

**Lunar and Planetary Laboratory
Department of Planetary Sciences**

LUNAR & PLANETARY LAB

PTYS - 594a

Nevada Test Site Field Trip

28 September - 1 October 1995

**The University of Arizona
Tucson, Arizona**

LIBRARY
LUNAR & PLANETARY LAB

17857

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PTYS 594a,

PLANETARY FIELD GEOLOGY PRACTICUM

Itinerary, Nevada Test Site Trip 28 September-1 October 1995

H. J. Melosh, 353 Space Sciences, 621-2806

We will assemble at 7:00 am on Thursday, 28 September at the LPL loading dock off Warren St. in seven 4-wheel-drive vans. Try to be at LPL by 7:00 am to get the vans loaded. Please be sure that you have had breakfast beforehand, have ice for the coolers, etc. before we are scheduled to leave: Breakfast and ice runs just before departure have caused long delays in the past, and time will be very precious on Thursday and Friday!

Our approximate itinerary, as worked out at the last class meeting is:

Thursday, 28 September:

- 8:00 am Distribute handouts, Depart LPL, turn right on Cherry to Speedway, then travel West on Speedway to I-10, proceed North on I-10 to Phoenix. Exit right from I-10 in Phoenix to I-17 North. Exit I-17 at State Route 74 and proceed west to State Route 93. Turn North on 93 toward Wickenburg. Continue on 93 to Burro Creek Canyon.
- 12:00 noon Lunch stop at overlook on South side of Burro Creek bridge. Observe columnar basalts and caliche (on which a few words by **Josh Emery**).
- 1:00 pm Continue North on Route 93 toward Wikieup. Intersect I-40 at exit 71, proceed West on I-40 toward Kingman. At Kingman, exit to Route 93, proceed North toward Boulder City., then across Hoover Dam, through Boulder City and on toward Las Vegas.
- 4:00 pm Exit Route 93 at Charleston Blvd (Nevada Route 159), proceed West approx. 20 miles to Red Rock Canyon Park.
- 4:30 pm Leave vehicles at overlook. Discussion of the Keystone Thrust and local geology by **Greg Hoppa**.
- 5:30 pm Return East on Route 159 toward Las Vegas. Turn North on Rainbow Blvd., merge onto Route 95 (Oran K. Gragson Expressway), then to I-95 Northbound. Talk *en route* on Las Vegas Shear Zone by **David Trilling** and **Karen Meyers**. Exit State Route 202 at State Prison, proceed South 12 miles to Toiyabe State Forest. Camp in vicinity of Whiskey Spring at USDA Forest Service Bonanza dispersed camping area.
- 6:30 Camp, make dinner. Fireside chats on the physics of nuclear explosions by **Robert Coker**, radiation hazards by **Vince Converse**.

Friday, 29 September:

- 8:00 am Break Camp, return North on Rte. 202. Stop at overlook over Indian Springs Valley (south of prison). Pediments and mountain front slopes will be presented by **Cynthia Phillips**.
- 8:30 am Continue North to I-95, turn West to Mercury, Nevada.

9:00 am Arrive at the Mercury DOE badge office at the entrance of the Nevada Test Site. Foreign citizens must have passports, and US citizens picture ID's to be admitted.

9:20 am to 6:10 pm, See DOE itinerary (next section). Talks scheduled for this segment (as time and site permits) are:

Nuclear Fallout, NTS to Chernobyl, Fatima Ebrahim and Vladimir Florenski

Geology of the Nevada Test Site, Jennifer Grier

Shock metamorphism of minerals, Will Grundy

Spall and nuclear excavation, Jim Head

Formation of explosion craters, Chris Schaller

Nuclear explosion vs. impact craters, Betty Pierazzo and Zibi Turtle

6:15 pm Depart Mercury, return to I-95, proceed East to Las Vegas. Turn East on I-15, drive 30 miles. Leave I-15 at exit 75 to Rte. 169. Proceed East 18 miles to Valley of Fire state park. Continue 1 mile past booth to "Beehives" group camping area, camp at group site #1. Fireside Chats on the history of the atomic program and NTS by Andy Rivkin, Yucca Mountain waste storage facility by Barbara Cohen and Doug Dawson, delivery of nuclear weapons by Ralph Lorenz. (this could be deferred until the next night).

Saturday, 30 September:

8:00 am Break camp, proceed North on Rte 169 toward Logandale.

8:30 am Stop at overview of Mormon Mesa. Josh Emery will discuss caliche and desert soils, then Nancy Chabot will describe the overall geology of the Basin Range province.

9:30 am Return South on Rte. 169, then continue South on Lake Mead shore road toward Boulder City. The general geology of the Valley of Fire and Split Mountain will be described by Beth Clark. Two geology stops are planned

12:00 noon Lunch stop at Hoover Dam. The dam, its history and its effect on the Colorado river will be presented by Eric Wegryn (on the dam itself).

1:30 pm Continue South on Rte. 93 toward Kingman. Turn left onto Pierce Ferry road at Dolan Springs and proceed East to Stockton Road. Travel South on Stockton Road approx. 6 miles and enter Red Lake Playa. Caution: Check that the playa surface is hard and dry before driving the vehicles onto it!

3:00 pm Drive to southern portion of Red Lake Playa (do not pass fenceline!). Giant dessication polygons will be described by gallop'n wild Bill Bottke.

4:30 pm Leave Red Lake Playa, return North on Stockton road to Pierce Ferry Road. Continue to bend in road, take ranch road to camp on Grapevine Mesa.

5:30 pm Camp at Grapevine Mesa

Sunday, 1 October:

8:00 am Break camp, return to Rte. 93 by Pierce Ferry Road. Turn South on Rte. 93, return to Tucson via Kingman, Wickenburg, Phoenix.

4:00 pm Arrive Tucson, unpack and clean vans, go home.

Primary Drivers: Cohen, Converse, Hoppa, Larson, Phillips, Turtle, Wegryn

Participants:

B. Bottke	N. Chabot
B. Clark	B. Cohen
R. Coker	V. Converse
D. Dagget	D. Dawson
M. Domiguez	D. Durda
F. Ebrahim	J. Emery
V. Florenski	J. Grier
W. Grundy	J. Hamilton
J. Head	G. Hoppa
D. Kring	H. Larson
R. Lorenz	K. Meyers
C. Phillips	E. Pierazzo
A. Rivkin	C. Schaller
D. Trilling	E. Turtle
E. Wegryn	

NTS Itinerary

Revised 9/27/95

**University of Arizona
Tucson, Arizona**

September 29, 1995

- 7:45 a.m. Derek S. Scammell, Public Affairs Officer, U.S. Department of Energy's Nevada Operations Office (DOE/NV), departs for Mercury Badge Office in government vehicle.
- 9:00 a.m. Arrives at Mercury Badge Office. Join visitors at badging.

Photo identification is required at time of badging. Foreign citizens must present a valid U.S. passport at time of badging.
- 9:20 a.m. Depart for Mercury Gate 100 in private four wheel drive vehicles.
- 9:25 a.m. Arrive at Mercury Gate 100 for badge check.
- 9:30 a.m. Depart for Mercury Cafeteria.
- 9:35 a.m. Arrive at Mercury Cafeteria. Escort picks up water container from cafeteria supervisor.
- 9:50 a.m. Depart for Control Point (CP), Building 672.
- 10:20 a.m. Arrive at CP, Building 672. Radiation monitor joins group and issues safety equipment.
- 10:40 a.m. Depart for Area 18, Danny Boy. Lunch enroute.
- 11:10 a.m. Arrive at Area 18, Danny Boy.
- 12:10 p.m. Depart for Area 20, Schooner.
- 1:10 p.m. Arrive at Area 20, Schooner.
- 2:10 p.m. Depart for Sedan Crater. Radiation monitor leaves group.
- 2:55 p.m. Arrive at Sedan Crater.

**Escort is authorized camera on tour. Briefings are unclassified.
Visitors will provide their own lunch.**

3:25 p.m. Depart for Mercury Cafeteria.

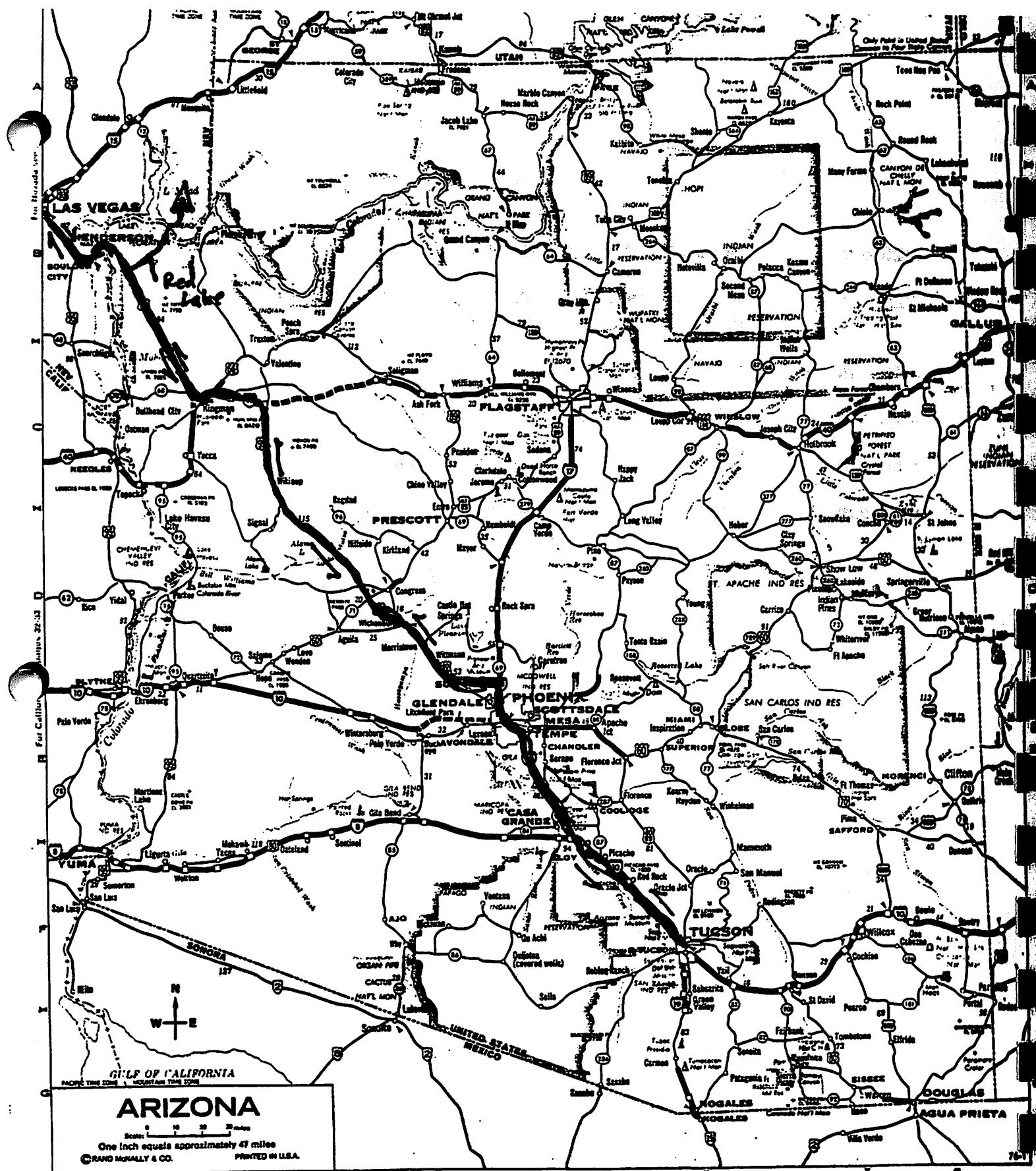
4:25 p.m. Arrive at Mercury Cafeteria. Escort returns water container to cafeteria supervisor. Rest stop.

4:40 p.m. Depart for Gate 100.

4:45 p.m. Arrive at Gate 100 for badge check.

4:50 p.m. Depart for DOE/NV Building, Las Vegas.

6:05 p.m. Arrive at DOE/NV Building.



ARIZONA

Scale 0 10 20 30 miles
 One inch equals approximately 47 miles
 GRAND HOUGHTAL & CO. PRINTED IN U.S.A.

ARIZONA
 Population: 1,787,820
 (1970 Census)
 Area: 113,908 Sq. Miles
 Capital: Phoenix

Cities and Towns
 Aguilera..... D-2
 Ajo..... F-3
 Apache Jct..... E-4
 Ash Fork..... C-3
 Avondale..... E-3

Beggs..... C-2
 Bisbee..... E-3
 Buckeye..... E-3
 Camp Verde..... E-4
 Casa Grande..... E-4
 Chandler..... E-4
 Chino Valley..... C-3
 Clarkdale..... E-3
 Clay Springs..... D-3
 Clifton..... E-3
 Colorado City..... A-2
 Coolidge..... E-3
 Cottonwood..... C-3

Douglas..... G-5
 Duxbury..... E-4
 Ehrenberg..... E-1
 Eloy..... E-4
 Flagstaff..... C-4
 Florence..... E-4
 Ft. Defiance..... E-3
 Ft. Thomas..... E-3
 Fredonia..... A-3
 Glendale..... E-3
 Globe..... E-3
 Grand Canyon..... E-3
 Green Valley..... E-3

Gu Achi..... F-3
 Happy Jack..... C-4
 Hayden..... E-4
 Mayer..... E-4
 Holbrook..... C-3
 Huschuka City..... C-3
 Humboldt..... D-3
 Jerome..... C-3
 Joseph City..... C-3
 Kayenta..... E-3
 Kaibab Canyon..... E-3
 Kearny..... E-3
 Kingman..... C-2

Lakeside..... D-3
 Litchfield Park..... E-3
 McNary..... D-3
 Mayer..... E-4
 Mesa..... E-4
 Miami..... E-4
 Moenaki..... E-4
 Morani..... E-4
 Morristown..... D-3
 Naco..... E-3
 Nogales..... E-3
 Nutrioso..... E-3
 Oracle..... F-3

Page..... A-4
 Patagonia..... G-5
 Payson..... D-4
 Peach Springs..... E-2
 Phoenix..... E-3
 Pinal..... E-3
 Pima..... E-3
 Pinetop..... D-3
 Prescott..... D-3
 Quartzsite..... E-3
 Safford..... E-3
 St. David..... E-3

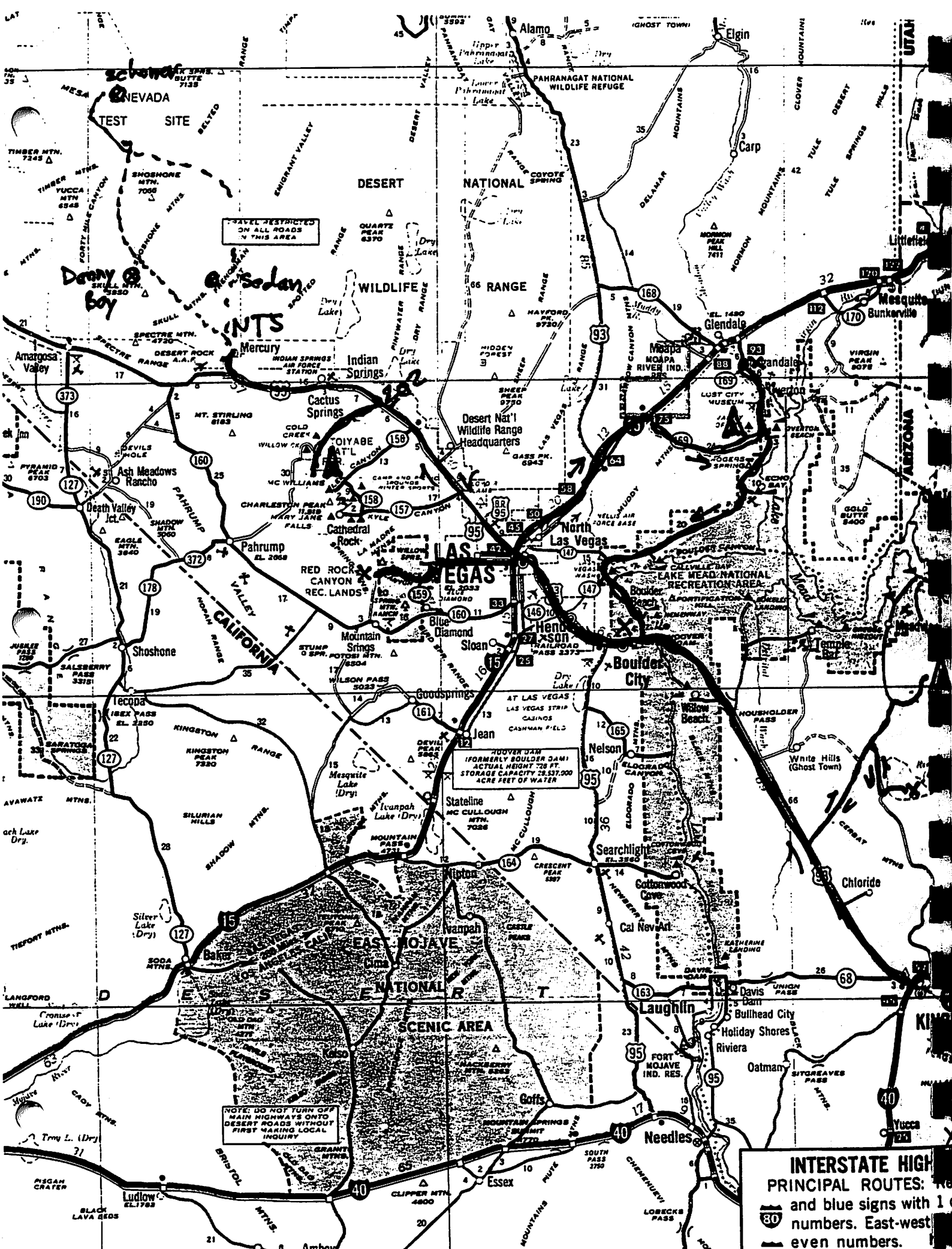
St. Johns..... D-3
 Salome..... D-2
 San Carlos..... E-3
 Scottsdale..... E-3
 Sedona..... E-3
 Selma..... C-3
 Sells..... C-3
 Show Low..... D-3
 Snowflake..... D-3
 Somerton..... F-4
 S. Tucson..... F-4
 Springville..... D-3
 Superior..... E-4

Tempe..... D-3
 Tombstone..... D-2
 Tuba City..... D-3
 Tucson..... E-3
 Wattoon..... E-3
 Willcox..... E-3
 Williams..... E-3
 Window Rock..... D-3
 Winslow..... E-3
 Yuma..... E-3

① Arizona Road Map



Fig. i Landforms of Arizona. A physiographic diagram of Arizona showing the relative positions of major structural-physiographic features. This style of illustrating features takes on more meaning when compared to the geologic map. Elevations are given in feet. Redrawn from Erwin Raisz, 1939.



TRAVEL RESTRICTED ON ALL ROADS IN THIS AREA

HOOPER DAM (FORMERLY BOULDER DAM) ACTUAL HEIGHT 728 FT. STORAGE CAPACITY 28,337,000 ACRES FEET OF WATER

NOTE: DO NOT TURN OFF MAIN HIGHWAYS ONTO DESERT ROADS WITHOUT FIRST MAKING LOCAL INQUIRY

INTERSTATE HIGHWAYS
PRINCIPAL ROUTES:
 and blue signs with 1
 numbers. East-west
 even numbers.

EVENTS IN ARIZONA

DOMINANT LIFE FORMS

AGE (mill yr)

EPOCH

PERIOD

ERA

ERA	PERIOD	EPOCH	AGE (mill yr)	DOMINANT LIFE FORMS	EVENTS IN ARIZONA	
CENOZOIC	Quaternary q	Holocene	01		Present erosion cycle gouges Pleistocene and Tertiary deposits. Basalt volcanism continues near San Francisco Peaks and at a few other sites.	
		Pleistocene	2		Regional uplift accelerates erosion; cyclic erosion creates terraces. Basalt volcanism occurs in several areas; San Francisco Peaks grow, collapse, and are glaciated. Colorado River flows through to Gulf of California. Pluvial lakes occupy some valleys.	
	Tertiary t	Pliocene	5		Colorado River turns west, initiates canyon cutting on Colorado Plateau. Little Colorado reverses as recurrent movements lift plateaus. In south, basins fill with stream and lake deposits.	
		Miocene	24		Basin and Range Orogeny 15 to 8 million years ago creates fault-block ranges with NW-SE grain. Basalt volcanism widespread.	
		Oligocene	38		Mid-Tertiary orogeny 30-20 million years ago pushes up mountains with NE-SW grain. Metamorphic core complexes form. Colorado Plateau rises; Colorado River flows south, east of Kaibab Arch. Downdropped Verde Valley intercepts northward drainage. Explosive volcanism common, with calderas in Chiricahua and Superstition Mountains.	
		Eocene	55		Tension faulting in south is accompanied by volcanism and intrusion of dikes, stocks, laccoliths. Intermountain valleys fill with debris from mountains. Verde Valley begins to form.	
	Paleocene				Laramide Orogeny ends 50 million years ago, leaving undrained intermountain valleys, some with lakes. No volcanism or intrusions mark Eocene magma gap. Northbound streams deposit rim gravels.	
					In south, Laramide Orogeny creates mountains with NE-SW trend; overthrusting may have occurred. Explosive volcanism occurs. Abundant small intrusions appear, some containing copper, silver, gold. In north, plateaus begin to form as large blocks are lifted or dropped.	
	MESOZOIC	Cretaceous K		63		Seas invade briefly from west and south; volcanism widespread. Laramide Orogeny begins 75 million years ago as west-drifting continent collides with outlying plates.
			Jurassic J	138		Deserts widespread; thick sand dune deposits in north. Explosive volcanism in south and west is followed by erosion.
Triassic R			205		Extensive coastal plain, delta, and dune deposits spread north from mountains in central and southern Arizona. Faulting, small intrusions, explosive volcanism occur in south.	
Permian P			240		Dunes form across northern Arizona, then a western sea invades briefly. Alternating marine and non-marine deposition in south and west.	
		Pennsylvanian P	280		Marine limestones deposited in south and south-central Arizona. floodplain and desert prevail in north.	
		Mississippian M	330		Widespread deposition of fossil-bearing marine limestone is followed by emergence and development of karst topography with sinks and caves.	
		Devonian D	365		Marine deposits form, then are removed from many areas by erosion.	
		Silurian S	410		No record.	
Ordovician O			435		Brief marine invasion, then no record.	
		Cambrian C	500		A western sea advances across denuded continent, depositing conglomerate and sandstone, then shale and limestone.	
PRE-CAMBRIAN			570		Great Unconformity - long erosion.	
	Younger pe		1700		Several episodes of mountain-building and intrusions of sills and dikes are followed by marine and near-shore sedimentation, faulting, and uplift. Sedimentary and volcanic rocks accumulate, then are compressed and altered into NE-SW-trending ranges extending beyond Arizona. 1.7 billion years ago granite batholiths intrude these older metamorphic rocks.	
Older pe						



**UNITED STATES DEPARTMENT of the INTERIOR
BUREAU of LAND MANAGEMENT
Red Rock Canyon National Conservation Area**



FACSIMILE MESSAGE

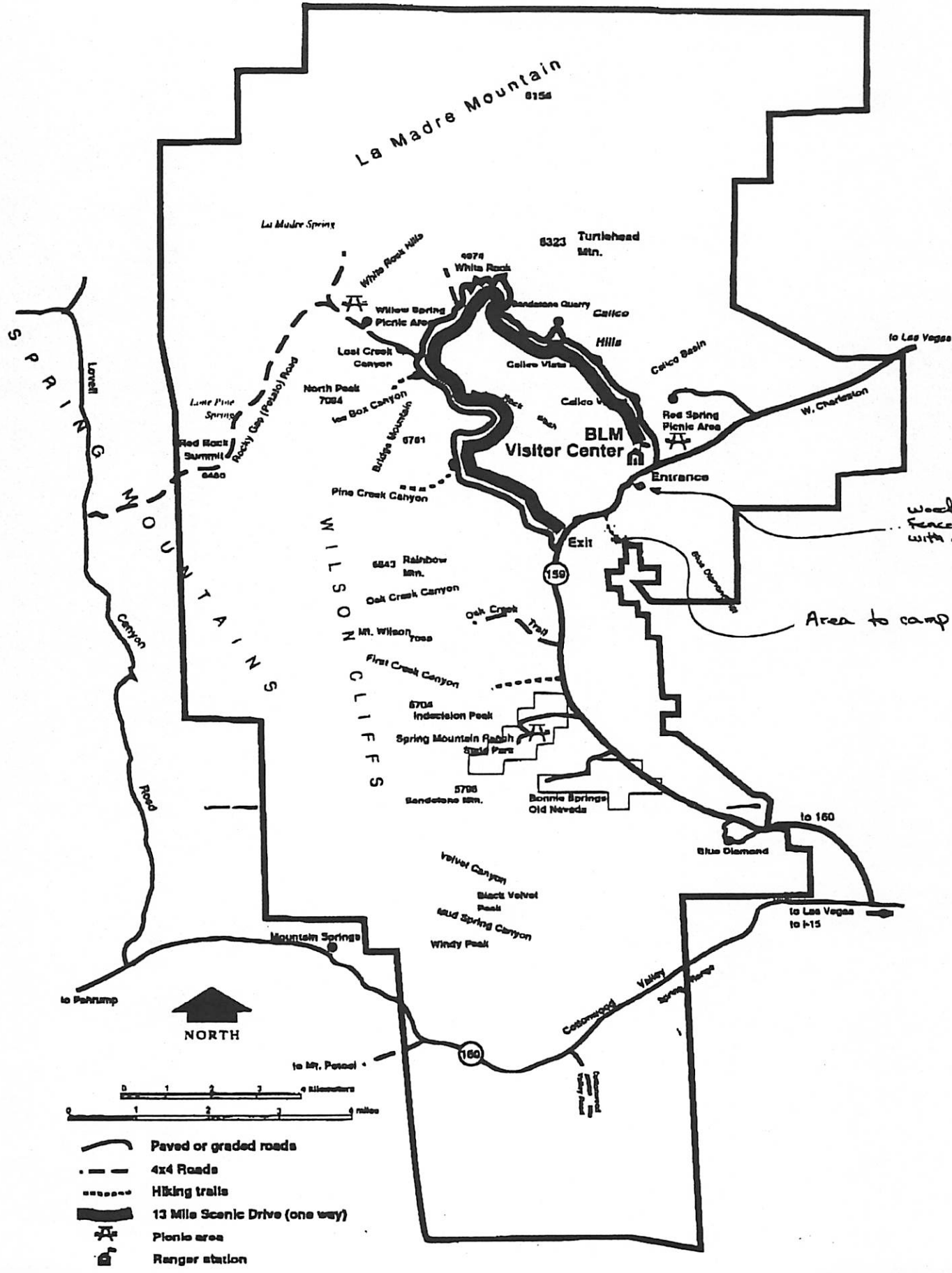
Date 9/22/95	Message No.	No. pages 2	Authorized by:	File code
TO: University of Arizona		FROM: GENE ARNESEN		
Attn: Jay Melosh		RED ROCK CANYON NCA		
		4765 WEST VEGAS DRIVE		
		LAS VEGAS, NV. 89108		
		(702) 647-5068		
		(702) 647-5000 (message)		
FAX: (520) 821-4933		FAX: (702) 647-5155		

SUBJECT: Campsite

Jay - You will probably enter Red Rock Canyon via Charleston Blvd. You will pass the turn to Calico Basin on your right and the Visitor Center turn will be 2 miles further, again on the right. Stay on the main road. After you pass the Visitor Center turn-off, continue on and after .9 mile you will pass a small parking area with a wooden fence and 3 green dumpsters off to your left. About another 3 or 4 tenths of a mile further, there will be a dirt road off to the left. This is your turn, and there will be a gate in a short ways. The chain and lock will be rigged so you can enter and continue on down the road until you reach the sparce vegetation. You will need to provide your own sanitation facilities (no deposits in the dessert please) and fires must be contained (no fire rings or fire directly on the ground).

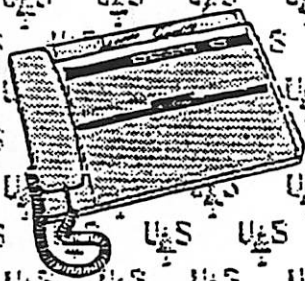
Please call the Vistor Center earlier in the day to advise, if you will be staying at 10-mile Canyon (as it has been dubbed).

Please call if any part of this message is unreadable or you require clarification.

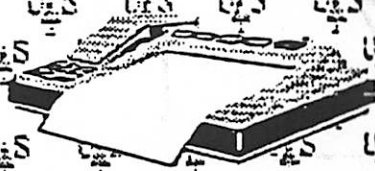


RRCNCA FACILITIES

MILEAGE SHOWN IS THE DISTANCE OF SITES FROM THE VISITOR CENTER.



FAX



Spring Mountains N.R.A.
Voice: (702) 873-8800
FAX: (702) 222-1599



TOIYABE NATIONAL FOREST

Name: Jay Melosh / Univ of AZ
Title: _____
Organization: University of AZ
Voice phone: (520) 621-6806
FAX phone: (520) 621-4933

\$5 Pages Including Cover Sheet.
Please be sure to read over carefully
before signing. Any questions
please call me at (702) 222-1542
Cyndi Carver
Remember... Smokey has for 50 years.

EXHIBIT 1

FS-2700-25

U.S. DEPARTMENT OF AGRICULTURE Forest Service TEMPORARY SPECIAL-USE PERMIT Authority: <u>Act of June 4th, 1897</u> This authorization is revocable and nontransferable	Holder No. <u>3 0 0 5-2 6</u>	Issue Date <u>0 9/2 9/9 5</u>	Expir. Date <u>0 9/2 9/9 5</u>	
	Type site(s) <u>1 4 2</u>	Authority <u>0 2</u>	Auth. Type <u>2 2</u>	
	Region/Forest/District <u>0 4/ 1 7 / 0 5</u>		State/County <u>3 2/ 0 0 3</u>	
	Cong. Dist. <u>0 2</u>	Latitude -----	Longitude -----	

UNIVERSITY OF ARIZONA, hereinafter called the Holder, is hereby authorized to use, subject to the terms and conditions of this permit, National Forest System lands within Sections (s) 15, T 18 S, R 55 E, N, as shown and/or further described in the attached Exhibit(s) B. This permit covers approximately 5 acres and/or 10 miles.

The holder is authorized to conduct the following activities on the permitted area: Group Campout for 31 people Camp Bonanza

The holder is authorized to install the following temporary improvements on the permitted area: No permanent facilities are permitted. One portable toilet per 25 people.

TERMS AND CONDITIONS

- Use under this permit shall begin on 09/28/95 and end on 09/29/95. The permit shall not be extended.
- The fee for this use is \$ 45.00. It shall be paid in advance and is not refundable.
- The holder shall conduct the authorized activities according to the attached approved plans and specifications, Exhibit(s) A (clauses 1-20).
- The holder shall not install any improvements not specifically identified and approved above.
- No soil, trees, or other vegetation may be destroyed or removed from National Forest System lands without specific prior written permission from the authorized officer.
- The holder shall comply with all federal, State, county, and municipal laws, ordinances, and regulations which are applicable to the area or operations covered by this authorization.
- The holder shall maintain the improvements and premises to standards of repair, orderliness, neatness, sanitation, and safety acceptable to the authorized officer. The holder shall fully repair and bear the expense for all damage, other than ordinary wear and tear, to National Forest System lands, roads and trails caused by the holder's activities.
- The holder shall be liable for any damage suffered by the United States resulting from or related to use of this permit, including damages to National Forest resources and costs of fire suppression.
- The holder has the responsibility of inspecting the use area and adjoining areas for dangerous trees, hanging limbs, and other evidence of hazardous conditions which would pose a risk of injury to individuals. After securing permission from the authorized officer, the holder shall remove such hazards.
- The holder shall hold harmless the United States from any liability from damage to life or property arising from the holder's occupancy or use of National Forest lands under this permit.
- The holder agrees to permit the free and unrestricted access to and upon the premises at all times for all lawful and proper purposes not inconsistent with the intent of the permit or with the reasonable exercise and enjoyment by the holder of the privileges thereof.
- This authorization is subject to all valid existing rights and claims outstanding in third parties.
- This authorization may be revoked upon breach of any of the conditions herein or at the discretion of the authorized officer. Upon expiration or revocation of this authorization, the holder shall immediately remove all temporary improvements except those owned by the United States, and shall restore the site within 7 days, unless otherwise agreed upon in writing. If the holder fails to remove the improvements, they shall become the property of the United States, but that will not relieve the holder of liability for the cost of their removal and restoration of the site.
- This authorization is not transferable. The holder shall not sublet occupancy of the authorized premises and improvements to third parties.
- Any changes to this permit, its provisions or requirements are subject to appeal per 36 CFR 251.88.
- This permit is accepted subject to the conditions set forth herein, condition(s) clauses 1-20 and Exhibit(s) A attached to and made a part of this authorization.

HOLDER

By: _____
 Address: Lunar Planetary Lab/University of AZ
Tucson, AZ 85721
 Tel #: 520-621-2806
 Date: _____

U.S. DEPARTMENT OF AGRICULTURE
 Forest Service

By: James S. Tallero
 Name: James S. Tallero
 Title: District Ranger
 (Authorized Officer)
 Date: 9/25/95

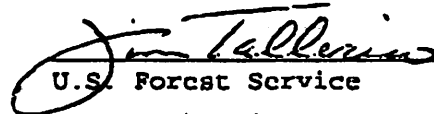
OPERATING PLAN

The permittee shall conduct the operations authorized by this permit with full recognition of the need for public safety. In furtherance of this requirement, the permittee shall abide by the following special provisions:

1. Fees are \$ 45.00 per each date of use of National Forest Systems lands.
2. Permit fees will not be refunded.
3. All vehicles must stay on designated roads and parked in designated parking areas.
4. Campfires will be limited to open areas away from overhanging branches, steep slopes, and rotten stumps or logs. All litter, duff, and burnable material will be scraped away within a 10 foot circle around the fire. During fire season, users are required to carry a shovel and at least five gallons of water. Fire restrictions in effect at the time of the activity/event may supersede these measures.
5. Fire restrictions may be imposed at any time during high fire danger, prohibiting the use of fire.
6. The holder will do everything reasonable to prevent and suppress fires caused by this event.
7. No pits for disposal or other purposes will be allowed.
8. Waste water of self-contained vehicles will not be discharged on National Forest System lands.
9. Portable toilets will be provided by the group at a rate of 1 toilet per 25 people. Self contained R.V.'s may be substituted for portable toilets.
10. Sewage will only be discharged at appropriate disposal sites in Las Vegas.
11. Complete cleanup of the site and immediate surroundings is required, as no garbage service is provide. Please take all garbage and other debris home where it can be properly handled by garbage pickup service or recycled.
12. Stakes, flagging materials, equipment, temporary facilities, litter, and all other event-related materials will be removed from the permitted areas before leaving the area.
13. No cutting of live trees, burn only dead and down wood.
14. This permit does not give permission to cross over or use any private lands during the event.

15. The holder will do everything possible to ensure participants and spectators do not collect or harass wildlife or plants.
16. The holder will instruct all participants and spectators of the status of the tortoise, pertinent laws, to insure protection of the species and habitat.
17. The holder will provide first-aid services sufficient to ensure that any accident victim can be located, treated and evacuated immediately following notification of an accident.
18. This permit is revocable for any group or individual whose conduct, behavior, or actions violate these conditions or regulations applicable to this area.
19. Check our 24-hour information number (222-1597) prior to your event for any change in conditions such as fire restrictions.
20. We ask for your cooperation in understanding and abiding by these conditions. Often misunderstandings arise because all members of a group do not know the rules. It is your responsibility to inform your group of the above conditions.

Date



U.S. Forest Service
9/25/95

Date

USDA - FOREST SERVICE

B I L L F O R C O L L E C T I O N
(Reference FSM 6530)

Place of Issue
2881 S. Valley View
Blvd., Ste. 16
Las Vegas, NV 89102

Please pay by money order, bank draft, or check payable
to FORRST SERVICE, USDA. Mail payment with a copy
of this statement in the enclosed envelope to:
COLLECTION OFFICER, FS, INTERMOUNTAIN REGION
P.O. BOX 60000, FILE NO. 61657
SAN FRANCISCO, CA 94160-1657

Date of Issue
September 25, 1995

University of Arizona
Jay Melosh
Lunar Planetary Lab
Tucson, AZ 85721

-Fold Here-

Date or Period	Description	Amount		
09/28/95 09/29/95	2720 Special Use Permit 3005-26 Spring Mountain Nat'l Recreation Group Event Permit Issued on 09/25/95 Jay Melosh Description/Location: Group Event Camp Bonanza Dispersed Group Site	\$ 45.00		
Bill No.	Unit No.	Contract No.	Date Payment Due	Amount Due
575294	TP-17		October 25, 1995	\$ 45.00

NOTE: Payments not received by the due date are subject to a LATE PAYMENT CHARGE
at the rate currently published by the Department of Treasury unless a different
rate is prescribed by contract or agreement; and in addition, may be subject to
an administrative charge as prescribed by the Debt Collection Act of 1982.

REMARKS:	Forest Service Accounting Data MANAGEMENT CODE	AMOUNT
DG to RL:R04F17A _/_/_	898486	\$ 45.00
	TOTAL DUE >	\$ 45.00

Caliche and Mormon Mesa

--Josh Emery

DEFINITION OF TERMS

Caliche. In this report the term caliche is used to encompass all secondary deposits of calcium carbonate. The term caliche has been commonly used to designate deposits of calcium carbonate by pedogenic processes. However, in the present study, deposits of calcium carbonate due to what are believed to be other than pedogenic processes have been found, and these play an important role in the investigation. Additionally, caliches of pedogenic origin are transitional with caliches of nonpedogenic origin. Therefore, it is felt best to here use caliche as a general term for all secondary calcium carbonate deposits.

Soil Caliche. A soil caliche is an accumulation of secondary calcium carbonate formed by pedogenic processes. It consists of two major transitional types depending mainly on thickness and degree of development:

1) Calcic horizon. As here used, this is a soil horizon of calcium carbonate accumulation which is more than six inches thick, has a calcium carbonate equivalent content of more than 15 percent, by weight, and has at least 5 percent, by volume, of identifiable secondary carbonates (Soil Survey Staff, p. 3-38, 1967). If a horizon of secondary carbonate accumulation is indurated or cemented such that dry fragments do not slake in water, it is a petrocalcic horizon, as discussed below.

2) Petrocalcic horizon. A laterally continuous, cemented or indurated calcic horizon is called a petrocalcic horizon. Dry fragments do not slake in water and noncapillary pores are plugged (Soil Survey Staff, p. 3-40, 1967). It may be capped by a laminar layer, and its structure may be either massive or platy. This horizon is often called calcrete (Figure 2). The term K-fabric has been used by Gile, et al. (1965), for petrocalcic horizons meeting certain qualifications as to fabric and content. In this report petrocalcic horizon will be used to subsume the K-fabric concept as the distinctions will not be required in this study.

