DOE/NV/10461--T61

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PETROGRAPHIC DESCRIPTION OF CALCITE/OPAL SAMPLES COLLECTED ON FIELD TRIP OF DECEMBER 5-9, 1992

SPECIAL REPORT No. 7
CONTRACT No. 92/94.0004

SPECIAL REPORT Submitted to the
Nuclear Waste Project Office
State of Nevada

June, 1993

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INTRODUCTION

A field trip was made to the Yucca Mountain area on December 5-9, 1992 by Don Livingston, Jerry Frazier, Russell Harmon, Christine Schluter, and Carol Hill to collect rock samples for analyses and measurement of isotopic properties. This study is part of the research program of the Yucca Mountain Project intended to provide the State of Nevada with a detailed analysis and assessment of the water-deposited minerals of Yucca Mountain and adjacent regions. Forty-three separate stops were made and 203 samples were collected during the five days of the field trip. This report describes petrographic observations made on the calcite/opal samples.

GENERAL OBSERVATIONS

Collection sites for the 203 samples are shown in Figure 1. For a listing of the location, brief description, and sample number of each sample refer to Appendix 1. Of the 203 samples collected, about 25 samples were bedrock and miscellaneous material (sand, etc.): all the rest were calcite/opal travertine ("calcrete" or "caliche").

In the past, petrographic observations on Yucca Mountain calcite/opal material have been limited. Vaniman et al. (1988) previously described calcite/opal from two faults (Trenches 14 and 17). Levy and Naeser (1991) discussed texture, mineralogy, field relationships of crushed-tuff-matrix (CTM) breccias and authigenic-mineral-cemented (AMC) breccias and cements. This is the first petrographic study which includes a large number of calcite/opal samples collected from many sites in and around Yucca Mountain. Observations on these samples were made with hand lens and petrographic microscope; fluorescence observations were made using a UVS-12 and UVG-54 (115 volts) Mineralights.

The most striking aspect about the calcite/opal deposits of Yucca Mountain and vicinity is their simplicity of mineralogy but diversity in texture. Calcite, opal, and gypsum were the only minerals found in the many travertine samples collected. Sepiolite was looked for, but not found, in the samples. This does not mean that the mineral was not there, only that it may not have been obvious by optical means. Vaniman et al. (1988) and Levy and Naeser (1991) both reported sepiolite (from Trench 14 and/or Busted Butte); however, the sepiolite fraction in these deposits was small and the mineral was identified by X-ray diffraction techniques.

PETROGRAPHIC TEXTURES

Texture is the size, shape, and arrangement (packing and fabric) of the component elements of a rock or mineral material. The crystal size of the calcite/opal travertine collected from the Yucca Mountain area is consistently very fine-grained (in the millimicron or less size range). The only exception to this are millimeter-sized calcite crystals filling vugs or veins within the finer-grained calcite/opal groundmass.

While the crystal size and mineralogy of the samples are simple and consistent, textures are diverse. The following describes a number of different textures observed in the calcite/opal samples collected at or near Yucca Mountain. Sample numbers in bold represent textures shown in the photographs (figures).

(1) **Pure texture.** This type of texture refers to either pure opal or pure calcite, with little or no mixing of the two minerals. Pure opal (hyalite) usually occurs in narrow (<1 cm) bands, but it can also occur as pods or isolated seams in a matrix of

dense, buff-colored, mixed calcite/opal (Figures 2a, b, c; 3a). The pearly to vitreous, pure opal fluoresces a brilliant green under ultraviolet light (Figures 2B, a, b, c, 3B, a), but wherever the opal is mixed with calcite it never fluoresces (Figures 2B, d, e, h, 3B). Pure calcite consists of crystals (sometimes a few millimeters in size) which occurs within vugs and veins. These fluoresce green and were also observed to phosphoresce (for a few seconds).

Vaniman et al. (1988, p. 15) described "almost-pure" transparent opal which may be equivalent to our "pure texture" opal. These authors identified this transparent opal as "opal-A" and it is possible that much (or all?) of our pure-textured, fluorescent opal is of the opal-A type.

