A-0297

PDR-LLL
LPDR-WM-10(2)
WM-11(2) WM-16(2)

Lawrence Livermore National Laboratory

NUCLEAR SYSTEMS SAFETY PROGRAM

Code L-196

WM-RES
WM Record File A-0297
LLL

WM Project 10, 11, 16
Docket No. ______
PDR ✓
LPDR B, N, S

Distribution:
Blackford
(Return to WM, 623-SS)

March 19, 1987

WM DOCKET CONTROL CENTER
'87 MAR 23 A11:45

Mr. M. E. Blackford, MS-623ss
Project Officer, WMGT
Geology/Geophysics Section
Technical Review Branch
Division of High-Level Management, NMSS
U.S. Nuclear Regulatory Commission
Washington, DC 20555

SUBJECT: Transmittal of Trip Report by McKague and Purcell

Reference: FIN A0297

Dear Mr. Blackford:

With this letter, we are pleased to transmit three (3) copies of the subject trip report entitled

"NRC Field Trip Feb. 23 to March 2, 1987" dated 3/18/1987.

Please note in this trip report the five points summary made by Larry McKague and Rus Purcell jointly.

If you have any questions, please let us know.

Sincerely yours,

Dae H. (Danny) Chung
Project Leader

DHC/ic

cc: Ms. C. Abrams, WMGT
Keith McConnel, EMGT
John S. Trapp, WMGT

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PDR WMRES EXILLL
A-0297 PDR

attachment in pocket #1 (1987)

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To: ME Blackford w/ ltr dtd 3/19/87 A-0297
Fm: Dee H. Chung

NRCGS 87-2
March 18, 1987

TO: D. Chung HLMcK

FROM: H. L. McKague and R. Purcell

SUBJECT: NRC Field Trip Feb. 23 to March 2, 1987

This trip was set up by the NRC and included participants from LLNL (2), NRC (8), DOE (2), SAIC (1-4) and the state of Nevada (varying number of UN-R graduate students and faculty, and Bureau of Mines and Geology staff). The trip in general was successful, but would have been more rewarding if the USGS had participated. From our standpoint the following could be considered high points of the trip:

(1) The review of a large number of trenches (10) crossing various types of faults allowed comparison of features. Especially valuable was the comparison of features in trenches CF 2 and 3, in Crater Flat, with a trench crossing a scarp resulting from horizontal movement during the 1932 Cedar Mountain earthquake. Similar features occurred in both trenches.

(2) Participation by Fred Peterson (UNR) was very valuable in that it provided a new view of problems related to soils based on 20 plus years of experience in Nevada.

(3) The stops in the Bullfrog Hills and in the canyon south of the Mormon Point turtleback provided a first hand view of two different detachment surfaces. A third detachment surface, at stop 2 of the first day, has been suggested by USGS. However, we saw no evidence for detachment.

(4) Stop 3 on day 3 was at a potential southern extension of the Solatario Canyon Fault. This could extend the length of the Solatario Canyon Fault by several miles or more. This location and one further south was discussed in Rus Purcell's report (10/3/86) of work done in Crater Flat in May 1986.

(5) Discussions with Hal Bonham (Nevada Bureau of Mines and Geology) were enlightening in suggesting the types of economic mineralization one might expect associated with the southwestern Nevada volcanic field.

Lists of the participants are given in Appendices A, B, C, and D.

Itinerary by Day

2/22/87 Travel to NTS from Pleasanton, CA

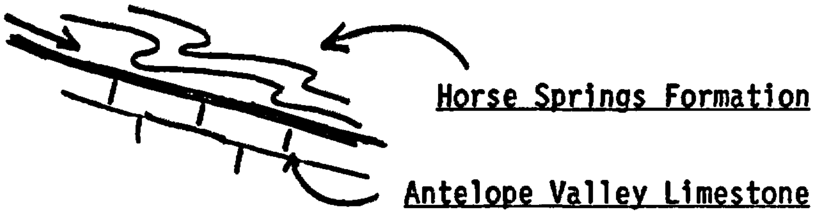
2/23/87 East central NTS

Stop 1 Southern Frenchman Flat

- North of Mercury on old Burma road.
- Hill south side. Oligiocene Horse Springs Fm over Ordovician Eureka Fm
- Earliest Tertiary Formation (29 my) on NTS.

Stop 2 ~2 miles to west.

- Horse Springs Fm over Antelope Valley Fm. According to USGS location of isoclinal folding due to slump of Tertiary rocks into Frenchman Flat.



Stop 3 Mine Mountain

- Devonian carbonates overthrust on Mississippian argillite.
- Overview of Yucca Flat.

Stop 4 Rotated Alluvium in Subsurface

- On 4-02L road - pointed out location of drill holes for Listric Fault study, (Elwood, McKague and Wagoner, 1985 UCRL 93405).

Stop 5 Carpetbag Fault

- Along northern trace of Carpetbag Fault in Area 2. Pointed out graben - discussed interpretation, i.e., tectonic movement vs compaction.

Stop 6 Yucca Fault

- Top of Yucca Fault scarp on Circle Road

- Normal fault, but with aeromagnetic evidence for right lateral slip
- Scarp displacement increases northward to about 40'

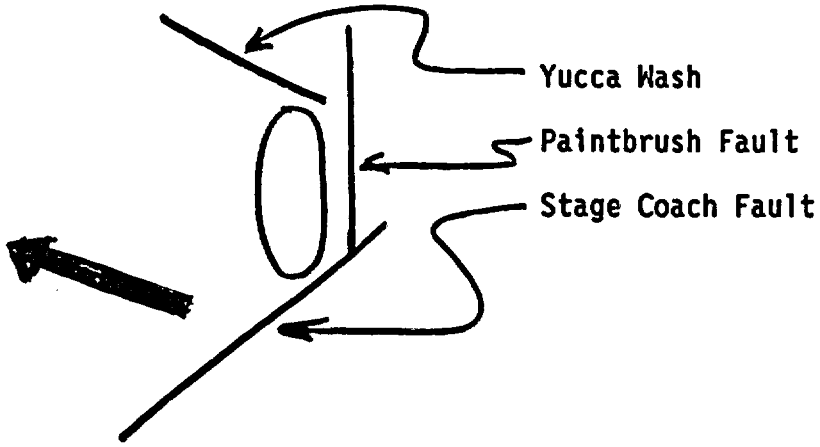
Stop 7 Boundary Fault

- Climax granite against down faulted alluvium.
- Drove by surface facilities of SFT-Climax.
- Drove back to Mercury by way of Area 17.

2/24/87 Geology South and East of Yucca Mountain

Stop 1 Stage Coach Fault

- N-S trending fault.
- Vertical caliche in wash.
- Scott's model was discussed. Stage Coach Fault is southern side of listric - detachment fault.



Stop 2 Trench 14

- Origin of vein filling.
- Discussion by Fred Peterson would lead to reconsideration of pedeogenic origin - (a) see similar phenomenon in horizontal soil formations, (b) bedrock surface would provide enough H_2O, (c) $CACO_3$ carried in solution and precipitated, (d) faulting could provide necessary space for growth, (e) Peterson thought material was similar to horizontal deposits in middle and west end of trench (duripan).

Stop 3 Trench 17

- 50' south of Ue25p-1

- Trench across Midway Valley Fault.
- A vertical calcite vein (<2" thick).
- Ue25p-1 reached Pz at ~8000'. Tuff-Pz contact used by Scott as evidence for detachment - not clear how.

Stop 3 Busted Butte

- Sand ramps cut by faults
- Soil surfaces offset ~20'

2/25/87 Geology Crater Flat

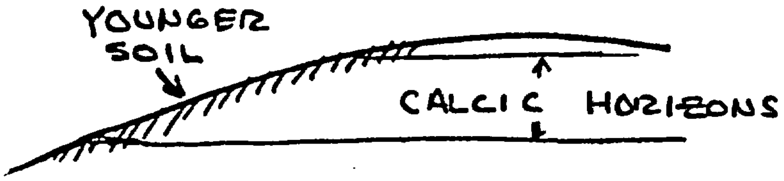
Stop 1 Lathrop Wells Basaltic Cone

- Death Valley - Pancake zone
- Variation in age dating (App. E #9)
- Handouts (see App. E 3, 4, 5, 6, 7 and 8).

Stop 2 Trenches CF 2 and 3

- Flower structures may indicate strike-slip movement
- Downslope clastic wedges are smaller and different from those associated with Wasatch Mountain front faults.

Surficial soils younger than surface they overlie



2 soil possibilities
polygenetic

Stop 3 Extension of Solatario Canyon Fault

- On road to WT-11
- Caliche filled veins north of road and in wash to south.