Laminar Layer. This layer consists of thinly laminated calcium carbonate which contains few or no coarse clasts and which is found under a variety of conditions. It may occur as a more or less continuous cap on a petrocalcic horizon (Figure 3) where it is believed by some to be a late stage feature of soil formation (Gile, et al., 1965). It may also occur on any relatively impermeable surface such as bedrock or clay. It may be found, not uncommonly, locally coating the sides of gullies and washes and also in discontinuous thin layers on clay. It is generally of very low permeability which is maintained because of a tendency to rapidly cement small fractures.

Gully-Bed Cementation (Lattman, L.H., unpublished manuscript, 1972). Gully-bed cementation, here called GBC, is a massive, generally nonlaminated, well cemented layer found on, or immediately beneath, the bed loads of many gullies and washes. It is of low permeability and commonly includes boulders, pebbles, and sand that were earlier bedload. Such layers are discontinuous laterally but otherwise may be indistinguishable from petrocalcic horizons or laminar layers. They may include some laminar horizons.

Case Hardening (Lattman and Simonberg, 1971). Case hardening is cementation of alluvial and colluvial material exposed in very steep to vertical slopes, such as gully sides and terrace risers (Figure 4). It is believed to be due to thin-film surface water causing solution of silt-sized calcareous material and redeposition. It is locally extremely hard and of low permeability, depending upon age and sorting of the cemented material. Older exposures are better cemented, and in any one exposure the poorer the sorting (the greater the range in grain size), the better the cementation.

Caliche Rubble. Caliche rubble consists of loose, generally irregular pieces of calcium carbonate lying loose on the surface (Figure 5). Such rubble may locally cover up to 75 percent of the surface in the area studied. It is believed to be derived from two sources: 1) mechanical breakup of laminar layers and near surface petrocalcic horizons; and 2) by separation of coating from pebbles and larger clasts.

In addition to the types of calcium carbonate deposits described above, there is present over all low relief surfaces in the study area a silt layer about one to four inches thick. This layer is generally at or immediately below the surface and is commonly very lightly cemented with calcium carbonate. It is thought to possess low permeability.

Stage	Gravel content ¹	Diagnostic morphologic characteristics	CaCO ₃ distribution	Maximum CaCO ₃ content ²
CALCIC SOILS				
I	High-----	Thin, discontinuous coatings on pebbles, usually on undersides.	Coatings sparse to common	Tr-2
	Low-----	A few filaments in soil or faint coatings on ped faces.	Filaments sparse to common	Tr-4
II	High-----	Continuous, thin to thick coatings on tops and undersides of pebbles.	Coatings common, some carbonate in matrix, but matrix still loose.	2-10
	Low-----	Nodules, soft, 0.5 cm to 4 cm in diameter	Nodules common, matrix generally noncalcareous to slightly calcareous.	4-20
III	High-----	Massive accumulations between clasts, becomes cemented in advanced form.	Essentially continuous dispersion in matrix (K fabric).	10-25
	Low-----	Many coalesced nodules, matrix is firmly to moderately cemented.	-----do-----	20-60
PEDOGENIC CALCRETES (INDURATED CALCIC SOILS)				
IV	Any-----	Thin (<0.2 cm) to moderately thick (1 cm) laminae in upper part of Km horizon. Thin laminae may drape over fractured surfaces	Cemented platy to weak tabular structure and indurated laminae. Km horizon is 0.5-1 m thick.	>25 in high gravel content >60 in low gravel content
V	Any-----	Thick laminae (>1 cm) and thin to thick pisolites. Vertical faces and fractures are coated with laminated carbonate (case-hardened surface)	Indurated dense, strong platy to tabular structure. Km horizon is 1-2 m thick.	>50 in high gravel content >75 in low gravel content
VI	Any-----	Multiple generations of laminae, breccia, and pisolites; recemented. Many case-hardened surfaces.	Indurated and dense, thick strong tabular structure. Km horizon is commonly >2 m thick.	>75 in all gravel contents

¹High is more than 50 percent gravel; low is less than 20 percent gravel.
²percent CaCO₃ in the <2-mm-fraction of the soil. Tr, trace of carbonate.

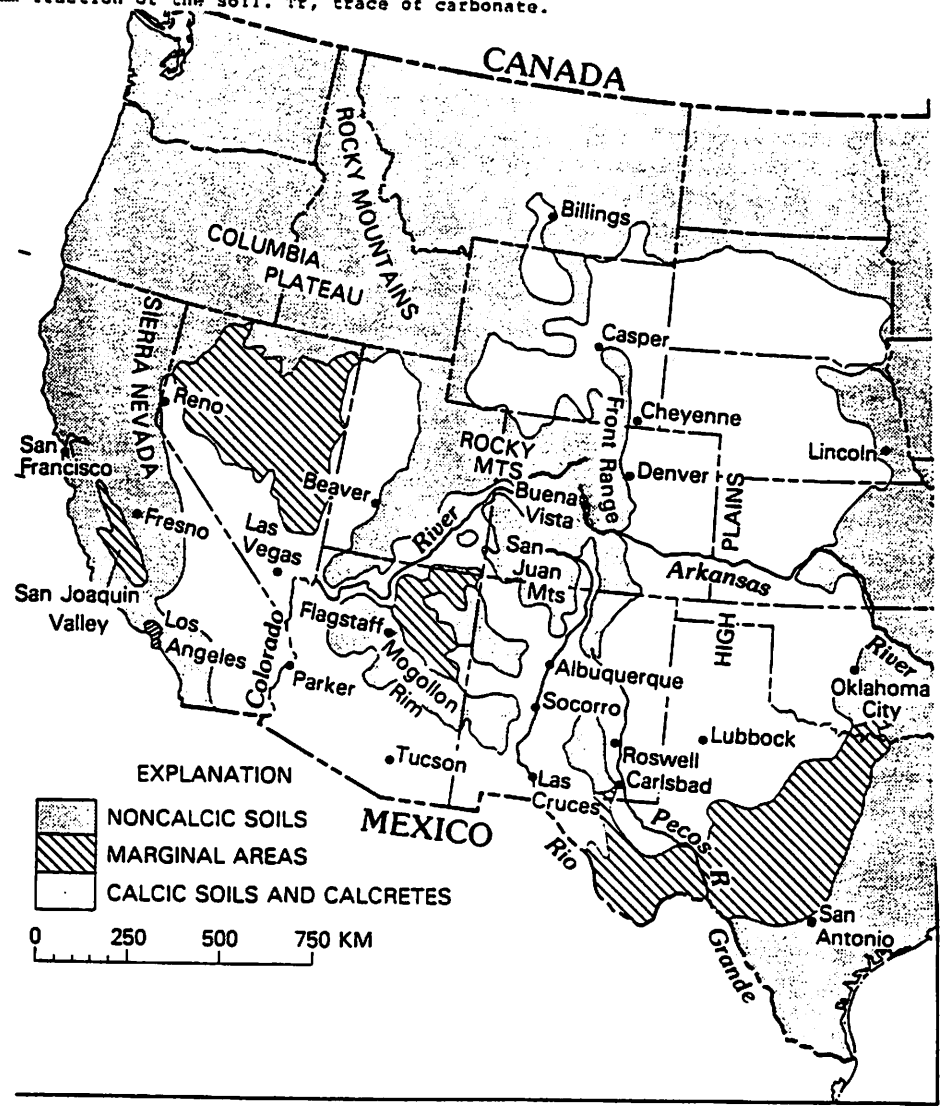
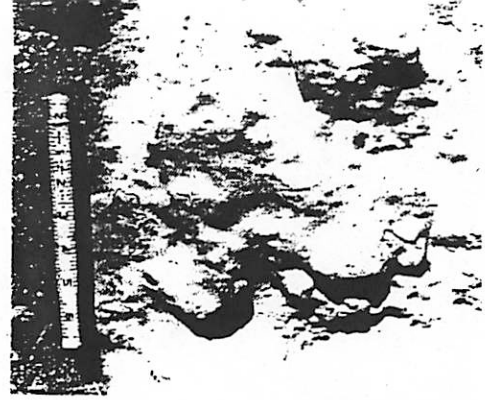
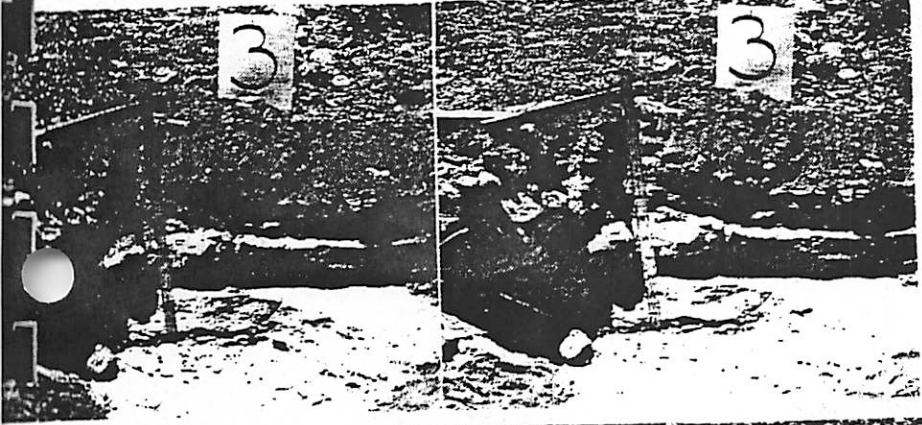


Figure 2. Areas where calcic soils may be present in the southwestern United States, as interpreted from the soils map of the United States (U.S. Soil Conservation Service, 1970). Areas of discontinuous or poorly preserved calcic soils are designated marginal.



Laminar layer coating a petrocalcic horizon

petrocalcic horizon exposed in rill



nodules overlying a petrocalcic horizon

FIGURE 5. Desert pavement made up largely of caliche rubble in the vicinity of transect station 1-7. Larger fragments are 6 to 3 inches across.

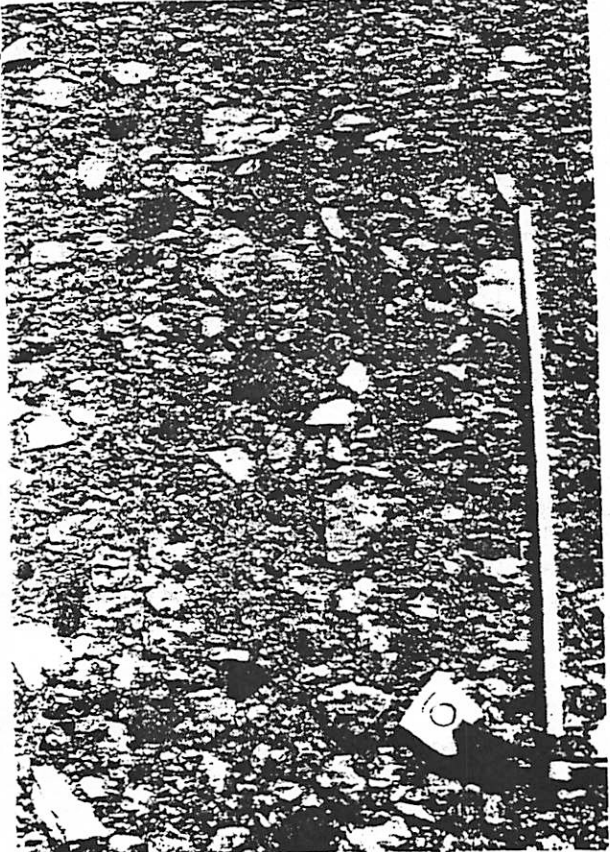


FIGURE 11. Chert nodule supported on a pedestal of caliche protected from rainfall illustrating solution of an exposed petrocalcic horizon. A minimum of 1.5 inches of caliche has been moved.

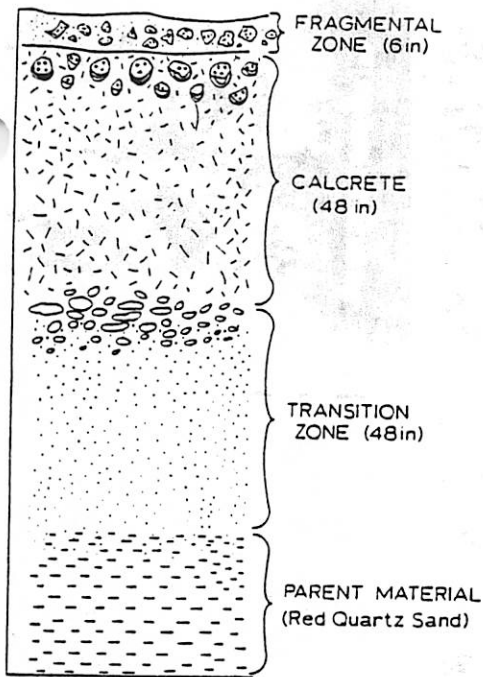
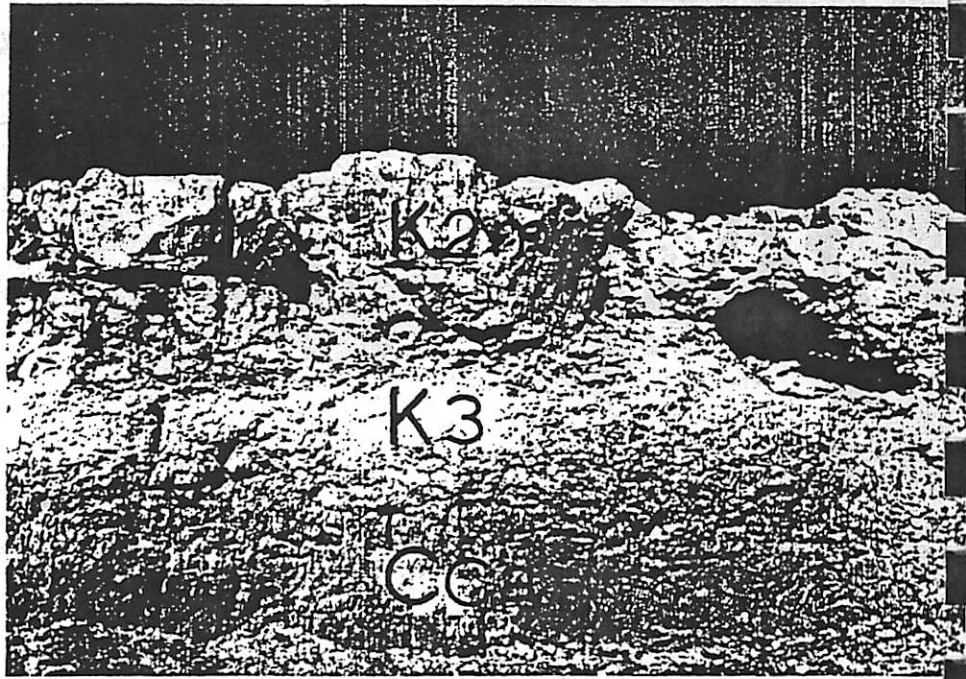
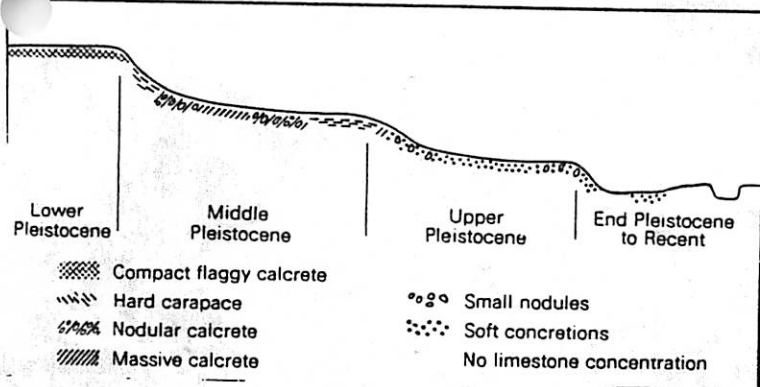


Figure 3. Diagram showing features and horizons of the Mormon Mesa caliche.



Photograph of Mormon Mesa caliche profile near sample site 5.



87. A. Calcretes on staged Pleistocene pediments in Morocco showing increasing development with age and with position on the terrace. After Ruellan, 1967.

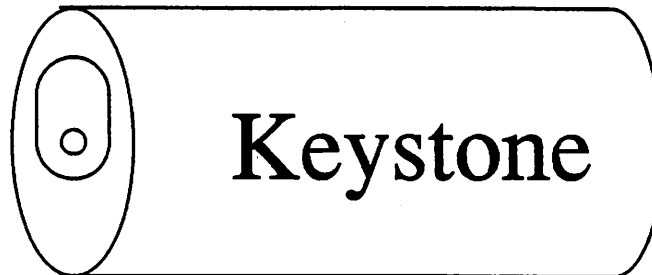
TABLE IV Evolutionary scheme of formation and breakdown of caliche

BREAKDOWN	Gravel pavement	Calcrete boulders	
	CRUSTING		
CRUSTING			Flaggy caprock Laminar crust Crusted layer
CEMENTATION	Cemented gravel or sand hardpan	Cemented nodular ('honeycomb') hardpan	Cemented chalky hardpan
	ACCUMULATION		
ACCUMULATION	Granular interfill	Concretionary horizon	Soft chalky horizon
	Pebble or grain coatings	Concretions	Powdery matrix
MATRIX	Filaments		
	GRAVEL OR COARSE SAND	SAND TO CLAY	

* After Beaudet *et al.*, 1967; Gile *et al.*, 1966; Goudie, 1973.

The Keystone Thrust Fault

Greg Hoppa



The Keystone Thrust Fault, discussed by and named by Hewett in 1931 is located in the Spring Mountains 10 miles to the west of Las Vegas. The fault is exposed over 45 miles along the eastern flank of the Spring Mountains, and the Wilson Cliffs, rising almost vertically over 2000 ft., can easily be seen from Las Vegas. Dark Cambrian dolomite rocks form the lower boundary with younger Jurassic Aztec sandstone. Due to the dramatic color changes at the fault boundary the Keystone Fault is typically used in basic geology text-books as an example of thrust faulting. Figure 1. shows the Keystone Thrust with respect to the Las Vegas Shear Zone and Las Vegas.

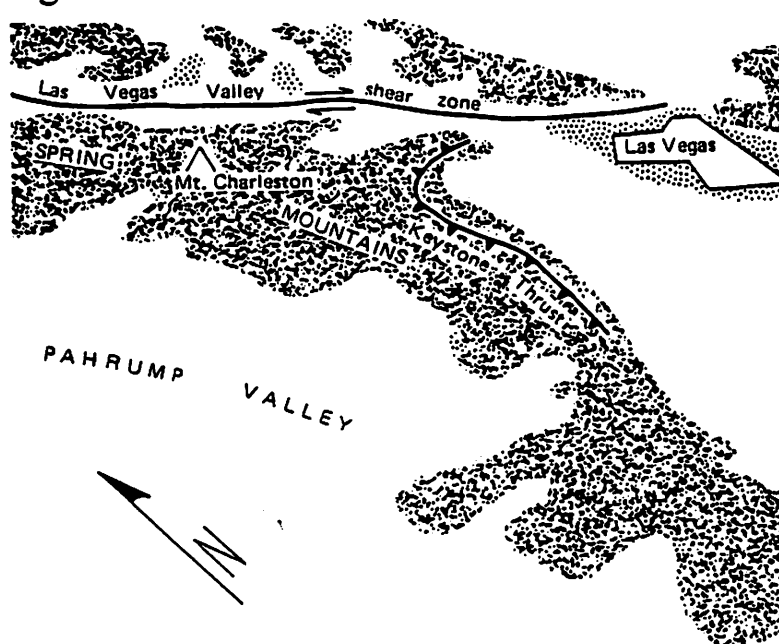


Figure 1.

The Paleozoic limestone was formed by the precipitation of calcium carbonate in an ancient ocean, while the Aztec sandstone was formed by large sand dunes. In general Aztec sandstone is brick red in color, but due to leaching the sandstone can appear orange or even white. Figure 2 shows the cross-section of the Keystone Thrust.

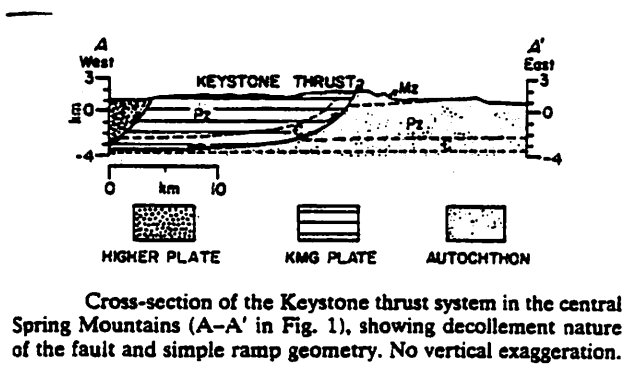


Figure 2.

The formation of the Keystone Thrust is associated with the Cordilleran foreland fold-and-thrust belt which extends from Canada down to Mexico. As subduction of the ancient Farllon plate took place compressional forces pushed older rocks up and over the younger rocks. The dramatic age discrepancy between the Cambrian limestone and the Aztec sandstone can be attributed to large movements of the Keystone Thrust plate.

The age of the Keystone Thrust has been estimated to be early Jurassic to early Cenozoic (Burchfiel 1974). Closer studies of fossils in the Muddy Mountains 40 miles to the north, where Baseline Sandstone overlies Aztec Sandstone with a slight angular unconformity reveal an age of 96-98 million years for the Keystone Thrust. After the formation of the Keystone Thrust basin and range extension dominated this region slicing normal faults going from the south-east to the northwest. Figure 3. shows the region tectonic Map of the Spring Mountains.

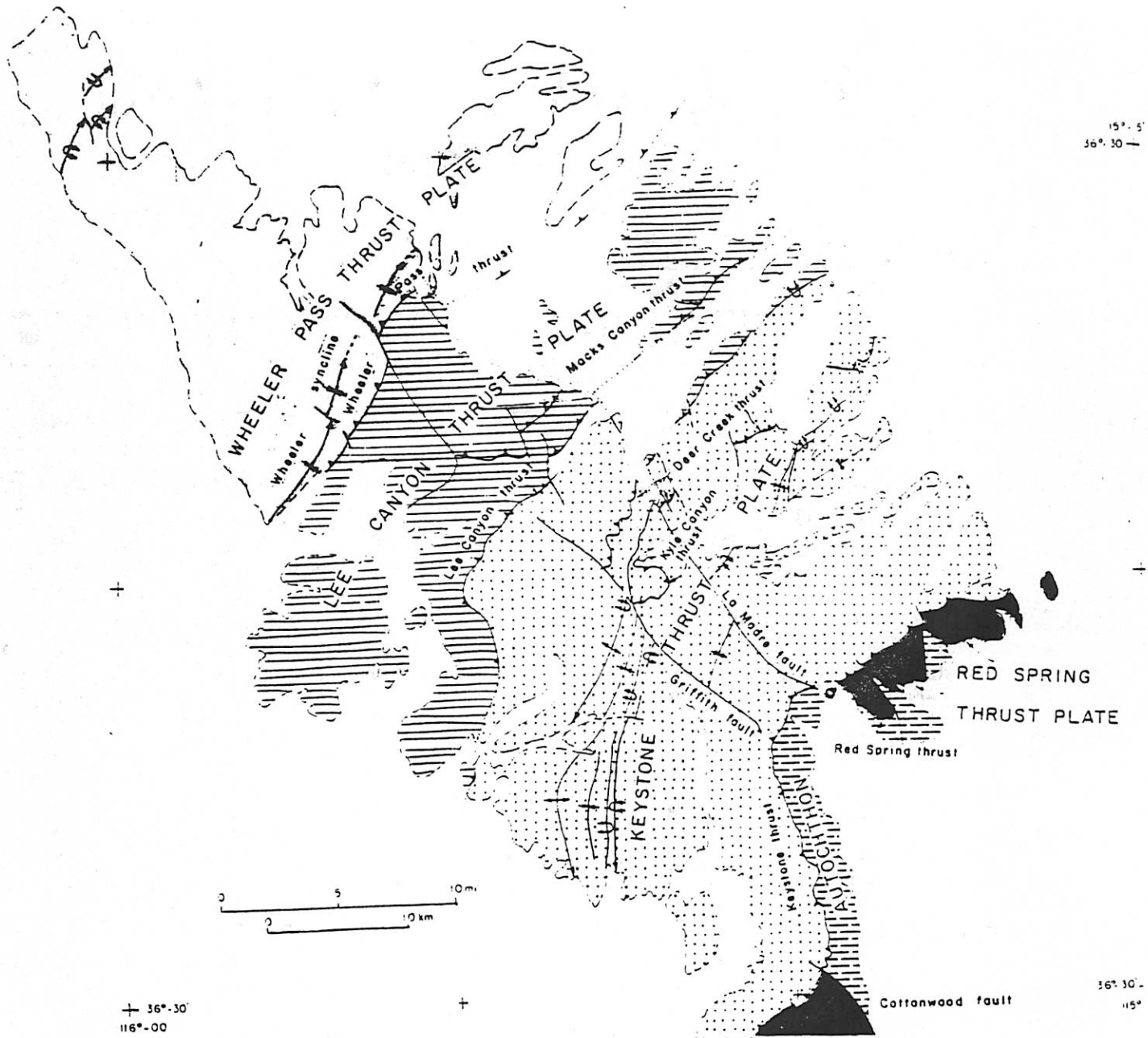


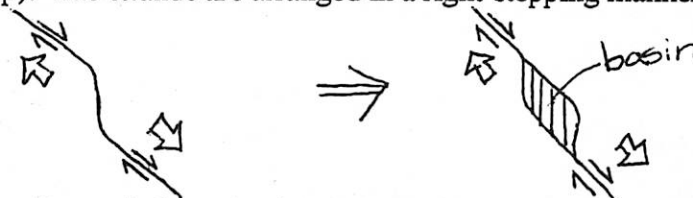
Figure 3.

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THE LAS VEGAS VALLEY SHEAR ZONE (ELVVIS Zone)

- Northwest-trending, with 30-60 km of right-lateral displacement
 - Evidence for right-lateral displacement:
 - Offset of thrust faults crossing the shear zone
 - e.g. the Gass Peak thrust and the Wheeler Pass thrust could be aligned by inferring a displacement of 48 km (additional displacement of about 7 km in either direction would cause significant misalignment) -- the same amount of displacement would also closely align the Keystone system ramp with its hanging-wall syncline
 - Clockwise horizontal bending (up to 90 degrees) of mountain ranges near the zone
 - e.g. the southern end of the Las Vegas Range
- Age of displacement: 17-11 Ma (Miocene)
 - Constraints on age:
 - Muddy Creek Formation (8-5 Ma) is not deformed by the shear zone
 - Structures in 15 Ma strata are rotated by same amount as Paleozoic strata
- Fault geometry (uh-huh-huh)
 - According to the interpretation by Campagna and Aydin (1994), the shear zone comprises 4 to 5 distinct fault strands averaging 40 km in length and trending more westerly than the shear zone in general (see map). The strands are arranged in a right-stepping manner, resulting in pull-apart basins:

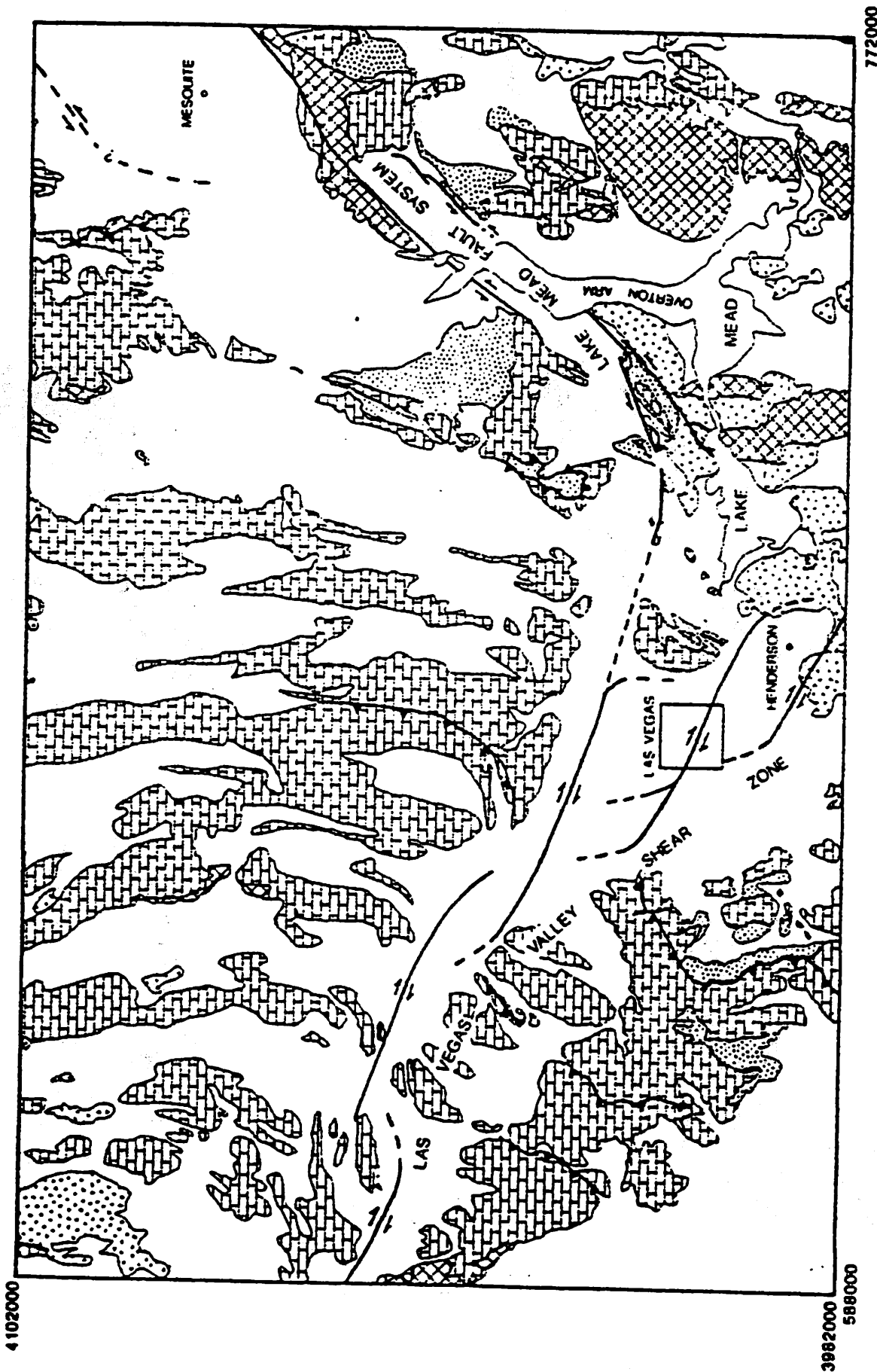


- Basins under Las Vegas (1.5 km depth to Mesozoic bedrock) and Henderson (1.2 km depth)
- The King is not dead
 - a hunka hunka burnin' love
- Mechanism of large-scale deformation within the shear zone
 - Possible mechanisms (see diagram):
 - a) underformed region prior to development of shear zone
paleomagnetic vectors all pointing in same direction
 - b) shearing along faults parallel to shear zone
paleomagnetic vectors still pointing in same direction
 - c) pervasive, continuous simple shear
small-scale deformation, smooth change in palomagnetic direction
 - d) large blocks rotating between two bounding strike-slip faults
paleomagnetism indicates rotation same everywhere in shear zone
 - e) small blocks rotating independently (All Shook Up)
paleomagnetism shows non-uniform block *rotation
 - Paleomagnetic data from LVVSZ can best be explained by e)

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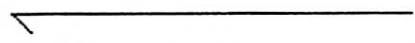
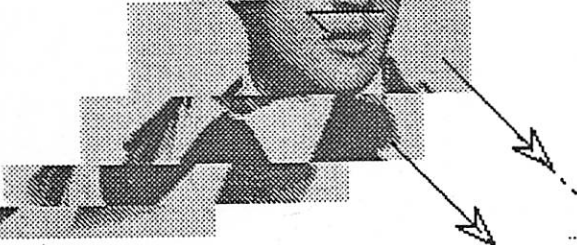
Campagna and Aydin: Basin Genesis and Strike-Slip Faulting, Nevada



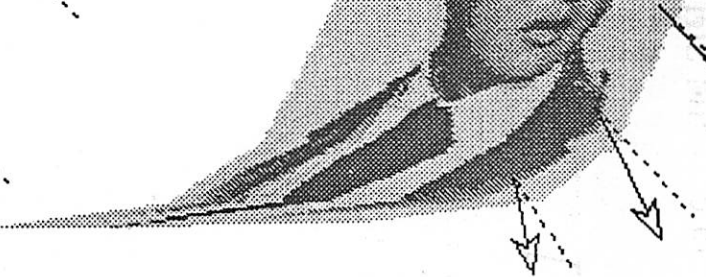
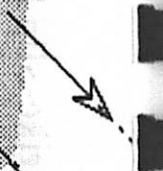
a)



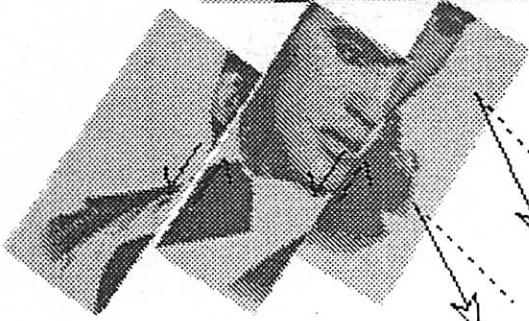
b)



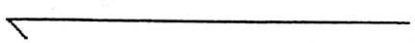
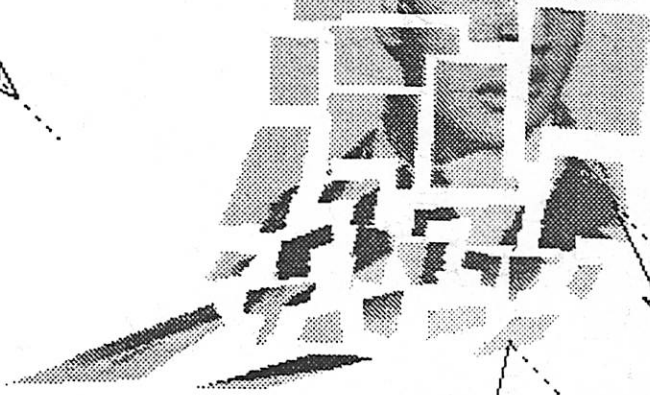
c)



d)



e)



THE PHYSICS OF NUCLEAR DEVICES

or

Recipe for a Nuclear Bomb

by

Robert F. Coker

A Rough Cookbook

Basically, find (and acquire) a material that, when hit with a thermal neutron, tends to spit off 2 or more neutrons. Then go to your nearest engineering supply center and buy a high-voltage vacuum tube neutron source (or just steal one from a research hospital). Cram about 10 kg of your chosen material into a thick explosive-lined spherical steel container with a small hole in it. Point the neutron source through the hole and set off the explosives – and voila, you're dead.

Is it that easy?

Yes and no. If all you want to do is wipe out a square mile or so, then yes, it's that easy to make an atomic bomb. The only hard part is acquiring your chosen material. And even that just takes time, a mass separator, and a mine. On the other hand if you have a grudge against an entire city, an atomic bomb just won't do the trick – you'd need a thermonuclear or hydrogen bomb.

Ok, an H-bomb is for me

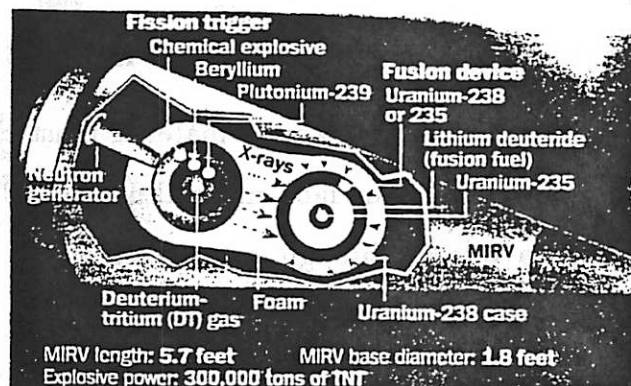
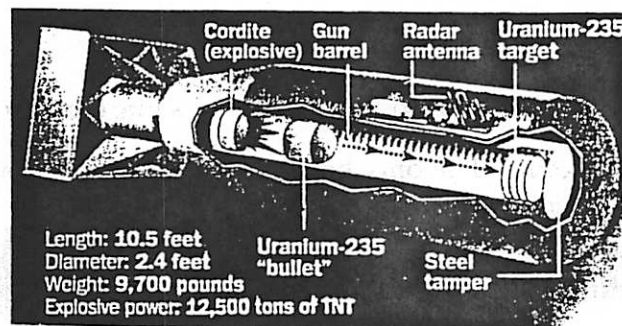
To get enough bang to wipe out a city your material must react (fission) very easily with neutrons. Only one naturally abundant material fits the bill – ^{235}U . ^{239}Pu does the job even better but you'd have to go through the rubbish of a nuclear plant to get some. A small atomic (fission) bomb such as described above is used merely as a trigger in a thermonuclear (fission+fusion) bomb. A fusion bomb needs either a deuterium (^2H) and

tritium (^3H) mixture or a lithium deuteride compound to work. ^2H can be (painfully) extracted from water and ^6Li can be gotten commercially. ^3H however is difficult to obtain in sufficient quantities – again, try a reactor's rubbish heap.

Making an H-bomb in your backyard is no easy task. The blast of the fission trigger must be focused so as to compress the fusion fuel to the point of criticality. A tamper of ^{235}U (separate from the fission trigger) can be used to do this. Also, the blast must be contained for just the right amount of time – otherwise you get a pop (albeit a very 'dirty' one) instead of a bang as the material quickly goes subcritical. An appropriately shaped casing of ^{238}U does the job nicely, adding significantly to the blast as it too undergoes fission.

What will my finished bomb look like?

There are many different possible configurations for nuclear bombs, from the simplest "Little Boy" to the most modern MIRV. The complete bomb assembly can be quite small (less than half a meter on a side) and weigh less than 100 kg. A few deliverable models are shown below.



But how do these things work?

All nuclear bombs use the idea of a physically contained chain reaction. This requires a material which fissions when hit with a photon or neutron, releasing more photons and neutrons. Due to the low cross-section, fission using photons has not been practical until recently. In order to ever get a chain reaction, you must release more neutrons than the material absorbs. For practical reasons, the material needs at least a moderate half life, a high fission cross-section for neutrons, and must be obtainable in quantity. Only ^{235}U and ^{239}Pu meet these criteria.

Let's walk through a sample A-bomb explosion using a hypothetical design. First, a spherical conventional explosive is used to compress and liquify a shell of beryllium that is inside it. This in turn compresses a 25 kg shell of ^{235}U that is inside of the beryllium shell, making the ^{235}U dense and hot enough to be fissionable. An external neutron source (ENS) is needed to initiate fission and to keep the rate of fission high. Inside the uranium shell is a few grams of cold DT gas. The imploding uranium compresses this gas, causing it to undergo fusion, producing yet more neutrons. The key is to produce as many neutrons as possible as quickly as possible so that the ^{235}U fissions as completely as possible through reactions such as: $^{235}\text{U} + n \rightarrow ^{93}\text{Rb} + ^{141}\text{Cs} + 2n$. In a reactor, the reaction would continue (due to the short half-lives of the byproducts) via decays such as: $^{93}\text{Rb} \rightarrow ^{93}\text{Sr} + e \rightarrow ^{92}\text{Sr} + n$ but in a bomb there is not enough time to form these "second generation" neutrons - thus bombs need a higher density ^{235}U than a reactor. Finally, surround the whole contraption with a ^{238}U casing and you have a nice 30kt bomb.