Samples: fluorescent opal: WT-7 (3), 5b, 5c, 5d, 7c, 10c, 19a, 28e, **36b, 36j, 36z**, 37-1a, 37-2, 39b, 39n.
Samples: fluorescent calcite: 1b, 1c, 1f.

(2) **Mixed texture.** Mixed texture is one that consists of a mixture of calcite and opal. This mixture varies in density and color depending on the relative amounts of calcite and opal. The denser, darker-tan samples contain more opal and the less-dense, light-colored samples contain more calcite (the relative amounts of these two minerals within a sample was estimated by the amount of fizzing in acid). Most samples of calcite/opal are fairly-dense and buff-colored (Figures 2A, d; 3, 4, 5, 6, etc.). Samples which display a mixed texture never fluoresce as do the pure-textured opal and calcite. Most of the calcite/opal samples collected in the Yucca Mountain region fall into this mixed category.

Vaniman et al. (1988, p.46) also noted that most calcite/silica bands are composed of an intergrowth of calcite and opal. These authors reported (p. 20) that the dense, buff-colored, silica component of the mixture was "opal-CT" and it is possible that much (or all?) of our opal intermixed with calcite is of the opal-CT type.

Samples: many including 5e, **7a**, 17a, **36b**, **36j**.

(3) **Banded/laminated texture.** Banded/laminated texture describes layered sequences of calcite/opal, calcite/opal. Layers within these sequences contain various amounts of mixed-textured calcite and opal, the darker layers containing more opal and the lighter ones containing more calcite (Figures 5 and 6). Layering can vary in thickness from millimeters (laminations; Figure 6A) to centimeters (bands; Figure 6B), and it can vary in orientation from the horizontal (Figure 5A) to the vertical (Figure 5B). Layers can be concisely banded or laminated, or they can be roughly banded or laminated. The layers can be aligned perfectly parallel to one another, or they can be aligned roughly parallel to one another. A majority of the calcite/opal deposits in and around Yucca Mountain display banded/laminated texture.

Vaniman et al. (1988) described banded samples collected from Trench 14. Their sample T14F was comprised of two bands representing two episodes of deposition: (1) an earlier, mixed calcite and opal-CT band, and (2) a later, pure opal-A band. In addition, their sample T14-10 displayed vertically-oriented, laminated texture.

Samples: vertical bands/laminations: Trench 14 and Busted Butte "feeder" veins, **28d**
Samples: horizontal bands/laminations: Trench 14 and Busted Butte "sheet" deposits, **5a**, **5d**, 8a, 10a, 10f, **19a**, 39d.

(4) **Massive texture.** Massive texture describes unlayered or very-roughly layered calcite/opal or calcite/gypsum deposits. Massive texture consists of material which is powdery to porous and light-weight and which resembles tufa travertine (Figures 2A, e; 7). Usually massive-textured deposits are composed mostly of calcite, with smaller amounts of opal, but at the Wahmonie travertine/gypsite mound, the massive-textured deposits are composed mostly (70-80%) of calcite with smaller amounts (20-30%) of gypsum (Hill, 1993). Massive texture is typical of "mound" deposits such as are deposited at springs.

Samples: Stagecoach Trenches A and B, Site 199, South Trench 14, 2d, 16c, 17b, 22a, 22e, **32a**, 36b.

(5) **Powdery texture.** Powdery texture refers to unlayered calcite/opal which is very powdery, even more so than massive-textured samples. Often powdery texture is found with, or grades into, massive texture, but in many other occurrences powdery texture can overlie (Figure 14B, b), be banded in-between (Figure 8), or be invasive of (Figure 16B, a) denser, buff-colored, calcite/opal layers. Usually the powder is composed primarily of calcite, but it can also be composed of some opal or even mostly opal.

Samples: 4d, 5b, 5d, 7a, **7d**, 8a, **10e**, **19b**, 36b, 36f, 36g, **36h**, 36j, 40c.

(6) **Patchy texture.** Patchy texture is where pieces of lighter (or darker) calcite/opal material occur within a groundmass of darker (or lighter), calcite/opal. The clasts may be rounded or angular (breccia-like), and these included pieces give the samples a patchy or mottled appearance (Figures 9; 15b).