Stop 4 Bare Mountain Fault

- In old prospect pit
- Poor exposure
- B. Troxell has mapped ~3 km horizontal displacement based on off set of Zabriski quartzite.

Stop 5 Beatty Fault

- Fluvial deposits but not conclusive about presence or absence of fault.
- Trench in front of scarp.

2/26/87 Geology Beatty and Goldfields, NV

Stop 1 Old Bull Frog Mine

- Detachment in Bull Frog Hills - Tertiary tuff overlying Precambrian - striations suggest direction of movement was N 70°E or S 70°W

  Outcrop 0.5-1 mile SW core complex - metamorphic rocks presumably from beneath detachment surface

Stop 2 Flurospar Canyon

- Potential steeply dipping detachment surface between Paleozoic carbonate and Tertiary tuffs according to Bob Scott - more likely typical Basin and Range normal fault.

Stop 3 Redtop Mine at Goldfield, NV

- Shown alteration and mineralization

2/27/87 Geology Tonopah, NV and Cedar Mountain earthquake

Stop 1 Mizpah Mine at Tonopah

- Shown vein structures by Hal Bonham
- Suggested this type of mineralization more likely in Yucca Mountain region than that shown to us in Goldfield.

Stop 2 Cedar Mountain Earthquake

- Cedar Mountain fault
- Flower structures

- Pressure ridge
- Fault 23 of Gianella and Callaghan (1934) BSSA v. 24, p 345-384.
- Wrench fault tectonics suggested as potential cause.

Stop 3 Dyer, NV

- Fish Lake - Death Valley fault zone - extension
- 200' scarp in alluvium upthrown to west. UN-R student Tom Sawyer will be working on this for M.S. thesis

2/28/87 Death Valley and Tecopa

Stop 1 Paleohydrology-Furnace Creek Wash

- Discussed calcite vein cutting Funeral Formation
- Looked at fracture filling along road at Monument boundary

Stop 2 Artist Drive Fault

- Thought to be youngest fault scarp in Death Valley
- N-S scarp is in alluvium
- Down to west up to ~3' displacement

Stop 3 Badwater, CA

- Discussed Turtleback surfaces as extensional features

Stop 4 Detachment Surface at Mormon Point (1 mile south)

- Detachment surface with listric faults. Quaternary alluvium overlying Precambrian carbonate rocks.

Stop 5 Southern Death Valley

- Shoreline Butte and faulted 600,000 year old cinder cone.
- Seismic reflection survey suggests magma at 10-15 km depth (Geology, 1986).

Stop 6 Shoshone, CA (1 mile south)

- Tecopa Lake beds - Pleistocene Lake
- Zeolitization - due to chemical gradient in lake water

Stop 7 Tecopa Hot Springs

- Tufa mounds
- Also found along east side of valley in Tecopa Lake beds - thought to mark a fault [Sheppard and Gude, (1968), USGS Prof. Paper 597]

3/1/87 Caldera Southeast of Las Vegas, NV

Stop 1 Trip to minicaldera in McCullough Mountains east of Sloan, NV

- A small caldera illustrating many features found in large calderas. M.S. (UNLV) thesis area of Casey Schmidt, LLNL-N.

3/2/87 P Tunnel

- Trip to P Tunnel with NRC engineers. Went in P 0.2 side drifts. Several small faults were observed and discussed. Also revisited Stops 5 & 6 of Day 1.

3/3/87 Sterling Mine

Stop 1 Trip to Sterling Mine

Overview of operation by Mr. Dwight Crossland. One interesting comment made by Mr. Crossland was that he believed major Bare Mountain frontal fault was further east than mapped by USGS.

HLMcK:be 389G

cc: R. Purcell
J. Yow

APPENDIX A

Participants 2/24, 2/27/87

Gil Cochran	DRI-WRC
Roger Jacobson	"
Nate Morley	DOE/NVO/WMPO
Gene Rodriguez	"
Larry McKague	LLNL
Rus Purcell	" Contractor
Don Shettel	Mifflin & Assoc.
Charlotte Abrams	NRC
Mike Blackford	"
John Bradbury	"
Bill Ford	"
A. K. Ibrahim	"
Keith McConnell	"
Paul Prestholt	"
John Trapp	"
Bruce Hardin	SAK/LV
Pat Cashman	UN-R
Alan Chamberlain	"
Ed Corbett	"
Diane Donovan	"
Becky Elwood	"
David Greene	"
Mac Jackson	"
Bill Morrison	"
John Perry	"
Bill Peppin	"
Fred Peterson	"
Tom Sawyer	"
Burt Slemmons	"
Rich Schweickert	"
Bob Waters	"
Steven Weiss	"
John Bell	" NBMG
Hal Bonnam	"
Craig dePolo	"
Alan Ramelli	"

APPENDIX B

Participants 3/1/87

Charlotte Abrams	NRC
Keith McConnel	"
Larry McKague	LLNL
Casey Schmidt	LLNL-N

APPENDIX C

Participants 3/2/87

Loren Lorig	ITASCA
David Conover	USBM
Kanaan Hanna	"
Charlotte Abrams	NRC
Bill Ford	"
Dinesh Gupta	"
Keith McConnel	"
John Peshel	"
Larry McKague	LLNL