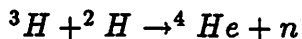
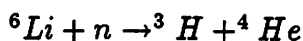
What's with this ^{235}U vs ^{238}U stuff?

Natural uranium ore is mostly [99.28%] ^{238}U , which has a very small fission cross-section for thermal [$\sim\text{eV}$] neutrons but a significant cross-section for high energy [$\sim\text{MeV}$] neutrons. ^{235}U , on the other hand, has a high fission cross-section for thermal neutrons - but upon fissioning emits $\sim\text{MeV}$ neutrons. Thus a 'tamper' (the beryllium in this case) is needed to slow down and reflect the high energy neutrons back into the ^{235}U to

continue the chain reaction. High energy neutrons not stopped by the tamper react with the ^{238}U casing, producing even more neutrons and assorted byproducts. This natural 'safety feature' is why, in general, natural uranium ore does not go critical and heavily 'enriched' (a higher percentage of ^{235}U) ore is required for reactors [3-20%] and bombs [70-90%]. ^{239}Pu has larger cross-sections and releases more energy (but fewer neutrons) so is preferred for compact bomb designs.

What about an H-bomb?

If you put another sphere near the explosive-beryllium- ^{235}U -DT sphere, you can produce a larger fusion reaction and get an H-bomb. The two spheres (other shapes are used but the timing becomes tricky) are usually held in place and separated by a light foam material (it must be easily vaporized and have a low neutron cross section). One possible configuration for the fusion sphere would be a ^{235}U , ^{239}Pu , and lithium deuteride combination. The thin ^{235}U sphere allows γ - and X-rays and fast neutrons in (from the A-bomb trigger) while preventing slow neutrons from escaping. The 5 kg ^{239}Pu shell is compressed by the photons and begins to fission due to the incoming neutrons. This in turn compresses 6 kg of ^6Li - ^2H in the center. The ^6Li then fissions, producing ^3H which then fuses with the ^2H , releasing more neutrons:



Again, the whole thing is surrounded by a 25 kg ^{238}U tamper case to provide a final fission burst for a total yield of about 200kt.

Scary isn't it?

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- Krane, K.S., "Introductory Nuclear Physics", 1988.
- Morland, H., "The Secret that Exploded", 1978.
- <http://www.greenpeace.org/~comms/nukes/nukes.html>

atomic number while all nuclides with the same mass number lie on a 45° diagonal line, running from upper left to lower right. Many nuclide charts contain additional information which has been omitted from the sample chart shown in Fig. 2.3 for the sake of clarity.

The nuclide chart can be used to obtain rapid information on the products of various nuclear reactions. For instance, a (n, γ) reaction on sodium-23 (²³Na) produces sodium-24 (²⁴Na). ²⁴Na decays with a half-life of 15.0 h by emitting β⁻ particles of energy 1.39 MeV and γ-rays of 2.75 MeV and 1.37 MeV. The nucleus resulting from the decay of ²⁴Na is magnesium-24 (²⁴Mg) which is stable.

It is obvious that, even in the simplified form shown in Fig. 2.3, the nuclide chart is an extremely valuable source of information on the properties of both stable and unstable nuclides.

2.9 Interaction of radiation with matter

2.9.1 Charged particles

Alpha and beta particles lose energy mainly through interactions with atomic electrons in the absorbing medium. The energy transferred to the electrons causes them either to be excited to a higher energy level (excitation) or separated entirely from the parent atom (ionization). Another important effect is that when charged particles are slowed down very rapidly they emit energy in the form of X-rays. This is known as *bremsstrahlung* (braking radiation) and is only of practical importance in the case of beta radiation.

2.9.2 X- and γ-radiations

X- and γ-radiations interact with matter through a variety of alternative mechanisms, the three most important of which are the *photoelectric effect*, *Compton scattering* and *pair-production*. In the photoelectric effect all the energy of an X- or γ-photon is transferred to an atomic electron which is ejected from its parent atom. The photon is, in this case, completely absorbed. On the other hand Compton scattering occurs when only part of the energy of the photon is transferred to an atomic electron. The photon is therefore scattered with a reduced energy.

In the intense electric field close to a charged particle, usually a nucleus, an energetic γ-photon may be converted into a positron -

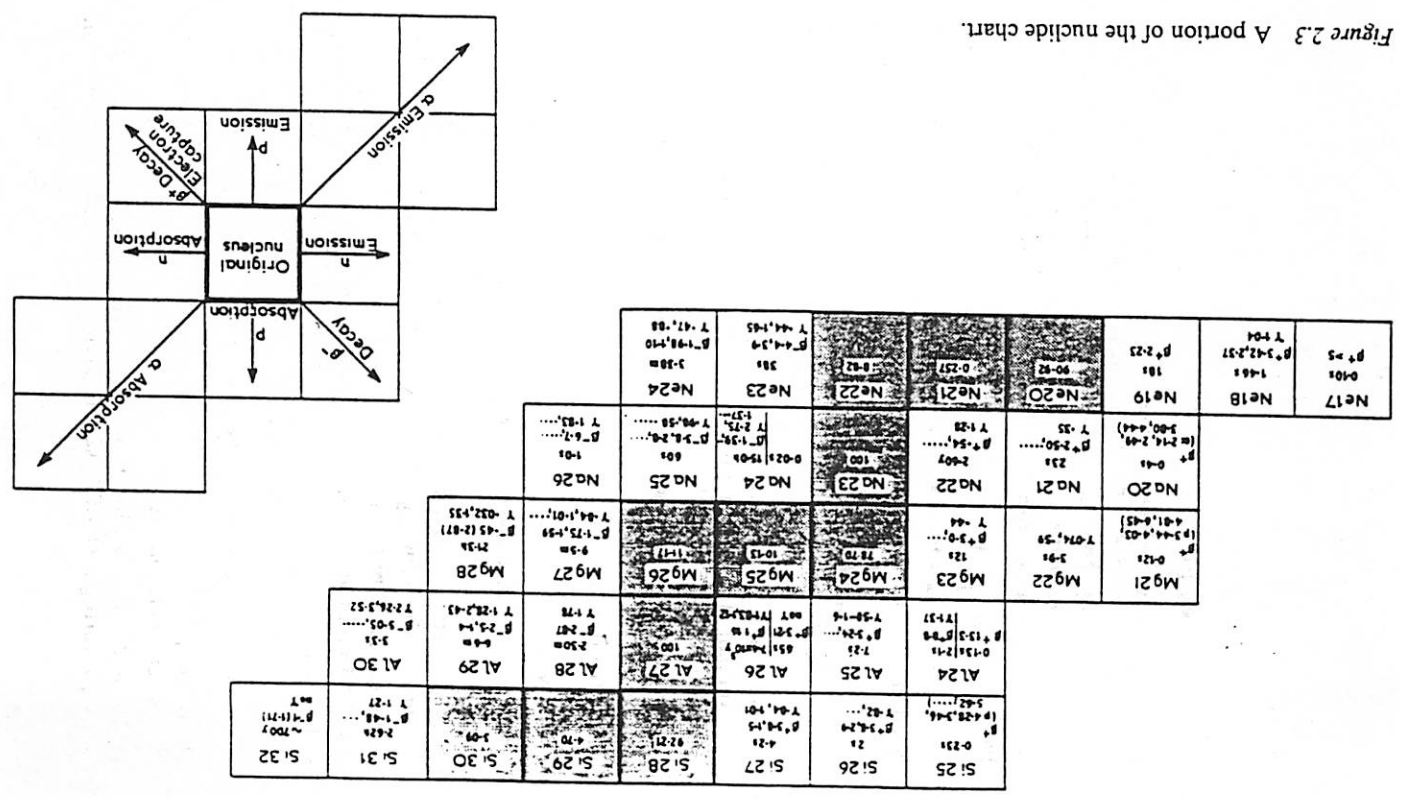


Figure 2.3 A portion of the nuclide chart.

Table 2.3. Interactions of nuclear radiations

Radiation	Process	Remarks
Alpha	Inelastic collisions with bound electrons	Leads to excitation and ionization
Beta	(i) Inelastic collisions with atomic electrons	Leads to excitation and ionization
	(ii) Slowing-down in field of nucleus	Leads to emission of bremsstrahlung
X- and γ -radiation	(i) Photoelectric effect	Photon is completely absorbed
	(ii) Compton effect	} Only part of the photon energy is absorbed
	(iii) Pair production	
Neutron	(i) Elastic scattering	Discussed in Chapter 8
	(ii) Inelastic scattering	
	(iii) Capture processes	

electron pair. This is pair-production and the two particles share the available energy.

Thus all three interactions result in the photon energy being transferred to atomic electrons which subsequently lose energy as described in Section 2.9.1.

2.9.3 Neutrons

Neutrons are uncharged and cannot cause ionization directly. As with γ -radiation, neutrons ultimately transfer their energy to charged particles. In addition a neutron may be captured by a nucleus usually resulting in γ -emission. These processes are described in greater detail in Chapter 8.

Table 2.3 summarizes the types of interactions of nuclear radiations with matter.

2.10 Penetrating powers of nuclear radiations

The alpha particle is a massive particle (by nuclear standards) and travels relatively slowly through matter. It thus has a high chance of interacting with atoms along its path and it will give up some of its energy during each of these interactions. As a consequence, alpha

Table 2.4. Properties of nuclear radiations

Radiation	Mass (u)	Charge	Range in air	Range in tissue
Alpha	4	+2	0.03 m	0.04 mm
Beta	1	-1 (+1 positron)	3 m	5 mm
	1840			
X-, γ -radiation	0	0	V. large	Through body
Fast neutron	1	0	V. large	Through body
Thermal neutron	1	0	V. large	0.15 m

particles lose their energy very rapidly and only travel very short distances in dense media.

Beta particles are very much smaller than alpha particles and travel much faster. Thus they undergo fewer interactions per unit length of track and so give up their energy more slowly than alpha particles. This means that beta particles travel further in dense media than alphas.

Gamma radiation loses its energy mainly by interacting with atomic electrons. It travels very large distances in dense media and is very difficult to absorb completely.

Neutrons give up their energy through a variety of interactions, the relative importances of which are very dependent on the neutron energy. For this reason it is common practice to divide neutrons into at least three energy groups: fast, intermediate and thermal. Neutrons are very penetrating and will travel large distances in dense media.

In Table 2.4 the properties and ranges of the various nuclear radiations are summarized. The ranges are only approximate since they depend on the energy of the radiation.

Summary of chapter

Radioactive decay: transformation of an unstable substance into a more stable form, usually accompanied by the emission of charged particles and gamma rays.

Alpha radiation: helium nuclei, $2p + 2n$, mass 4 u, charge +2 units.

Beta radiation: high speed electrons which originate in the nucleus, mass $1/1840$ u, charge -1 (electron) or +1 (positron).

Gamma radiation: electromagnetic radiation, very short wavelength,

$E \propto 1/\lambda$, mass 0, charge 0.

Electromvolt: energy gained by an electron in passing through an electric potential of one volt.

$$10^6 \text{ eV} \equiv 10^3 \text{ keV} \equiv 1 \text{ MeV}$$

Natural radioactive series: consist of naturally occurring radioactive substances; the three series are thorium, uranium-radium and actinium.

Radioactive decay law: $N = N_0 e^{-\lambda t}$.

Half-life: time required for one half of the nuclei of a radioactive species to decay:

$$T_{1/2} = \frac{0.693}{\lambda}$$

Curie (Ci): former unit of radioactivity, defined as 3.7×10^{10} dis/s

$$1 \text{ Ci} \equiv 10^3 \text{ mCi} \equiv 10^6 \mu\text{Ci}$$

Becquerel (Bq): unit of radioactivity, defined as 1 dis/s

$$1 \text{ TBq} \equiv 10^6 \text{ MBq} \equiv 10^{12} \text{ Bq}$$

Nuclide chart: compilation of data on all known nuclides.

Alpha particles lose energy in matter through excitation and ionization.

Beta particles lose energy by:

- (a) excitation and ionization of atomic electrons,
- (b) rapid slowing down with emission of bremsstrahlung.

γ -photons lose energy through:

- (a) photoelectric effect,
- (b) Compton effect,
- (c) pair-production.

Neutrons lose energy through:

- (a) elastic scatter,
- (b) inelastic scatter,
- (c) capture reactions.

Revision questions

1. Name the products of the following radioactive decay processes:

(a) α -decay of uranium-238, $^{238}_{92}\text{U}$,

(b) β^- -decay of tritium, ^3_1H ,

(c) β^+ -decay of copper-62, $^{62}_{29}\text{Cu}$.

2. Explain why there are only three naturally occurring radioactive series.

3. Calculate the half-life of a radioactive sample from the following series of measurements:

Time (min) 0 1 2 3 4 5 6 7 8

Activity (counts min^{-1}) — 820 605 447 330 243 180 133 98

4. Express the following activities in megabecquerels (MBq):

(a) 5×10^6 dis/s,

(b) 750 kBq,

(c) 1.3 GBq,

(d) 6×10^7 dis/min.

5. Convert the following activities to becquerels:

(a) 1 μCi ,

(b) 5 mCi,

(c) 2.7 Ci,

(d) 10^6 Ci.

6. Why is an α -decay usually followed by a β^- -decay?

beta decay,

[Index] any of three processes of radioactive disintegration by which some unstable atomic nuclei spontaneously dissipate excess energy and undergo a change of one unit of positive charge without any change in mass number. The three processes are called electron emission, positron (positive electron) emission, and electron capture. Beta decay was named (1899) by Ernest Rutherford when he observed that radioactivity was not a simple phenomenon. He called the less penetrating rays alpha and the more penetrating rays beta. Most beta particles are ejected at speeds approaching that of light.

All atoms heavier than ordinary hydrogen have a nucleus consisting of neutrons and protons (neutral and positively charged particles), surrounded by negative electrons; these orbital electrons are not involved in electron emission. In **[Index]** electron emission, also called negative beta decay (symbolized β^{-} -decay), an unstable nucleus ejects from itself an energetic electron (of relatively negligible mass) and an antineutrino (with no rest mass), and a neutron in the nucleus becomes a proton that remains in the product nucleus. Thus, negative beta decay results in a daughter nucleus, the proton number (atomic number) of which is one more than its parent but the mass number (total number of neutrons and protons) of which is the same. For example, hydrogen-3 (atomic number 1, mass number 3) decays to helium-3 (atomic number 2, mass number 3). The energy lost by the nucleus is carried away by the ejected electron and the antineutrino, so that **[Index]** beta particles from a radioactive material have energy ranging from zero to a distinct maximum, characteristic of the unstable parent.

In **[Index]** positron emission, also called positive beta decay (β^{+} -decay), a proton in the parent nucleus decays into a neutron that remains in the daughter nucleus and ejects a positron, which is a positive particle like an ordinary electron in mass but of opposite charge, along with a neutrino, which has no mass. Thus, positive beta decay produces a daughter nucleus, the atomic number of which is one less than its parent and the mass number of which is the same. Positron emission was first observed by Irène and Frédéric Joliot-Curie in 1934.

In **[Index]** electron capture, an electron orbiting around the nucleus combines with a nuclear proton to produce a neutron, which remains in the nucleus, and a neutrino, which is ejected. Most commonly the electron is captured from the innermost, or *K*, shell of electrons around the atom; for this reason, the process often is called *K*-capture. As in positron emission, the nuclear positive charge and hence the atomic number decreases by one unit, and the mass number remains the same.

Each chemical element consists of a set of isotopes the nuclei of which have the same number of protons but differ in the number of neutrons. Within each set the isotopes of intermediate mass are stable or at least more stable than the rest. For each element, the lighter isotopes, those deficient in neutrons, generally tend toward stability by positron emission or electron capture, whereas the heavier isotopes, those rich in neutrons, usually approach stability by electron emission.

In comparison with other forms of radioactivity, such as gamma or alpha decay, beta decay is a relatively slow process. Half-lives for beta decay are never shorter than a few milliseconds.

gamma decay,

[Index] type of radioactivity in which some unstable atomic nuclei dissipate excess energy by a spontaneous electromagnetic process. In the most common form of gamma decay, known as gamma emission, [Index] gamma rays (photons, or packets of electromagnetic energy, of extremely short wavelength) are radiated. Gamma decay also includes two other electromagnetic processes, internal conversion and internal pair production. In [Index] internal conversion, excess energy in a nucleus is directly transferred to one of its own orbiting electrons, thereby ejecting the electron from the atom. In internal pair production, excess energy is directly converted within the electromagnetic field of a nucleus into an electron and a positron (positively charged electron) that are emitted together. Internal conversion always accompanies the predominant process of gamma emission to some extent. Some nuclei of a sample decay by gamma emission, others by internal conversion. [Index] Internal pair production requires that the excess energy of the unstable nucleus be at least equivalent to the combined masses of an electron and a positron (that is, in excess of 1,020,000 electron volts).

The unstable nuclei that undergo gamma decay are the products either of other types of radioactivity (alpha and beta decay) or of some other nuclear process, such as neutron capture in a nuclear reactor. These product nuclei have more than their normal energy, which they lose in discrete amounts as gamma-ray photons until they reach their lowest energy level, or ground state.

Typical half-lives for gamma emission are immeasurably short (from about $10^{\sup -9}$ to $10^{\sup -14}$ second). When the half-lives for gamma emission are measurable, the nucleus in the higher energy state before radiating a photon and the one in the lower energy state are called nuclear isomers. *See also* [isomer](#).

alpha decay,

[Index] type of radioactive disintegration in which some unstable atomic nuclei dissipate excess energy by spontaneously ejecting an [Index] alpha particle. Because alpha particles have two positive charges and a mass of four units, their emission from nuclei produces daughter nuclei having a positive nuclear charge or atomic number two units less than their parents and a mass of four units less. Thus polonium-210 (mass number 210 and atomic number 84, *i.e.*, a nucleus with 84 protons) decays by alpha emission to [Index] lead-206 (atomic number 82).

The speed and hence the energy of an alpha particle ejected from a given nucleus is a specific property of the parent nucleus and determines the characteristic range or distance the alpha particle travels. Not very penetrating, alpha particles, though ejected at speeds of about one-tenth that of light, have ranges in air of only about one to four inches (corresponding to an energy range of about 4 million to 10 million electron volts).

The principal alpha emitters are found among the elements heavier than bismuth (atomic number 83) and also among the rare-earth elements from neodymium (atomic number 60) to lutetium (atomic number 71). Half-lives for alpha decay range from about a microsecond ($10^{\sup -6}$ second) to about $10^{\sup 17}$ seconds.

Pediments:
A Brief Guide to these Fun-loving Features

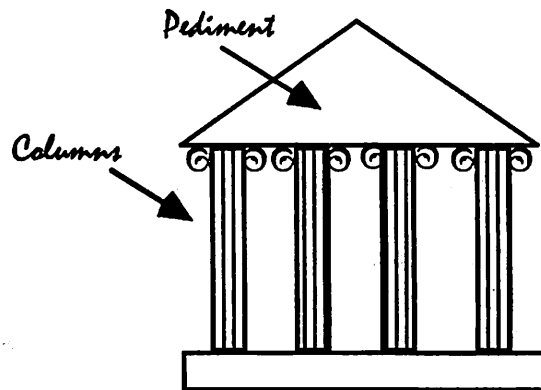
*With your host, Dr. Science
(and her winsome assistant, Cynthia Phillips)*

*"Because she knows more...than you do!"
"I've got a college degree...in Science!"*

*Sponsored by the people who brought you Mowgli, king of the desert,
and Dr. Ruth's guide to the Sex Life of the Date*

Definitions:

1. **Pediment (noun).** Architectural term for the little triangle-thing on top of a Grecian-style colonnade. See ever-so-explanatory diagram below.



ped.i.ment \ped-*m**n\ \ped-*'*ment-*\n [obs. E periment, prob. alter. of E pyramid] : a triangular space forming the gable of a 2-pitched roof in classic architecture; also : a similar form used as a decoration ¹

2. im.ped.i.ment \im-'ped-*m**n\ n 1a: OBSTRUCTION 1b: something that impedes; esp : an organic obstruction to speech 2: a bar or hindrance (as lack of sufficient age) to a lawful marriage ¹

From the two definitions above, it is clear that the word pediment, as used geologically, can mean only one of two things:

- 1. An obstruction to the lawful marriage of the aliens who built the pyramids. This is probably why they became extinct, like the dinosaurs, because they were unable to marry, and perhaps even unable to speak, which is certainly true of the dinosaurs.*
- 2. A broad gently sloping rock-floored erosion surface or plain of low relief, typically developed by subaerial agents (including running water) in an arid or semi-arid region at the base of an abrupt and receding mountain front or plateau escarpment, and underlain by bedrock (occasionally by older alluvial deposits) that may be bare but are more often partly mantled with a thin discontinuous veneer of alluvium derived from the uplift masses and in transit across the surface.²*

Although it is difficult to discount explanation 1, above, and explanation 2 seems a likely candidate for government conspiracy, given the long convoluted nature of the description, since this is a geology trip, we regretfully will follow the latter for the remainder of this explanation.

(please disregard any evidence of government conspiracy in the previous sentence)

So, you may ask, what relevance do pediments have to my everyday life?

A good question, replies the panel of experts. None whatsoever, replies the alternate panel of experts, which has heard rumors of refreshments available in the adjoining room, and quickly vacates the premises.

Panel of experts number 1 breathes a sigh of relief. 'Our little scheme worked', they cackle ominously. Thunder rumbles in the distance. Somewhere, in Kansas, a dog howls in the night.

But, back to pediments. In arid and semi-arid mountainous environments, like those we are presently traversing, pediments form when water, the primary erosional agent, does its thing. Not having a bootie to shake, it instead erodes the bedrock surface it encounters while racing down a mountainside.

Pediments appear similar to alluvial fans, which form when water, again racing down an arid mountainside, deposits sedimentary material in a fan-shaped region at the base of the mountain range. Many of these fans can combine to form a bajada along the base of a mountain range.

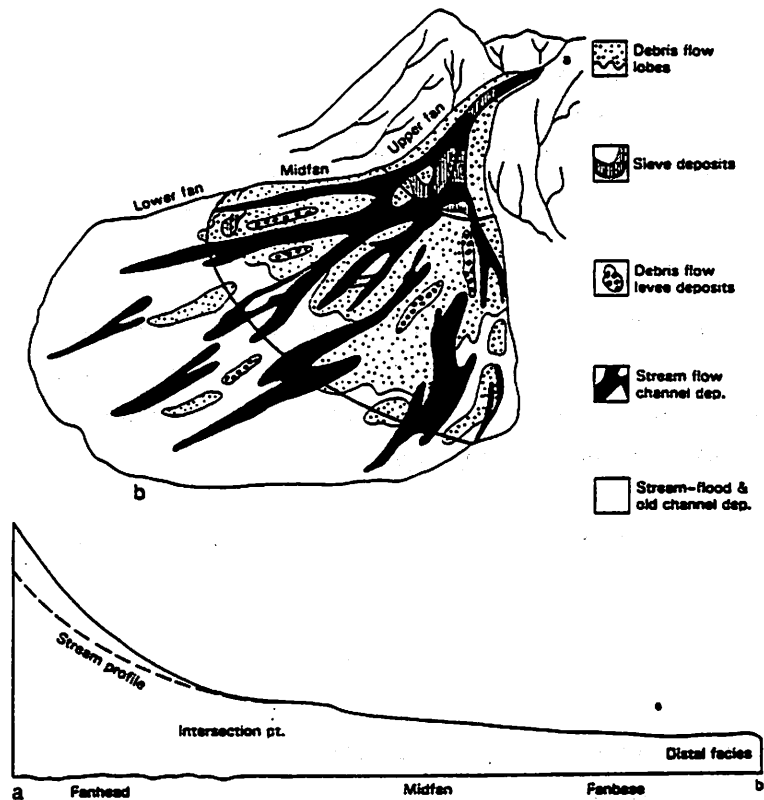


Figure 6-3 Distribution of sedimentary deposits (facies) and profiles of an idealized arid region fan. (Modified from Spearing, 1975.)

(diagram shamelessly reproduced from ³, without permission)

While a pediment has a similar sloping shape leading away from the mountain range in question, it is not a deposit of sedimentary material. Instead, it is a sloping bedrock surface extending away from the mountain range, which may be covered with a thin layer of alluvium.

See the horrible copy of the fabulous satellite picture below, for some local interest and even a bit of relevance to the above discussion:



FIGURE 11.8 An elongate pediment surrounds residual rock highlands of the Tucson Mountains near Tucson, Arizona, which lies along the right side of this satellite image.

*P*ediments are still relatively controversial. Said one expert witness, before being called away to testify in the OJ trial,

“It is generally agreed that pediments are slopes across which sediment is transported. However, the exact manner in which pediments form is still not established.”⁴

And, of course, the theory of alien abduction of sediment has never been satisfactorily disproved.

Tune in next time, same Bat-Time, same Bat-Channel, when you'll hear Dr. Science say:

Soly eroded bedrock, Batman!

1: Definitions courtesy of *webster* (<http://c.gp.cs.cmu.edu:5103/prog/webster>)

2: Bates, R. and J. Jackson, eds. *Glossary of Geology*. Falls Church, VA: American Geological Institute, 1980.

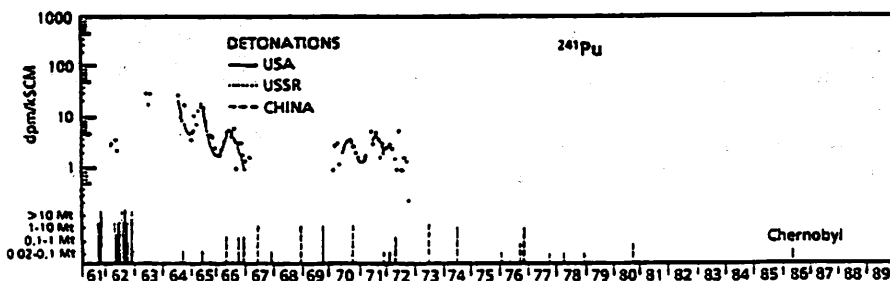
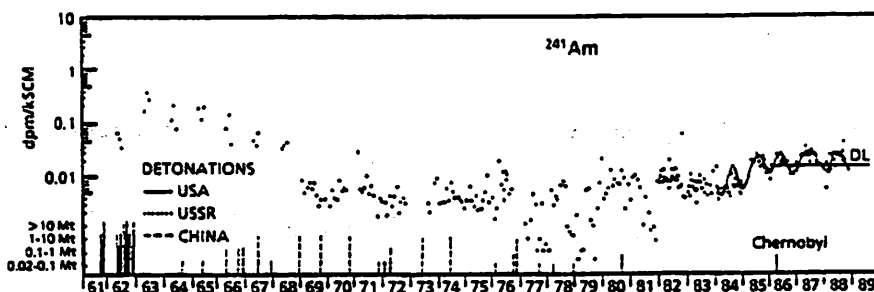
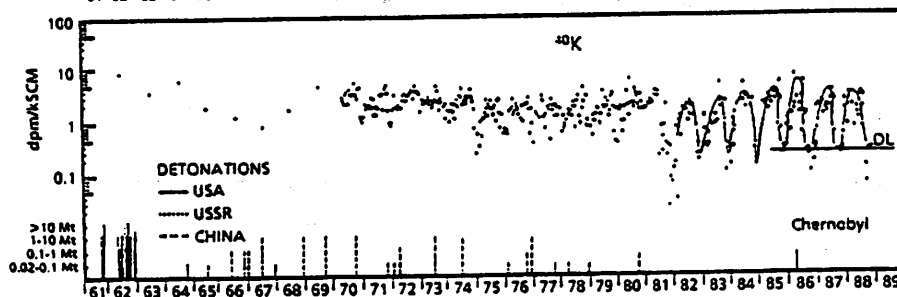
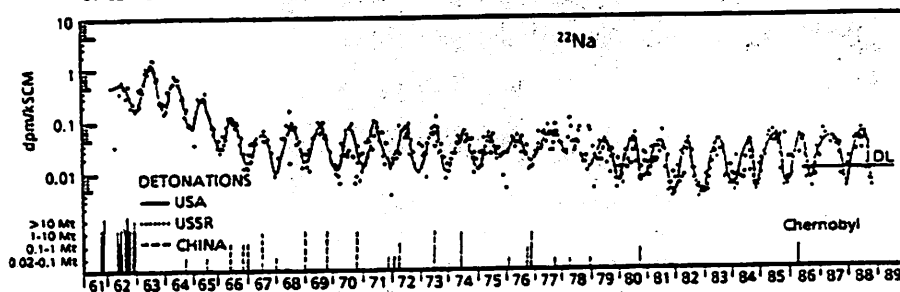
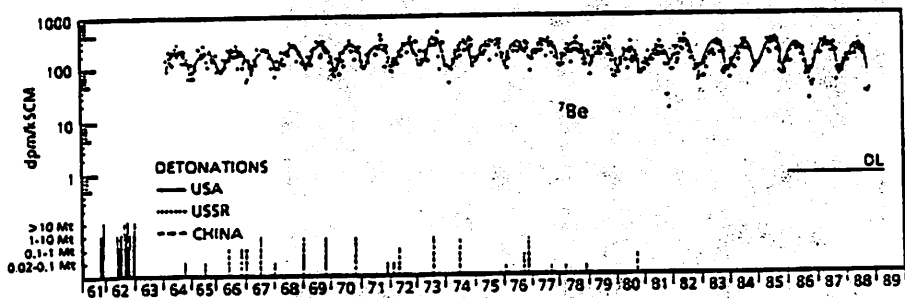
3: Davis, R. *Depositional Systems*. New Jersey: Prentice Hall, 1992.

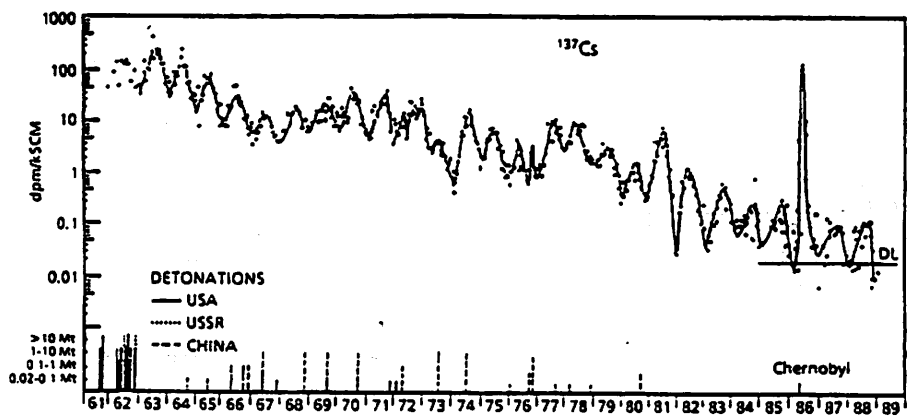
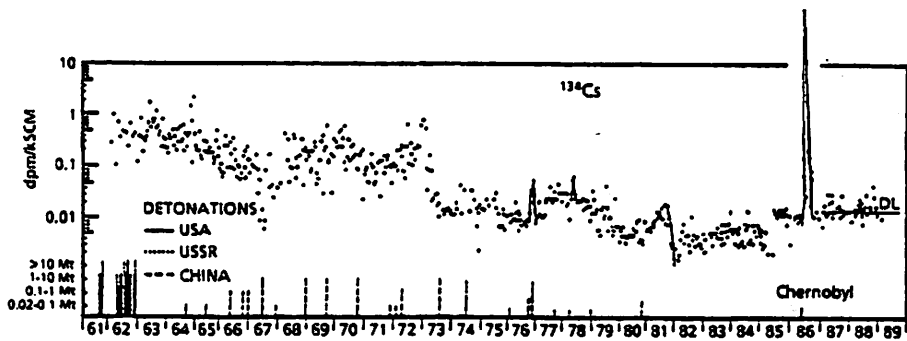
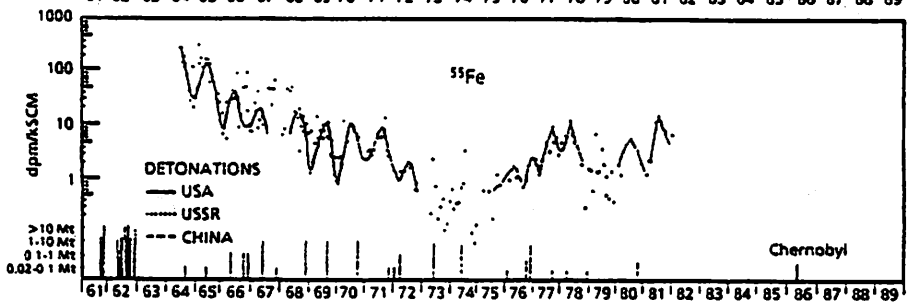
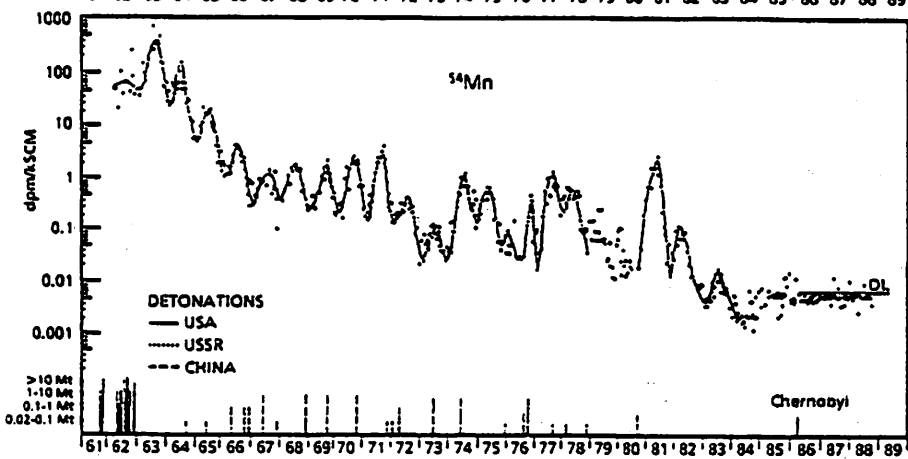
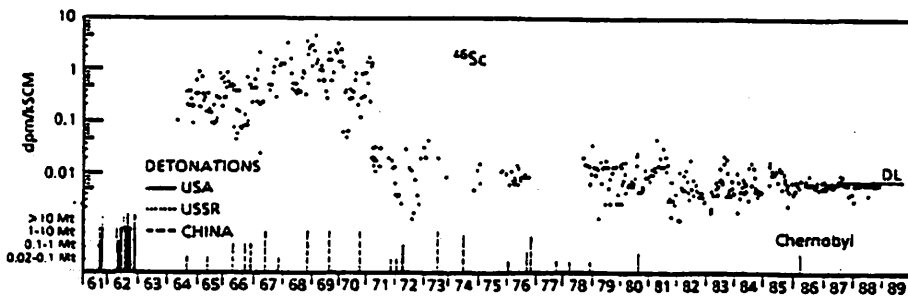
4: Skinner, B., and S. Porter. *The Dynamic Earth*. New York: John Wiley & Sons, 1989.