Vaniman et al. (1988, p. 14) may have been referring to "patchy texture" when they described patchy, mineral-clast rich, fragmental and ooidal layers (their sample T14B). This texture indicated to these authors that an earlier episode of calcite/opal deposition had occurred followed by brecciation and then recementation by calcite/opal during a later episode.

Samples: **4d**, **4e**, 5b, 8a.

(7) **Brecciated texture.** Brecciated texture is where foreign pieces of material are surrounded by a calcite/opal matrix. This type of texture differs from patchy texture in that the clasts are not composed of calcite/opal, but instead are composed of fractured and filled bedrock (e.g., Figure 10B), or fragments of bedrock (e.g., talus clasts from the Tiva Canyon; Figure 4). Subtypes of brecciated texture are (a) *floating-brecciated texture*, where the foreign pieces are isolated from one another and look like they are "floating" in a groundmass of calcite/opal (Figures 4a, b; 10A), and (b) *mosaic-brecciated texture*, where the clasts resemble pieces of a puzzle which can be "fitted" back together" into their original position (Figures 10B; 11).

Samples of mosaic-brecciated texture: Wailing Wall, WT-7, Trench 14, **5g**, 36z, **WT-7 (3)**.
Samples of floating-brecciated texture: **5g**, **7a**, 10b, 14g, 22a, 22e.

(8) **Flow texture.** Flow texture is where darker and lighter bands of calcite/opal exhibit a marbly or wavy pattern (Figures 6; 12). These undulatory bands give the appearance that the calcite/opal groundmass was once in a plastic or fluid state. Often holes or vugs (sometimes filled with calcite crystals) are aligned along the flow bands (Figures 13A, c, d).

Samples: WT-7, 5d, **10a**, **36z**.

(9) **Vesicular/phenocrystic texture.** Vesicular/phenocrystic texture is where the calcite/opal matrix material is full of holes. Sometimes the holes are empty (vesicular texture); less often they are filled with calcite and/or opal (phenocrystic texture). The holes may be randomly spaced within the calcite/opal matrix or they may be aligned in rows along roughly-banded sequences or flow texture (Figures 2A, f, g, h, i; 14A, a, b, c, d). The holes themselves can be ellipsoidal, the ellipsoids being elongated in the direction of the flow bands or layering. Rarely, the holes are aligned in swirl-shaped rows. Holes usually occur in a dense, mixed-texture, calcite/opal groundmass (Figures 2A, f, g; 14B, a), but they can also occur in a powdery- or massive-textured groundmass (Figures 2A, h; 14B, b).

Levy and Naeser (1991, p. 12) reported vesicular texture in the fine-grained, carbonate cements of AMC (authigenic-mineral-cemented) breccias. Some of these vesicles contained residual void space but most were completely filled with silica. Other vesicle-filling material included sparry and acicular calcite and a possible mixture of sepiolite and minor silica (Levy and Naeser, 1991, p. 14).

Samples: WT-7 (3), 5a, 5h, **10a**, 10e, 19e, **36b, 36h**, 36p.

(10) **Veined texture** Veined texture is where calcite/opal veins crosscut the calcite/opal matrix (Figure 15). This type of texture was not commonly observed in our samples, but Levy and Naeser (1991, p. 14) reported abundant fracture fillings composed mainly of silica in their samples from Trench 14.

Sample: **4e**.

(11) **Invasive texture.** Invasive texture is where a "blob" or "finger" of calcite/opal material penetrates the main mass of calcite/opal (Figure 16). The

invasive material can be distinguished from the matrix by its lighter (or darker) color and its more calcitic (or opalitic) composition.

Samples: 7c, **7d**, 10e, **19b**, 36b.

(12) **Botryoidal texture.** This type of texture is where the mineral deposits assume a botryoidal appearance. Botryoidal opal is quite common in the Yucca Mountain area (e.g. Harper Valley; Figure 17A), occurring as fracture fillings within the Tiva Canyon or other stratigraphic units. This textural type also occurs as surface coatings on calcite or gypsum. Botryoidal gypsum occurs at the Wahmonie mound as crusts overlying the main mass of travertine/gypsite (Figure 17C). These crusts represent diffusion of the more soluble gypsum component of the mass toward the outside of the mound due to an evaporation gradient at the air/mound-surface interface (i.e., these form similar to "popcorn" botryoids in caves; Hill, 1993, p. 13). Calcite "popcorn" crusts were also observed at Trench 14 in small cavities within the calcite/opal vein mass (Hill, 1993, p. 13).