APPENDIX D

Participants 3/3/87

Charlotte Abrams	NRC
Keith McConnel	"
Larry McKague	LLNL

APPENDIX E

Handouts Provided by
LAWRENCE LIVERMORE NATIONAL LABORATORY

#1

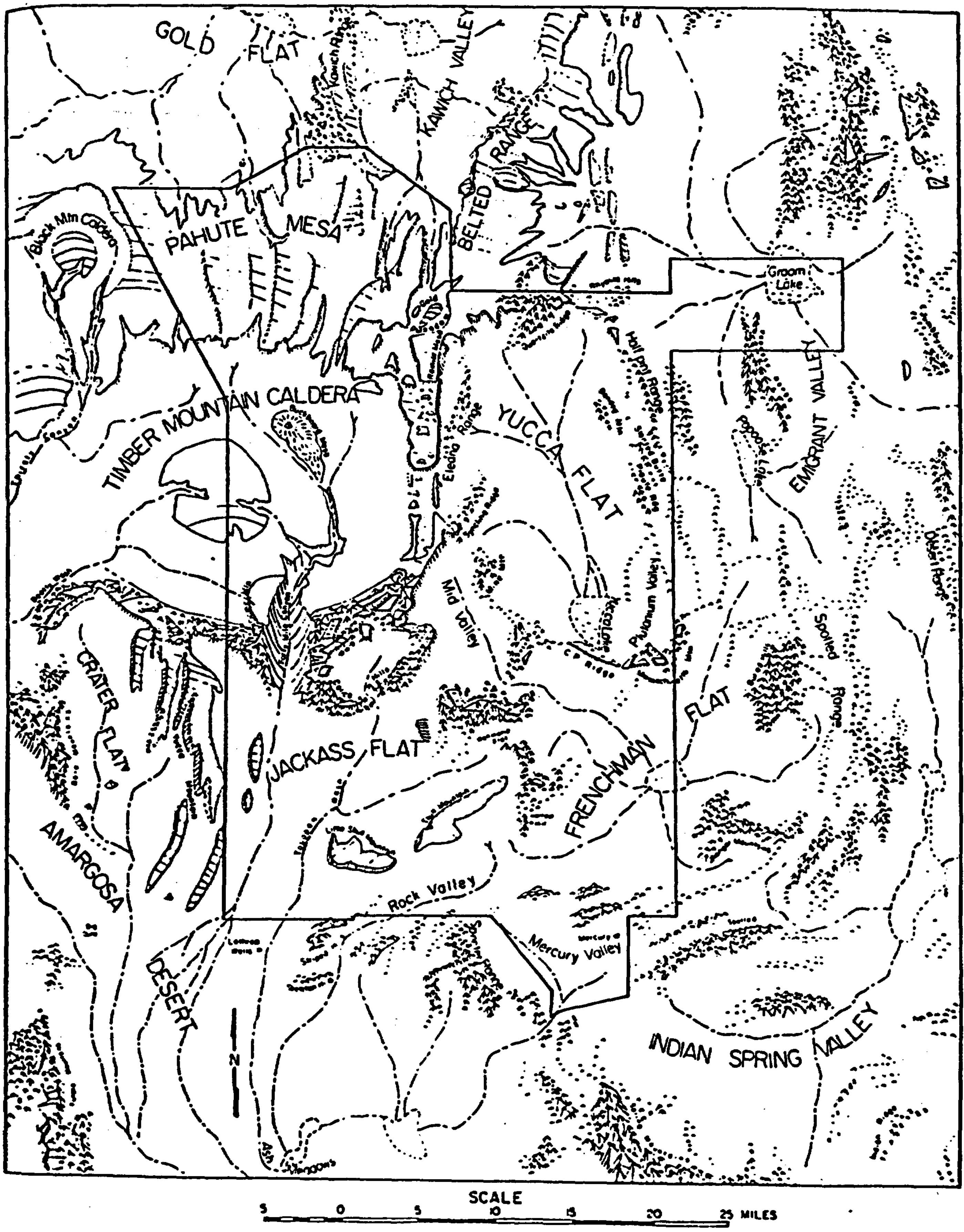


Figure 2. Physiographic Diagram of the NTS and Surrounding Areas

& SINNOCK, S (1982) GEOLOGY OF THE NEVADA TEST SITE AND NEARBY AREAS, SOUTHERN NEVADA. SANDIA NAT. LABS. SAND82-2207

ALLUVIUM
STRATIGRAPHY
YUCCA FLAT

TABLE VIII

Lithologic Log of U2cq

Depth (m)	Description
0-146	Mixed Alluvium, generally subequal amounts of Tertiary tuff and fragments of Paleozoic clastic rocks and subordinate limestone from 0-91 m, clastic and limestone fragments are dominant from 91-116 m, and tuff fragments are dominant from 116-146 m, coarse gravel beds are common between 57-123 m, calcareous.
146-159	Basal Tuffaceous Alluvium, light brown, gravelly sand, essentially no fragments of Paleozoic sedimentary rocks, calcareous.
159-172	Bedded Tuff related to the Timber Mountain Tuff, grayish fine-grained bedded tuff, common quartz, glass shards, white pumice, magnetite, and feldspar. There may possibly be associated non-welded ash-flow (Ammonia Tanks?) from 159-167 m.
172-271	Rainier Mesa Member of the Timber Mountain Tuff, mainly non-welded pinkish-brown ash-flow tuff and associated ash-fall, common quartz, feldspar, glass shards, pumice, lithics, and biotite, vitrophyre from 182-188 m, local vapor phase alteration between 223-238 m, basal shard zone from 244-271.
271-408	Paintbrush Tuff, generally light-colored bedded, ash-fall, and reworked tuff, common glass, quartz, feldspar, and lithics, mafic-rich zone from 331-348 m.
408-424	Grouse Canyon Airfall, gray airfall tuff, common dark gray glass blebs and pumice.
424-442	Tunnel Beds, light colored bedded and reworked tuff, common quartz, feldspar, lithics, and mafics.

MIXED ALLUVIUM

BASAL
TUFFACEOUS
ALLUVIUM

JLW 7/26/83 Lithology interpreted from cuttings, downhole photography, and natural gamma and magnetometer logs.

#2

Surface Effects Map

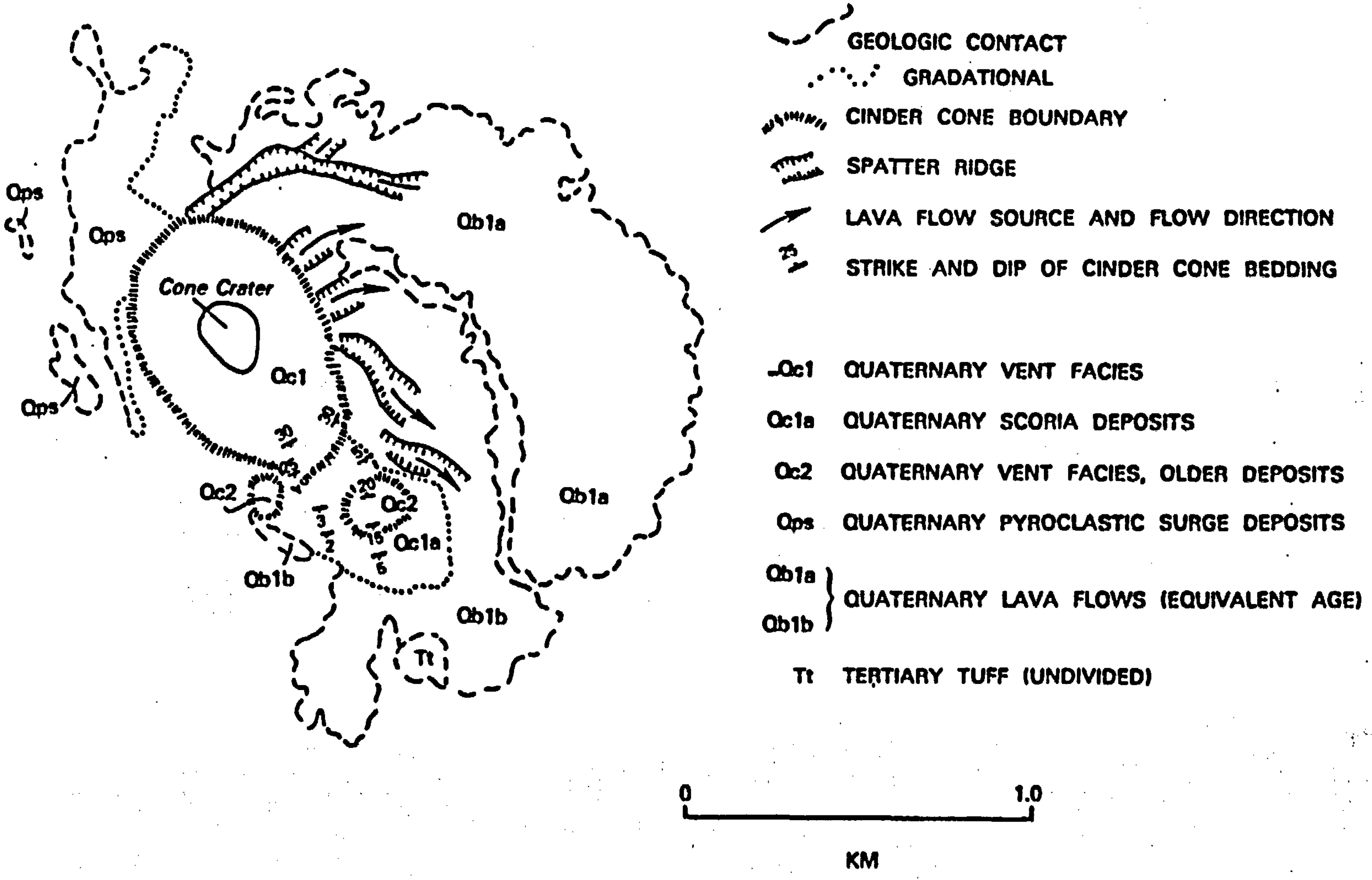


Fig. 4.
Geologic map of Lathrop Wells volcanic center (Stop 2).