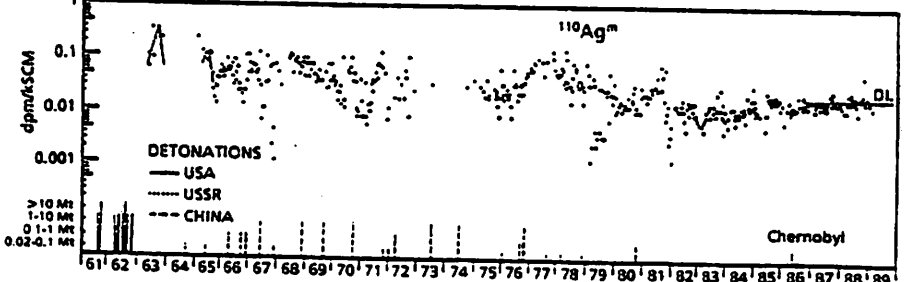
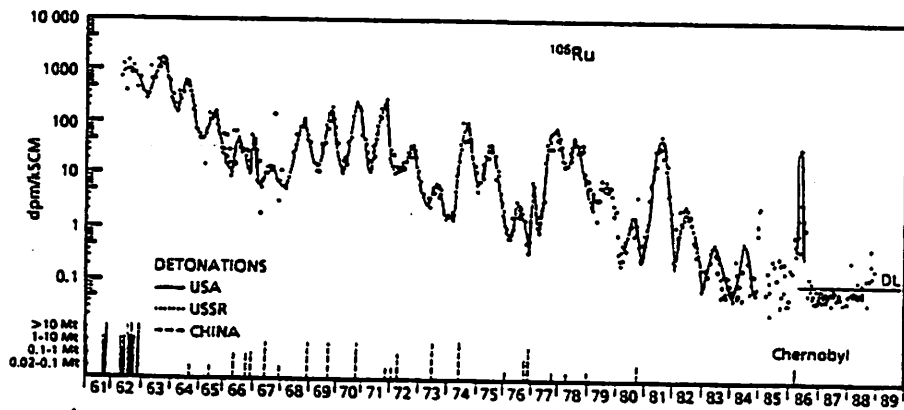
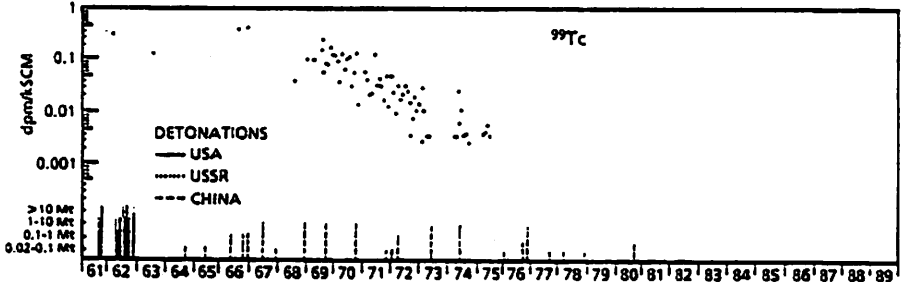
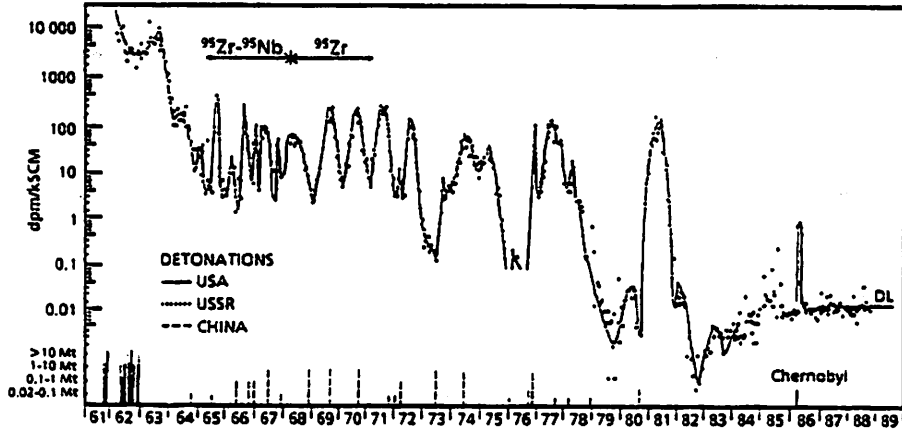
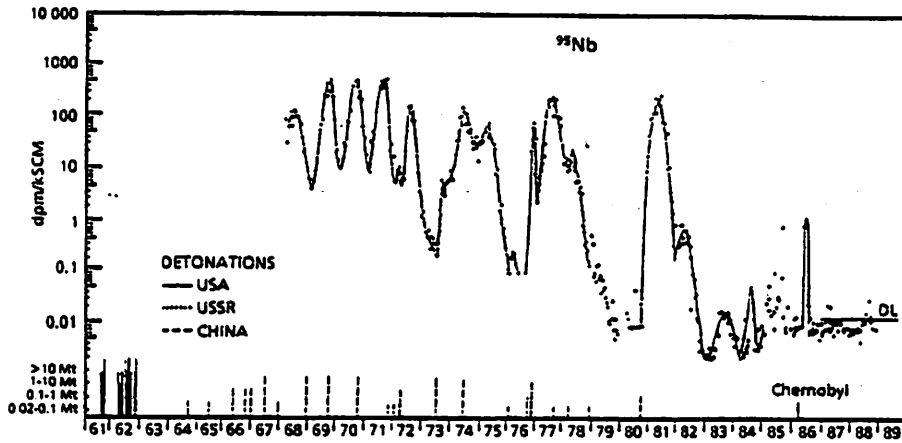
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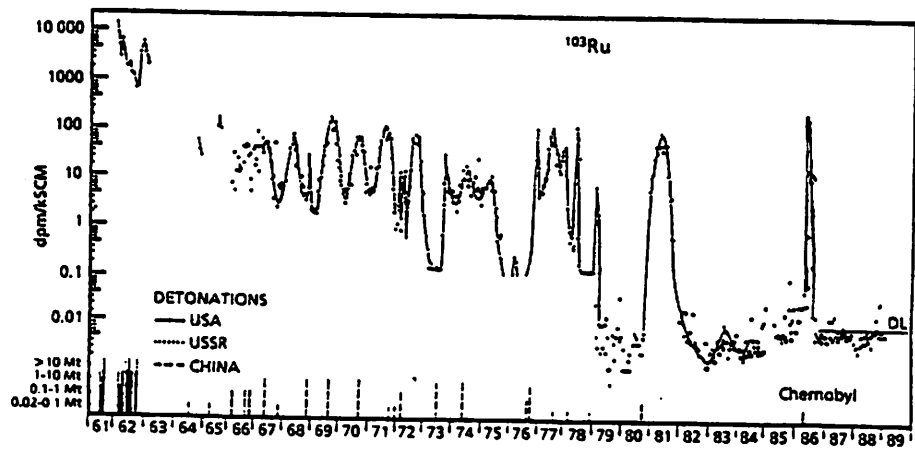
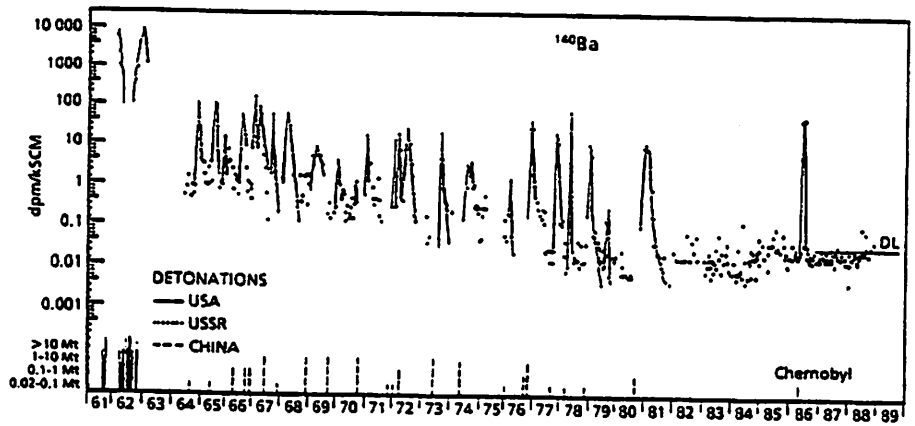
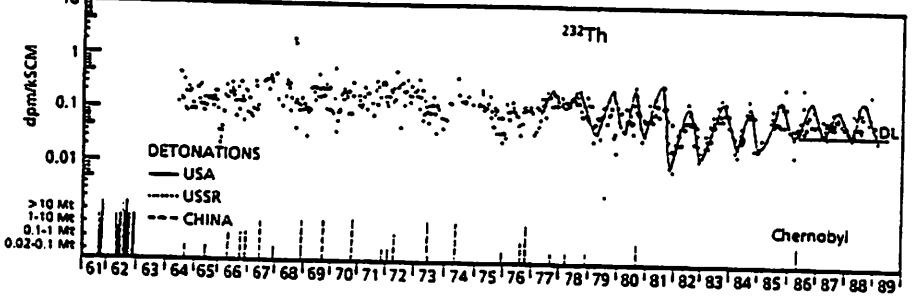
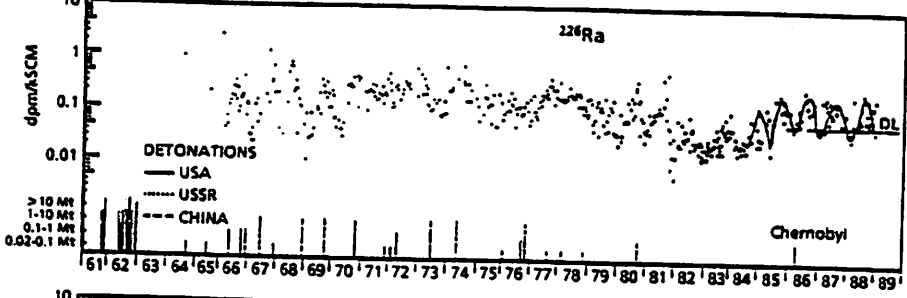
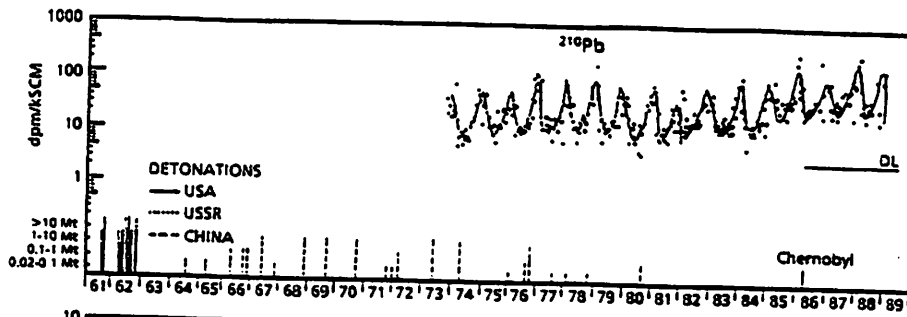
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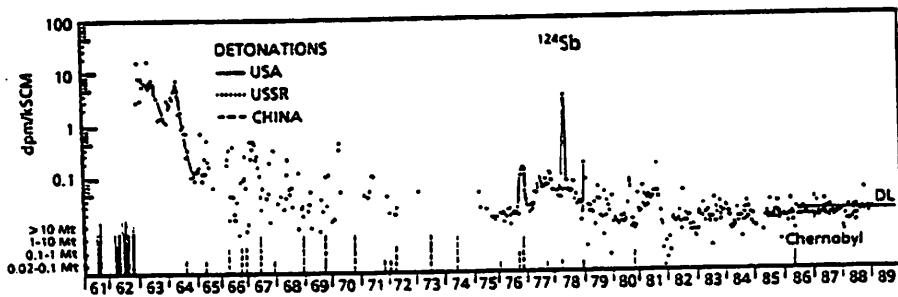
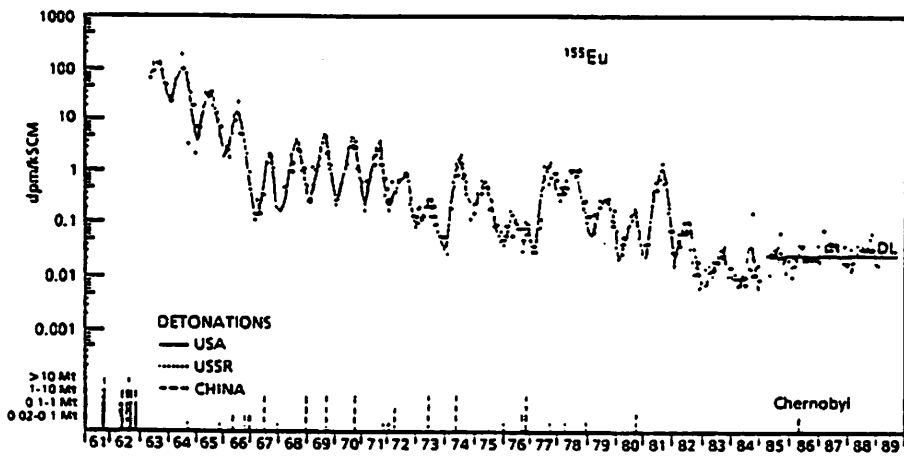
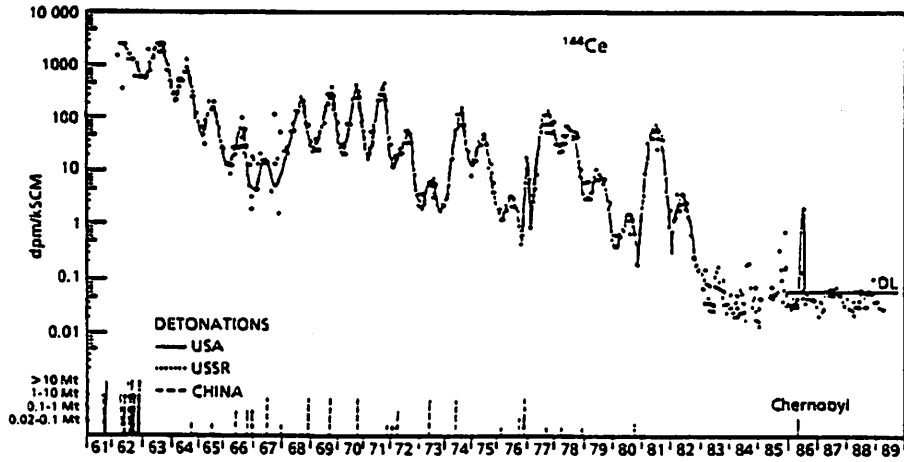
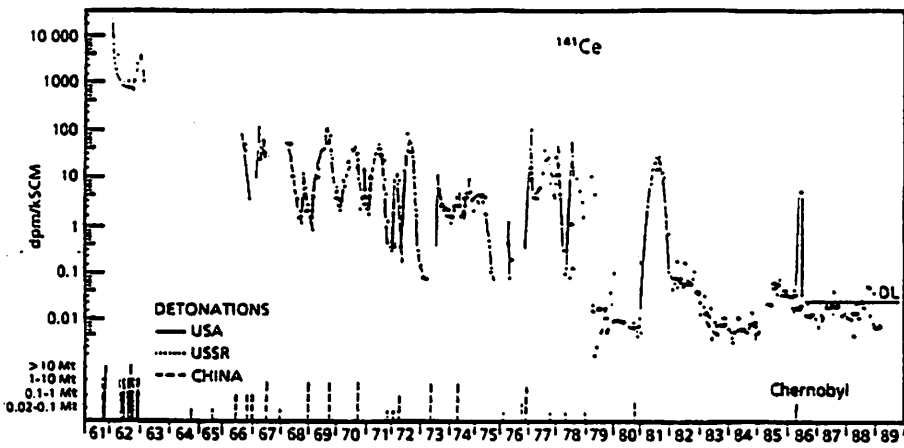
AIRBORNE RADIONUCLIDE CONCENTRATIONS DURING THE PAST THREE DECADES.

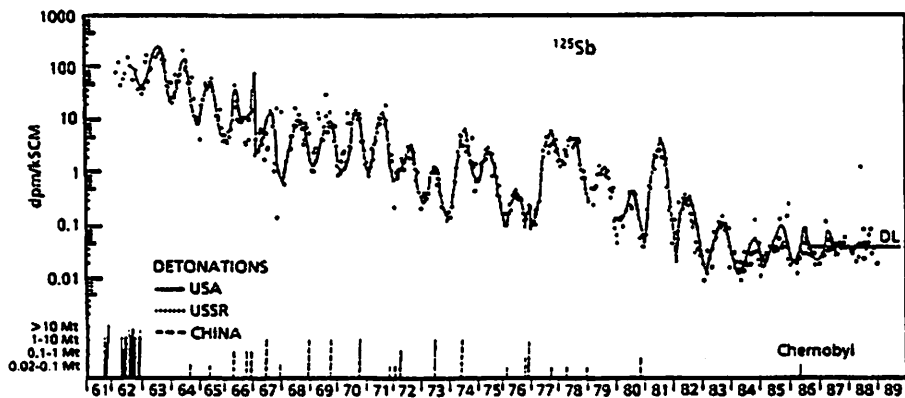
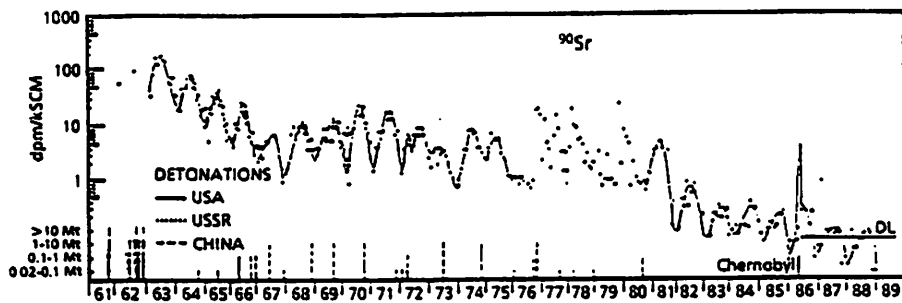
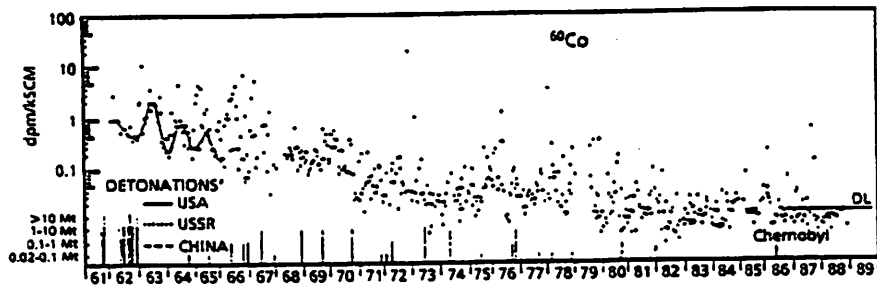
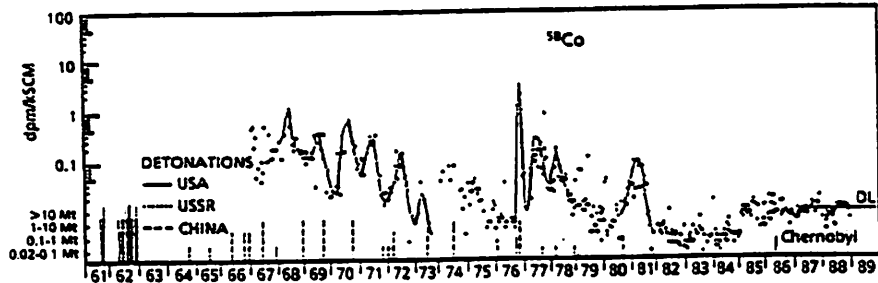
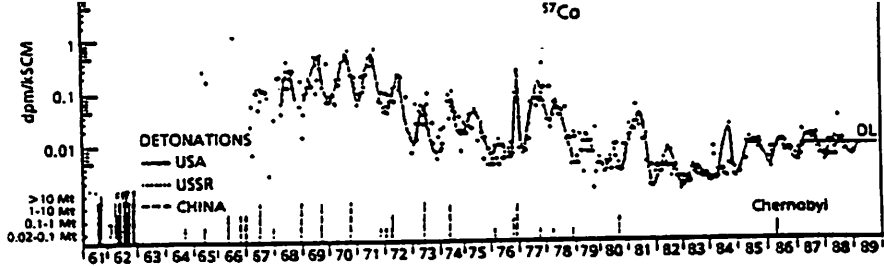


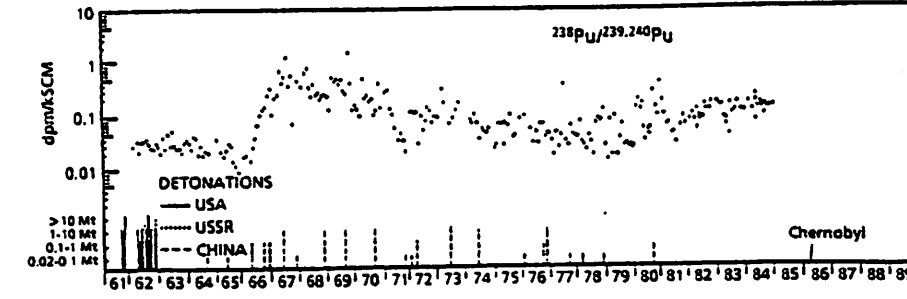
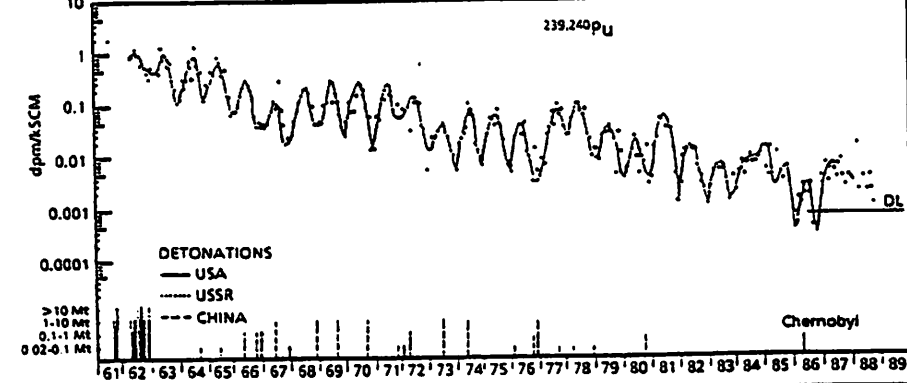
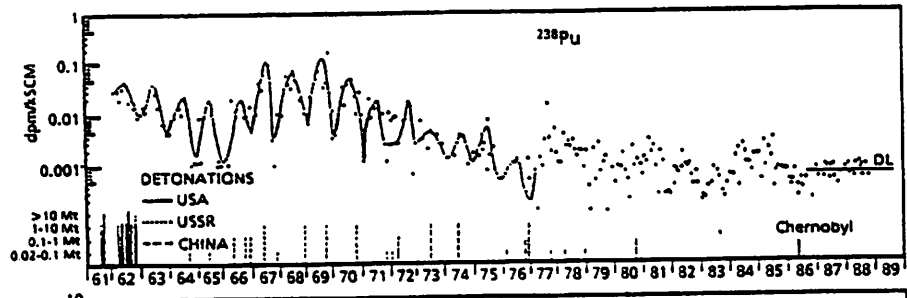
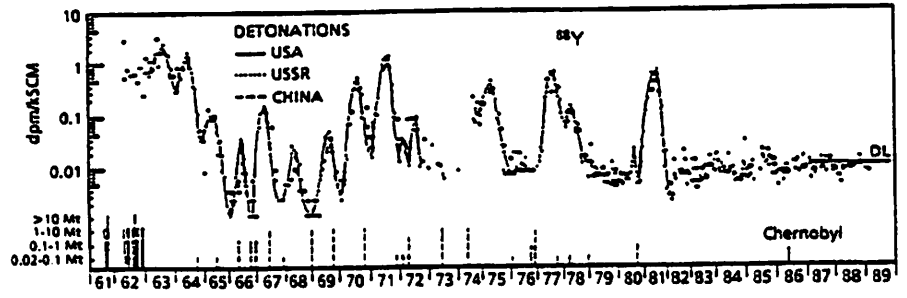
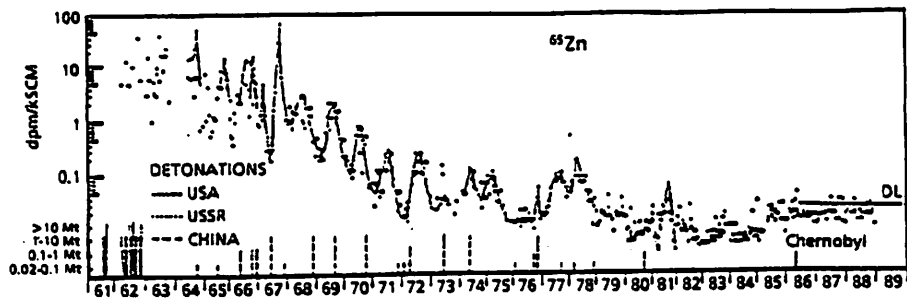












CHERNOBYL NUCLEAR REACTOR ACCIDENT

Vladimir Florinski

Units definitions (SI units):

Activity: 1 Bq (Bequerel) = 1 decay per second.

Absorbed dose: 1 Gy (Gray) = 1 joule of energy (γ -rays) absorbed per 1 kg of the poor exposed fellow. Doses larger than 10 Gy are usually lethal.

Exposure: 1 R (Roentgen) — amount of radioactivity capable of producing ionization charge of 1 unit SGS in 1 cm³ of air. About 140,000 people had been evacuated from the 30-km zone around the reactor where levels of γ -radiation exceeded 5 mR/hr.

Some radioactive isotopes released from the damaged reactor:

Isotope	Half-life	Released by May '86, 10 ¹⁶ Bq
⁹⁰ Sr	29 years	0.81
⁹⁵ Zr	6.4 days	14.1
¹³¹ I	8.0 days	27.0
¹³³ Xe	5.3 days	167
¹³⁴ Cs	2.1 years	1.85
¹³⁷ Cs	30 years	3.7
¹⁴⁰ Ba	13 days	15.9
¹⁴⁴ Ce	284 days	8.9
²³⁹ Pu	24100 years	0.0003

Worldwide radioactive contamination:

Country	Exposure Rate, μ R/hr	Total dose after 50 years, mGy	¹³⁷ Cs deposition, 10 ¹⁴ Bq
Finland	50	0.8	19
Germany	33	0.9	5.9
Italy	30	0.9	19
Japan	0.3	0.01	0.2
Spain	0.0	0.0	0.0
Turkey	10	0.25	18
United States	0.06	0.005	2.8

To compare: in Kiev average exposure rate was 440 μ R/hr, total absorbed dose in 50 years about 25 mGy. About 24,000 people received a dose exceeding 0.45 Gy.

Total release from reactor: $\sim 10^{17}$ of ¹³⁷Cs, $\sim 10^{18}$ of ¹³¹I.

Natural radioactive background: 1 mGy/yr.

Contamination map of the European part of the former USSR:

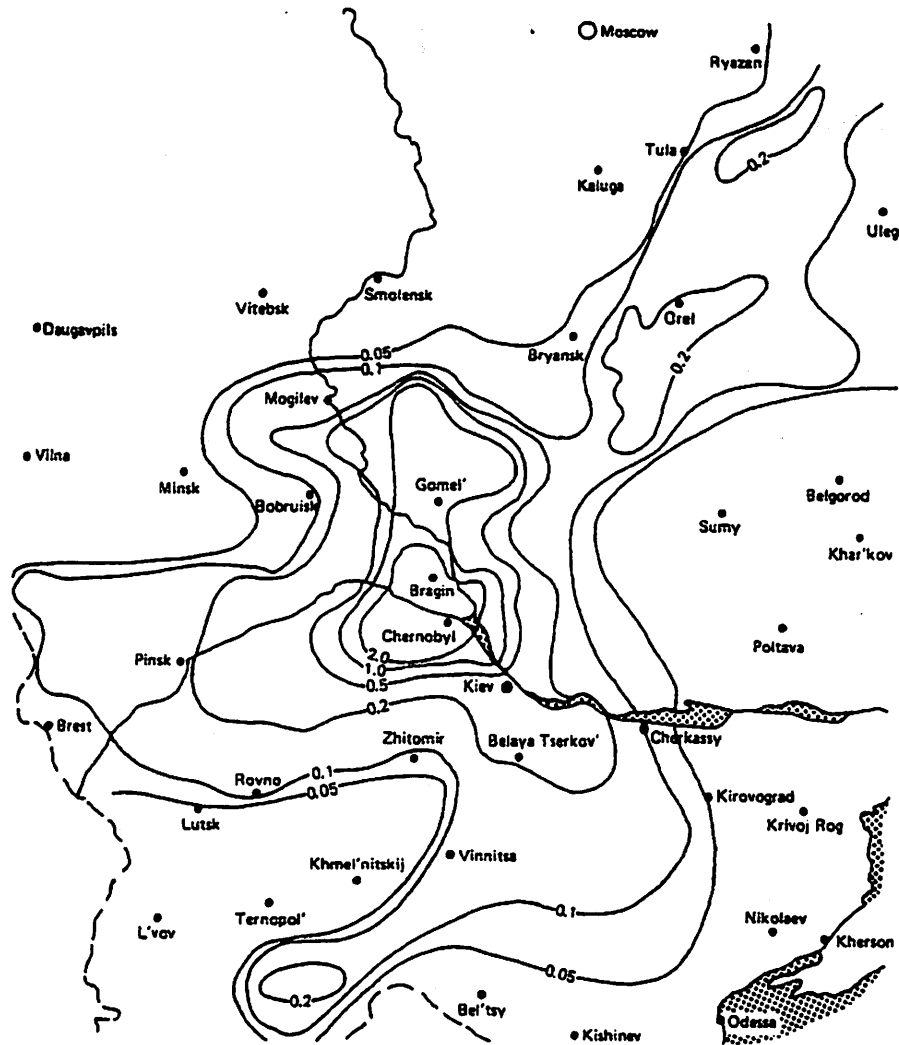


FIG. 4. Map of gamma dose rates (mR/h) in the European part of the USSR (late May to early June 1986).

Transport of radioactive particles in the atmosphere:

$$\frac{\partial c}{\partial t} + u \frac{\partial c}{\partial x} = \frac{\partial}{\partial z} \left(D \frac{\partial c}{\partial z} \right) + \frac{c}{\tau} + Q$$

(u - wind; D - diffusion; τ - half-time; Q - source).

Simple solution (no wind, instantaneous source) — Gaussian plume

$$c = \frac{Q}{\sqrt{4\pi Dt}} \exp\left(-\frac{z^2}{4Dt}\right)$$

Important physical processes: wind, atmospheric diffusion, radioactive decay, ground absorption, precipitation, particle size differentiation.

Mathematical models:

- ⇒ Eulerian models use fixed grid, solve transport eq. for concentration inside each cell. Take very long time and a lot of memory to run; used for small-scale predictions.
- ⇒ Lagrangian and Particle-in-Cell models follow each particle's trajectory, sum over to obtain concentration. Used for long distance transport.

Example (from Israehl, et al.)

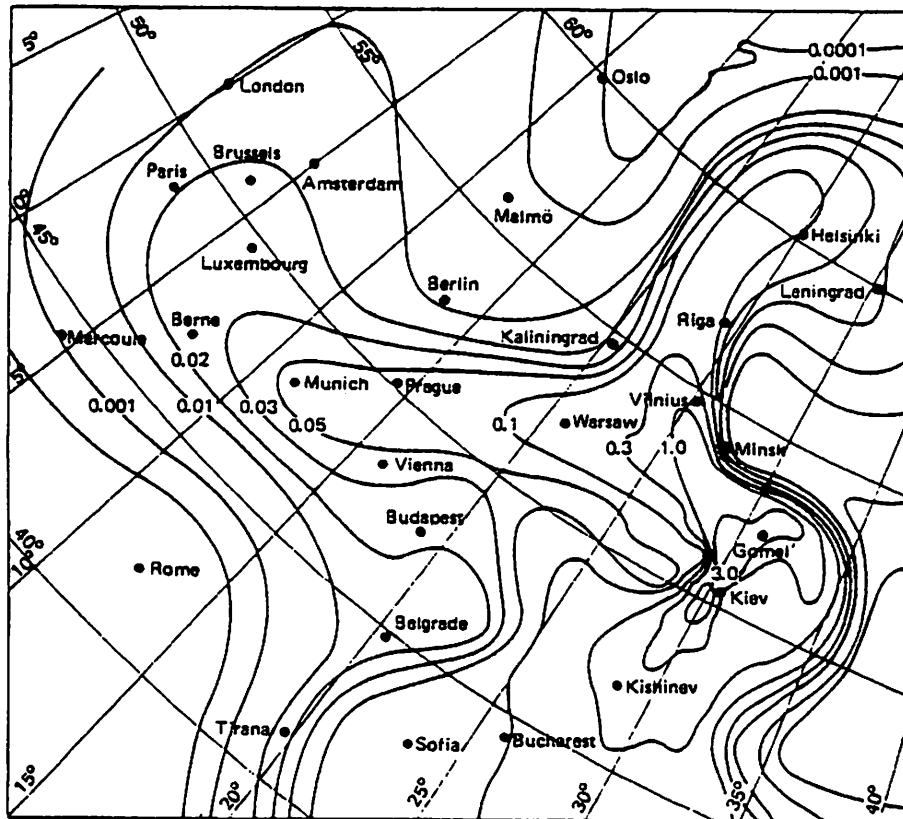


FIG. 6. Map of cumulative ¹³⁷Cs fallout density (Ci/km²) calculated from the model (1 Ci = 3.7 × 10¹⁰ Bq).

Sources:

1. Environmental Contamination Following a Major Nuclear Accident, Proceedings, International Atomic Energy Agency, 1990.
2. Health and Environmental Consequences of the Chernobyl Nuclear Plant Accident, Report to the US Department of Energy, 1987.

Geology of the Nevada Test Site

with your hostess with neuroses

 Jennifer Grier

Age	Volcanic Center, Unit, or Event	Formation	Member or Unit	Some Random Stuff
recent		fans		Continued development of alluvial/fluvial deposits.
> 7.0 Ma		basalt lavas		
7.5 Ma	Black Mountain Caldera	Thirsty Canyon Tuff		
11 Ma	Timber Mountain Caldera	Timber Mountain Tuff	Tuffs of Crooked Canyon Tuff of Buttonhook Wash Ammonia Tanks Member Rainier Mesa Member	Two major subsidences of the Timber Mountain caldera were associated with the eruption of the Rainier Mesa 1200 km ³ , and Ammonia Tanks 900 km ³ . Resurgence is evidenced by the dome in the central area of the caldera.
13.2 - 12.5 Ma	Claim Canyon Cauldron	Paintbrush Tuff	Tuff of Pinyon Pass Tiva Canyon Member Yucca Mountain Member Pah Canyon Member Topopah Spring Member	Tiva Canyon Member responsible for the Chocolate Mountain tuff. Claim Canyon Cauldron experienced episodic subsidence during each eruption of the ash-flow sheets of the Paintbrush Tuff. Some cauldron resurgence may have occurred subsequently.
13.8 - 13.2 Ma	Silent Canyon Caldera	Stockade Wash Tuff		
		Belted Range Tuff	Grouse Canyon Member	The most densely welded tuff in the test site area. Actually flowed during welding; more closely resembles lava than a welded tuff.
16-14 Ma	Sleeping Butte Caldera	Crater Flat Tuff	Prow Pass Member Bullfrog Member	These two tuffs may have constituted 1400 km ³ . Bullfrog member extends into Death Valley.
		Redrock Valley Tuff		
17.5 Ma		Fraction Tuff		First of the dominantly rhyolitic volcanic products.
26.5 Ma		Tuff of Monotony Valley		Oldest of the Tertiary Volcanic-related rock outcrops. Exceedingly voluminous and widespread. Rhyodactitic composition.
Precambria and Paleozoic	Rock	Mountains		Thirty Percent of the NTS consists of outcrops of these rocks. Mostly S and E. Sedimentary. Subsequently filled by tuff, alluvium, and other volcanic products. Also altered by extensive movement along faults.

Geology of the Nevada Test Site: The Long Form (or "what the heck is that huge table supposed to mean, anyway")

To first order, the Nevada Test Site is composed of three main geologic units. These include alluvium-filled basins, Precambrian and Paleozoic sedimentary rock outcrops, and outcrops of volcanic rocks and related products of Tertiary Age.

Thirty percent of the NTS consists of outcrops of the older Precambrian and Paleozoic sedimentary rocks. These can be found predominantly in the South and East of the NTS. These rocks were subsequently altered by extensive movement along faults, and filled by alluvium, tuff and other volcanic products. (See below).

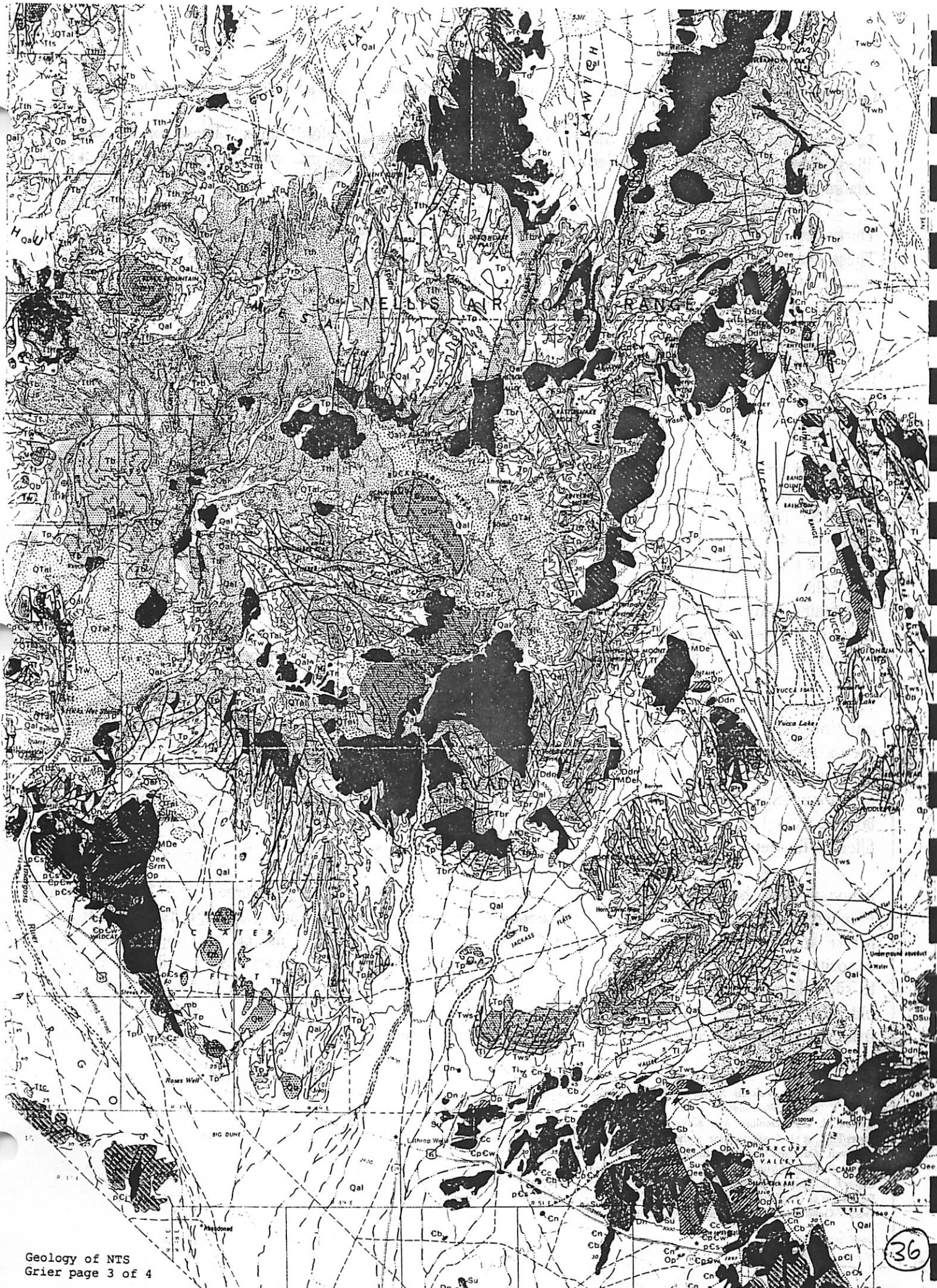
Sixty percent of the NTS consists of outcrops of volcanic rocks and related materials of Tertiary Age. The principal volcanic rocks are ash-flow tuffs of rhyolitic and quartz-latic composition. Several of these have lateral extents of more than 200 km. The ash-flow tuffs have radiometric ages raging from 26 Ma to 7 Ma (See table).

The oldest of these volcanic units is related to the Tuff of Monotony Valley which was emplaced about 26.5 Ma. It was followed at 17.5 Ma by the Fraction Tuff, which was erupted from vents to the north of the NTS. Then a series of important caldera formations and eruptions occurred. Beginning with Sleeping Butte 16-14 Ma, dominantly rhyolitic volcanics began to be implaced. The tuffs of Sleeping Butte may have had a total volume of 1400 km³. Silent Canyon Caldera erupted 13.8-13.2 Ma., and is responsible for the Belted Range tuff, the most densely welded tuff in the region. The Claim Canyon and Timber Mountain Calderas which followed, erupted a series of tuffs, and experienced subsequent subsidence, faulting, and resurgence. The Tiva Canyon Member of the Claim Canyon Cauldron is responsible for the Chocolate Mountain tuff. The subsidence and resurgence of the Timber Mountain Caldera was particularly profound. Both the huge 900 km volume of the Ammonia Tanks Member, and the immense 1200 km volume of the Rainier Mesa Member caused considerable subsidences of the caldera after their eruption. The Rainier Mesa subsidence was the bigger of the two, as expected. Subsequent resurgence of the caldera is evidenced by the dome in its center. Later, the Black Mountain Caldera (not quite in the NTS) erupted the Thirsty Canyon tuff, which covered the last tuffs and volcanic products from previous eruptions. Since then the area has (volcanically) been reasonably inactive, with only a few small basalt lavas extruded since 7 Ma ago. These deposits of volcanic rocks etc, have subsequently been altered and filled by fan deposits (see below).

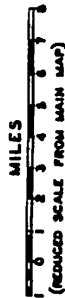
Alluvium-filled basins total the remaining 30 percent of the NTS. These areas, like Yucca Flat and Frenchman Flat, consist of a series of fan deposits, altered by wind and water. Upslope, the deposits are of rubble and coarse gravel, which grade to talus further upslope. Downslope, the composition of the deposits merges to pebbles, then to more fine grained material in the lowlands. Eventually the fans grade to silty playa-like deposits at the bottom of the basins. Most of these fans and deposits are recent, but older fanglomerates consist of well-rounded gravel derived from the Paleozoic rocks, and angular rubble from the Tertiary volcanics; they are by now deeply dissected.