Levy and Naeser (1991, p. 8) reported botryoidal silica fillings within large fractures at Busted Butte, Yucca Mountain.

Samples: 4d, 5f, **32a**, 32e, **39b**, 39f, 39n.

(13) **Algal/ooidal texture.** Algal (or ooidal) texture is where algae- or pea-shaped bodies comprise the main mass of calcite/opal (Figure 18). This type of texture may actually be produced by algae or other types of biota. At Cane Springs, a presently-active spring located about 25 km east of Yucca Mountain, small calcite mounds are associated with live algae.

Vaniman et al. (1988, p. 14) reported "ooidal" layers in calcite/opal bands at Trench 14 (their sample T14-FB). This may (or may not) be equivalent to what we are calling algal/ooidal texture.

Samples: 16c, 17b, 19a, **19d**, 36a, 36i.

(14) **Root-cast texture.** Root-cast texture is where plant roots have grown into the calcite/opal deposits and where they have become incorporated into the travertine mass. Root-cast texture is particularly well displayed in the sheet travertines of Busted Butte (Figure 19), but it also occurs within many other travertine deposits at Yucca Mountain (Figure 20).

Vaniman et al. (1988, p. 46) reported root-cast texture at Trench 14 and thought that organic materials such as root casts were perhaps responsible for the deposition of opal-A.

Samples: **22a, 23a, 28c**, 29f, **30b**, 30h.

(15) **Speleothemic texture.** Speleothemic texture is where dripstone- or rimstone-like forms are produced where calcite from the main mass of travertine has been dissolved and reprecipitated on the undersides of the travertine or on below-lying bedrock (Figure 21).

Samples: **4f**, 17b.

FIELD RELATIONSHIPS OF CALCITE/OPAL

The calcite/opal deposits at or near Yucca Mountain were observed to have the following field relationships:

(1) There appears to be no correlation between location and textural type of a calcite/opal deposit. Different textural types are found throughout the region - even in the Bare Mountain mining district to the west of Yucca Mountain. For example, powdery, laminar, vesicular/phenocrystic, and floating-brecciated textures were all observed in calcite/opal travertine associated with ore mineralization at Bare Mountain (Figures 8 and 13A).

(2) Various textures of calcite/opal do not appear to be correlative with a specific host-rock type (e.g., rhyolite, limestone, dolomite).

(3) Different textural types exist in close proximity to one another. For example, at Plug Hill, powdery, laminated, and mottled texture was seen in the same sample (within a centimeter or so of each other).

(4) Where calcite/opal directly overlies host bedrock, the first layer in a banded/laminated sequence may be opal, it may be calcite, or it may be of mixed texture (i.e., one mineral does not seem to consistently appear first in a precipitative sequence). This observation is in contrast to that of Levy and Naeser (1991, p. 11) who reported that "most tuffaceous clasts (in AMC breccias) have complex, crudely-interlayered coatings of silica and calcite, with silica as the innermost layer."

(5) The calcite/opal can occur as sheet travertine, vein- or fault-filling travertine, coatings over colluvium or alluvium, or cementing material.

(6) The calcite/opal travertine cemented whatever lay in its way as it was deposited: talus/colluvium, alluvium (sand to cobble sizes), breccia fragments, or bedrock (Hill, 1993). For example, at Busted Butte, sheet travertine has cemented sand, breccia fragments of rhyolite and opal, and the soft tuff of the Bedded

member. At WT-7, Wailing Wall, and Plug Hill, the calcite/opal travertine has cemented talus/colluvium, and at Livingston Scarp, it has cemented alluvium (cobbles).

(7) How "sandy" the calcite/opal travertine is (e.g., at Busted Butte) seems to have been dependent on whether the travertine was in direct contact with a sandy stratum; that is, wherever solutions flowed over sand, some sand was incorporated into the precipitated travertine.

