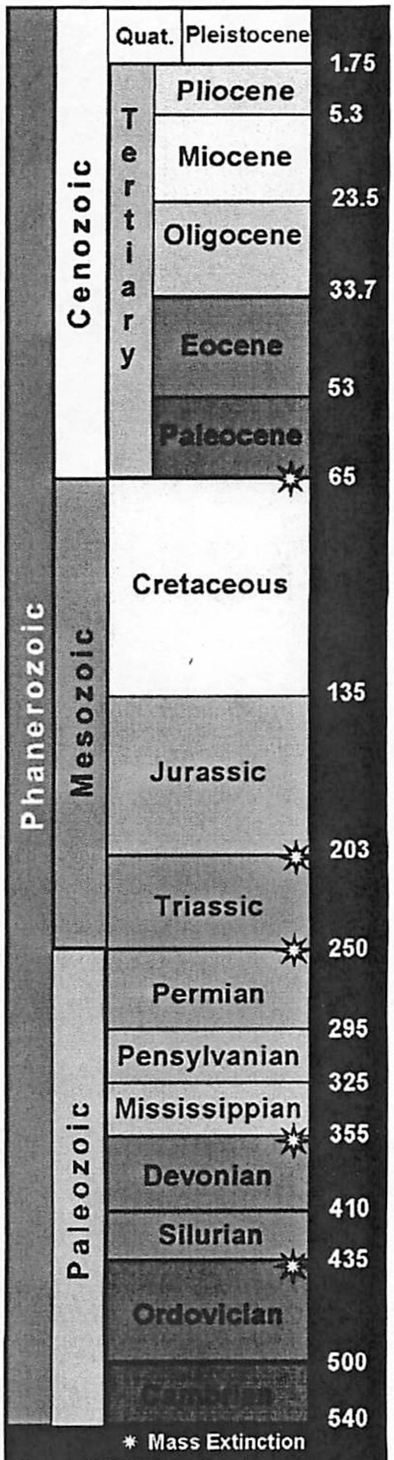
The K/T Boundary

- The K/T boundary refers to the geologic contact layer between rocks of the Cretaceous (K) and Tertiary Periods.
- This coincides with a mass extinction of about 75% of all terrestrial species, the most well known being the dinosaurs.
    - The fossil record indicates that dinosaurs and other species had been in decline for at least 10 Ma.
    - Marks the change from the age of reptiles to the age of mammals



Adapted from Sepkoski, Jr J.J. *Paleobiology 19, no.1* (1993)

- In 1980, a team led by Luis and Walter Alvarez found a fossilized sedimentary layer at the KT boundary that was enriched in iridium by at least 20 times.
    - The isotopic ratios of the iridium are consistent with meteoritic origin
    - This layer has been found all around the world and is frequently associated with impact created objects such as melt spherules
- An impact of this size would have had global environmental effects
    - Debris/dust would reach the upper atmosphere-long residence time
    - Superheated ejecta would ignite fires worldwide leading to more atmospheric particulates
    - This results in a large cooling effect that impacts primary producers and hence the entire food chain



Source IUGS International Stratigraphic Chart 2000