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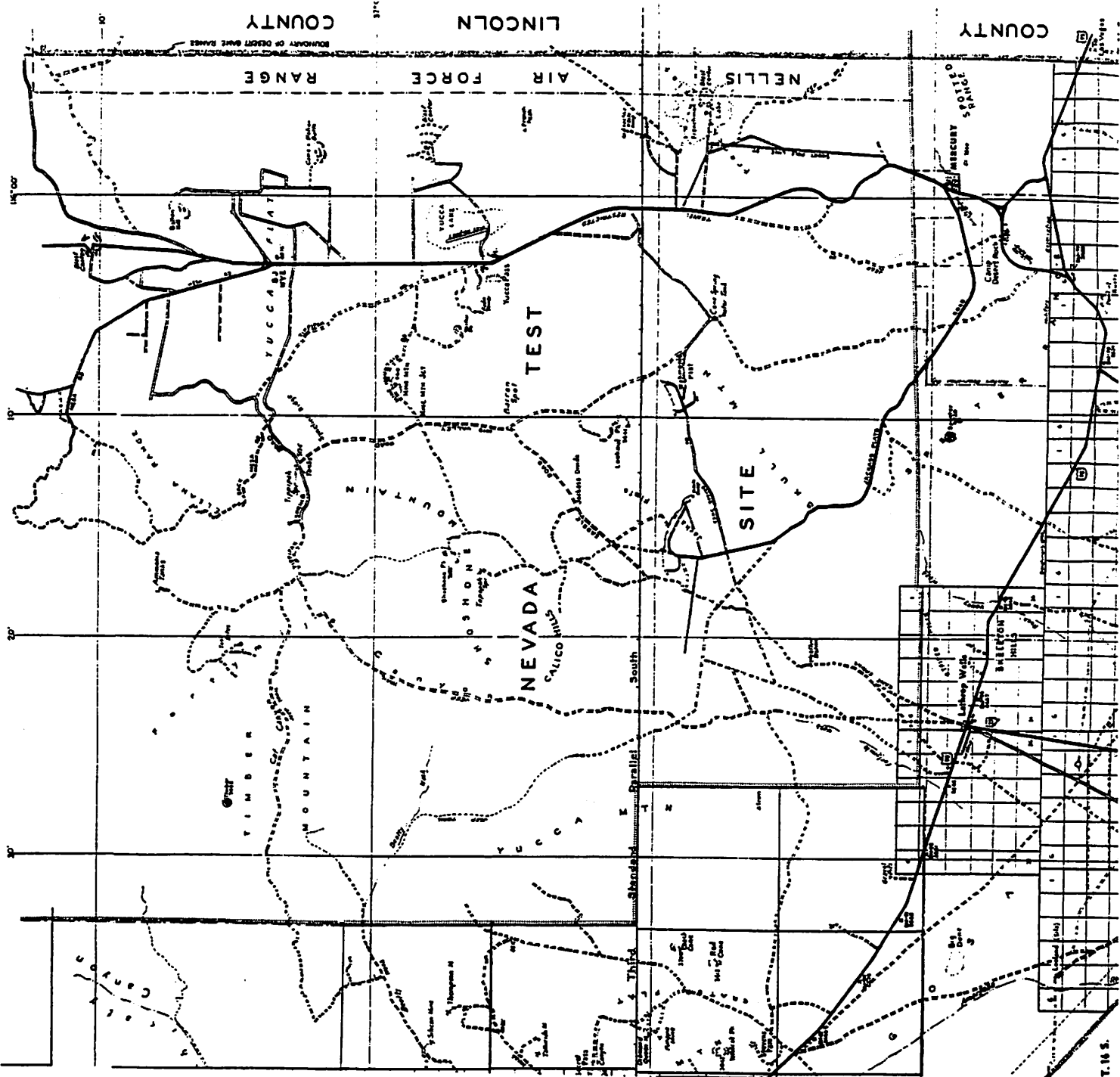


INSET MAP OF SOUTHERN PART NYE COUNTY



LEGEND

- PAVED ROADS (ASPHALT OR GRAVEL)
- OILED ROADS - MACADAMIZED
- GRAVELLED ROADS
- SOIL SURFACED ROADS
- GRADED & DRAINED ROADS
- UNIMPROVED ROADS
- PRIMITIVE ROADS
- U.S. HIGHWAY NUMBER
- STATE SIGNED HIGHWAY NUMBER
- TUNNEL
- FORD
- HIGHWAY BRIDGE
- F.A. FEDERAL AID HIGHWAY SYSTEM
- F.A.S. FEDERAL AID SECONDARY HIGHWAY
- RAILROAD - R.R. STATION
- RAILROAD TUNNEL
- RAILROAD CROSSING
- R.R. ABOVE - UNDERPASS
- R.R. BELOW - OVERPASS
- LIVE STREAM
- INTERMITTENT STREAM
- IRRIGATION DITCH
- COUNTY SEAT
- INCORPORATED CITY
- CONGESTED AREA (DETAILS NOT SHOWN)
- DAM
- TRIANGULATION STATION
- BENCH MARK & ELEVATION
- PROMINENT ELEVATION
- MINES
- CEMETERY
- POST OFFICE
- RADIO STATION
- FORREST RANGER STATION
- FARM UNIT OR DWELLING
- ROW OR GROUP OF DWELLINGS (NUMERAL INDICATES NUMBER)
- STORE OR SMALL BUSINESS (NUMERAL INDICATES NUMBER)
- HOTEL OR RESORT
- CHURCH
- SCHOOL
- HOSPITAL
- FACTORY OR WAREHOUSE
- CAMP OR LODGE



Physical Evidence for Shock History

Fractures - Widely spaced parallel sets of cracks, or concentrations of cracks at contact points between adjacent mineral grains.

Mosaicism - Undulatory optical extinction in cross polarized illumination.

Deformation Bands - Regions where orientation in crystal grain is altered by lattice gliding from plastic deformation. Other terms used include **kink bands** and **mechanical twins**.

Shock Lamellae - Sets of closely spaced planar regions of lower density, shorter range order, and lower refractive index. Caused by shock transformation to a high pressure phase and then subsequent phase changes on pressure release. Known as **diaplectic minerals**.

Birefringence - Dependence of refractive index on polarization angle is reduced as a crystal becomes more disordered.

Melt Glass - Regions of isotropic glass, generally found along interfaces between grains.

Some Characteristic Mineral Phases

Quartz	(trig., hex.) SiO ₂	$\rho = 2.6 \text{ g/cc}$	$\eta \approx 1.54$	uniaxial
Coesite	(mcl.) SiO ₂	$\rho = 2.9 \text{ g/cc}$	$\eta \approx 1.59$ 300 < P < 550 kbar from higher P phase.	uniaxial
Stishovite	(tetr.) SiO ₂	$\rho = 4.3 \text{ g/cc}$	$\eta \approx 1.82$ 120 < P < 450 kbar leaves stishovite intact.	uniaxial
Lechatelerite	(amorph.) SiO ₂	$\rho \approx 2.2 \text{ g/cc}$	$\eta = 1.45$ P > 550 kbar	isotropic
Plagioclase	(trcl.) (Na,Ca)[Al(Si,Al)Si ₂ O ₈]	2.6 < ρ < 2.8 g/cc	1.53 < η < 1.58 (P > 100 kbar shock reduces birefringence)	biaxial
Maskelynite	(amorph.) ~plagioclase composition	1.8 < ρ < 2.5 g/cc	1.49 < η < 1.58 350 < P < 500 kbar solid state transition. P > 500 kbar Maskelynite appears vesicular.	isotropic

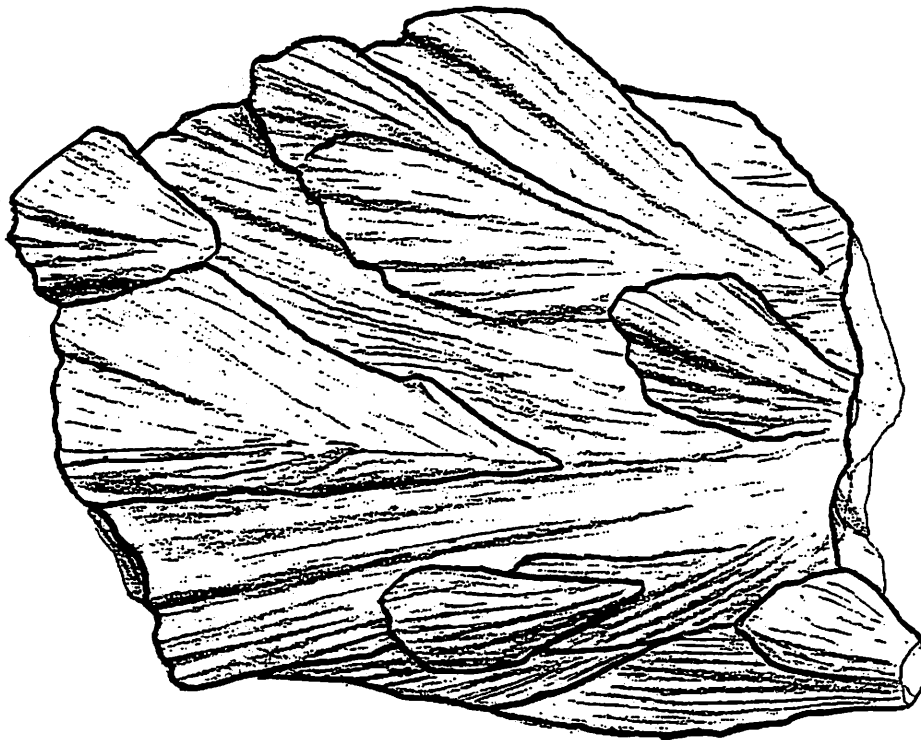
TABLE 2. Comparison of Various Classifications of Nonporous Quartzofeldspathic Rocks from Natural-Impact Craters and from Nuclear-Explosion Craters

Shock Effects in Framework Silicates or Whole Rocks	Shock Stages, This Work and Stöffler [1965, 1966]; von Engelhardt and Stöffler [1968]	Shock Categories Chao [1968] Pressure, kb	Postshock Temp., °C	Shock Zones Dence [1968]	Shock Categories James [1969]†	Shock Categories James [1969]† [1969a]	Peak Pressure (Approx.), kb	Postshock Temperature (Approx.), °C
Fractured quartz and feldspar	0	1	81	i		B	100	100
		2		ii	i			
Diaplectic quartz and feldspar	I	200	168	ii	? ? ?	C		
		3		iv	↑ ↑ ↑			
		380	282	v	↑ ↑ ↑		350	300
Diaplectic quartz and feldspar glasses	II	4	1080	vi?	ii	D	450	900
		5			iii	E		
Fused feldspar (vesiculated glass)	III	510	1600		iv		550-600	1300-1500
		6			v	F	>800	>3000
Inhomogeneous rock glasses	IV	7	2580	'melt zone'				
Silicate vapor	V							

Data on rocks from natural-impact craters from Chao [1968], Dence [1968], and text of this paper. Data on rocks from nuclear-explosion craters from James [1969] and Skert [1969a]. (Chao's peak pressure and postshock temperature have been taken from experimental data of Mackereth [1962].)

*Temperature data of stage III are estimated from the softening temperatures of feldspar glass and rock glasses, as suggested by O. B. James (personal communication).

† Arrows indicate that the boundary between i and ii, as defined by O. B. James (personal communication), may be set somewhat below the boundary between stages I and II.



Shatter Cones (also called "Cone-in-cone")

Appearance: Radially striated conical fracture surfaces in near-surface rocks exposed to a shock wave.

Size: Length of shatter cones ranges from less than 1 cm to greater than 10 m.

Orientation: The apex usually points towards the source of shock, but occasionally points 180° away instead.

Habit: The apex frequently terminates at an inclusion, contact, or other inhomogeneity in the shocked rock. When surfaces of different cones intersect one terminates against the other, so the distribution of defects in the rock influences the spacing and size of shatter cones. Apical angles range from 65° to over 120°, depending on the level of shock and the nature of the shocked material.

Shock level: Shocks with peak pressures ranging from 10 to 200 kbar have produced shatter cones in various materials. The highest quality cones usually experienced peak pressures around 50 kbar, but the behavior varies in different materials.

Observed: Shatter cones have been observed in near-surface rocks below and/or around most terrestrial impact structures, as well as resulting from laboratory high velocity impact experiments and from nuclear and conventional explosion experiments.

More info.: Milton (1977), Roddy and Davis (1977), both in Roddy *et al.*, eds. *Impact and Explosion Cratering*.

Spall Mechanisms in Nuclear (and similar) Explosions

conducted by Jim Head (West)

Spall Mechanisms

- 1) Reflection of a compressive wave from a free surface.
- 2) Rayleigh and shear waves from a surface source.
- 3) Airblast effects over a porous material.
- 4) Material properties of porous materials

1) When a compressive wave strikes a free surface, it reflects as a tensile wave traveling back into the rock. When the tensile stress exceeds the combined tensile strength of the rock, the lithostatic stress and the tail of the compressive stress pulse, the rock fails in tension (Figure 1). A substantial part of the momentum of the stress wave is trapped in the detached rock layer and it flies upward. The parting of the rock also forms a new surface which itself is subject to spallation.

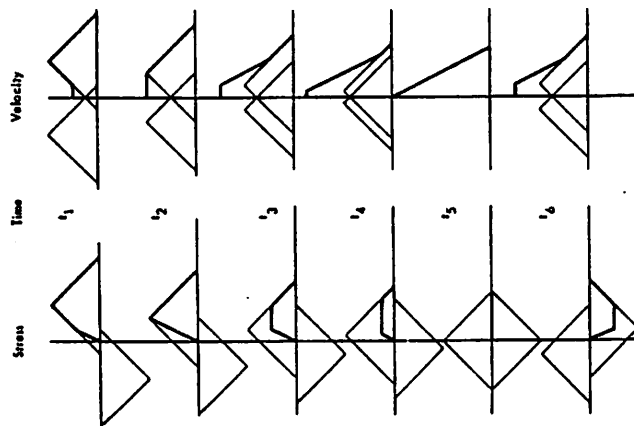


Fig. 1. Graphical solution for the interaction of a triangular compression pulse with a free surface. The left column shows the stress component parallel to the motion. The stress is positive in compression, and the wave is shown moving to the left. The right column shows the particle velocity. Spallation occurs at time t_6 for the inelastic case. Time t_6 shows the tension reflection that would occur if material did not fail in tension.

Vicelli, 1973

2) For surface explosions in the absence of an airblast, some of the energy is carried away in Rayleigh and shear waves. One can calculate the stress field by inverting the observed waveform. The solution shows that there is a vertical tensile stress that could lead to spallation. I do not know if this mechanism has actually ever been observed.

3) After the initial pulse of an airblast passes over the surface, the ambient pressure can drop below the initial atmospheric pressure. Air trapped in porous material will rush into the partial vacuum, carrying rock with it. Loading of the pore air by the initial pulse magnifies this effect. This process accounts for the swallow "wings" of spalled material in Figure 2. The wings disappear in above ground blasts where the airblast is eliminated by a berm. If one assumes no loading, the upper limit for the depth to which this effect might be important is the depth at which lithostatic pressure equals the normal atmospheric pressure. This is about 4 meters for earth, 300 meters for Venus. This only works for porous materials.

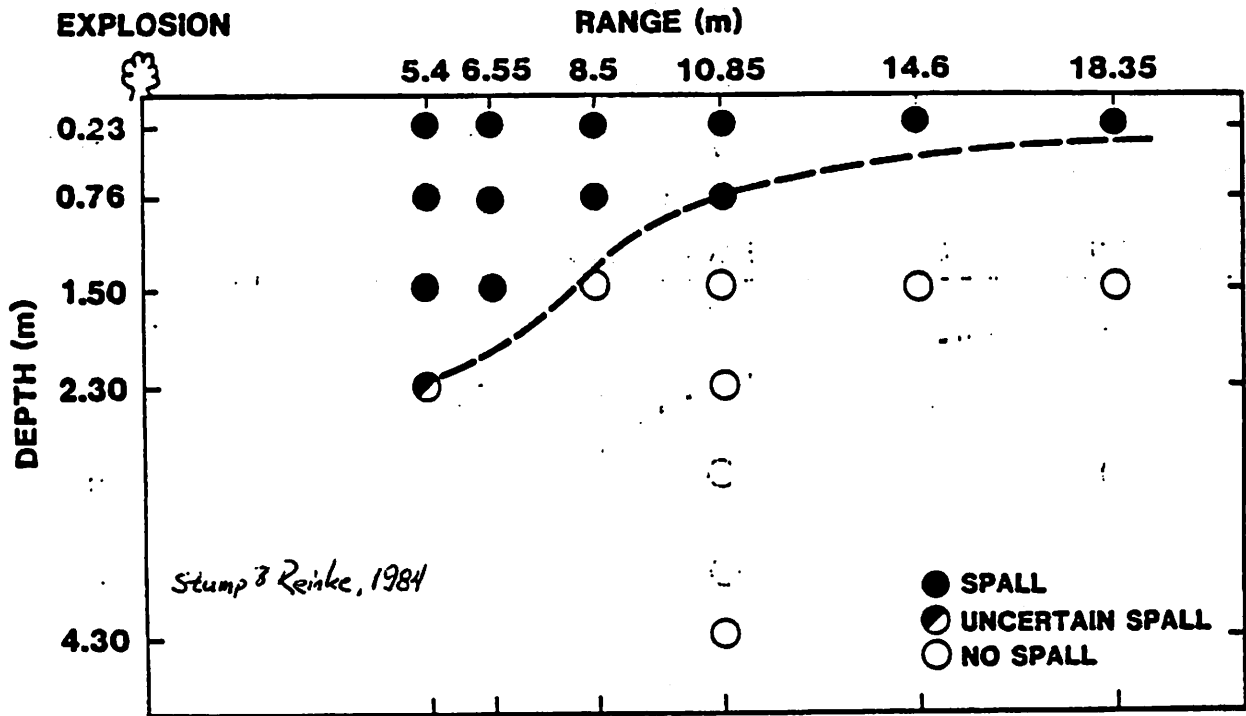


Figure 2

4) Subsurface accelerometer data for two tests in alluvium at Yucca Flat show spall initiation at depth, propagating upward. The deepest spall occurred before the compressive wave reached the surface, ruling out reflection from the free surface as the mechanism responsible for this. It has been postulated that in dry particulate matter of high porosity the compressive wave compacts the material. This produces a moving shell of concentrated solid grains followed by a shell of much lower bulk density, through which the material in the compressed shell may fall under gravity (line dd in Figure 3). The closure of these spall gaps (line ee) propagates upward at a rate much slower than the stress wave.

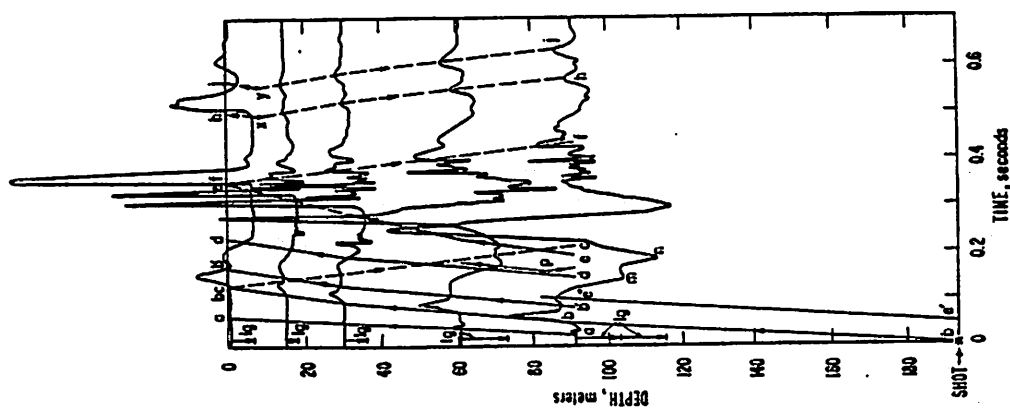


Fig. 3. Acceleration traces illustrating multiple subsurface spalling for a shot in alluvium (W. R. Perret and D. G. Palmer, unpublished data, 1961). Along the ordinate, the amplitudes corresponding to the acceleration $-1g$ are indicated.

Eisler et al. 1966

Eisler et al (1966) Multiple Subsurface Spalling.... JGR 71 3923.

Stump and Reinke (1984) Spall Observations and Mechanisms in Aluvium, unpublished draft for JGR.

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Nuclear craters vs. explosion craters

Elisabetta Pierazzo and Elizabeth Turtle

A cratering event is initiated by a sudden, localized release of a large amount of energy; in this respect impact and explosion events are the same, even though the source of energy is different: the hypervelocity impact of a large body on a surface, versus the detonation of explosive (High Energy, HE, or Nuclear Energy, NE). This difference produces a very different energy coupling in the impact event: while for explosion craters only a minor component of the explosion energy is coupled to the ground (about 6% for NE, about 5-10% for HE), in a hypervelocity impact most of the available energy (50-100%) is coupled into the ground, making it a much more efficient cratering process. Nonetheless, once initiated the actual cratering processes are independent whether the energy source was rapid deceleration of a fast-moving projectile or the detonation of chemical or nuclear explosives.

Energy

Figure 1 is a plot with a multiple abscissa showing the pressure levels of interest and the equivalent impact velocity (in this example, for a Nickel impact). For an ice meteorite impact, the pressure is roughly 3-4 times lower. Also indicated on the abscissa is a temperature rise in the shocked material.

In the lower portion of figure 1 are listed some of the important physical phenomena in a cratering event.

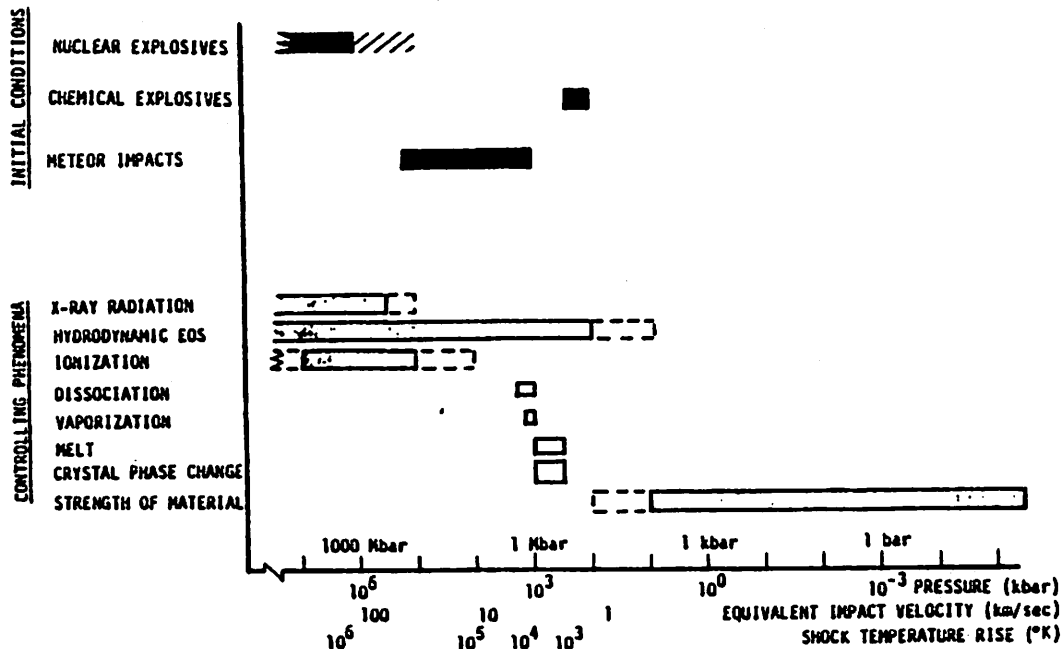


Fig. 1: Pressure, Temperature, and equivalent impact velocities associated with sources and relevant physical phenomena for cratering. (From Knowles and Brode, 1977)

Scaling

To correlate results from cratering explosions with different yields or charge weights, dimensional analysis suggests a basic scaling law in which dimensions are proportional to $W^{1/3}$, where W is the weight of the explosive (in kt; $1\text{kt}=4.2\cdot 10^{12}$ J). Distances or times associated with the explosions of different charge weights can be put on the same scale for comparison purposes by dividing them by $W^{1/3}$. Quantities like pressures and velocities are constants. Thus, at the same scaled distance and the same scaled time, we should have the same actual pressure in the shock wave and the same actual particle velocity. However, this scaling ignores the action of several factors such as gravity and the strength or internal frictional forces of the medium. Their effect is to lower the exponent and lead toward $W^{1/4}$ scaling. The best scaling for the available data results to be $W^{1/3.4}$.

Figure 2 is a plot of the scaled crater radius vs. the scaled depth of burst (i.e. depth of burial) of the explosive charge. As the explosive is buried deeper the crater dimensions increase, go through a maximum (optimum depth of burial) and ultimately fall to zero.

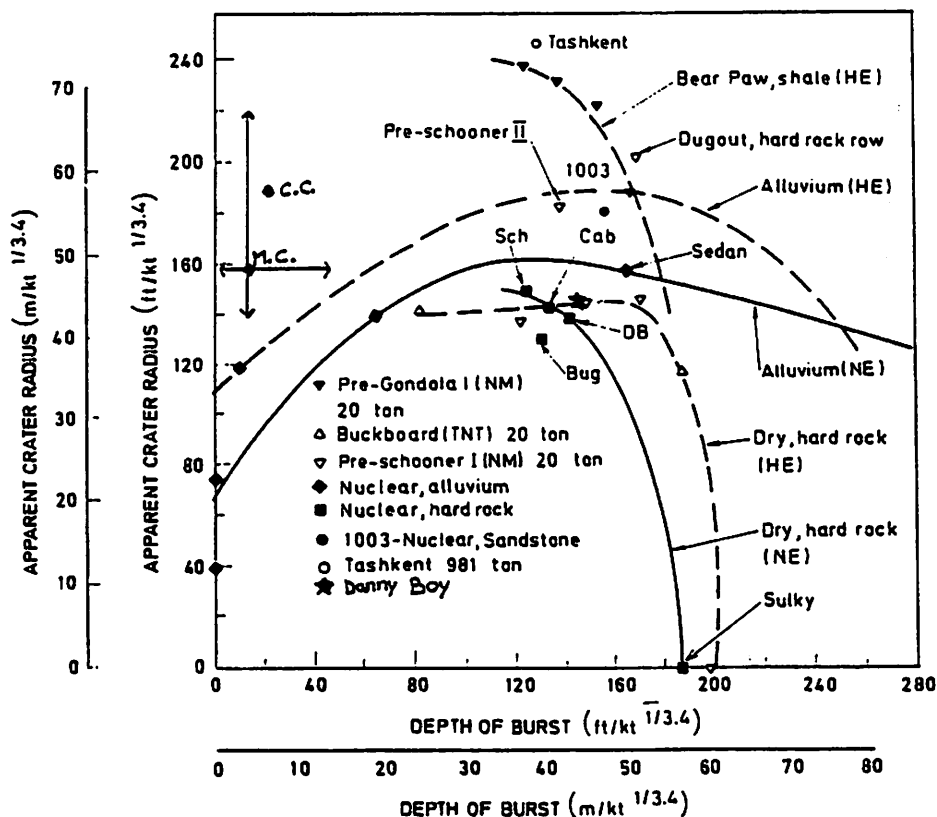


Fig. 2: Scaled crater radius vs. depth of burst for explosion craters; Meteor Crater (M.C.) and Chicxulub Crater (C.C.) are included for comparison with impact craters. The error bars associated to Meteor Crater indicates the range of estimates by previous authors (Shoemaker, 1960; Baldwin, 1963; Bryan, 1978; Schmidt, 1980). (From Cooper, 1976)

Obviously the physical properties of the target rocks play an important role, contributing to the large scatter in the data points. The figure also shows a couple of impact craters: Meteor Crater and Chicxulub Crater. The explosive energy is substituted, in this case, by

the kinetic energy of the impacting body, $mv^2/2$, while the depth of burial has been roughly estimated from the classic jet-penetration formula: $d_b \cong L(\rho_p/\rho_t)^{1/2}$, where L is the projectile diameter, and ρ_p and ρ_t are the density of the projectile and target respectively. *Table 1* gives the important parameters for some explosion craters of interest and for the impact craters.

<i>Name</i>	<i>Approx. equivalent yield (kt)</i>	<i>Depth of burst (m)</i>	<i>App. crater diameter (m)</i>	<i>App. crater depth (m)</i>	<i>Target Material</i>
Danny Boy	0.42	34	66	19	Basalt (dry)
Sedan	100	194	370	98	Alluvium (dry)
Schooner	35	108	260	63	Tuff (wet)
Sulky	0.087	27	—	—	Basalt (dry)
Meteor Crater	4700	~54	~1,000	~150	Sediments
Chicxulub Crater	$7.5 \cdot 10^{10}$	~10,500	~180,000	?	Evaporites

Table 1: Parameters relative to the explosion and impact craters of interest. (Explosion craters data from Nordyke, 1970)

Cratering Mechanics

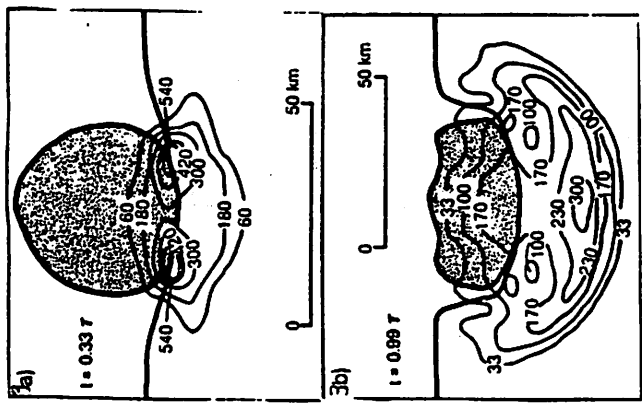
While the processes involved in shallow buried explosion events are very similar to those in impact events, the craters we are scheduled to see are the result of deeply buried explosions. Figures 3 and 4 show schematically the processes involved in the creation of both impact and deep burial explosion craters to illustrate the differences.

Morphology

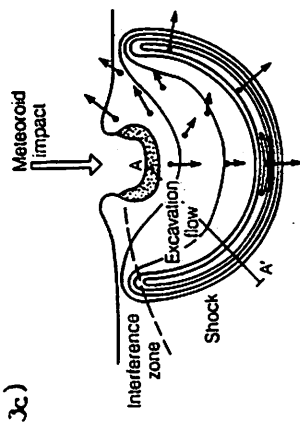
The shape of explosion craters varies greatly with the depth of burst. Surface and shallow burial crater production is dominated by processes like compaction and plastic deformation (shallow burial), and spallation (shallow burial). An optimum burial crater is the one with the maximum crater dimensions for a given charge, while deep burial craters are produced by charges placed deeper than the optimum burial depth. For these last two types "gas acceleration" (acceleration produced by the adiabatically expanding gases trapped in the cavity) becomes the most prominent feature in the cratering process.

It is apparent from figure 2 that impact craters are "shallow buried", meaning that their effective depth of burial is much less than the optimum depth of burial. This can also be seen in comparing the shapes of impact and explosion craters.

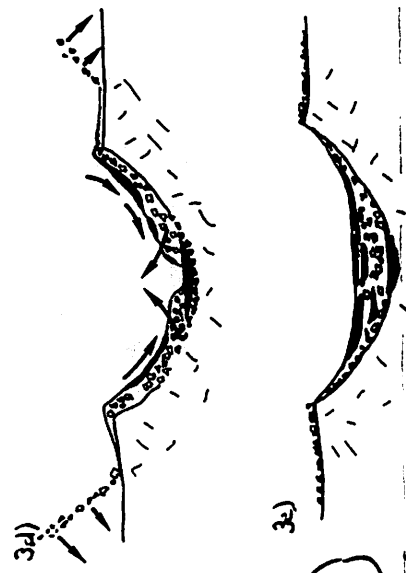
Figure 5 shows geological cross sections of typical explosion craters, while the cross sections of some well-known impact craters are shown in figure 6. Simple bowl-shaped low-velocity impact craters, like Meteor Crater (6a), are similar to surface burial explosion craters (5a); parabolic-shaped high-velocity impact craters, like Brent Crater (6b), are similar to shallow burial explosion craters (5b). No real analog to the deep burial and optimum burial explosion craters exists among impact craters, due to the crucial role played by gas acceleration for the explosion craters. Complex craters (6c) are associated to very high impact events; tentative analogs, among explosion craters, are those created on water-saturated targets, like the Snowball Crater (5e).



Contact and compression:
 shock wave generation
 melting/vaporization of the projectile
 jetting



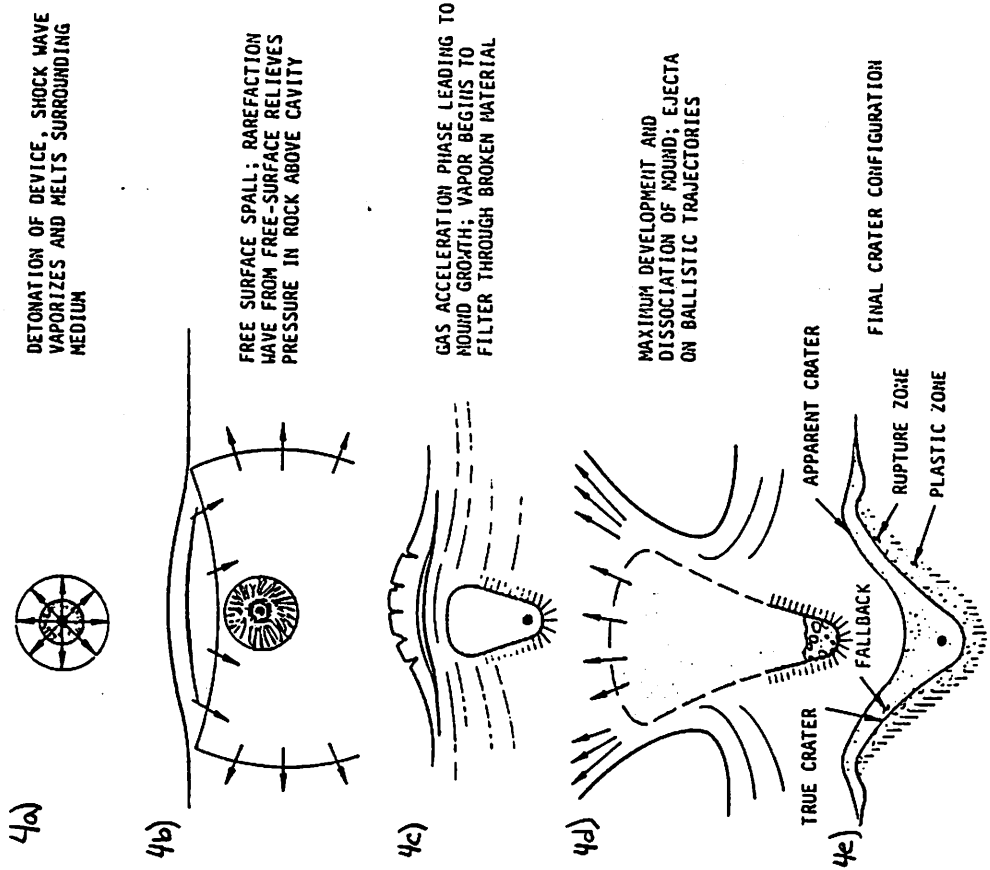
Excavation:
 shockwave propagation and decay
 melting/vaporization of target
 acceleration of material out of crater



Modification:
 slumping due to gravity
 isostatic rebound (longer term)

Figure 3 (right): Sequence of the cratering processes involved in a hypervelocity impact. (From Melosh, 1989).