DOCKERY ET AL (1985) NEVADA TEST SITE FIELD TRIP GUIDEBOOK 1984 LOS ALAMOS NAT. LAB — LA-10428-MS

#3

#4

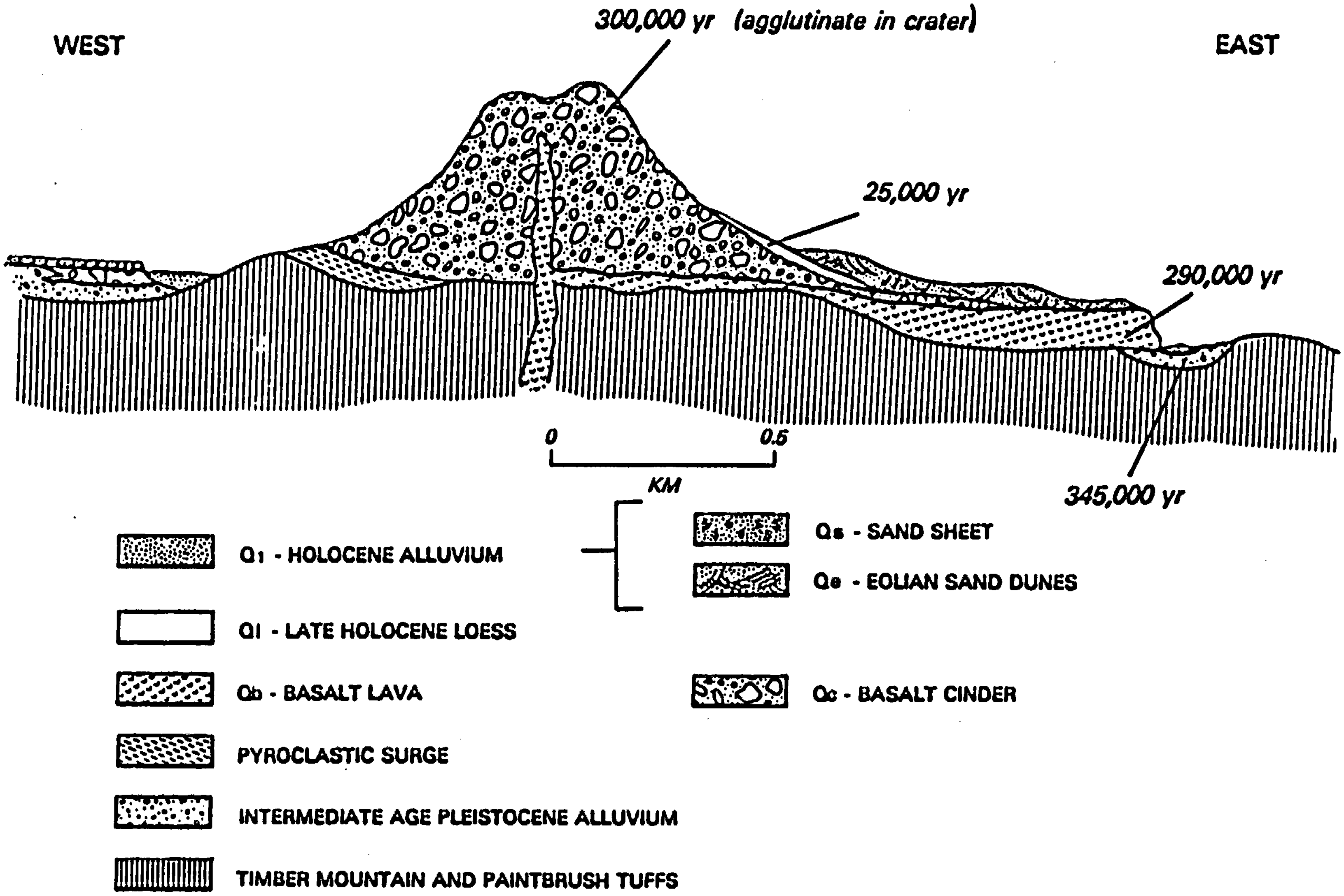


Fig. 5.
Sketch of geologic relations at Lathrop Wells volcanic center (Stop 2).

DOCKERY ET AL (1985)

#5

TABLE I

PETROLOGIC TYPES OF BASALTIC ROCKS FOR THE NTS REGION LISTED BY BASALT EPISODE

Basalts of the Silicic Episode (11 to 8.5 Myr)

Straddle Type	Hypersthene Hawaiites	Basaltic Andesite
Basalt of Jackass Flat Basalt of Black Mountain	Basalt Dike of Yucca Mountain Older Basalt of Crater Flat Basalt of Beatty Basalt of Amargosa Basalt of Cat Canyon Basalt of Beatty Wash	Basaltic Rocks of Kiwi Mesa Basaltic Rocks of Dome Mountain Basaltic Rocks of Skull Mountain

Older Rift Basalts (9 to 6.5 Myr)

Straddle Type	Hypersthene Hawaiites	Basaltic Andesite
Basalt of Kawich Valley Basalt of Silent Canyon Basalt of Rocket Wash Basalt of Nye Canyon Basalt of Scarp Canyon Basalt of Paiute Ridge	(None)	(None)

Younger Rift Basalts (<3.7 Myr)

Straddle Type	Hypersthene Hawaiites	Basaltic Andesite
Basalt of Little Cone Basalt of North Cone Basalt of Sleeping Butte Subunits of 3.7-Myr Basalt of Crater Flat Basalt of Lathrop Wells	Subunits of the 3.7-Myr Basalt of Crater Flat	Basaltic Rocks of Buckboard Mesa

CROWE, B.M. ET AL (1986) STATUS OF VOLCANIC HAZARD STUDIES FOR THE NEVADA NUCLEAR WASTE STORAGE INVESTIGATIONS..

#6

TABLE II. Principal Volcanic Units in the Nevada Test Site Area (not in Chronologic Order)

Unit	Volcanic Center	General Lithology	Age (Myr)
Thirsty Canyon Tuff	Black Mountain caldera	Peralkaline ash-flow tuffs	7-9
Timber Mountain Tuff	Timber Mountain caldera	Rhyolitic to quartz-latitic ash-flow tuffs	10-13
Paintbrush Tuff	Claim Canyon cauldron	Rhyolitic to quartz-latitic ash-flow tuffs	12-13
Wahmonie Formation Salyer Formation	Wahmonie-Salyer volcanic center	Dacitic to rhyodacitic lavas, breccias, tuff, and sandstone	12-13
Stockade Wash Tuff	Silent Canyon caldera	Calc-alkalic rhyolitic ash-flow tuff	13-15
Belted Range Tuff		Peralkaline ash-flow tuffs	
Crater Flat Tuff	Crater Flat and Tram calderas	Low-silica rhyolitic ash-flow tuffs	13-14
Tuff of Yucca Flat Redrock Valley Tuff	Sleeping Butte caldera	Low-silica rhyolitic ash-flow tuffs	14-16
Older Ash-Flow Tuff	Calderas north of Nevada Test Site	Rhyolitic to dacitic tuffs	14-17

distribution of these tuffs. Synchronous with the deposition of the tuffs of the lower Paintbrush, the Wahmonie volcanic center erupted ash flows, lavas, and air-fall tuffs (Fig. 7).

Timber Mountain Tuff was erupted from the Timber Mountain caldera and was deposited over the entire NTS area with, as already stated, more than 100 miles (161 km) in lateral extent and a volume of 530 cubic miles (2200 km^3) (Fig. 8).

Following approximately a 1-Myr hiatus, the Thirsty Canyon Tuff erupted from the Black Mountain caldera, the main portion of the ash flows being deposited to the northwest (Fig. 9). The Timber Mountain moat was filled, and thin tongues of ash-flow tuffs spilled into Yucca and Frenchman Flats. These ash-flow units have provided excellent stratigraphic markers within the basins.

Figure 10 is a diagrammatic cross section[3] from Oak Spring Butte to northwestern Frenchman Flat showing the stratigraphic position of the various tuff and lava units in Yucca and Frenchman Flats areas.

The structure of the NTS is complex, corresponding to other areas in southern Nevada where intense crustal deformation has taken place. Several thrust faults in the region of the NTS show upper Precambrian and lower Paleozoic rocks on top of middle and upper Paleozoic rocks. These occurrences include the Mine Mountain and CP thrusts in the Yucca Flat area, the Specter Range thrust west of Mercury, and the Spotted Range thrust east of Mercury, each with displacements of several tens of miles. Figure 1 shows the approximate location of the vast zone of the CP thrust and the east edge of the CP outliers, which correspond approximately with the axis of the Spotted Range. Regionally the direction of movement is toward the southeast, but local underthrusting as in the CP Hills has resulted in some overturning of folds toward the west. The preponderance of evidence suggests that folding, thrusting, and continued folding occurred at moderate depths during Mesozoic time. Most of the thrust plates have been extensively sliced by strike-slip faults and by later normal faults during Tertiary time.

A variety of Tertiary structural styles occurs throughout the NTS.[4-6] The structures appear to be influenced by rock type as well as by pre-existing structural grain. On the west, a dissected volcanic tableland contains

ORKILD, P.P. (1983)