IMPORTANT QUESTIONS RAISED BY THE TEXTURAL TYPES

The calcite/opal deposits at Yucca Mountain have been interpreted by many investigators to be of supergene-pedogenic origin (e.g., Quade and Cerling, 1990). However, the textures described in this report raise some important questions as to the validity of this model:

(1) The diversity and heterogeneity of textures displayed by the calcite-opal deposits, even within centimeters of each other, favor a dynamic fluid system rather than a pedogenic system. For example, pure-textured opal seams can occur interbanded with mixed-textured, vesicular-textured, calcite/opal layers (Figure 2). These opal bands do not seem to have come in a later or earlier episode than the calcite/opal; yet, the opal is pure (not mixed with calcite) and is uraniferous (fluorescent).

Such a situation might be explained if a highly-dynamic fluid system is invoked where variations in the chemistry of precipitating solutions are reflected in mineral-content gradations ranging from essentially pure calcite to pure opal. A plausible precipitation scenario for the above might be: (a) degassing of carbon dioxide from solution caused the vesicular texture of a precipitating calcite/opal mass (Figure 2f, g), (b) solutions out of which the mixed calcite/opal deposited were then enriched in calcite leading to massive-textured calcite/opal (Figure 2h), and (c) pure silica was left in solution, leading to the pure-opal seams high in uranium (Figure 2a, b).

While the above specific scenario is speculative, it is at least tenable that a dynamic fluid system could have produced the above combination of textures and other textures described in this report. It can also explain the closeness (a few centimeters) of different textural types. In contrast, it is extremely difficult to imagine how pedogenic processes could have produced the diversity of textures seen in the calcite/opal deposits at Yucca Mountain.

(2) The very-fine grain size of the calcite/opal travertine is in direct contrast to pedogenic carbonates which are "nearly always aggregates of silt-sized calcite crystals" (Dixon and Weed, 1989, p. 281). Why is the calcite/opal travertine at Yucca Mountain so fine-grained if it is pedogenic? Such a small grain size is more indicative of material precipitated as a result of fast cooling and/or degassing of solutions.

(3) How can one get pure, fluorescent (uraniferous) opal from pedogenic processes? How could a pedogenic process have concentrated the uranium and constrained the purity of the opal to separate bands or seams? Hydrothermal solutions, however, such as those which were responsible for altering volcanic rock (Livingston, 1993), could have precipitated pure opal veins and layers.

(4) How could flow texture be produced by any mechanism other than fluid injection? Pedogenic processes might be expected to produce massive, laminated, or algal/ooidal textures, but not flow texture. Elevated fluid pressures are indicated by dilated and brecciated flow textures.

(5) How could vesicular/phenocrystic texture be produced by pedogenic processes? The holes look like they are gas cavities created by the degassing of fluids out of which the calcite/opal precipitated. Vesicular swirl textures are especially indicative of flow and degassing.

(6) How could the puzzle-brecciated texture be produced by any process other than fluid injection (e.g., sample 36z)? Not only have the breccia fragments been forced apart in this sample, they have also been moved sideways from their original position (i.e., sample 36z shows flow texture in addition to mosaic-brecciated texture; Figures 12; 13).

(7) How could the floating-brecciated texture be produced by a pedogenic process? Floating textures indicate that the calcite/opal was precipitated from solution at a faster rate than erosional detritus was being introduced by seasonal storms.

(8) Likewise, invasive and patchy textures show penetration of later fluids of slightly different composition after sections of the main calcite/opal matrix had partially "hardened" or become brecciated. It seems like this penetration could occur by fluid injection of heterogeneous fluids, but not by a pedogenic build-up of material.

(9) Calcite/opal samples from the Bare Mountain mining district display the same textural types as those at Yucca Mountain, even though the Bare Mountain samples are more enriched in metal than samples from Yucca Mountain (e.g., metal content of the Bare Mountain calcite/opal was measured at: As = 96 ppm, Cd = >100 ppm, W = 130 ppm, Zn = >10,000 ppm). It may be that metals were more accessible at depth in the vicinity of Bare Mountain, but that the process of deposition of the calcite/opal (i.e., from hypogene solutions) was the same over the region.