Figure 4 (below): Sequence of the cratering processes involved in a deeply buried nuclear explosion. (From Cooper, 1976)



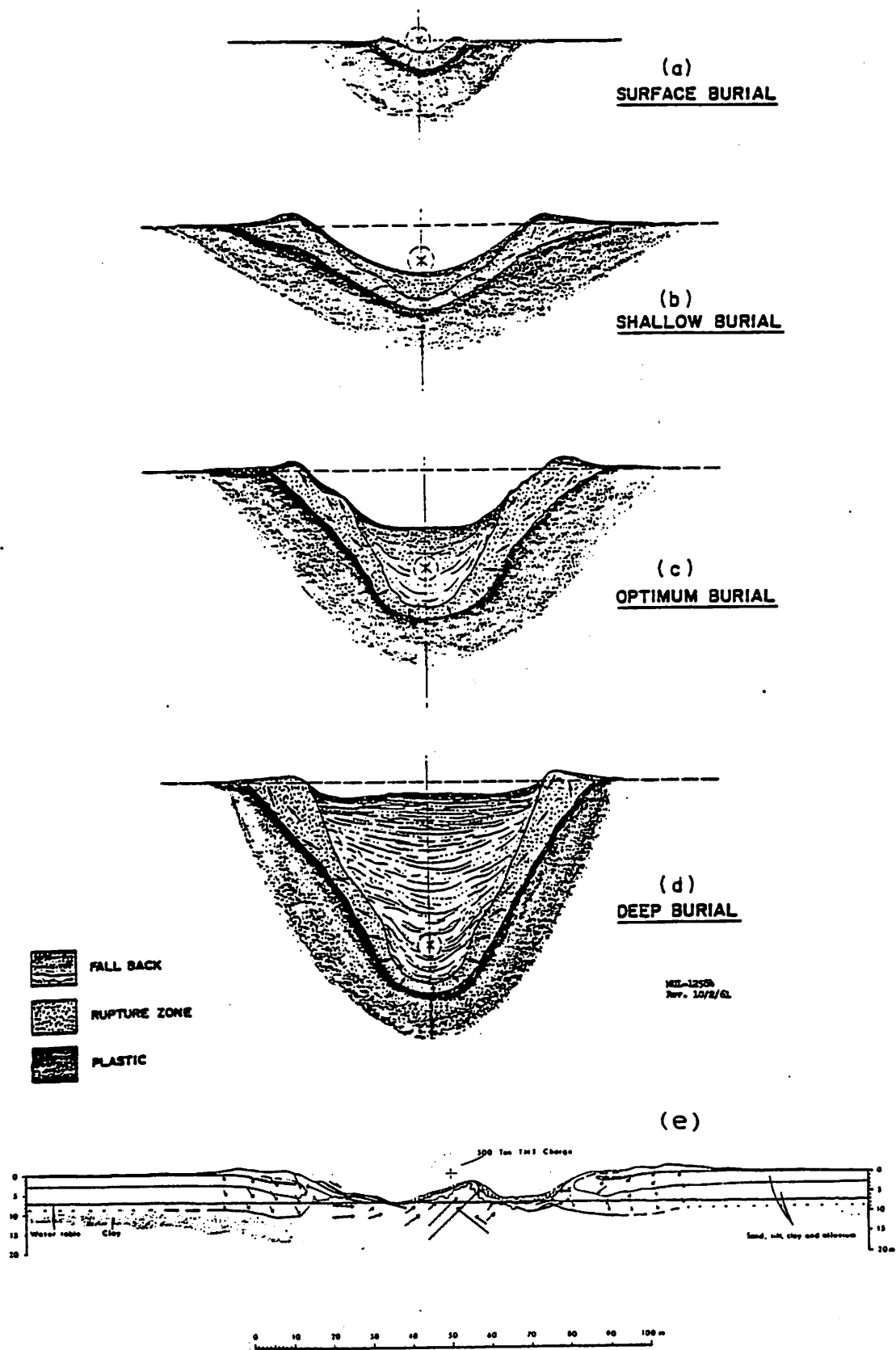
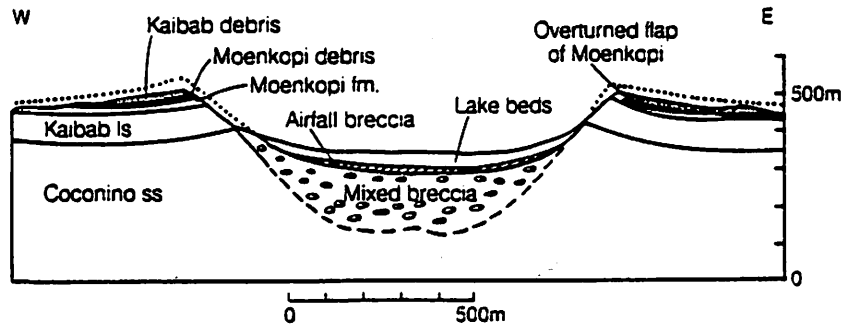
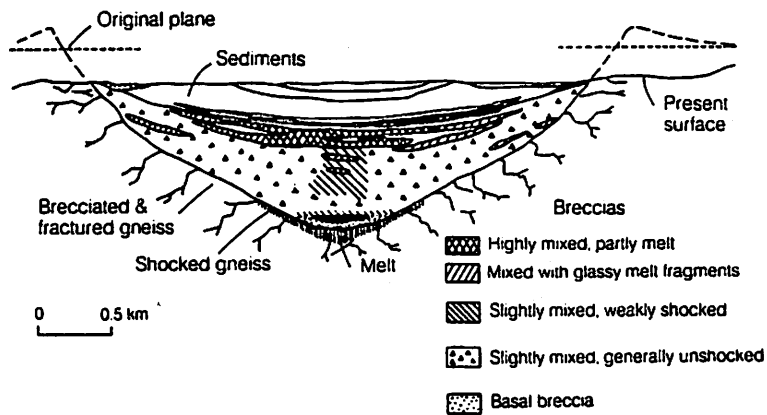


Figure 5: a-d) Cross-section of typical explosion craters (From Lawrence, 1961) e) Cross-section of Snowball crater. (From Roddy, 1976)

(a)



(b)



(c)

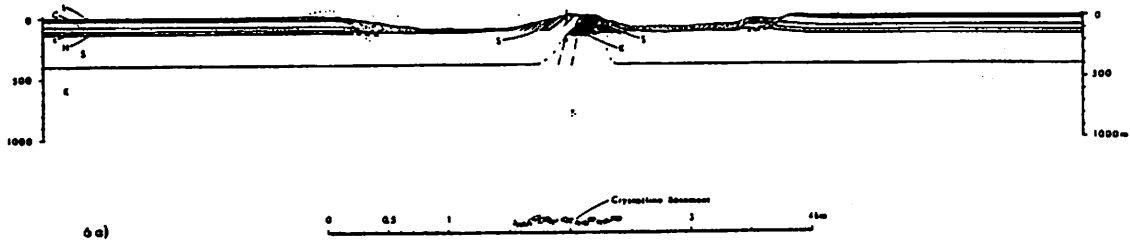
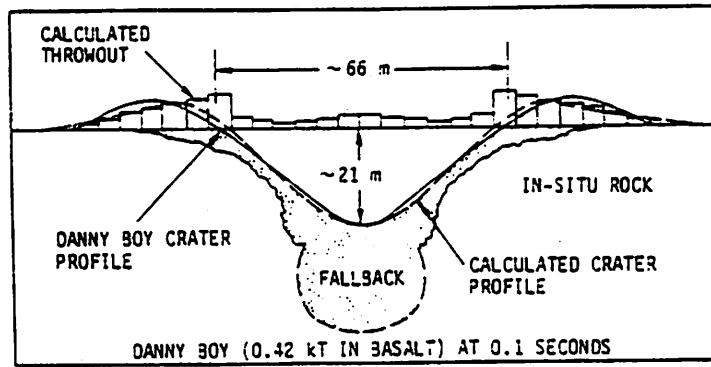
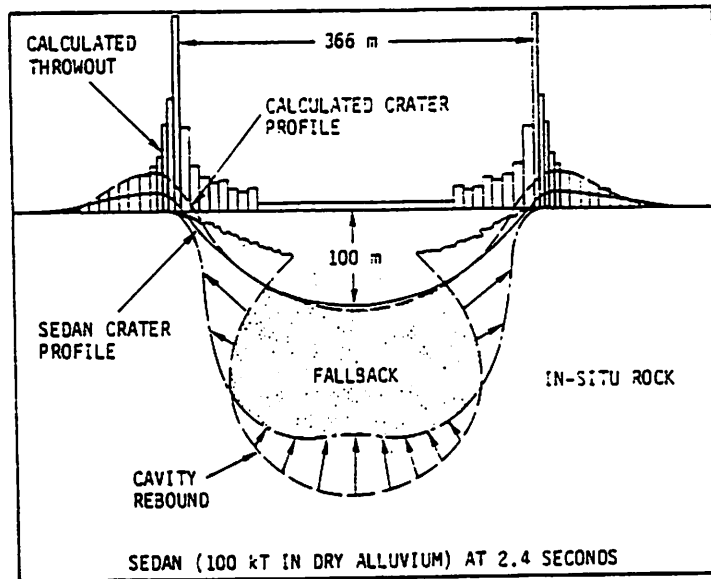


Figure 6: Cross-section of known impact craters: a) Meteor Crater (From Melosh, 1989), b) Brent Crater (From Melosh, 1989), and c) Flynn Creek. (From Roddy, 1976)

Danny Boy (Cooper, 1976)



Sedan (Cooper, 1976)



Schooner (Nordyke, 1976)

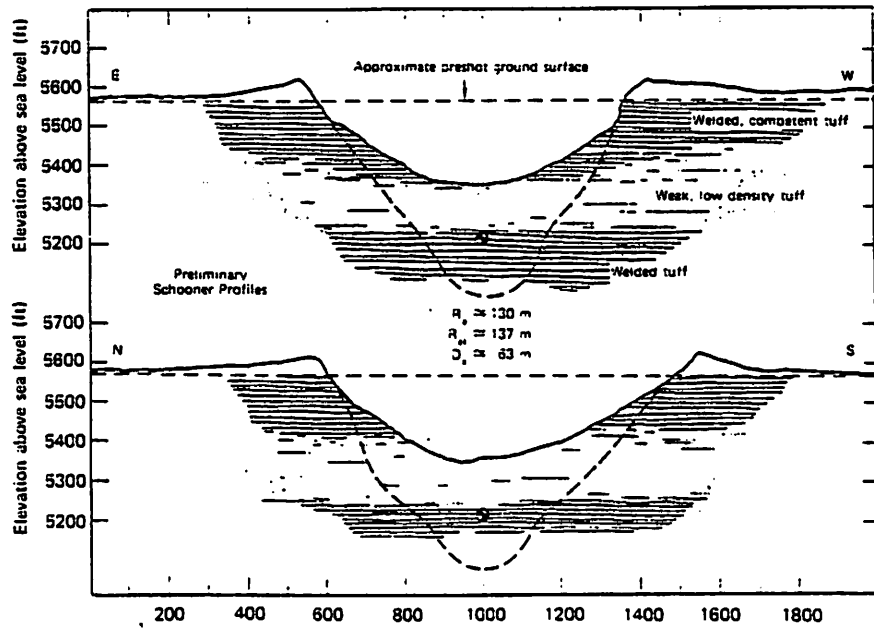


Figure 7: Cross-sections of the three NTS explosion craters to be visited.

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Manhattan Project: Important Dates

with your implosive host, Andy Rivkin

- 1913: H.G. Wells publishes *The World Set Free*, futuristic novel climaxing in nuclear war
- 1934: Leo Szilard takes out patent describing how (he thought) a chain reaction would work
- 1938: Otto Hahn bombards uranium with neutrons, gets barium out- first "splitting of atom"
- Spring 1939: Alarmed by the possibility of Nazis following up on Hahn's research and building a bomb, Szilard tries to enlist fellow Allied scientists to try and interest the U.S. government in atomic research.
- 1 September 1939: German army enters Poland; World War II begins.
- 11 October 1939: President Roosevelt first becomes interested in building atomic weapons via a letter from Einstein warning of German progress.
- 21 October 1939: \$6000 awarded for nuclear research by U.S. Army.
- Spring 1940-Summer 1941: Calculations by British physicists Otto Frisch and Rudolph Peierls show only 5-10 kg of uranium needed for bomb (vs. American estimates of ~100 tons).
- April 1941: Japanese Army asks Yoshio Nishina to explore feasibility of an A-bomb.
- June 1941: Germany invades Soviet Union.
- 9 October 1941: Roosevelt gives go ahead for full atomic program, with whatever funding was necessary.
- 7 December 1941: First pure U-235 produced at Berkeley. Also, Japanese bomb Pearl Harbor, bringing U.S. into war.
- Spring/Summer 1942: Oppenheimer put in charge of a group of theoretical physicists to try and work out details of the bomb at Berkeley.
- 4 June 1942: Werner Heisenberg briefed Nazi Munitions Minister Albert Speer on producing an atomic bomb. Hitler made no move to speed up the project, preferring guided missiles.
- Summer 1942: Igor Kurchatov assigned to build an atomic bomb by Soviet Union.
- 18 July 1942: Meeting of senior Japanese scientists concludes it would take Japan at least a decade to build a bomb.
- 17 September 1942: General Leslie Groves put in charge of atomic bomb program.

- 16 November 1942: Los Alamos chosen as the center for atomic bomb research.
- 2 December 1942: Fermi and group at University of Chicago perform first chain reaction, under Soldier's Field.
- 15 April 1943: Los Alamos opens. Work begins on all different stages of the "gadget" simultaneously.
- late April 1943: Seth Neddermeyer conceives of "implosion".
- Summer 1943: Stalin orders Kurchatov *et al.* to push Soviet atomic program, afraid of falling behind the United States. Meanwhile, American scientists worry about German progress, prompting Harold Urey to ask the Army to warn the public of a possible German atomic attack.
- August 1943: Oak Ridge uranium plant begins operation.
- Christmas 1943/New Year's 1944: University of Chicago atomic physicists become convinced that Chicago is targeted for nuclear strike. They are wrong.
- Summer/Autumn 1944: Niels Bohr attempts to convince Roosevelt and Churchill to share the atomic bomb with the Soviets after the war as a means of averting an arms race. The attempt, along with others over the next year by other scientists, fails.
- 12 April 1945: Roosevelt dies, Truman becomes president and immediately learns about the atomic program.
- 2 May 1945: Soviet Union captures Berlin. War in Europe closes.
- Spring 1945: With German A-bomb program no longer a threat, scientists push for a demonstration of the bomb in hopes of avoiding a military use on Japan.
- 31 May 1945: "The Interim Committee" advises Truman to use the A-bomb in a surprise attack against Japan when available.
- 16 July 1945: Implosion bomb tested successfully at Trinity site, New Mexico. First doubts about morality of bomb arise at Los Alamos.
- 24 July 1945: Potsdam summit: Truman tells Stalin, vaguely, about the existence of the A-bomb. Meanwhile, possible target for first A-bomb narrowed to Kokura, Niigata, Nagasaki and Hiroshima.
- 2 August 1945: Hiroshima chosen as primary target.
- 6 August 1945: Hiroshima bombed with uranium gun-type bomb.

Information plagiarized mercilessly from

Day One by Wyden, 1984.

Now a major motion picture!

- 9 August 1945: Soviet Union declares war on Japan. Nagasaki bombed with plutonium implosion bomb, Japan surrenders to Allies.
- 29 August 1947: The Soviet Union, thought to be unable to create an atomic bomb for another decade, tests its first nuclear weapon.

Alamogordo, N.M.: The Trinity Test



0.034 SEC
N

100 METERS

It worked: fireball ascending .034 seconds after blast.

The oddest couple: Oppenheimer and Groves after the test.



Make love,
not war.

YUCCA MOUNTAIN WOES

B. Cohen
D. Dawson

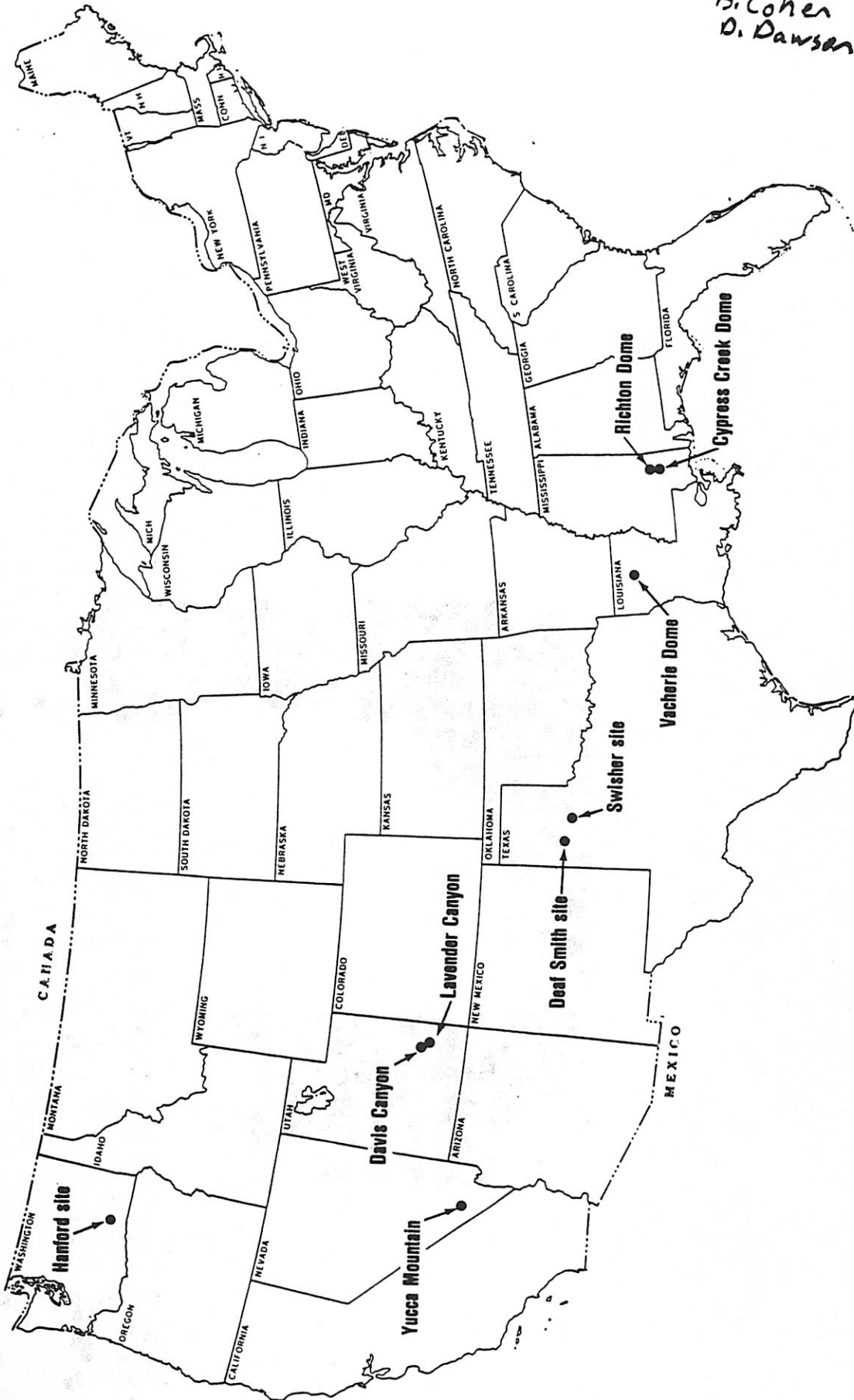


Figure 1. Potentially acceptable sites for the first repository.

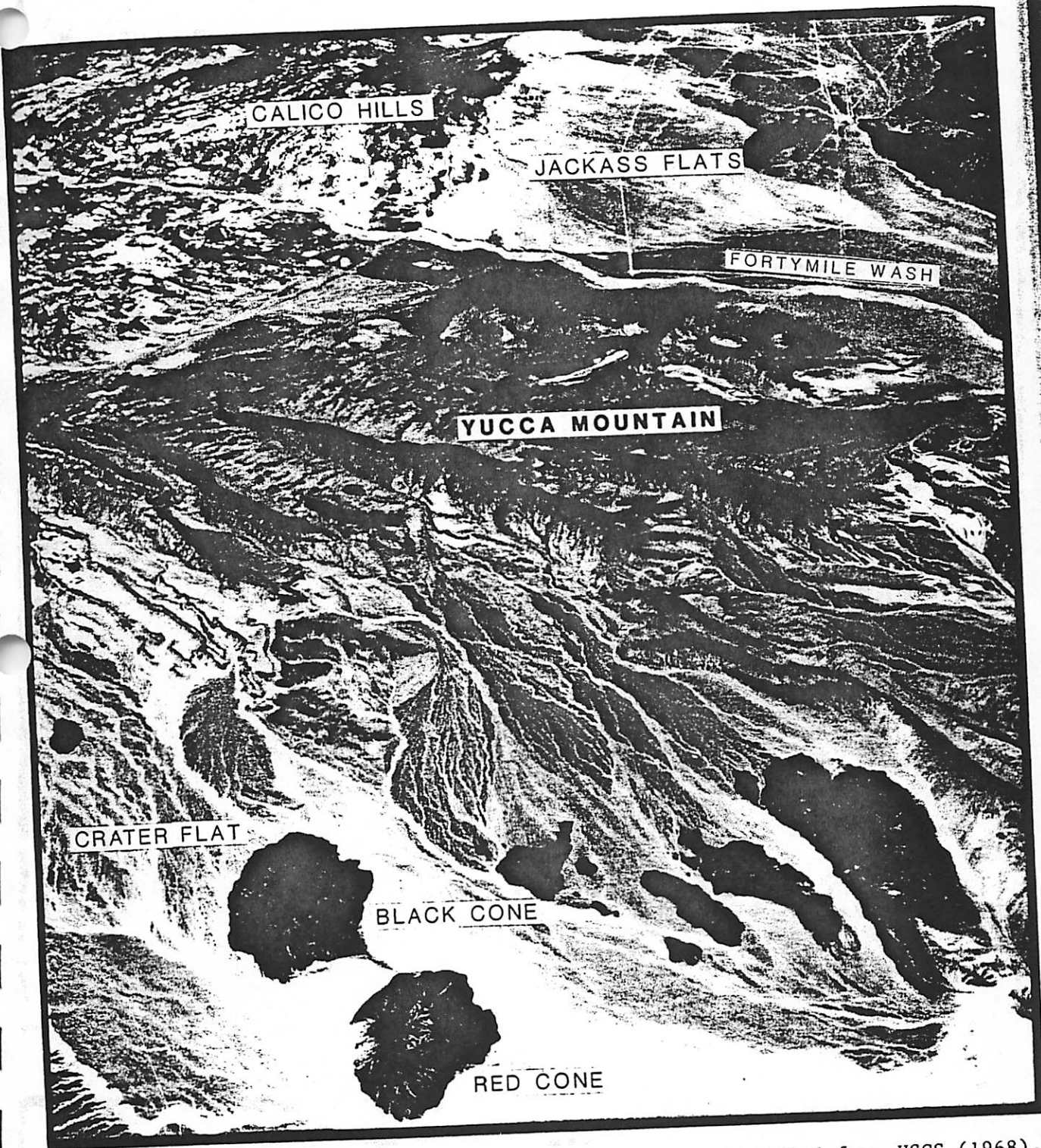


Figure 2-2. View of Yucca Mountain looking northeast. Modified from USGS (1968).

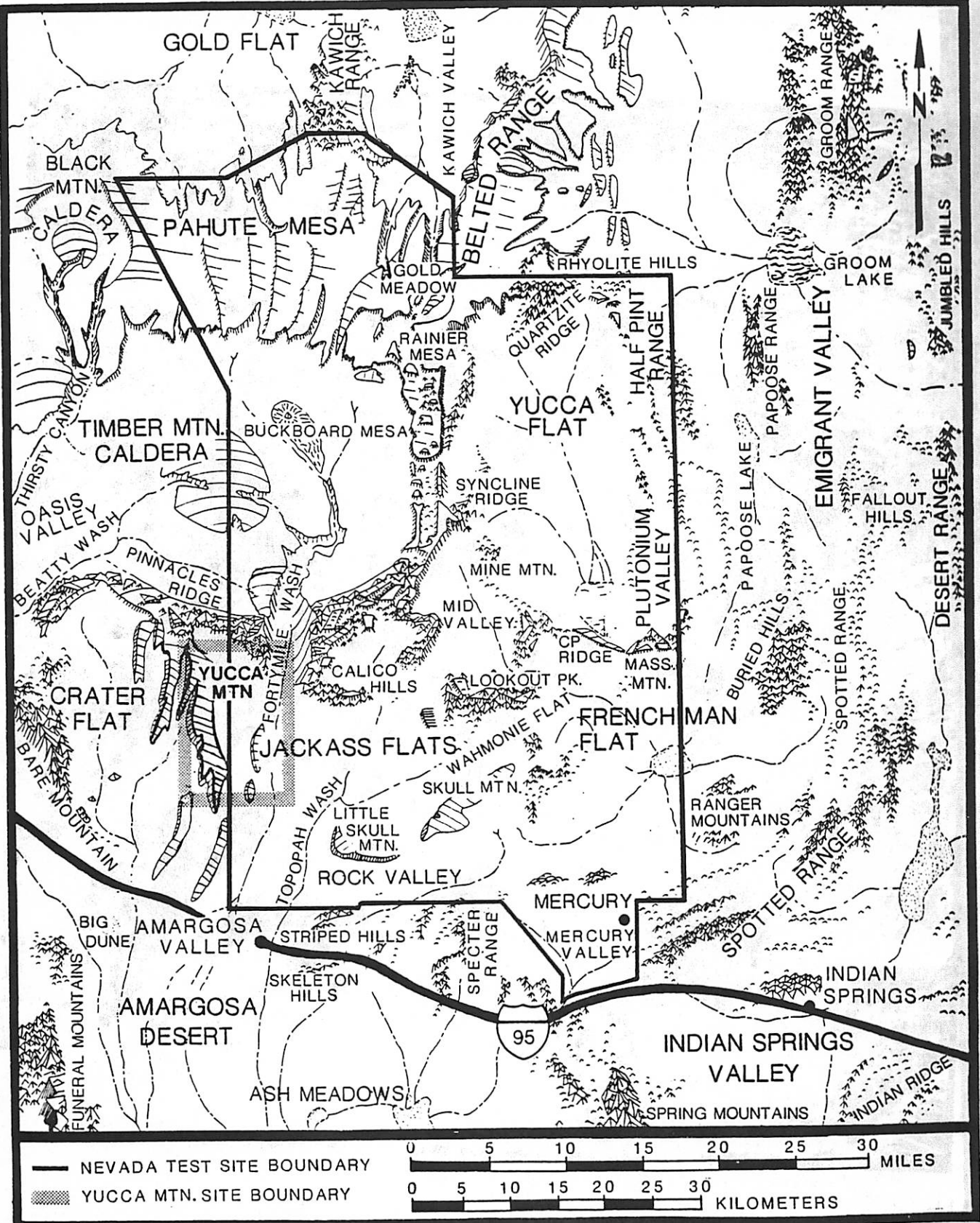
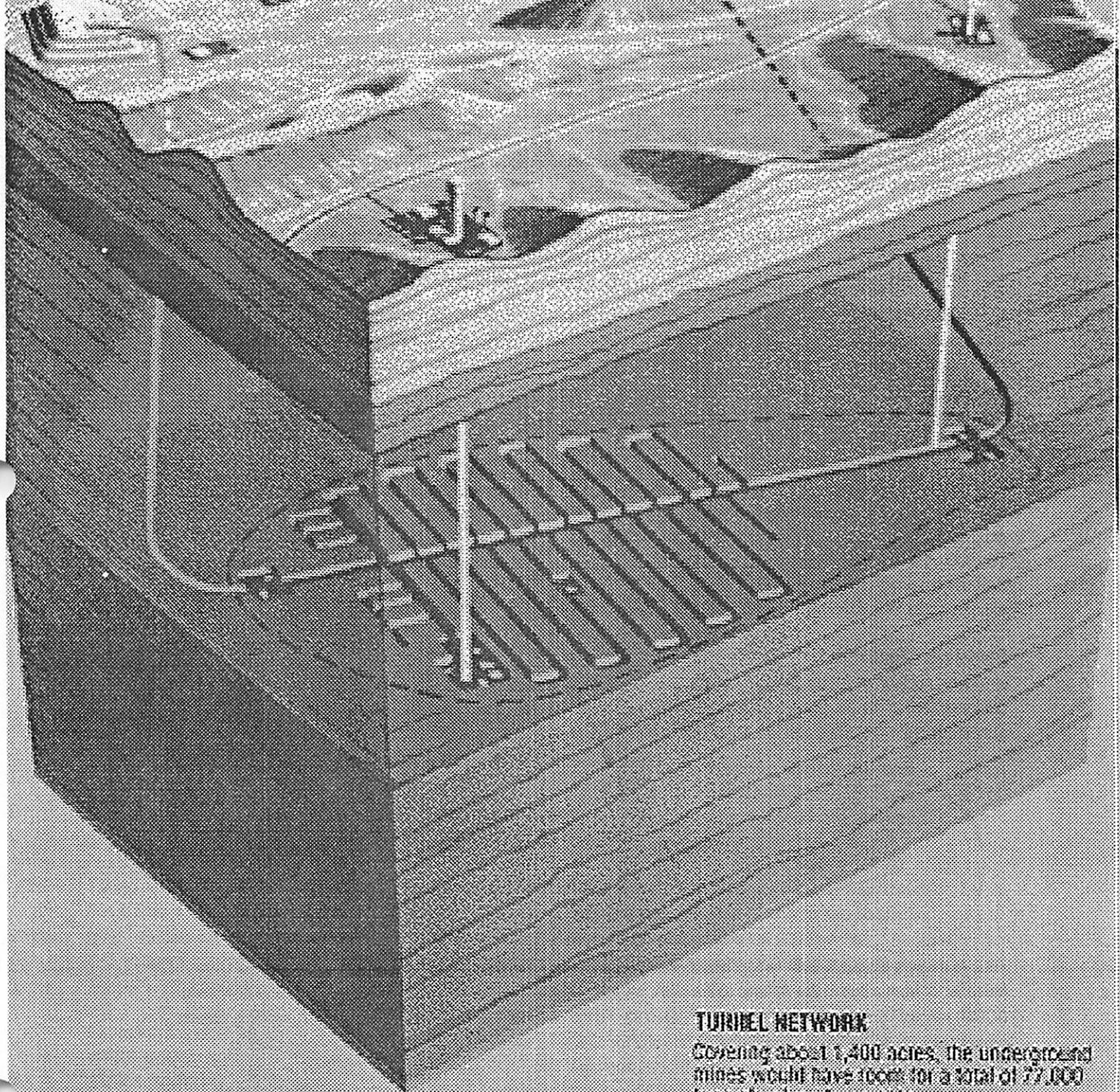


Figure 3-2. Physiographic features of Yucca Mountain and surrounding region. Modified from Sinnock (1982).

E
of compacted
ash and dust.
excavations
piled at the
then used
used the

SURFACE FACILITY
Delivered by rail or
truck, nuclear waste
would be unloaded,
resealed in casks,
then transported via
ramps to the storage
area below.



TUNNEL NETWORK
Covering about 1,400 acres, the underground
mines would have room for a total of 77,000
tons of radioactive waste.

A CROSS-SECTION OF THE PROPOSED FACILITY

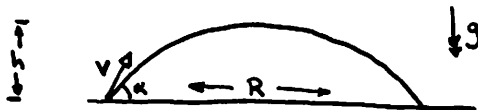
Scope : This discussion describes the fundamentals of surface-surface delivery of nuclear weapons, and comprises an introduction to ballistics, aerospace vehicles, and system design. THERE ARE EQUATIONS HERE, BUT THEY ARE EASY. DO NOT BE FRIGHTENED. Air-to-air applications (the 'Genie' missile), nuclear-armed torpedoes, depth charges etc. are not discussed. Planetary applications of the relations are mentioned.

Requirement

A low-technology nuclear explosive (e.g. the gun-type device developed in South Africa, with 55kg of Uranium, and tungsten reflectors) might have a mass of 1000kg. A high-technology device, using the implosion technique and a minimum critical mass of 5-8kg of plutonium with beryllium reflectors, might be of the order of 20kg. Nuclear explosives are typically robust. We require to emplace this device some distance away.

Guns and Ballistics

Consider a simple model of classic ballistics. Consider a flat earth, uniform gravitational field and ignore the atmosphere and earth rotation



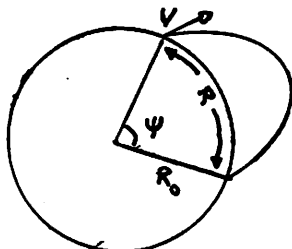
Launch velocity V , angle α
 Gravitational Acceleration g_0
 Range $R = V^2 \sin^2 \alpha / g_0$
 Max Altitude $h = V^2 \sin^2 \alpha / 2g_0$

This approximation is moderately valid for short ranges on Earth. It can be shown that in the absence of air resistance, range is maximised for $\alpha = 45^\circ$. Typically $V \sim 1000$ m/s or less, giving a theoretical range of 50 km : in reality air resistance reduces this. Consider a modern US 155mm howitzer : it can deliver a small nuclear-armed shell (the W-79-0 projectile has a selectable yield from a few tons to 1.1 kT) somewhat over 30km. There is an old joke in the nuclear community that villages in Germany are spaced, on average, 10 kilotonnes apart.

In WW1, the Germans developed a gun specifically for the long-range bombardment of Paris : the 'Paris Gun' fired a 130kg shell a range of 79 miles (>120km) : the trip took about 200 seconds, with the shell reaching an altitude of just under 30 miles. Maximum range ($V \sim 1500$ m/s) was achieved for an elevation of 54° . (during earlier trials with a smaller weapon, the test shells were not recovered because they travelled 160,000 ft rather than a predicted 105,000 - the trick is that the long range corresponds to a high apogee where the low air density makes standard air resistance corrections (based on sea-level air density) overly pessimistic. The low drag at high altitudes leads to a steeper angle for maximum range of 54° in this case. cf also the Iraqi 'supergun' effort.

Planetary Ballistics

However, nuclear weapons can be strategic weapons : there may be the requirement to deliver them over distances comparable with the planetary radius, so the flat earth approximation fails. (Even for the 130km range of the Paris gun, the curvature of the Earth leads to an error of ~ 1 km). Thus a new geometry must be defined.



Define range R as ΨR_0 , with R_0 the planetary radius (6370km for Earth) and Ψ the angle along the great circle linking the launch and impact site. It can be shown, by fitting an elliptical orbit to the launch and impact sites that $\sin(\Psi/2) = Q/(2-Q)$ where $Q = \sqrt{2} R_0 / \mu$ (the ratio between the launch speed and circular orbit speed at R_0). Earth $\mu = 4 \times 10^{14} \text{ m}^3 \text{ s}^{-2}$

Thus to throw a projectile over typical IRBM (Intermediate Range Ballistic Missile) ranges, or something like UK-Moscow, or from a sub in the Atlantic to the USA, we have $\Psi \sim 20^\circ$ and $Q \sim 0.41$. For Intercontinental Ballistic Missile (ICBM) ranges Tucson-Moscow, say $\Psi \sim 90^\circ$, $Q = 0.83$. To the other side of the world, $\Psi = 180^\circ$, $Q = 1$, and V is circular orbital velocity, or 7.9 km/s. Clearly the technology for delivering weapons over strategic distance scales is essentially the same as that for launching vehicles into orbit. These velocities are larger than can be practicably attained with guns (due to acceleration limits on the projectile, propellant combustion rates and other practical

considerations), so the rocket is used. In fact, the Treaty of Versailles, which Germany was forced to sign after WW1, banned it from having artillery of greater than 170mm calibre, and hence prompted the development of the long-range rocket missile (rockets were not covered by the treaty), culminating in the V2 (although small rockets had been used in war in China, in India (in 1799 against the British), in Copenhagen and Leipzig in 1807 and 1813 (by the British) and by British ships against Fort McHenry (Baltimore) in 1814 - hence "the rockets' red glare"). The role of treaties in the development and deployment of nuclear weapons and their delivery systems is significant.

Rockets

Typically a vehicle (structure, engines + payload) can be made with a mass ratio (fuelled/empty) of about 5:1, with the payload ratio (fuelled mass/payload) of about 10. Adding more fuel means larger tanks, larger structure to support them, larger engines to lift them, etc., so this practical limit can only be overcome by technology improvements (lighter structures, etc). Tsiolkovsky developed the 'rocket' equation which describes how large a change in velocity a rocket can produce : $\Delta V = g_0 I_{sp} \ln(M_0/M)$. I_{sp} is the specific impulse of the rocket, or the impulse per unit weight of propellant (in Newton-seconds per Newton, or just seconds). This quantity depends principally on the fuel and oxidiser used, and to a lesser extent on the engine design: the product $g_0 I_{sp}$ describes the effective exhaust velocity of the engine. M_0/M is the mass ratio.

The German V-2 rocket, with an I_{sp} of about 220s (alcohol and oxygen propellants) and a mass of 13.5 tonnes, of which 8 tonnes propellant (Mass ratio ~ 2.45) achieved a velocity exceeding 2 km/s. With a ratio of 5:1, and a higher I_{sp} (280-300s are typical for solid-fuel rockets or those with storable propellants) a modern single-stage missile could achieve a ΔV of 4.7 km/s (or a range of ~2000km, using the equation above). Longer ranges require staging, whereby an upper stage rocket is the payload of the lower stage and the ΔV s of the two stages add arithmetically. This 'beats' the rocket equation, although at the cost of a more complex vehicle (higher cost, more failure modes).

Equating rocket ΔV to ballistic velocity requirements disregards the presence of an atmosphere. To a first order, the velocity of an ascending projectile, mass to area ratio β , 'sapped' by an atmosphere may be given by $\rho_0 H V / \beta$, where H is the scale height of the atmosphere (~8 km on Earth) and ρ_0 the surface atmospheric pressure. For a typical missile β of 10^4 kg/m³, and ρ_0 of 1.25 kg/m³, or about all of V. By first lofting the vehicle slowly a few scale heights up, the drag penalty is reduced to acceptable levels. However, taking off slowly means the vehicle carries its own weight longer, introducing a 'gravity loss'. Practical vehicle trajectories (and their stage weights) are tediously optimised to trade off these losses and to get the best performance. It may be desirable to have a non-optimal (e.g. fast-burn) trajectory, to beat a defensive system, however.

Aeroplanes

Nuclear weapons may also be delivered by bomber. The range of an aircraft may be estimated by the Breguet range equation, $R = (V/s) (L/D) \ln(W_0/W)$

V is the cruising speed of the aircraft, s is the specific fuel consumption, (L/D) is the lift-to-drag ratio of the aircraft, and W_0 and W are the weight of the aircraft at the start and end of the flight (i.e. $W_0 - W$ is the weight of fuel.) For a modern turbofan, $s \sim 0.7$ lb/hr/lb (aeronautics, being a discipline in which the US has had a significant role, suffers from ludicrous units), and most airliners or transport/bomber aircraft have (L/D) ~ 15-18.

Taking an MD-11, with $V = 530$ knots, max payload = 105,000lbs, take-off weight of 621,000lbs and empty weight of 304,000lbs (data from the American Airlines home page http://www.amrcorp.com/aa_home/servinfo/aacraft.htm) gives $W_0/W = 1.52$. Inserting these numbers above gives about 6600 miles (cf. printed value of 6260 miles). (NB 1 knot = 1 nautical mile per hour, where 1 nautical mile subtends one minute of arc at the Earth's equator, or is 1.85 km, or 1.15 statute miles).

Inspecting the equation above, it is seen that flying faster means going further. This is the theory - in practice it is difficult to attain high L/D at high Mach numbers (530 knots is $M \sim 0.85$, or 85% of the local speed of sound at 35000ft : going much faster leads to shock waves on the wings and hence drag increases). Even vehicles designed for efficient supersonic cruise (Concorde, $M = 2.2$) have poor L/D, in this case about 8. It becomes harder

to achieve good specific fuel consumption at high speed as one needs to use more compact (lower drag), but less efficient engines (Modern efficient engines are big - 'high bypass' : the small turbojets used in cruise missiles are less efficient - sfc ~ 1 lb/hr/lb)

Conventional, crewed aircraft are only able to perform global (R~20,000 miles - there and back to the antipodes) if they beat the Breguet equation by in-flight refuelling. If there is no requirement to carry a crew (or, indeed, to bring the vehicle safely home) the effective mission range can be increased. Aircraft can also perform a kind of 'staging' of the release of cruise missiles from aircraft.

Guidance

In nuclear and conventional warfare, the accuracy with which a weapon can be delivered drives the amount of ordnance that must be delivered. Accuracy is usually expressed as a CEP (circular error probable) - the distance from the aim point within which 50% of the warheads will fall. It can be shown that the probability of getting within lethal radius Z (defined by warhead size and hardness of the target) is $P(Z) = 1 - \exp(-0.69Z^2/C^2)$ where C is the CEP. Minimising CEP is clearly beneficial, increasing the probability of landing within lethal range.

E.g. to destroy a silo (5000 psi overpressure), a single 100kt cruise missile at \$8M will do, but (on average) 2.3 less accurate 1.1MT air-dropped bombs (at a cost of \$34M) would be required. However, to deliver a 6 psi blast overpressure to a wide industrial area (say 50 square miles) would need 3.8 cruise missiles (at \$34M), but only 1.3 bombs (a bargain at \$19.2M) (Figures from Betts, 1981)

Supreme accuracy is attained by the cruise missile, which compares a digital model of the enemy terrain with that seen by its radar altimeter (plus a combination of inertial and/or GPS data) to reach the target area. For conventionally-armed variants used in Bosnia and Iraq, the lethal radius is small, so accuracy is fine-tuned by TV imaging and scene matching, giving CEPs of a few metres.

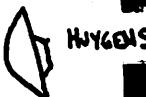
The builders of the Paris Gun are rumoured to have checked whether the moon's gravity would lead to an appreciable perturbation of the shell's trajectory (it didn't). However, on strategic distance scales, the shape of the Earth (i.e. its departure from sphericity) and the higher-order terms of its gravitational field can result in significant (~km) errors. For some time the high-order terms of the geopotential were classified (whereas the equivalent data for other planets were not).

Entry Aerodynamics and Aerothermodynamics

An object travelling at orbital or near-orbital speeds has considerable kinetic energy. Comparing the kinetic energy per unit mass of a typical re-entering body ($V^2/2 \sim 2.5 \times 10^7$ J/kg) with latent heats of evaporation suggests that few materials (except perhaps graphite) could re-enter without melting or evaporating. Thus somehow most of the kinetic energy must be diverted elsewhere - typically this is achieved by having a blunt end to the re-entry vehicle (RV), such that a strong shock wave is formed a distance ahead of the vehicle - most of the energy is thereby radiated away. The shock layer typically is at several thousand K and is luminous (hence red glow outside shuttle windows, luminous meteors, etc.) At these temperatures there is substantial ionisation, and the free electron density is high enough to make the shock (and in some cases, the wake) radio-opaque, hence the radio blackout during re-entry, and the use of the meteoric E-layer to bounce radio signals.