#7

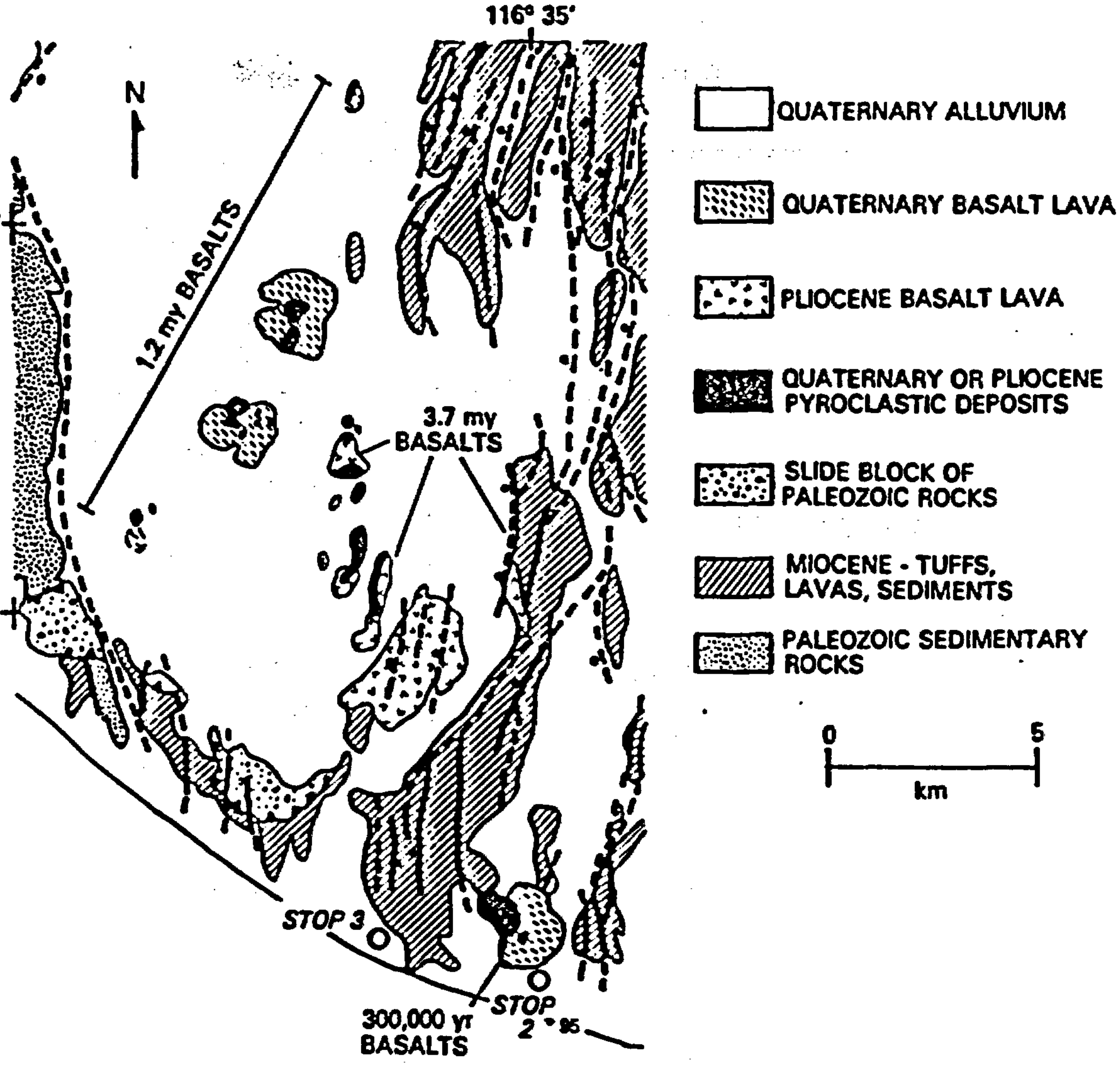


Fig. 3.
Southern Crater Flat area showing basalt centers and Stops 2 and 3 (modified from Crowe and Carr, 1980).

and a loessial silt deposit accumulated on the cinder cone and regionally on the Q2 alluvium before about 25,000 yr ago.

The structural controls for the location of the center are not obvious. The cone, summit crater, and the satellite cones are aligned northwesterly, probably due to northwest-trending structural control. Faults striking north-northeast are also present though poorly exposed. The center is located on a regional northeast-trending structural lineament marking the western edge of the Spotted Range-Mine Mountain northeast-trending structural zone (Figs. 3 and 6); faults west of this lineament have a more northerly trend. It is suggested that the strike of the faults influenced the location of the center; that is, the eruptions were fed from dikes whose trends were controlled by the regional stress field, i.e., least compressive stress direction.

DOCKERY ET AL (1985)

#2

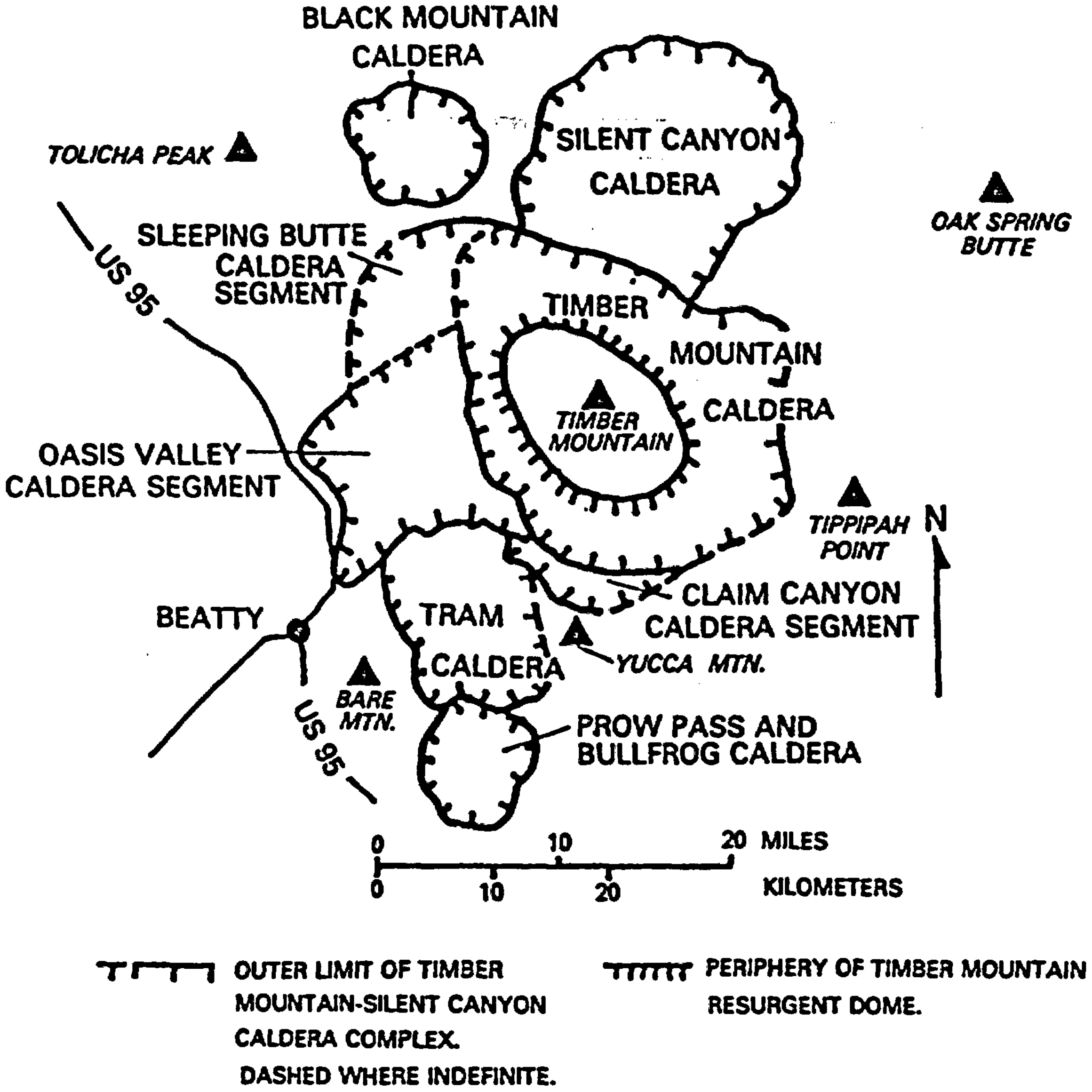


Fig. 2.
NTS region showing caldera outlines, known and inferred.

extending east and southeast of the cone. The lavas have unmodified flow margins and rubbly flow surfaces consistent with their young age. They are locally covered by loess and eolian sands. The probable oldest deposits of the Lathrop Wells cone are well-bedded pyroclastic (base) surge deposits (Fig. 5) that are exposed only on the northwest side of the cone where they overlap a topographic ridge upheld by welded tuff. They probably underlie the scoria deposits of the cone and thus record an episode of phreatomagmatic activity during the early eruptive stages of the center.