(10) All of the textural types which make a pedogenic origin questionable were found at Trench 14.

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APPENDIX 1

Detailed List of Samples Collected at Each Stop

STOP #	SAMPLE	TYPE		STOP #	SAMPLE	TYPE
STOP #1	US 95 mile 10			STOP #10	Bare Mountain	
1a	dolomite	Nopah Fromation		10a	calcite-opal	loose material
1b	silica	breccia zone		10b	lmst/opal	brecciated, cemented
1c	calcite			10c	calcite-lmst	
1d	dolomite	organic lithofacies		10d	limestone	Ely Springs
1e	silica	vein		10e	opal	siliceous
1f	calcite	vein		10f	carbonate	in stream bed
1g	calcite					
				STOP #11	Diamond Queen M.	
STOP #2	US 95 mile 12.47			11a	white mineral	filling, metamorphosed
2a	quartzite (clean)	Stirling Quartzite		11b	calcite	float sample
2b	quartzite (dirty)	Stirling Quartzite		11c	phyllite	Johnnie Formation
2c	epidote	vein		11d	carbonate	incrustations
2d	calcite	vein		11e	Nopah formation	
				11f	Iceland spar	massive
STOP #3	US 95 mile 18.8			11g	calcite	vein
3a	dolomite/lmst			11h	quartz	
				11j	fluorite	
STOP #4	Pull Apart Fault			11k	fluorite	
4a	limestone	fault related alteration		11m a	calcite	coating
4b	calcite	coating		11m b		
4c	calcite-opal-breccia			11n	calcite	crust
4d	calcite-opal	bulk samples		11o	kaolinite clay	from breccia pipe
4e	opal breccia			11p	chert nodule	in fluorite breccia
4f	calcite	riverbed		11q	porphyry	volcanic breccia
4g	carb.-coated rock			11r	fluorite breccia	
				11s	chert nodule	
STOP #5	WT - 7					
5a	calcrete-coated rock			STOP #12	Chuckwalla Canyon	
5b	calcite-opal	surficial deposit		12a	Iceland spar	massive
5c	opaline layer	on breccia		12b	opal-calcite	inter-layers
5d	calcite-silica			12c	carbonate	white & black minerals
5e	calcite	fracture fill		12d	dolomite	Lone Mt.
5f	breccia			12e	calcite	
5g	breccia			12f	calcite	fracture filling
5h	calcium crystals	Carol's sample		12g	calcite	columnar crystals
STOP #6	USW H - 6			STOP #13	Tarantula Canyon	
6a	carbonate crust	surficial coating		13a	limestone	Meiklejohn
				13b	rhyolite	
STOP #7	roadside (WT-7)					
7a	calcite	caliche?/calcrete		STOP #14	Trench 8	
7b	silica-calcite			14a	calcite	root casts
7c	opal			14b	ash	
7d	indurated layer	coating on surface rock		14c	calcite-opal-silica	
				14d	clacite-opal	fault infilling
STOP #8	Plug Hill			14e	black glassy material	in altered vitrophyre
8a	carbonate	coating on colluvium		14f	carb., some silica	cement
				14g	silica-calcite	vein
STOP #9	roadside (WT-7)					
9a	calcite	coating				