Even though most of the heat is radiated away, the thermal loads on the vehicle are formidable, and require high-temperature materials (e.g. phenolic resins on Apollo, and 20MT Titan warheads - visit the Titan II missile museum south of Tucson ; silica blocks on Space Shuttle and Huygens). If accuracy (you have a big warhead) and vehicle mass (you have a big rocket) are not concerns, lower-technology materials (plywood on early USSR warheads, and oak on current Chinese photo-return entry capsules) can be used.

Ballistic missile RVs differ from those used for space probes and manned space capsules - the latter typically have much poorer tolerance of g-loads, and thereby wish to decelerate earlier (at higher altitude). Thus they have lower mass-to-area ratios than missile RVs - and look much blunter. Further, the more slender conical shape of military RVs gives them better lift-to-drag ratio, so a MIRV may move a greater distance from its ballistic trajectory - either to evade ground defences or to increase the dispersion in targets accessible from a single launcher.



As military RVs decelerate less, they are moving faster near impact. Speed makes them difficult to engage, although kinetic heating generates an IR signature that ground defences may use to track the inbound warhead. The high speed (even with the V-2) makes fuzing the weapon (i.e. timing the detonation) difficult.

Choice of Delivery Vehicle, and Defenses against them

The optimum delivery vehicle for the weapon will depend on the nature of the target (e.g. area (city) or hardened (e.g. silo)) and the size of the weapon. Release from a manned aircraft is normally the least expensive means of delivering a weapon, but specific costs are very sensitive to attrition rate (i.e. even a bomber is accurate enough that only 1 bomber is needed to kill the target, if 8 bombers will be shot down before reaching the target, the bombers do not represent a cost-effective solution. Przemieniecki (1990) gives a good discussion of the mathematics of defense, game theory, etc). Vulnerability typically scales with size and inversely with speed - against a defended target, large, slow bombers have difficulty getting through. Further, in modern Western democracies, the political costs of casualties are high, making unmanned delivery more attractive. In this context, the cruise missile has found recent favour, with its high accuracy minimising collateral damage as a bonus.

Modern fighter aircraft, with pulse-doppler radars (or other technologies) offering look-down shoot-down capability have begun to threaten the cruise missile's invulnerability, although stealth improvements will help. Further, cruise missiles are limited in range (to 1500 miles for the nuclear-tipped Tomahawk : the conventionally-armed variants used in the Gulf War have more massive (1000kg vs 500kg) warheads, and hence shorter range.)

Attractive aspects of the ballistic missile include its rapid delivery of results (<45min), potentially anywhere in the world. Its speed of flight make it difficult to counter : it is most vulnerable at launch, when the IR signature of the rocket exhaust marks its presence (and, to a limited extent, its destination) to airborne or satellite surveillance for about 2 minutes. Then, coasting in space in the so-called bus phase, it becomes hard to detect. Then the target-and-kill problem for the defender becomes significantly multiplied, as warheads ('MIRV's) are released on independent trajectories, together with decoys (about 20 decoys can be carried in place of 1 warhead, typically): these coast ballistically in the 'midcourse' phase for 20 minutes or so. Once the targets enter the atmosphere, the 'real' warheads can be discriminated from the decoys and attacked, but now the engagement is perilously close to friendly territory, so the risk of collateral damage from, or failure of, the defense becomes a problem..

Space-based defense against ballistic missiles on a strategic scale is currently impracticable, although ground- or air-based point defense is perhaps possible, and a system of limited effectiveness surrounds Moscow. The US developed but abandoned a defense system, using nuclear-armed missiles (Spartan for exoatmospheric interceptions and X-ray kills, Sprint for endoatmospheric neutron kills). The Patriot missile system demonstrated a potential for terminal defense against conventionally-armed missiles (although its actual success rate was small: the Scud threat it countered was of similarly poor military value - both attack and defense were political/psychological weapons). Laser systems are possible, but as it requires 20 kJ/cm^2 of energy to destroy a warhead (unshielded), they are difficult (indeed, most strategic defense systems are more expensive than potential countermeasures e.g. fast-boost launchers, decoys, warhead shielding etc. to beat the defense). Thus, at present the ballistic missile is probably the toughest delivery vehicle to beat.

In today's chaotic international scene, however, the delivery vehicles of most concern are perhaps suitcases and trucks. Unauthorized light aircraft have landed on Red Square and crashed on the White House lawn. A modern weapon could be delivered by all these methods. That these methods of delivery offer less technical fascination makes them all the more frightening.

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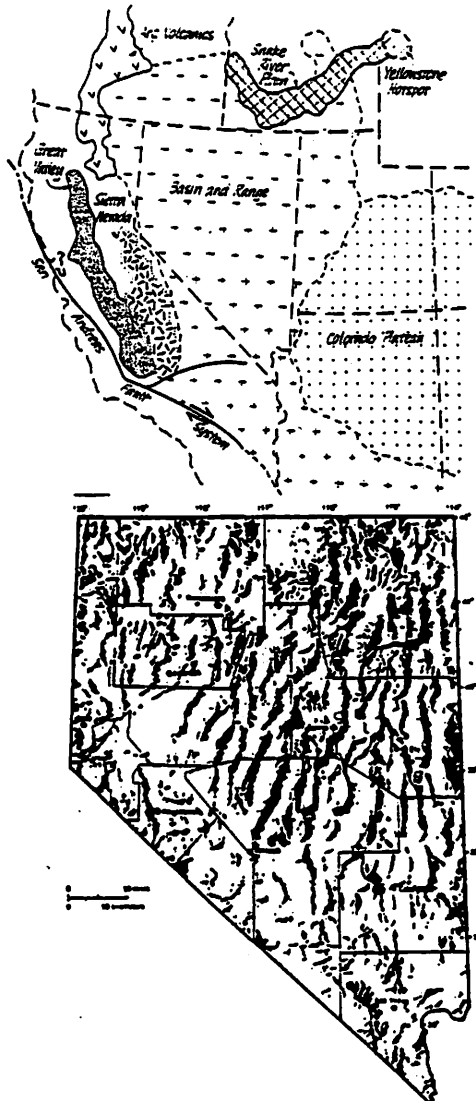
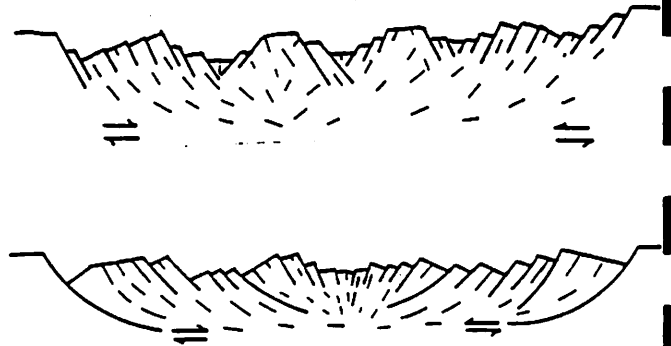
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BASIN and RANGE TECTONICS

Nancy Chabot 09/23/95

What is....

Basin and range structure refers to the valleys and mountains that form as a result of some extensional event. The crust is pulled apart, forming either: 1. a horst and graben (graben is the down dropped block) structure. In this case, the graben becomes the valley and the horst is the mountain range. or 2. tilted block structure. Here, the edge or corner of the block forms the mountain. Also, unlike classical normal faults, some of these faults are thought to curve at depth until they run parallel to the original crustal surface.



The Basin and Range Province

This region covers all of Nevada and a considerable fraction of the neighboring states, and stretches further south down into Mexico. Like its name suggests, the province is dominated by evenly spaced parallel mountain ranges and intervening desert basins. The illustration at left shows the mountain ranges of Nevada. Note the regular N-S trending pattern. The basin and range structure is obvious from just looking at the region. In the Nevada area, mapped faults are found to lie on average 15 km apart. The block faulting structures observed in this region started forming about 17 m.y. ago. This age determination is made by noting a change in the type of volcanic rocks erupted, as well as observing the oldest sediments first deposited in the newly created basins. The estimated extension to produce the structures observed is thought to have increased the entire region by about 35% of its original width. Of course, locally, the structure varies, with blocks dominantly tilted east or west in different areas. And some areas are thought to have been extended by 100%!

Characteristics:

The basin and range structure observed in the western United States is rather unique, and its origin or cause is not certain. When trying to understand the Basin and Range Province better, some characteristics of the region must be taken into account:

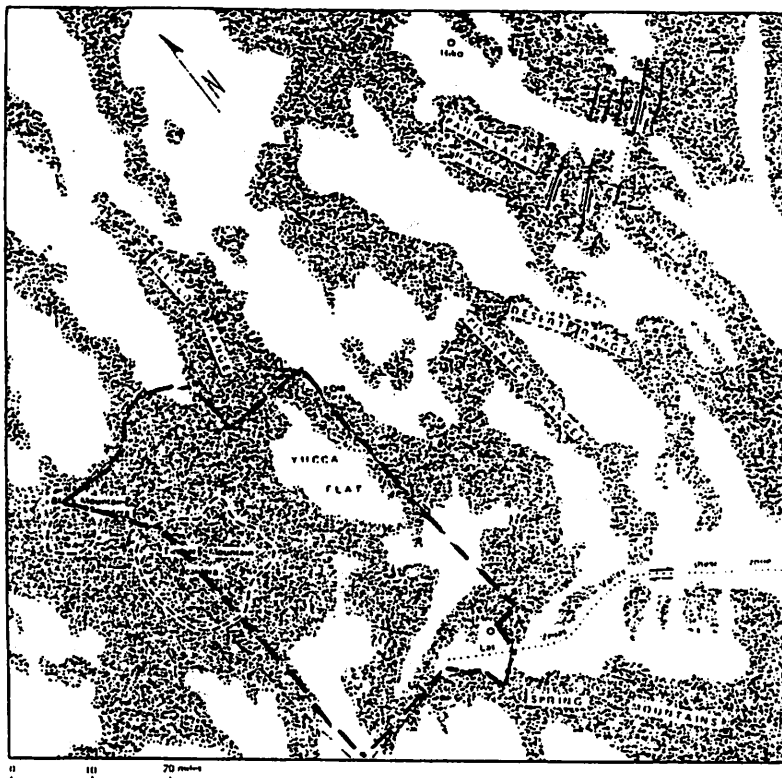
ELEVATION - the entire region has been uplifted and now stands well above sea level, and in many areas is of comparable height to the Colorado Plateau to the east.

THINNED CRUST - as one would expect, extension has caused the crust to thin under the Basin and Range Province. It is generally 20 to 35 km thick. (Colorado Plateau: 35 to 50 km)

HIGH TEMPERATURE - the region is characterized by high heat flow values and the crust in the province has a temperature higher than that of stable continental crust.

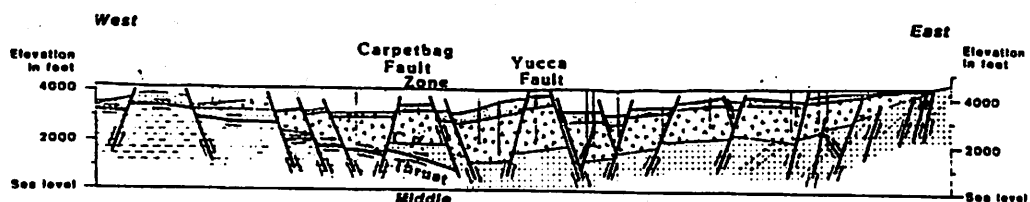
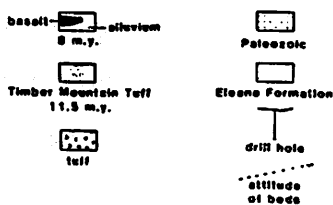
PAST ACTIVITY - with the subduction zone to the west, and the changing interactions between different oceanic plates, the region had already undergone considerable compression, marked by folding and thrusting before basin and range structure formed.

LOW UPPER MANTLE VELOCITIES - this lower seismic velocity value may indicate partial melting of the mantle.



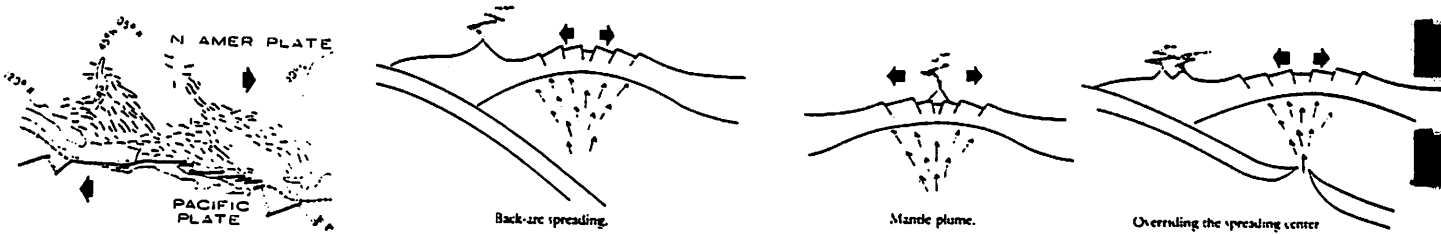
**Basin and Range Tectonics --
NEAR THE NEVADA TEST SITE**

The illustration at left is a "map" made from a Skylab image. It shows the N-S trend of the mountains in the region. Though the trend of this area looks similar to other basin and range regions, it is thought this structure may be volcano-tectonic in origin rather than caused by a detachment fault. Also, below is a cross section through the middle of Yucca Flat, showing that many different blocks and faults make up just that small section. The basin is not simply just a down dropped block, but rather it is a set of extensively fragmented ones.



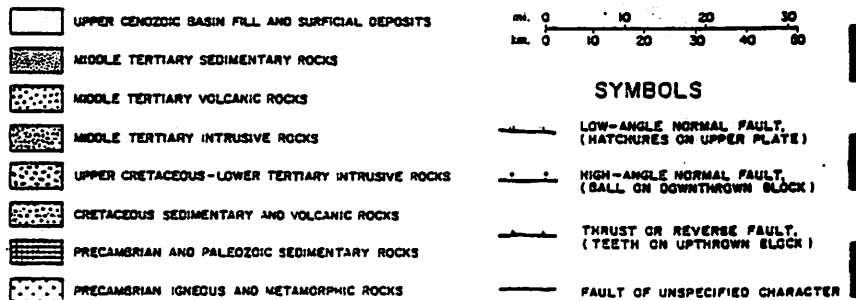
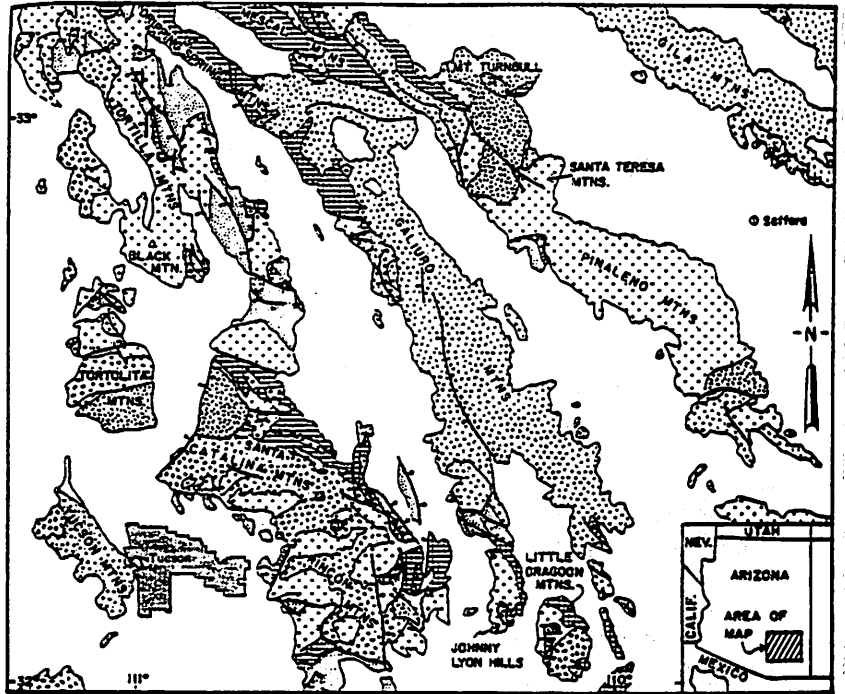
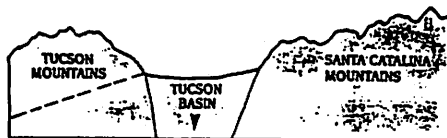
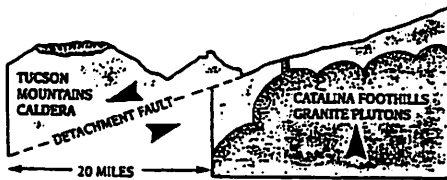
What Causes This Structure?

That's a good question. Unfortunately I don't have a good answer. Actually, it's not just that I don't have a good answer; it's everyone. Following are some ideas, each with their own strengths and weaknesses: *Wrench Faulting* - caused by differential motion between the North American and Pacific plates. *Back-Arc Spreading* - relates to mantle upwelling and associated spreading by a subduction zone. *Mantle Plumes* - similarly can cause uplift and consequent extension. *Subduction of the East Pacific Rise* - somehow the spreading center gets subducted below the Basin and Range province and provides the driving mechanism for extension



Basin and Range Tectonics -- TUCSON AREA

As is shown on the illustration of the Basin and Range Province, Tucson is contained in this region. To the right is a geologic map of the area. Notice here how the dominant trend is in the NW-SE direction and not simply N-S as before. As mentioned before, different regions having different characteristics, even if they are all dominantly basin and range structures. Also, note that the Tucson mountains are simply a tilted block that separated from the Catalinas.



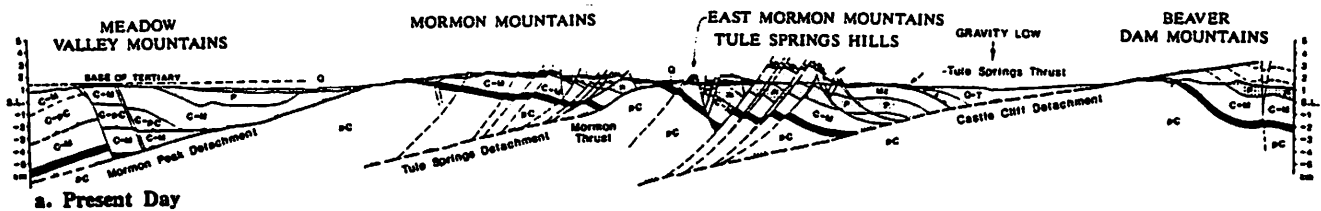
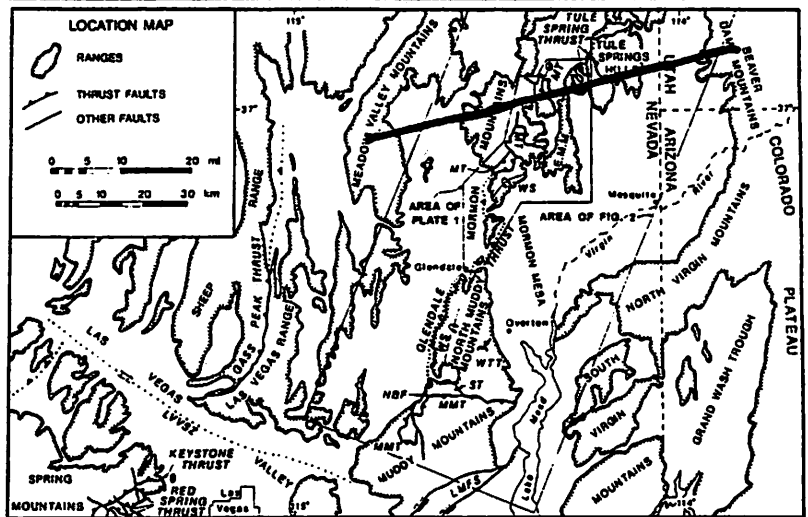
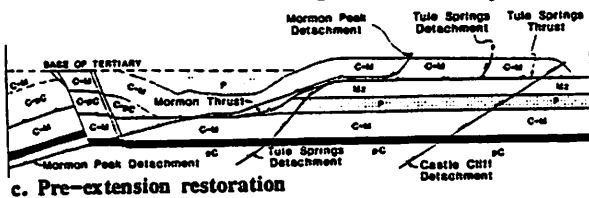
Unanswered Questions

There are whole books on the Basin and Range Province. Each different area has its own little mysteries, relating to fault mechanics, origin, timing. The whole region still has unanswered questions, like discussed in the previous section. Areas of the province appear to still be active today, with quakes and faults being reported in this century.

The bottom line is there was an extensional event which produced evenly spaced valleys and ranges, but the details are unknown and probably complicated. There seems to be evidence for different rates of extension at different times in the past, so any theory has to take this as well as the other characteristics mentioned previously into account. But why is this south-western region of the United States so special? Why do we see this extensive basin and range structure? These remain unanswered questions.

Basin and Range Tectonics -- NEAR MORMON MESA

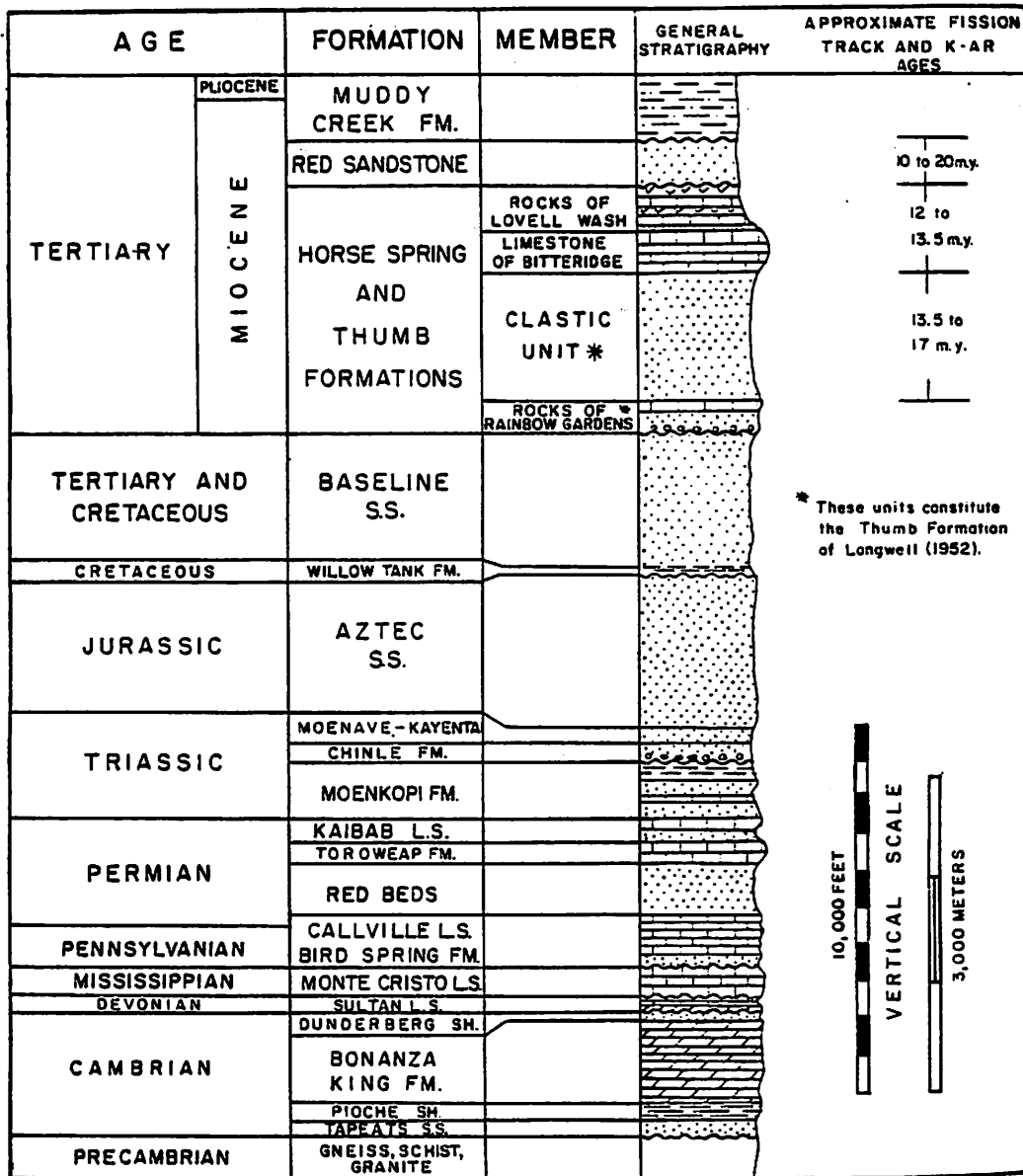
The diagram to the right illustrates the local ranges. The solid line is the location of the cross sections. The cross sections show how extension created the ranges seen today.



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Geology of the Valley of Fire



General Key:

Tertiary Rocks: deposited in complex system of basins, evolved during Miocene Basin and Range formation.

Mesozoic rocks: chiefly non-marine clastic rocks, tidal flat, floodplain, fluvial and swamp environments, autochthonous with respect to Mesozoic thrust faulting.

Paleozoic rocks: chiefly carbonates, shallow marine sea, allochthonous above the Muddy Mtn thrust fault.

Geology of the Valley of Fire

Road Log

0 131.93 (STOP 1) Muddy Mountain thrust relationships to SW. See Figure 9. Due south: Cambrian dolomite on upper plate of Muddy Mtn. - high gray hills. Thrust dips 20-35° S. To SW upper plate overlies light-gray cliff forming Pennsylvanian and Permian Limestone. The Valley of Fire is underlain by complexly faulted Aztec (red cross-bedded sandstone, generally red-brick in color although near faults etc. leaching may have changed color to lavender, orange, buff and whitish gray). Moenave and Kayenta equivalent, Chinle (+ Shinarup Congolm) and Moenkopi.

The Valley of Fire is autochthonous. Only the summit block of the SW part of N Muddy Mtns is thought to be allochthonous.

0.8 131.13 Minor N-trending high angle fault cuts both plates of Muddy Mtn thrust. Kaibab (Permian Limestone - the nonresistant, gypsiferous siltstone and SS unit between the two similar resistant cherty limestone units is part of the Kaibab) and Toroweap on W are juxtaposed against Permian red beds on E.

2.6 129.33 Road is on upper Summit plate, which is also lower plate of Muddy Mtn thrust. @ 2:00: contact btwn overturned Toroweap (cliffs N) and Permian red beds (SW of cliffs).

3.8 128.13 @2:00 Tilted block of Tertiary conglomerate rests unconformably on Aztec.

5.7 126.23 @2:30 Tertiary conglom tilted block - may be equivalent to younger Tert rocks of White Basin. @9:00 Chinle formation.

7.0 124.93 Valley of Fire Visitor Center. View of Arrowhead Fault to south across Valley of Fire. Fire Alcove is due south.

8.11 123.82 Halfway up hill, road crosses contact of Aztec with underlying Moenave and Kayenta equivalent rocks.

8.8 123.13 Road to White Domes (no turn) Proceed to pavement.

9.6 122.33 Fire Canyon and Silica Dome overlooks.

9.7 122.23 Aztec is visible in Valley of Fire to south. Lighter colored bleached Aztec is localized beneath unconformity with Baseline Sandstone. Baseline is chiefly cross bedded fluvial quartz arenite, but contains interfingering conglom wedges in its northern exposures. The fern "Tempskia" in Willow Tank provides only age control. Color change is possibly due to ancient ground-water leaching.

9.8 122.13 Aztec occurs on both sides of road.

10.0 121.93 @9:00 Willow Tank rests unconformably on Aztec. Willow Tank consists of basal conglomerate, claystone and SS.

10.9 121.03 Well developed cross stratification occurs in Aztec on both sides of the road. High index ripple marks occur on many stratification surfaces and indicate an aeolian origin.

11.2 120.73 (STOP 2) Hike up small hill rt of road for panorama of Willow Tank, Baseline, and overlying rocks of Rainbow Gardens.

To E dark conglom of Rainbow Gardens caps low hogbacks and dips east. It rests unconformably on Baseline SS. To N - an older conglom interfingers with Baseline quartz arenite and is called Overton Member. May have been derived from thrust sheets advancing to the E over an erosion surface during the Late Cretaceous and early Tertiary time. The Baseline is no older than Cretaceous and no younger than 17-18 m.y.

12.5 119.43 Willow Tank and Baseline contact near road.

12.8 119.13 @1-3:00: Cretaceous Willow Tank conformably underlies Baseline.

14.1 117.83 Turn right into Lake Mead Recreation Area

17.7 114.23 Virgin River Valley to E - several outcrops of salt were exposed before filling of Lake Mead. Salt is interbedded with Tertiary sed (Muddy Creek) Here Muddy Creek (The gently deformed to flat lying pink beds beneath Mormon Mesa) is highly deformed - near salt exposures Quaternary gravels dip steeply, probably result of salt doming and dissolution subsidence.

24.1 107.83 @9:00 Rogers Spring fault juxtaposes the Mississippian Monte Cristo Limestone and Muddy Creek.

24.2 107.73 Route enters alluvial fan deposits and leaves exposures of Muddy Creek. The rocks of Rainbow Gardens were exposed on either side of road at top of terrace.

26.23 105.7 Echo Bay Intersection. Overton arm of Lake Mead to E fills valley of Virgin River. @4:00 across Overton arm in Jumbo Peak area, Precambrian rapakivi granites - source for granite clasts in breccias near Frenchman Mountain.

Southern Virgin Mts @3:00 consist of a cratonic platform section of Paleozoic and Mesozoic rocks. Virgin Peak is the high one at 2:00.

Route on terrace of Quaternary alluvial fans, capped by caliche-cement.

30.73 101.2 West of road, high gray peaks are allochthonous Paleozoic carbonate rocks above Muddy Mtn. thrust. All these rocks tectonically overlie Aztec. Upper plate of thrust within view includes Ordovician thru Pennsylvanian rocks. Devonian and younger rocks are similar above and below thrust fault.

To W high angle Rogers Spring fault bounds thrust plate on east and southeast. juxtaposes upper plate rocks with autochthonous Aztec and rocks of Rainbow Gardens and clastic unit (sandstone, siltstone, and conglomerate with interbedded green tuff).

42.8 89.1 (STOP 3) Pull out on N side of road. S of road, Kaibab and Toroweap are exposed above Permian red beds. Moenkopi is conformable on Kaibab and is overlain unconformably by basal rocks of Rainbow Gardens.

Bitter Spring Valley fault near road separates Permian rocks S of fault from clastic unit on N. N of fault, rocks are folded and highly faulted. (see Figure 7 Panorama) The syncline involving the limestone of Bitter Ridge and the rocks of Lovell Wash are still visible to W near Lovell Wash itself. Bowl of Fire, visible to N, is an anticline in Mesozoic rocks, which are overlain unconformably by the rocks of Rainbow Gardens. Stratigraphy of Bowl of Fire anticline is of the cratonic platform type.

High-angle faults bound both flanks of Bowl of Fire anticline. On W, Aztec is faulted against the limestone of Bitter Ridge, which makes up light-colored ridge btwn the Muddy Mts and the hogbacks of basal Tertiary conglomerate.

E flank of anticline is faulted against the non-resistant clastic unit in valleys to NE. This fault trends slightly NW at N end of Bowl of Fire, but bends sharply around to E-W at S end of Bowl, where it joins Lake Mead fault system. This bending is shown by changes in strike of faulted ridges of basal conglomerate.

Small dark-colored hill on skyline to N is probably Mississippian Monte Christo Limestone, but it tectonically overlies Aztec. This juxtaposition probably results from Miocene low-angle gravity sliding, which is not part of the Muddy Mtn thrust of Sevier age.

Rocks visible to NW around Muddy Peak are allochthonous on Muddy Mtn thrust, which surfaces in Buffington Window area behind Muddy Peak. Paleozoic rocks above the thrust dip S towards stop. Because thrust generally follows one stratigraphic horizon, it too probably dips S towards autochthonous rocks of the Bowl of Fire. Thus, there is a major discontinuity between Muddy Peak and Bowl of Fire, which is called the Gale Hills Fault. This discontinuity marks the Northern basinal boundary of the Horse Spring-Thumb clastic unit (non-resistant Miocene red beds) and apparently began forming during the deposition of the clastic unit (13.5-16 m.y. B.P.)

Assembled by: Beth Clark

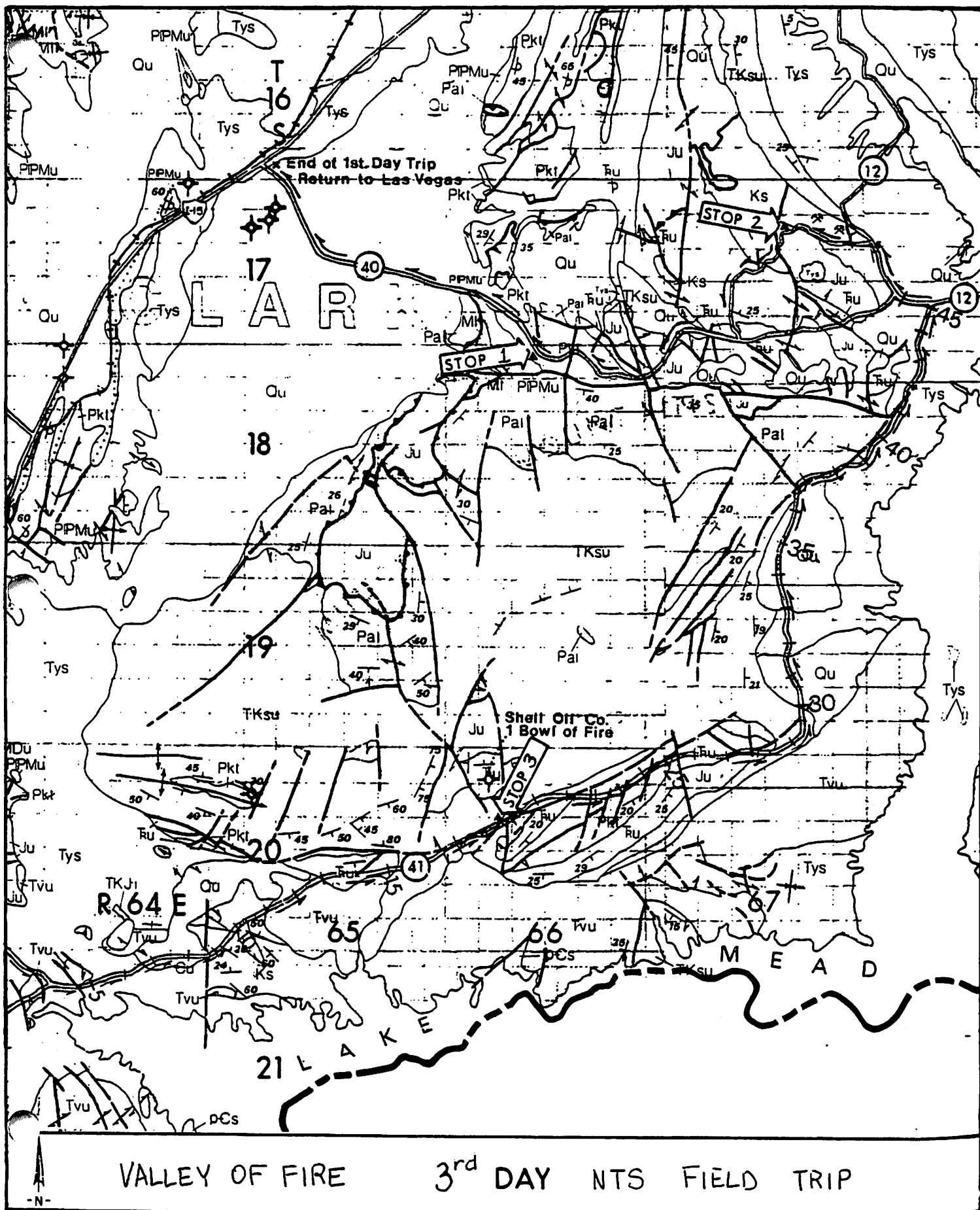
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VALLEY OF FIRE

3rd DAY NTS FIELD TRIP



Figure 7.—Photographic panorama of Bowl of Fire region. View is to north from STOP 3

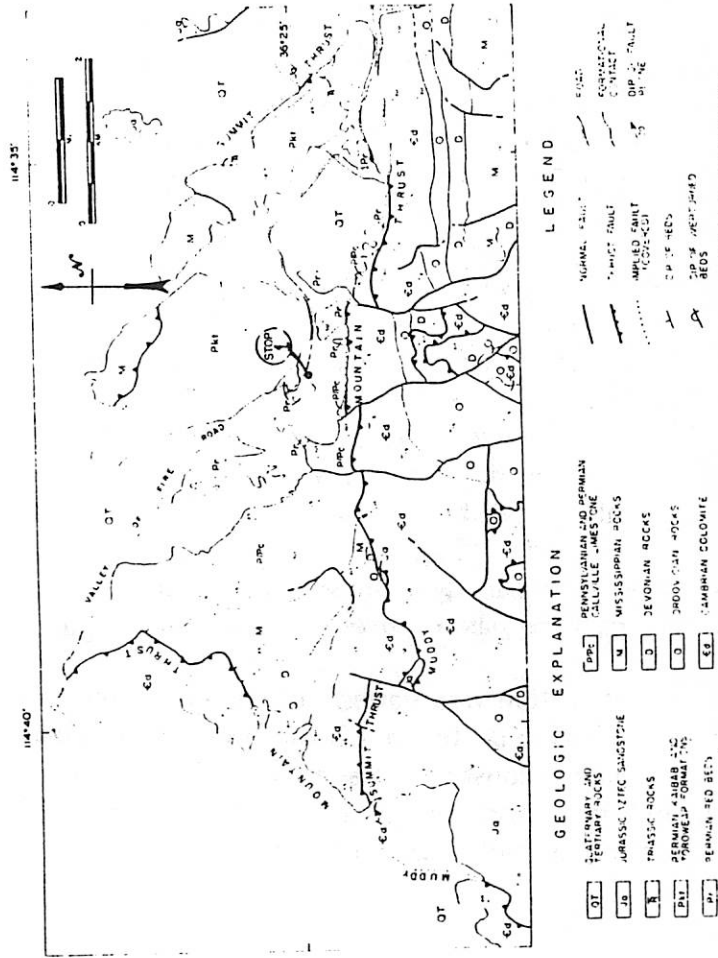


Figure 9.—Generalized map of north end of Burlington Pockets and southwest part of North Muddy Mountains.