The ages of the Quaternary alluvial deposits are consistent with ages on the basalt. Before eruptions, alluvium of middle Pleistocene age locally developed a dense K-horizon that gave a uranium series age of about 345,000 yr (Fig. 5). The pyroclastic material became incorporated locally in upper Pleistocene alluvium (Fig. 5),

DOCKERY ET AL (1985)

#9

USGS0.25

Table 2. Reported K-Ar Ages, Precision Brackets, and Overall Site Means for Crater Flat Basalt Samples

Site			Laboratory A	Laboratory B	Laboratory C
SITE 1	Mean Age Reported		0.73	0.08	0.57
	Standard Deviation		0.19	0.08	0.09
	Average Precision Reported		±0.11	±0.13	±0.12
	Sample Set	1	0.70 ± 0.07	0.12 ± 0.03	0.60 ± 0.09
		2	0.65 ± 0.07	−0.01 ± 0.29	0.61 ± 0.16
		3	0.77 ± 0.08	−0.03 ± 0.14	0.66 ± 0.10
		4	0.59 ± 0.06	0.08 ± 0.03	0.56 ± 0.09
		5[1]	1.1 ± 0.3	0.125 ± 0.18	0.59 ± 0.21
		6[1]	0.58 ± 0.08	0.175 ± 0.09	0.39 ± 0.07
SITE 2	Mean Age Reported		1.53	1.12	1.55
	Standard Deviation		0.31	0.27	0.15
	Average Precision Reported		±0.19	±0.36	±0.20
	Sample Set	7	1.7 ± 0.2	0.965 ± 0.09	1.46 ± 0.11
		8	1.8 ± 0.2	0.95 ± 0.11	1.76 ± 0.19
		9	1.5 ± 0.2	0.975 ± 0.05	1.40 ± 0.13
		10	1.8 ± 0.2	1.66 ± 1.52	1.61 ± 0.24
		11[1]	0.99 ± 0.15	1.08 ± 0.24	1.64 ± 0.35
		12[1]	1.5 ± 0.2	1.11 ± 0.13	3.66 ± 0.14[2]
SITE 3	Mean Age Reported		4.27	3.73	3.89
	Standard Deviation		0.46	0.06	0.17
	Average Precision Reported		±0.45	±0.09	±0.32
	Sample Set	13	4.8 ± 0.5	3.637 ± 0.04	3.86 ± 0.11
		14	4.3 ± 0.5	3.815 ± 0.11	3.90 ± 0.92
		15	3.6 ± 0.4	3.78 ± 0.06	3.99 ± 0.12
		16	4.7 ± 0.5	3.745 ± 0.04	3.77 ± 0.32
		17[1]	4.3 ± 0.3	3.695 ± 0.22	4.14 ± 0.13
		18[1]	3.9 ± 0.5	3.73 ± 0.06	1.41 ± 0.38[2]
SITE 4	Mean Age Reported		4.22	3.69	4.00
	Standard Deviation		0.08	0.09	0.13
	Average Precision Reported		±0.32	±0.06	±0.12
	Sample Set	19	4.3 ± 0.3	3.79 ± 0.08	3.99 ± 0.10
		20	4.2 ± 0.3	3.795 ± 0.05	3.99 ± 0.12
		21	4.2 ± 0.3	3.555 ± 0.04	4.14 ± 0.11
		22	4.2 ± 0.3	3.64 ± 0.10	4.02 ± 0.12
		23[1]	4.3 ± 0.3	3.68 ± 0.06	3.76 ± 0.11
		24[1]	4.1 ± 0.4	3.705 ± 0.05	4.10 ± 0.15

	Overall Reported Ages from Each Site	
	Mean Reported Age	Standard Deviation
Site 1 – Lathrop Wells Cone	0.46	0.31
Site 2 – Red Cone	1.41	0.31
Site 3 – Along Wash in Central Crater Flat	3.96	0.35
Site 4 – Flow on Ridge Top in Central Crater Flat	3.97	0.24

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[1] Unidentified samples

[2] Apparently labels of samples were interchanged, ages were switched between sample sets for the statistical analysis, including the calculation of means shown in this table. In the analysis all ages were rounded to two decimals.

SINNOCK & EASTERLING (1983)

#10

Table 1. Generalized major stratigraphic units in Nevada Test Site region, with emphasis on the Yucca Mountain area

Unit		Volcanic center or caldera	Age
Alluvium			Miocene-Holocene
Basalts			Miocene-Quaternary
Tuff of Stonewall Flat		Stonewall Mountain	Middle Miocene
Thirsty Canyon Tuff		Black Mountain	Do.
Rhyolite of Shoshone Mountain		Shoshone Mountain-Fortymile Canyon area	Do.
Rhyolites of Fortymile Canyon			Do.
Tuff of Buttonhook Wash		Timber Mountain	Do.
Timber Mountain Tuff	Ammonia Tanks Member Rainier Mesa Member	do.	Do.
Rhyolite of Windy Wash		do.	Do.
Paintbrush Tuff	Tiva Canyon Member Yucca Mountain Member Pah Canyon Member Topopah Spring Member	do.	Do.
Wahmonie and Salyer Formations		Wahmonie	Do.
Rhyolite lavas and tuffs of Calico hills		Fortymile Canyon area	Do.
Crater Flat Tuff	Prow Pass Member Bullfrog Member Tram Member	Crater Flat-Prospector Pass	Do.
Belted Range Tuff		Silent Canyon (Pahute Mesa)	Do.
Lavas of intermediate composition		Various sources, locations poorly known	
Lithic Ridge Tuff			Do.
Older tuffs and lavas			Early to middle Miocene
Tuffs and sedimentary rocks			Middle Oligocene to Middle Miocene

After Carr (1984) U.S.G.S. OFR 84-854

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TABLE I. Pre-Cenozoic Rocks Exposed in and near Yucca Flat, Nevada Test Site

Age	Formation		Approximate Thickness (ft)	Dominant Lithology	
Permian (?) and Pennsylvanian	Tippipah Limestone		3600	limestone	Upper carbonate (3600)
Mississippian and Devonian	Eleana Formation		7900	argillite, quartzite	Upper clastic (7900)
Devonian	Devils Gate Limestone		1380	limestone	Lower carbonate (15 4000)
	Nevada Formation		1525	dolomite	
Devonian and Silurian	Dolomite of Spotted Range		1415	dolomite	
Ordovician	Ely Springs Dolomite		305	dolomite	
	Eureka Quartzite		340	quartzite	
	Antelope Valley Limestone	POGONIP Group	1530	limestone	
	Ninemile Formation		335	siltstone	
	Goodwin Limestone		950	limestone	
Cambrian	NOPAH Formation		2010	limestone, dolomite	
	Bonanza King Formation		4600	limestone, dolomite	
	Carrara Formation		1000	limestone	
			1000	siltstone	Lower clastic (9500+)
	Zabriskie Quartzite		220	quartzite	
	Wood Canyon Formation		2285	quartzite, siltstone	
	Stirling Quartzite		3000	quartzite	
Precambrian	Johnnie Formation (base not exposed)		3000	quartzite, limestone, dolomite	

The Sleeping Butte caldera (Fig. 4), the oldest documented caldera structure in the NTS area, is believed to have given rise to the tuff of Yucca Flat (formerly called Crater Flat Tuff), the Redrock Valley Tuff, and possibly the tuff of Tolicha Peak. The Redrock Valley Tuff was mostly confined to old valley bottoms and topographic lows.

New data from the exploratory drilling, mapping, and petrographic studies in the Bare Mountain-Crater Flat area have provided sufficient evidence to redefine the relations between the tuff of Yucca Flat and the Crater Flat Tuff. The field relations in the southern part of the NTS show that the type section of the Crater Flat Tuff is stratigraphically above the Grouse Canyon Member of the Belted Range Tuff, whereas the tuff of Yucca Flat is stratigraphically below the Grouse Canyon Member. Two calderas have been defined in the Crater Flat area and are the source area for the Crater Flat Tuff (Fig. 5).

Shortly after the Sleeping Butte eruptions, and before the Crater Flat and Tram calderas evolution, the Silent Canyon caldera became active, erupting the Belted Range Tuff from the northeast quadrant of the caldera. The ash flows (Grouse Canyon and Tub Springs Members) were deposited over the northern part of Yucca Flat on subdued topographic surfaces (Fig. 6). After the eruption of Belted Range rocks, the Tram and Crater Flat calderas erupted and deposited ash flows confined to the southern part of NTS (Fig. 6). Following or nearly synchronous with the above episode, the southwest quadrant of the Silent Canyon caldera became active; tuffs and lavas of Area 20 were deposited within the caldera, and the Stockade Wash Tuff was deposited over much of Yucca and Frenchman Flats (Fig. 6).