STOP #	SAMPLE	TYPE		STOP #	SAMPLE	TYPE
STOP #15	roadsie (trench 8)			STOP #26	roadside (FOC)	
15a	carbonate	matrix		26a	lmst, dolomite	Bonanza King
STOP #16	New Trench			STOP #27	roadside (FOC)	
16a	carbonate	vein		27a	calcite	secondary
16b	ash			27b	carbonate? in basalt and	cement filling
16c	carbonate	matrix		27c	travertine	surficial cap
STOP #17	Site 106			STOP #28	East Busted Butte	
17a	tufa	spring		28a	silica	vein
17b	carbonate	spring		28b	sand	
				28c	carbonate?	root casts
STOP #18	Livingston Scarp			28d	carbonate?	vert. vein
18a	carbonate	fracture fillings		28e	opaline-coral	slope deposit
18b	opal-carbonate	vein		28f	travertine	upslope
STOP #19	Wailing Wall			STOP #29	East Busted Butte	
19a	opal-calcite	coating		29a	calcrete	
19b	carbonate	vein		29b	rat midden	
19c	carbonate	coating		29c	sheet deposit	
19d	algal?			29d	vitrophyre	
19e	opal-calcite	Carol's sample		29e	travertine, breccia	sheet deposit
				29f	carbonate?	root casts
STOP #20	roadside ("scarp")					
20a	glass	volcanic		STOP #30	West Busted Butte	
				30a	carbonate?	vert. vein
STOP #21	Red Cliff Gulch			30b	carbonate?	root casts
21a	carbonate	surface coatings		30c	opal-calcite	
				30d	carbonate?	vein
STOP #22	Stagecoach Trench	(North)		30e	carbonate?	vein
22a	carbonate	root casts		30f	calcite	vein
22b	tuff	calcite overlies		30g	carbonate?	punchbowl
22c	quartz?	calcite overlies		30h	carbonate?	root casts
22d		full of clasts				
22e	carbonate	surficial		STOP #31	roadside (Mercury)	
				31a	calcite	coating
STOP #23	Stagecoach Trench	(South)				
23a	carbonate	root casts		STOP #32	Wahmonie Mounds	
23b	glass	vitrophyre		32a	gypsum with calcite	
				32b	carbonate	
STOP #24	Site 199			32c	calcite-gypsum	
24a	silicified material	some clasts		32d	calcite	
24b	breccia (Carrera)	conglomerate		32e	gypsum	crust on carbonate
24c	breccia	Bonanza King				
24d	tufa	some brecciated carb.		STOP #33	Mines (Wahmonie)	
				33a	carbonate?	vein
STOP #25	roadside (site 199)			33b	fluorite? in quartz	
25a	carbonate	root casts (burrows?)		33c	calcite crystal in quartz	
25b	seds.	marsh/lake				