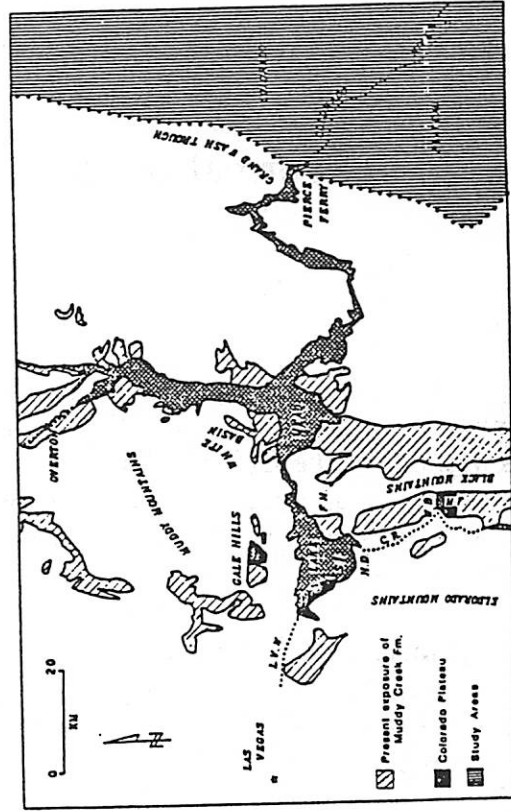


Figure 1. Regional location map showing the present exposures of the Muddy Creek Formation in the western Lake Head area. Also shown are names and locations of some of the areas discussed in this thesis: LVW = Las Vegas Wash, FH = Fortification Hill, SI = Saddle Island, CR = Colorado River, HD = Hoover Dam, WB = Willow Beach, MF = Malpais Flattop. (Modified from Anderson, 1978a and Bohannon, 1984).

Hoover Dam and the Colorado River

The Formation of Lake Mead

Eric Wegryn

For millions of years the mighty river now known as the Colorado flowed powerfully through the mountains and plateaus of the West, cutting great canyons and splendiferously deep gorges on its way out to the Gulf of California. Then one day humans came along and decided that this was not at all acceptable; the river would have to be stopped. "Dam this river!" they said, and work was begun on a project of monumental proportions: Boulder Dam.

The reasons advanced for building a dam were threefold: (1) flood control, (2) control of water supply, and (3) electric power generation. In early attempts to provide irrigation for southern California's Imperial Valley, canals had been built to carry water westward from the lower Colorado. For political and financial reasons, one canal was constructed south of the Mexican border, but a headgate was not built for it. In early 1905, the unruly Colorado flooded, sending its *entire* water flow down this canal, into the Alamo River, and toward the Salton Sink.^{1,2} Once the northern part of the Gulf of California, this sub-sea level depression had been cut off from the sea by the accumulated silt of the Colorado river delta. In an ironic reversal, the very river that had isolated the Salton Sink was now filling it with water. For two years the entire Colorado flowed into southern California, defying several major attempts to fix it, until finally returned to its "natural" course out into the Gulf in February 1907. Realizing that the puddle it had left behind was much too large to mop up, local residents renamed the Salton Sink the Salton Sea and tried to pretend that it was a good thing.

Still, something had to be done about the incorrigible river. After years of debate, seven States (WY, CO, NM, NV, CA, UT, and AZ) entered into the Colorado River Compact, an agreement (which only Arizona failed to ratify) to dam the Colorado and divide its waters. Two sites below the confluence with the Virgin River were considered for the dam. The first choice, Boulder Canyon, had bedrock of granite, but it was found to be seriously jointed and faulted.¹ Farther downstream was Black Canyon, a lovely yet inhospitable little canyon inconveniently separating millions of gamblers in Arizona from Las Vegas. Black Canyon, offered a foundation of andesite breccia, and would create a larger reservoir, and so the choice was made. The dam was to be built by Six Companies, and entirely funded by the U.S. Government, to be paid off over 50 years by selling the electricity it produced.

Construction was started in 1931. To begin with, four diversionary tunnels 16 meters in diameter had to be drilled 1.2 km through the walls of the canyon to carry the flow of the river around the construction site. The Colorado was diverted into the tunnels in November 1932, and two large cofferdams were built, upstream and downstream of the riverbed construction site, isolating it from the river.

Next the dam site had to be excavated, removing the sand and silt, and the loose boulders and gravel of the river bed so that the dam would rest upon a solid foundation of volcanic bedrock. The first concrete was poured for the base of the huge arch-gravity dam in June 1933, and pouring continued 24 hours per day for the next two years (about 6×10^9 kg). The base, 200 m thick, was situated between two transverse fault lines in the canyon floor, exerting a maximum compressive stress of ~ 3.8 MPa.¹ The dam tapers down with increasing height to about 14 m thick at the crest, 221 m above the foundation. In February 1935, as the dam neared completion, the diversion tunnels were closed, the Colorado was penned, and the new reservoir began filling with water. Finally after four years of construction, during which 112 men lost their lives³ in various, often boneheaded accidents, Boulder Dam was dedicated by President Roosevelt in late 1935 and turned over to the U.S. Government the following March. The two powerhouses (one on the Arizona side, one in Nevada) were completed not long after. Two of the original diversion tunnels became penstocks feeding the powerhouses from the four 120 m tall intake towers; the other two tunnels were connected to spillways on either side of the canyon.

The most obvious effect of the dam was the creation of the world's largest human-made reservoir, Lake Mead (also America's first National Recreation Area). As the water level rose 180 m over the next six years, the Boulder basin was flooded, then the Virgin basin and the lower 50 km of the Virgin river (forming the Overton Arm), and Gregg basin (fully 185 km up river). The tremendous new mass of water ($\sim 3.5 \times 10^{13}$ kg over ~ 590 km²) caused Earth's crust to deform slightly, resulting in frequent tremors throughout the area while the reservoir was filling. The cool, refreshing lake is much flatter and much more pleasing to the eye than the bumpy, rocky gorges that are now submerged, but no doubt less interesting to wacky geologist types.

The dam not only regulates the water flow of the Colorado, it also causes the river to release its load of silt as it slows down upon entering Lake Mead. The result is the gradual filling of the reservoir with silt (Fig. 1). In addition, the water that comes out below the dam is relatively clean, with a great capacity to pick up new material. This causes faster cutting of its channel for many miles downstream of the dam, reducing its slope until a new equilibrium is achieved.⁴

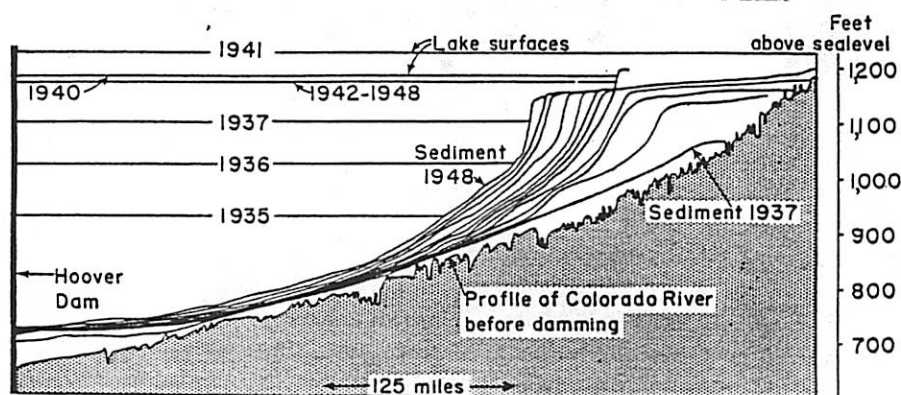
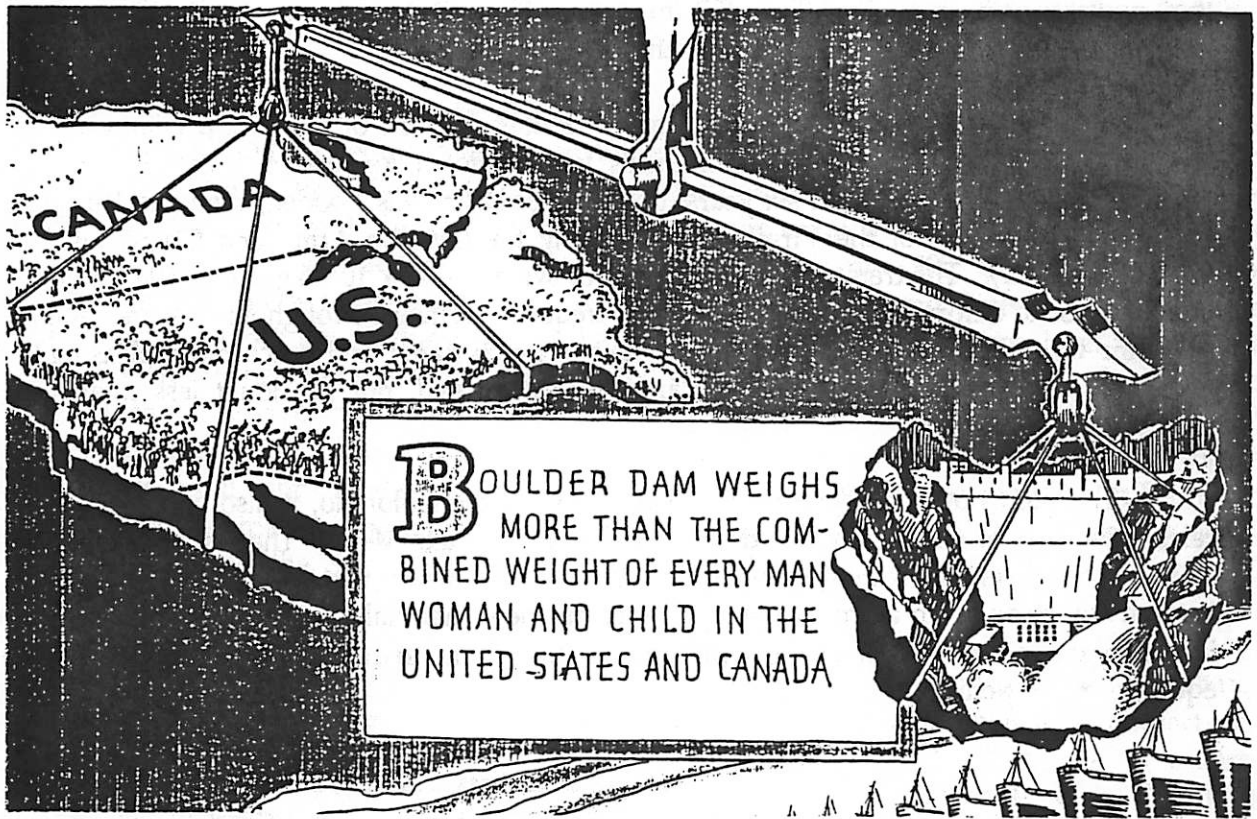


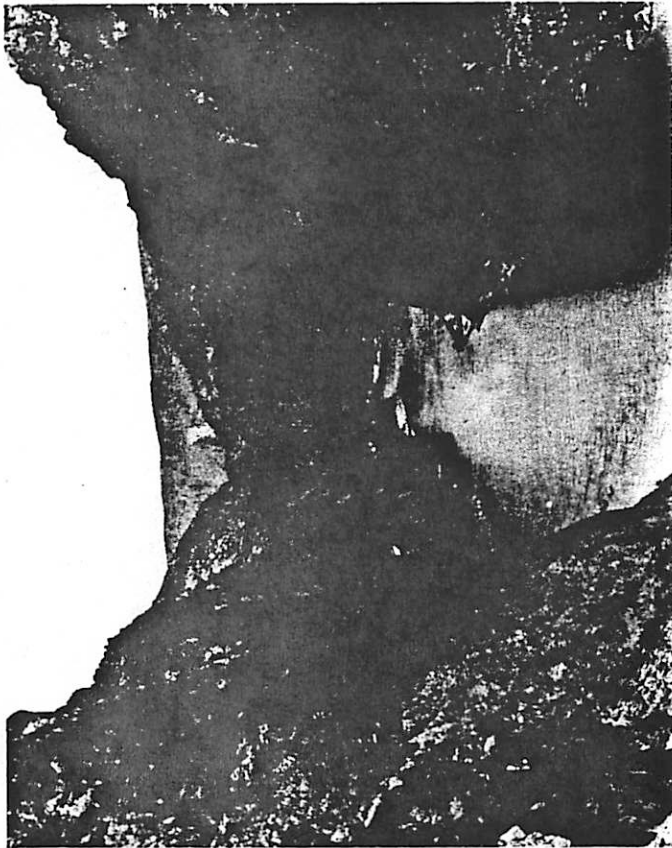
Fig. 1 Successive profiles of the body of sediment gradually filling the basin of Lake Mead, determined by annual surveys. (After C. P. Vetter.)

Boulder dam (renamed Hoover Dam in 1947) was heralded as a "conquest of nature" by Harold Ickes, Roosevelt's Interior Secretary. To others it was "one of the greatest monuments to man's ingenuity and conceit."¹ The dam has fulfilled its purposes of flood control, water regulation, and power generation well (and even provides a route of passage across the Colorado for college students traveling to Nevada). However, in 1983 a major flood reminded us that nature has not been completely tamed. After massive snowmelting far upstream, the spillways in the dam had to be opened, letting the floodwaters through, and causing millions of dollars worth of damage downstream. The Colorado still runs wild at times.

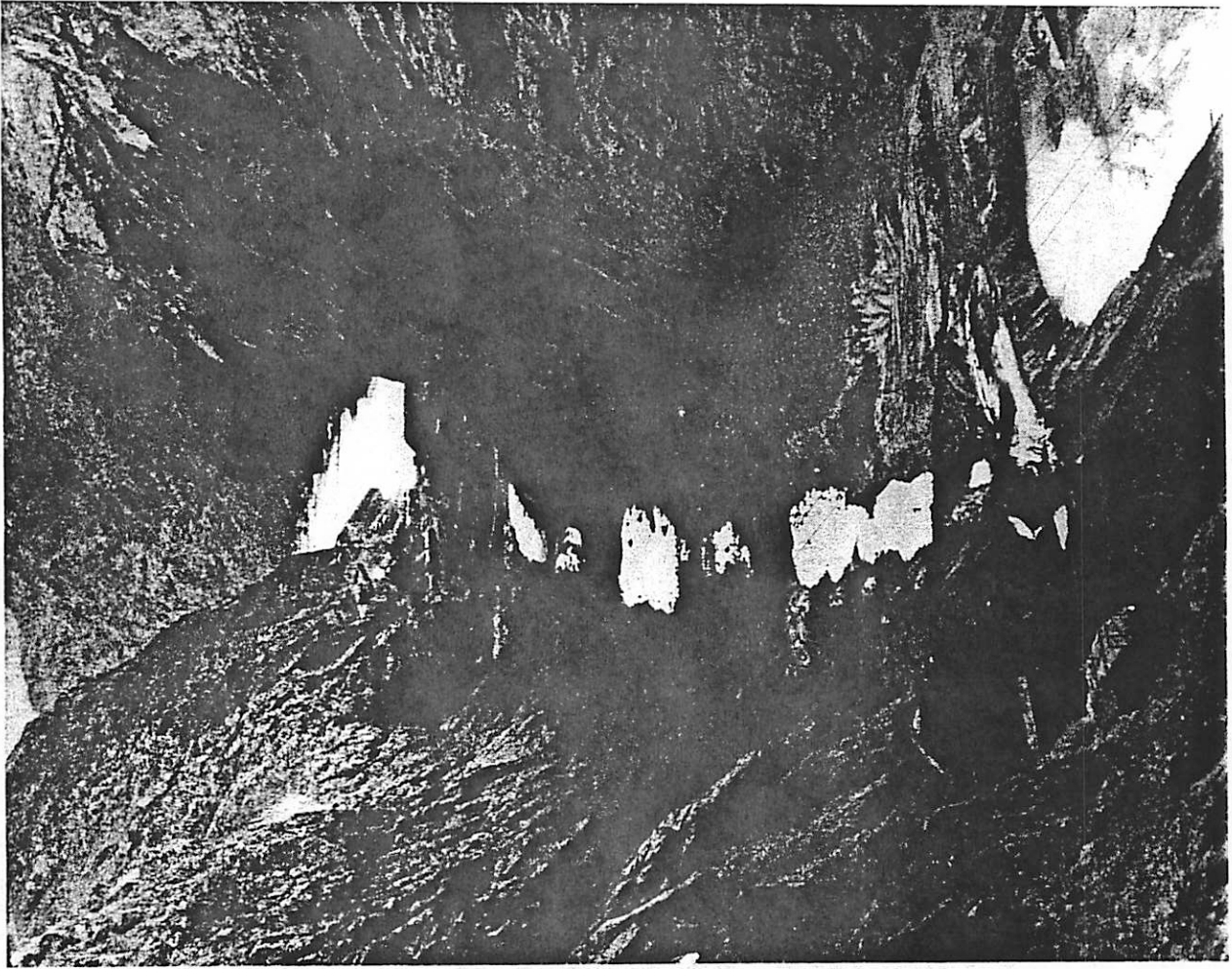


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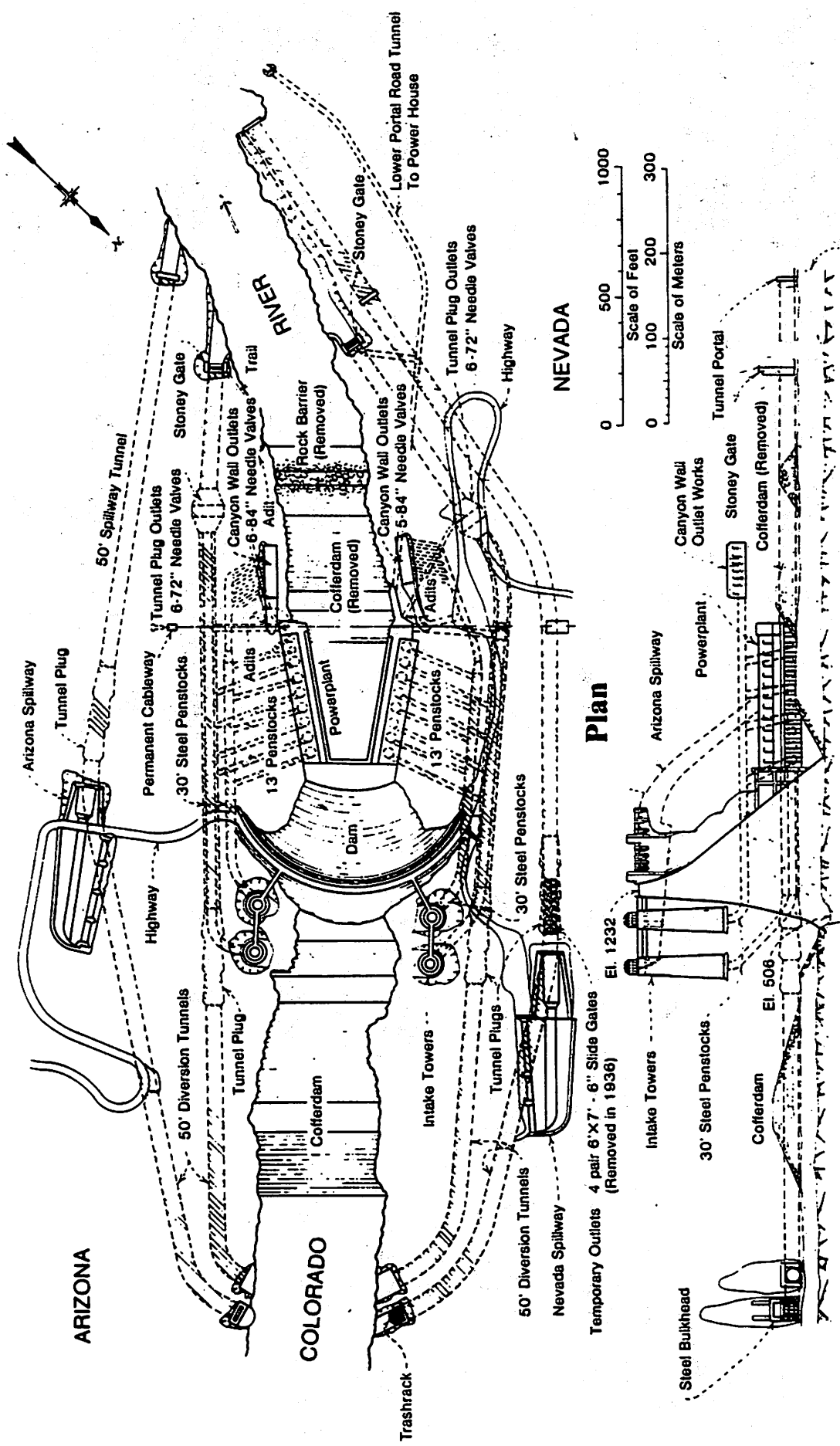
- 1 J.E.Stevens, *Hoover Dam, An American Adventure*, 1988
- 2 Colorado River Commission, *Colorado River and Boulder Canyon Project*, 1931
- 3 A.J.Dunar & D.McBride, *Building Hoover Dam, An Oral History of the Great Depression*, 1993
- 4 C.R.Longwell & R.F. Flint, *Introduction to Physical Geology*, 1955
- 5 Boulder Dam Service Bureau, *Boulder Dam Book of Comparisons,,* 1937



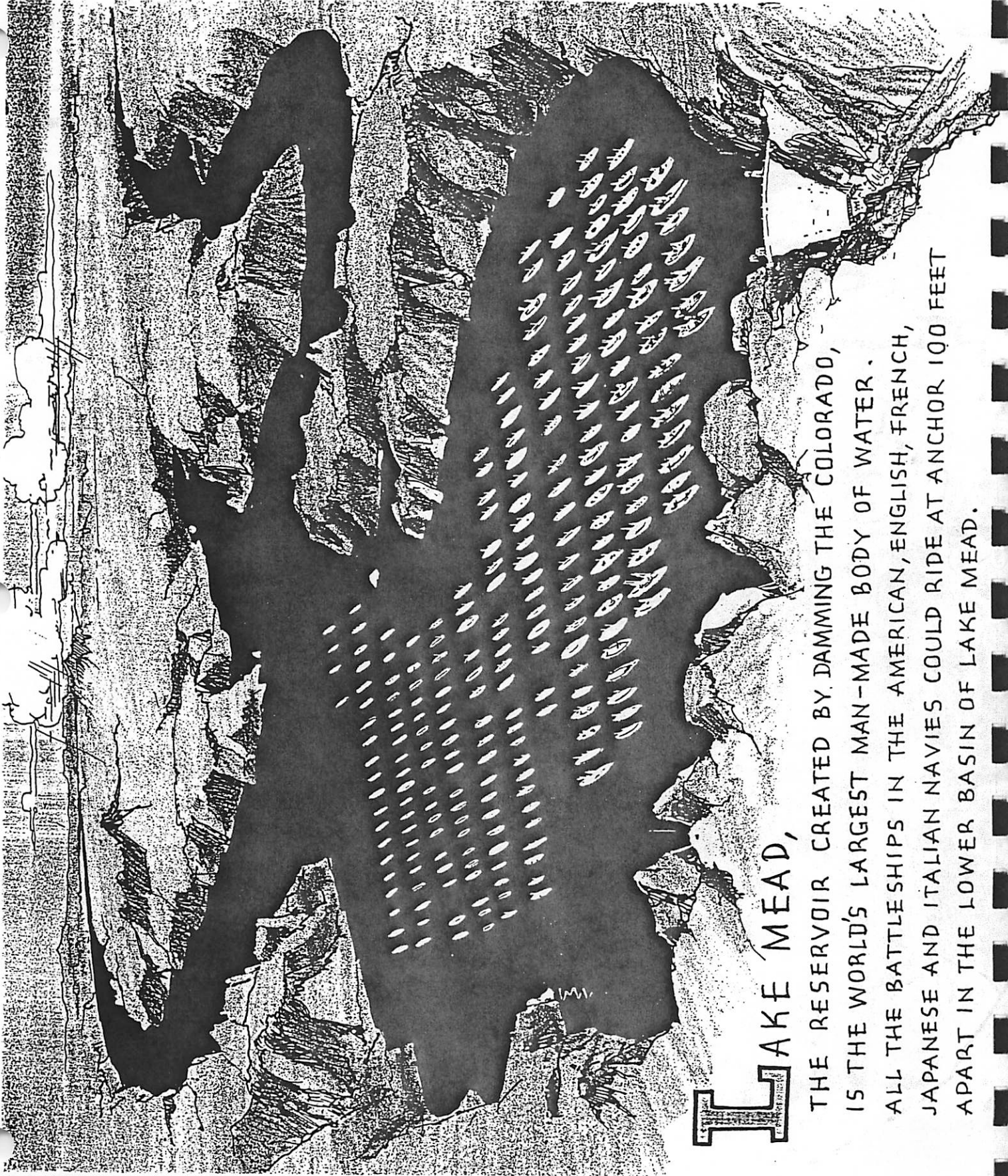
Black Canyon as it looked in 1922. The rocky point jutting into the river at right center marks the site chosen for Hoover Dam. (Bureau of Reclamation)



The floor of Black Canyon with the river diverted, 1 December 1932



**Longitudinal Section
Hoover Dam and Appurtenant Works**



Lake Mead,

THE RESERVOIR CREATED BY DAMMING THE COLORADO, IS THE WORLD'S LARGEST MAN-MADE BODY OF WATER. ALL THE BATTLESHIPS IN THE AMERICAN, ENGLISH, FRENCH, JAPANESE AND ITALIAN NAVIES COULD RIDE AT ANCHOR 100 FEET APART IN THE LOWER BASIN OF LAKE MEAD.

Red Lake Playa and the Giant Desiccation Polygons

(Guest Starring Bill Bottke as Chin Ho)

What is a playa?

Playas (spanish for shore or beach) are flat and barren portions of arid basins that periodically flood and accumulate sediment, often to depths in excess of 50 m. They form in climates which sustain high annual evaporation/precipitation ratios (often 10:1). Seasonal flooding and evaporation leave a thin layer of fine mud on the valley floor, which dries in the sun to form a very flat, dry lake bed of hard, mud-cracked clay. In some cases, this surface layer may also be covered with a bright white layer of dried salt. Ground water under playas is often deep, such that dryness extends many meters beneath the surface.

What are "giant desiccation polygons"?

Giant desiccation (drying) polygons are networks of fissures (frequently 1/2 m wide, 5 m deep, and 15 to 300 m long) oriented orthogonal to one another along a playa's surface. These patterns have been observed on 39 playas in the Southwest U.S. They tend to develop on playas with hard clay crusts composed of sheet silicates and carbonates; these playas also tend to contain low abundances of granules and soluble salts. Crusts formed from these compounds are extremely impermeable, such that they can flood and dry without wetting material 10 cm beneath the surface. This playa property suggests that deep desiccation, much deeper than can be produced by seasonal variation, causes contractual stress sufficient to rupture the surface in a giant fissure formation.

How do fissures form?

Over time, the clays in the playa can undergo both internal and interparticle dehydration, producing very high volume changes. The near-surface region can end up drier than the shrinkage limit (i.e. the water content in sediments, below which no further volume reduction takes place upon evaporation of soil moisture). This intense evaporating and drying seems to play an important role in making fissures. At these low moisture levels the clay can no longer deform plastically; instead, it behaves essentially as a brittle mass. At several meters below the surface the sediment contains more moisture but it is still below the plastic limit. The depth of the fissures (up to 5 m) and their large size suggest that these clays are resistant to strain.

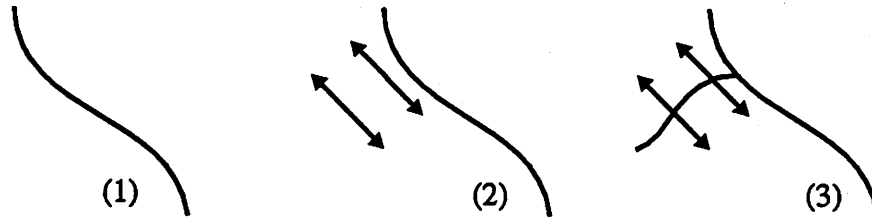
Dehydration proceeds from the surface to deep playa sediments, eventually penetrating the capillary fringe above the water table. Desiccation produces contraction in these sediments, creating a rupture at depth which can reach upward towards the surface. Additional stress may be placed on the rupture by a sinking subsurface water layer. This severe desiccation at depth may be caused by: (a) Intense evaporation extending from the surface downward. (b) Lowering of water levels because of man's activity (c) Natural variations flowing pluvial or other cyclic events.

Giant polygons

Giant polygons are created by intersecting fissures which seldom form symmetrical patterns. The polygonal pattern is common and seen on many surfaces (e.g. paints, glazes, basalt, etc.). It results from contraction of a layer of homogeneous material perpendicular to the cooling or shrinking surface. New fissures on playas generally extend 90° to older fissures, frequently at convex curvatures.

How do we get polygons?

1. A new crack formed in an uncracked area will follow randomly distributed zones of weakness. Thus, a sinuous course may develop.
2. Where the crack curves, the tangential stress is greatest on the convex side. Thus, the horizontal tension will be anisotropic (least in the direction perpendicular to first formed crack) with the zone of stress relief.
3. Secondary cracks will form perpendicular to the greatest tension, and thus intersect the primary crack at right angles, making them orthogonal. Contraction and rupture do not involve the surface layers, implying the fissure initiates below the surface. In many cases, the fissures fill in with sediments from the collapsed walls after formation.



Details on Red Lake Playa

- **Location:** Red Lake Playa is located in Hualapai Valley, NW Arizona, an alluvial basin having interior surface drainage and ground water outflow. It is roughly circular in shape and covers ~20 sq. miles. A fan terrace lies on east side of valley, pediment surface on west side.
- **Geology:** The local geology consists of igneous intrusive, metamorphic, sedimentary and volcanic rocks. Alluvial deposits of Tertiary age underlies NE part of Hualapai Valley. It consists of fragments of granite, schist, gneiss, and volcanic rocks in silty clay and sand. The playa surface is primarily silty clay. No pedogenic horizons seen.
- **Ground Water:** Ground water generally flows northward and bypasses the playa. The aquifer is mostly confined to the South-end of the playa. Ground water reaches roughly 100 m below the surface.
- **Fissure System:** There are two distinct systems of cracks. (1) An orthogonal system producing a "Y" pattern that radiates in from the center of an extinct pluvial lake in the south-central portion of the playa. It has branches that extend NE, NW, and S-SE to the flood plain of Truxton Wash. (2) Curvilinear features located just south of the center of the playa which form a nearly circular concentric ring structure centered on the same extinct pluvial lake.
- **Causes:** (a) Four wells have been dug in the last few decades near the playa. Since that time, several fissures have developed near/around the well sites. The implication is that pumping has caused the water table to sink, which increased desiccation at depth, added stress to the clay sediments below the surface, and eventually caused brittle failure. (b) Salt flows and faulting underneath the playa may have created a new topographic low, which would produce the same kind of failure discussed in (a). The salt appears to have flowed from the valley and formed a ridge near the NE branch of the "Y" formation.

References: (1) Neal et al. (1968) *GSA Bull.* 79, 69-90. (2) Fife, D. (1980) *Geol. and Mineral Wealth of the California Desert.* 414-429. (3) Lister and Secrest (1985) *Bull. Assoc. Eng. Geologists.* 223, 229-314. (4) McLarty and Wood (1994) *LPL Grand Canyon Trip Handout.*

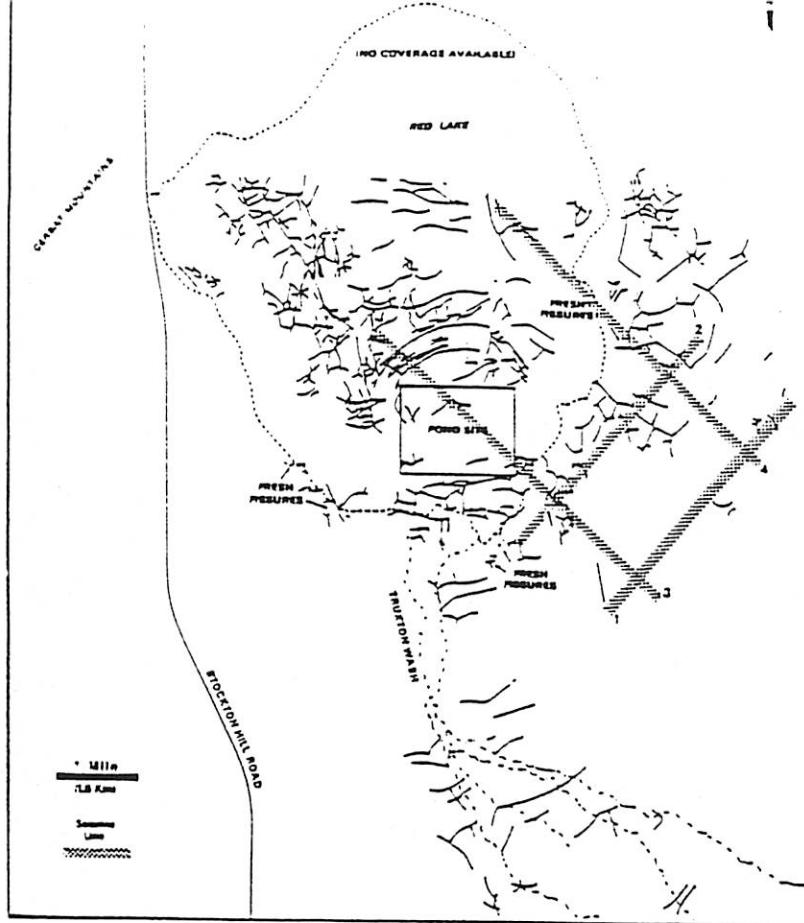


Figure 1: This is a sketch of Red Lake Playa showing the general structure and locations of the desiccation polygons and curvilinear cracks.



PHOTO 2. Antelope Playa, spring 1977, showing eroded fissure which completely drained 15 to 30 cm. of water from the playa surface in a few hours. The greater erosion on the right is the result of the wind "blowing" playa waters into the fissure from that direction. Surface waters probably reached the water table over one hundred meters below.

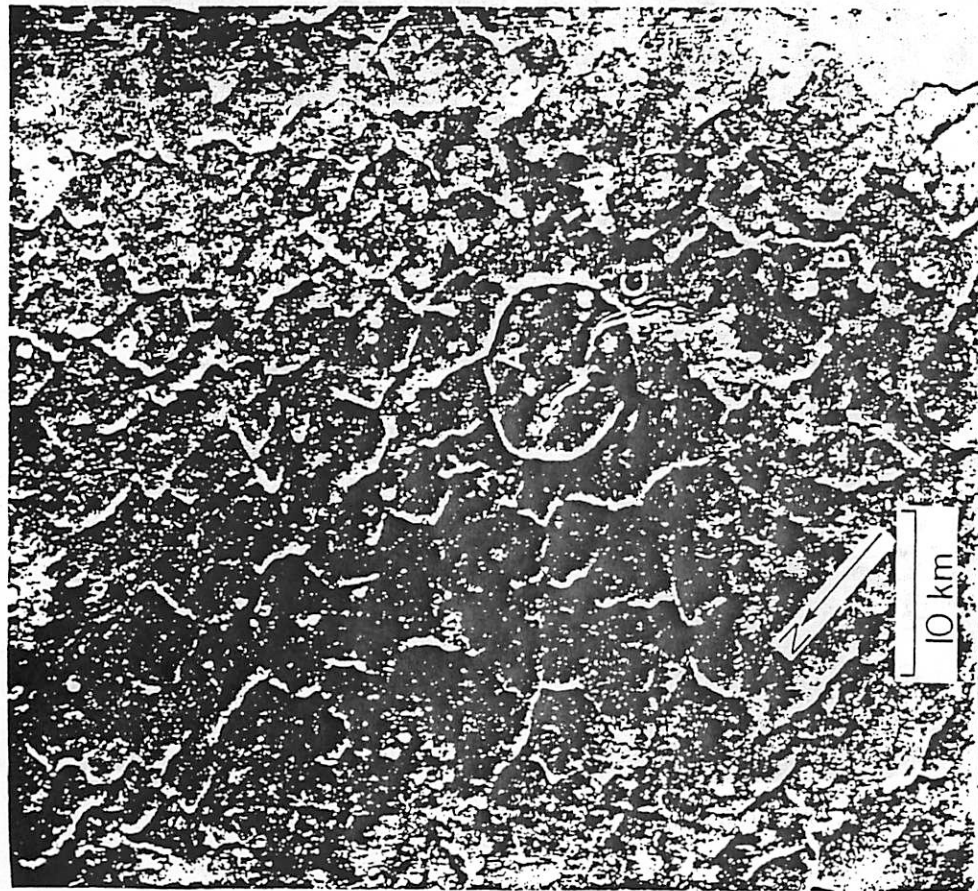


FIG. 6. Troughs in southeastern Acidalia Planitia showing preferred north-northeasterly orientation. Other features of interest include the circular trough at A, the ridge at B, and the ridge with the trough running down the crest at C (Viking orbiter frame 032A18).

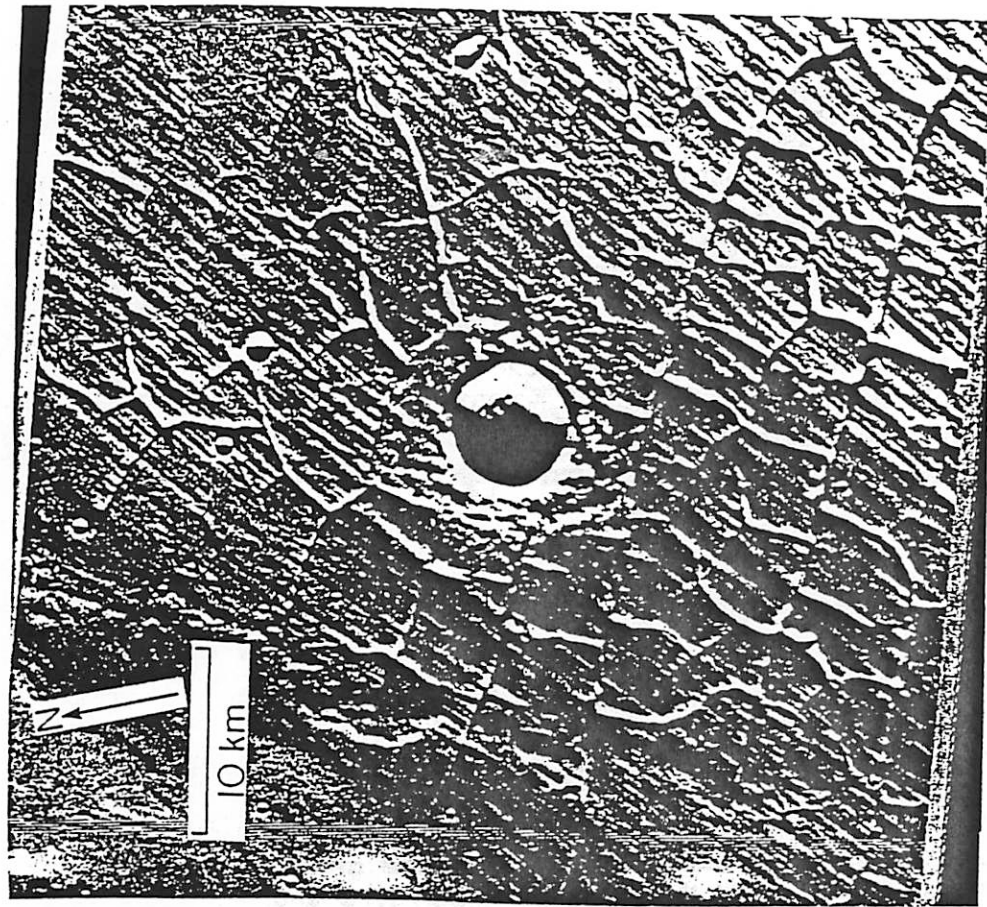


FIG. 11. Polygonal troughs northwest of Kasei Vallis (Viking orbiter frame 664A04).

Grown up fractures on Mars

JC Pechmann, 1980, "The Origin of Polygonal Troughs on the Northern Plains of Mars,"

Icarus 42, 185-210.

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