The Paintbrush Tuff was erupted from both the Claim Canyon and Oasis Valley calderas; Fig. 7 shows the

ORKILD, P.P. (~~[illegible]~~ 1983) GEOLOGY NEVADA TEST SITE, PROC MONTEREY CONT. SYMPOSIU
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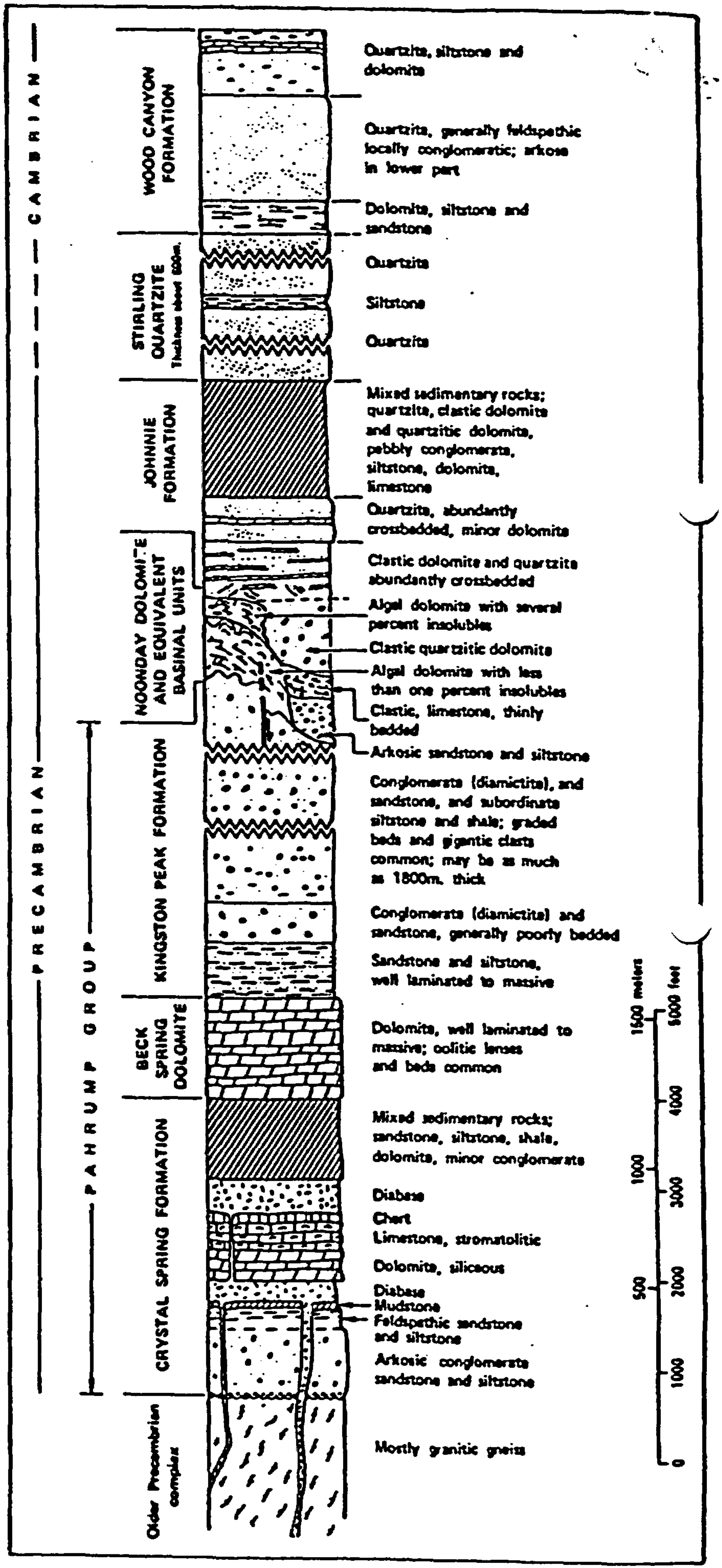

Figure 1. Generalized columnar section of Precambrian to Lower Cambrian strata, Death Valley region.

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Distribution and Genesis of Authigenic Silicate Minerals In Tuffs of Pleistocene Lake Tecopa, Inyo County California

By RICHARD A. SHEPPARD *and* ARTHUR J. GUDE 3d

GEOLOGICAL SURVEY PROFESSIONAL PAPER 597

Zeolites, potassium feldspar, searlesite
and clay minerals formed during diagenesis
of rhyolitic vitric tuffs that were
deposited in a saline lake

U.S. DEPARTMENT OF THE INTERIOR

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1968

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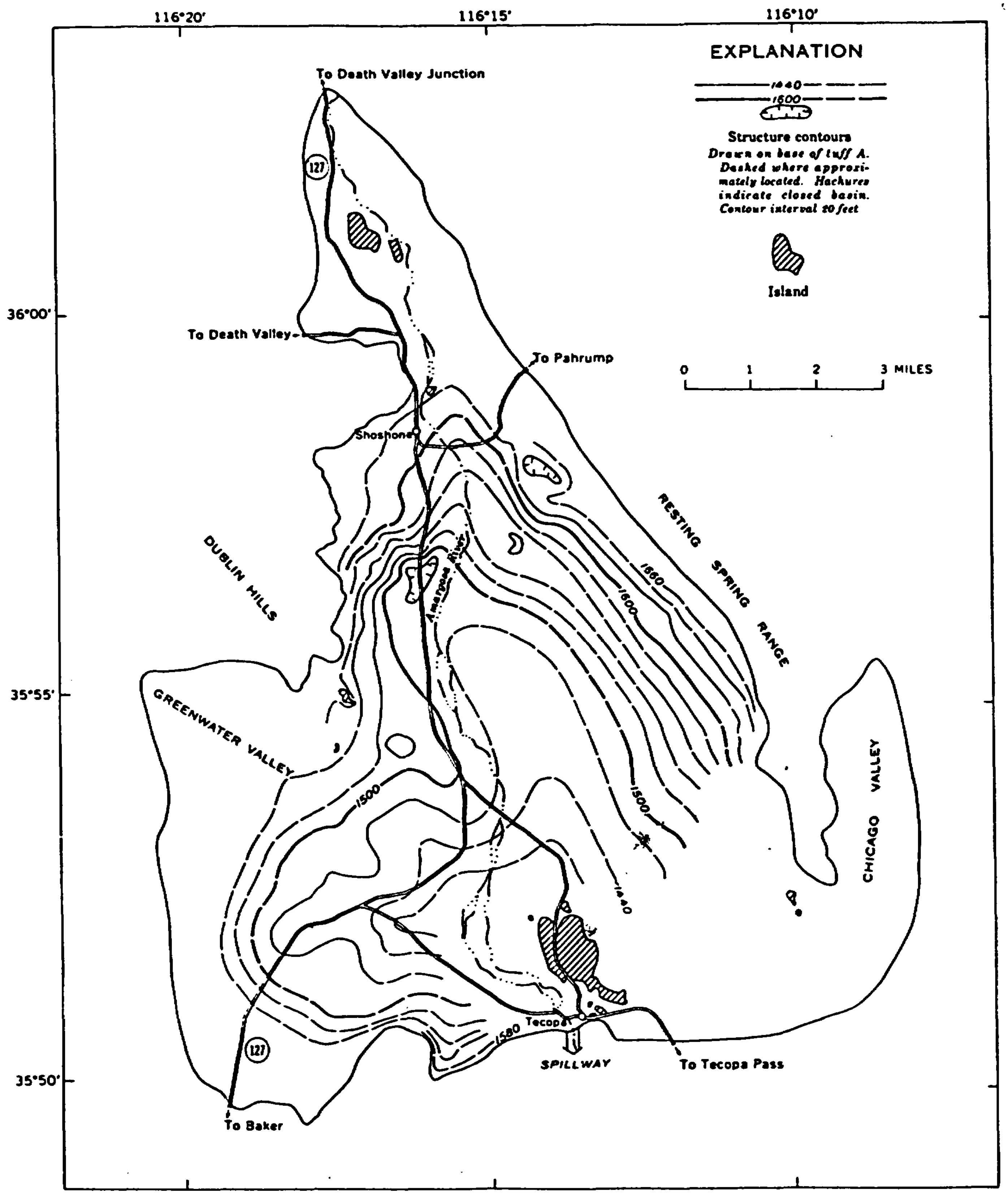

FIGURE 5.—Structure contour map of deposits of Lake Tecopa. No data for southeastern part of lake.

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STRATIGRAPHY AND LITHOLOGY OF THE LAKE DEPOSITS

The stratigraphy of the deposits of Lake Tecopa (fig. 6) is known from several short measured sections that were pieced together by study of many other unmeasured sections. Correlation of outcrops between the measured sections was facilitated by tracing the distinctive tuffs. Because a vast volume of lake beds was eroded by the Amargosa River in the central part of the basin, only the lower beds crop out there. Nowhere, however, are the basal beds exposed. Only the upper beds crop out along the marginal parts of the basin where the uppermost beds locally grade laterally into and interfinger with coarse fluviatile rocks.

The dominant lithology of the deposits of Lake Tecopa is mudstone or a calcareous, silty, or sandy variar[illegible] These rocks grade marginward into siltstone and sa[illegible]stone interbedded with conglomerate. Near the basin margin lacustrine rocks interfinger with the fluviatile rocks and commonly are difficult to differentiate. Calcareous rocks are common throughout the basin but are especially abundant and rich in calcite at the northern end of the lake, in the vicinity of Shoshone and northward. Evidently the calcium-bearing "fresh" waters of the ancestral Amargosa River precipitated their calcium as calcite upon coming in contact with the alkaline and saline lake water.

Several thin beds of dolomite are recognized in the Lake Tecopa deposits. The dolomite is white to light gray, very finely crystalline, and powdery. Commonly, the dolomite beds contain as much as 20 percent argillaceous impurities.

[illegible]a deposits are common near the margins of the lake, especially near Shoshone and along the western flank of the Resting Spring Range. The tufa is white to light tan, porous, and finely crystalline. Tufa is locally interbedded with the uppermost lake deposits, but elsewhere it cements younger alluvial fan material. Apparently the tufa was deposited by springs marginal to the lake. The springs evidently were active during the late stages of the lake and rather continuously for a period after the lake was drained. Inasmuch as some of the tufa deposits west of the Resting Spring Range are alined, the springs may have emerged along a fault bounding the range.

A well-developed soil occurs above tuff A in the abandoned "silica" quarry southwest of Shoshone. The soil is pale greenish yellow and 1.5–2.5 feet thick, and it grades into the underlying vitric tuff. Thin white veinlets of calcite are common throughout the soil but are especially abundant in the upper clayey part. This soil has not been recognized elsewhere in the lake deposits—perhaps because it is inconspicuous at natural exposures, but more likely because it was formed locally near the lake margin.

The total exposed thickness of the lake deposits is about 220 feet. Even though erosion by the Amargosa River and its tributaries has produced a topographic

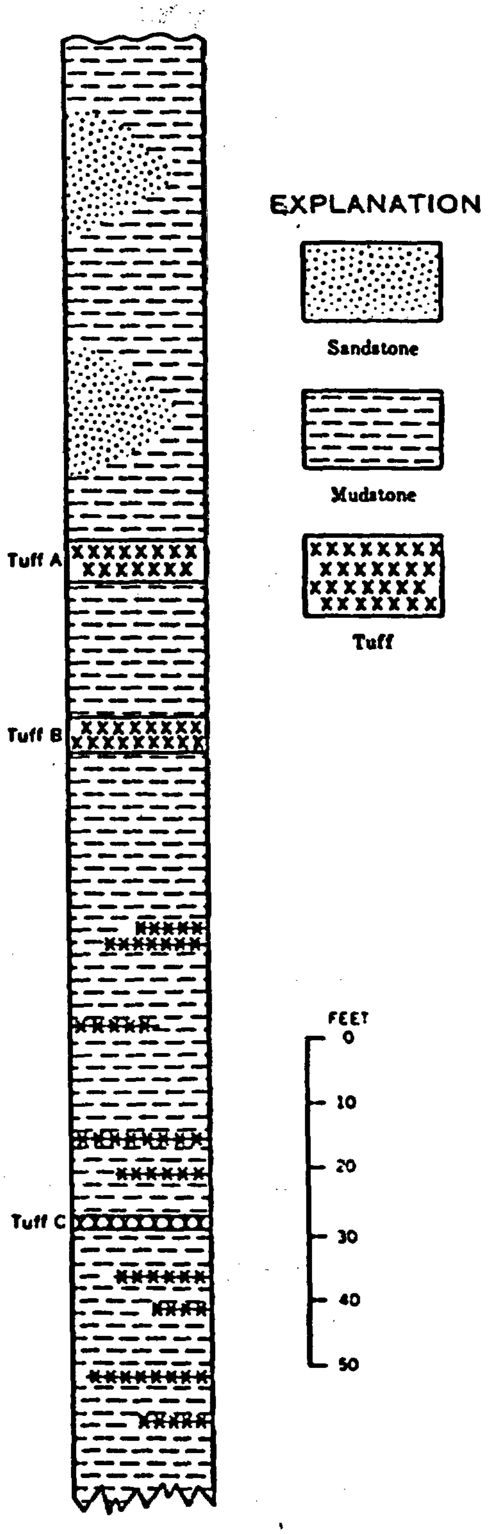

FIGURE 6.—Generalized stratigraphic section of the deposits of Lake Tecopa. Base of deposits is not exposed; top is eroded.

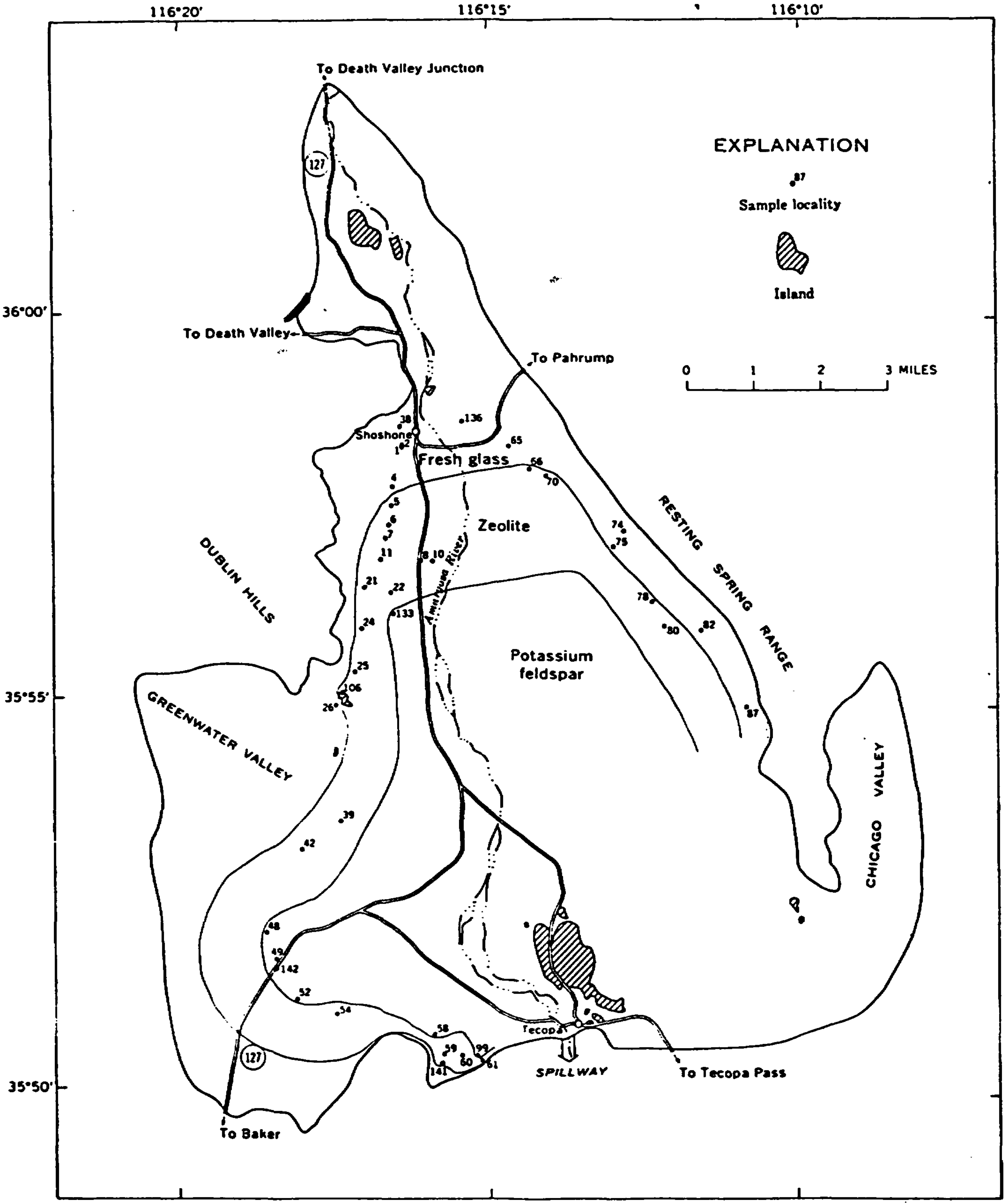

FIGURE 13.—Map of Lake Tecopa showing diagenetic facies for tuff A. X-ray analysis of samples given in table 10.