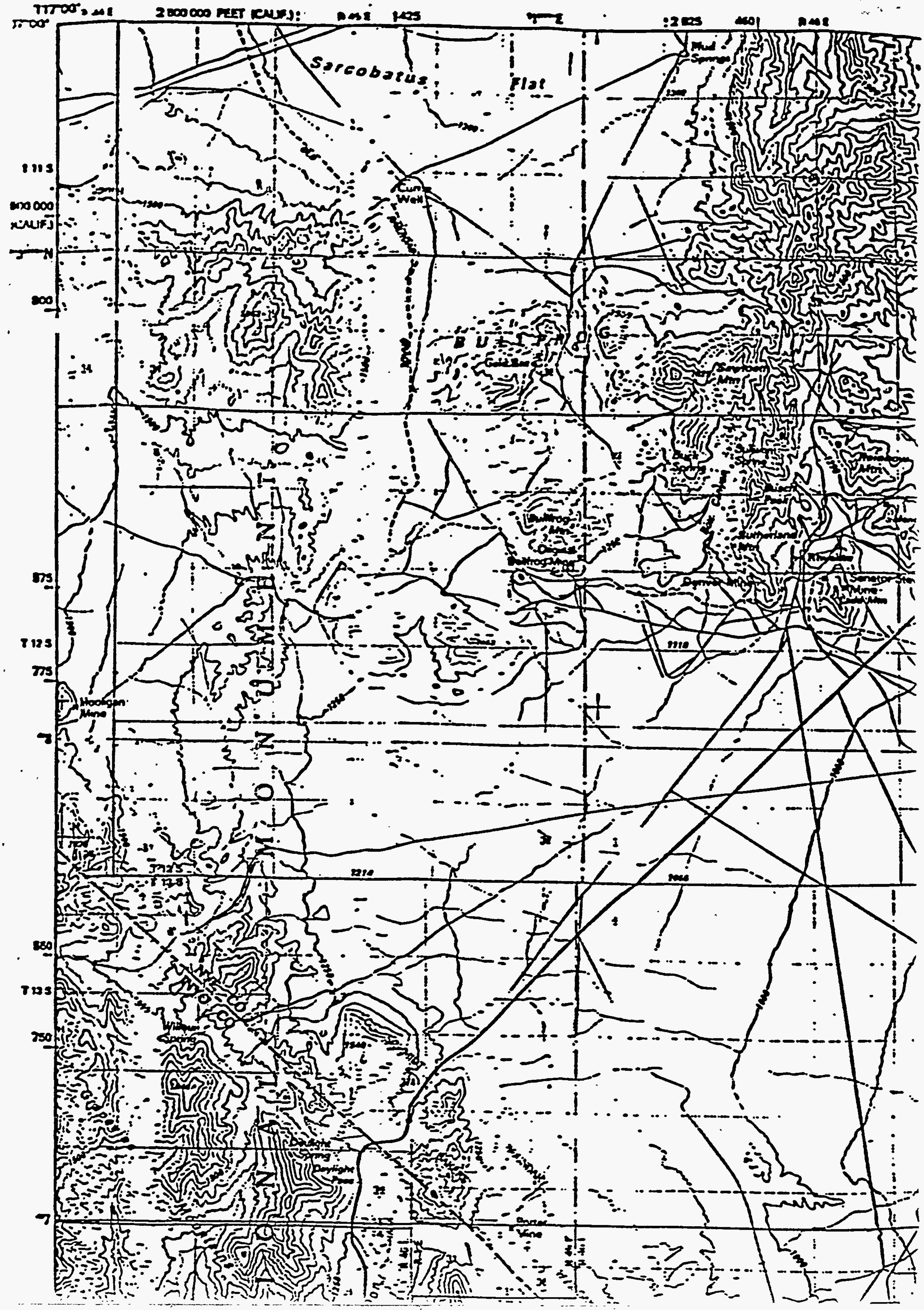
STOP #	SAMPLE	TYPE		STOP #	SAMPLE	TYPE
STOP #34	Calico Hills			STOP #37-2	Mercury	
34a	shale	Eleana		37-2a	dolomite	fault zone
34b	limestone	Eleana		37-2b	carbonate	vein
34c	pyrite	cubes				
34d	pumice and silicified	Calico Hills		STOP #38	West Busted Butte	
34e	kaolinitized clay			38a	sand	windblown
34f	ironized tuff	Calico Hills		38b	travertines	
34g	calcite	slslickenside		38c	opal-calcite	
34h	yellow hot rock			38d	pumice tuff	bedded tuff
				38e	tuff	red altered
STOP #35	Shoshone Mt. road			38f	travertine	
35a	kaolinite			38g	carbonate	caps tuff
35b	Topopah	red sample				
35c		cavity fillings		STOP #39	Harper Valley	
				39a	carbonate	in streambed
STOP #36	Trench 14			39b	silica	botryoidal (opalite)
36a	carbonate			39c	Tiva	partially welded
36b	opaline			39d	flowstone	laminated
36c	carbonate	finely laminated		39e	carbonate	vein filling
36d	carbonate	vein		39f	opal	botryoidal
36e	silica	vein		39g	calcite	vein
36f	carbonate	vein		39h	some opal	pinnacles
36g	carbonate	vein		39i	carb?-silica	"Z" veins
36h	silica	vein		39k	tuff	red altered
36i	carbonate	vein		39m	carbonate	vein
36j	opal	vein		39n	opal	Carol's sample
36k	opal-breccia-carbona	finely laminated				
36m	calcite	vein		STOP #40	Trench 14	
36n	carbonate	vein		40a1	mostly carbonate	vein
36o	carbonate	vein		40a2	carbonate?	vein
36p1	calcite-opal	vein		40a3	carbonate?	vein
36p2	calcite-opal	vein		40b	calcite	vein
36r	carbonate	vein		40c	calcite	subsurface
36s	opal	vein				
36t	carbonate	vein		STOP #41	Lathrop Cone	
36v	carbonate	vein		41a	sulfur or jarosite	
36w	opal	vein		41b	carbonate	coatings
36x		Calico Hills?		41c	sulfur?	
36y	breccia-calcite					
36z	breccia			STOP #42	Lathrop Cone	
				42a	sand	
STOP #37-1	UE 25 p#1					
37-1a	opal	opaline				
37-1b	opal	Carol's sample				

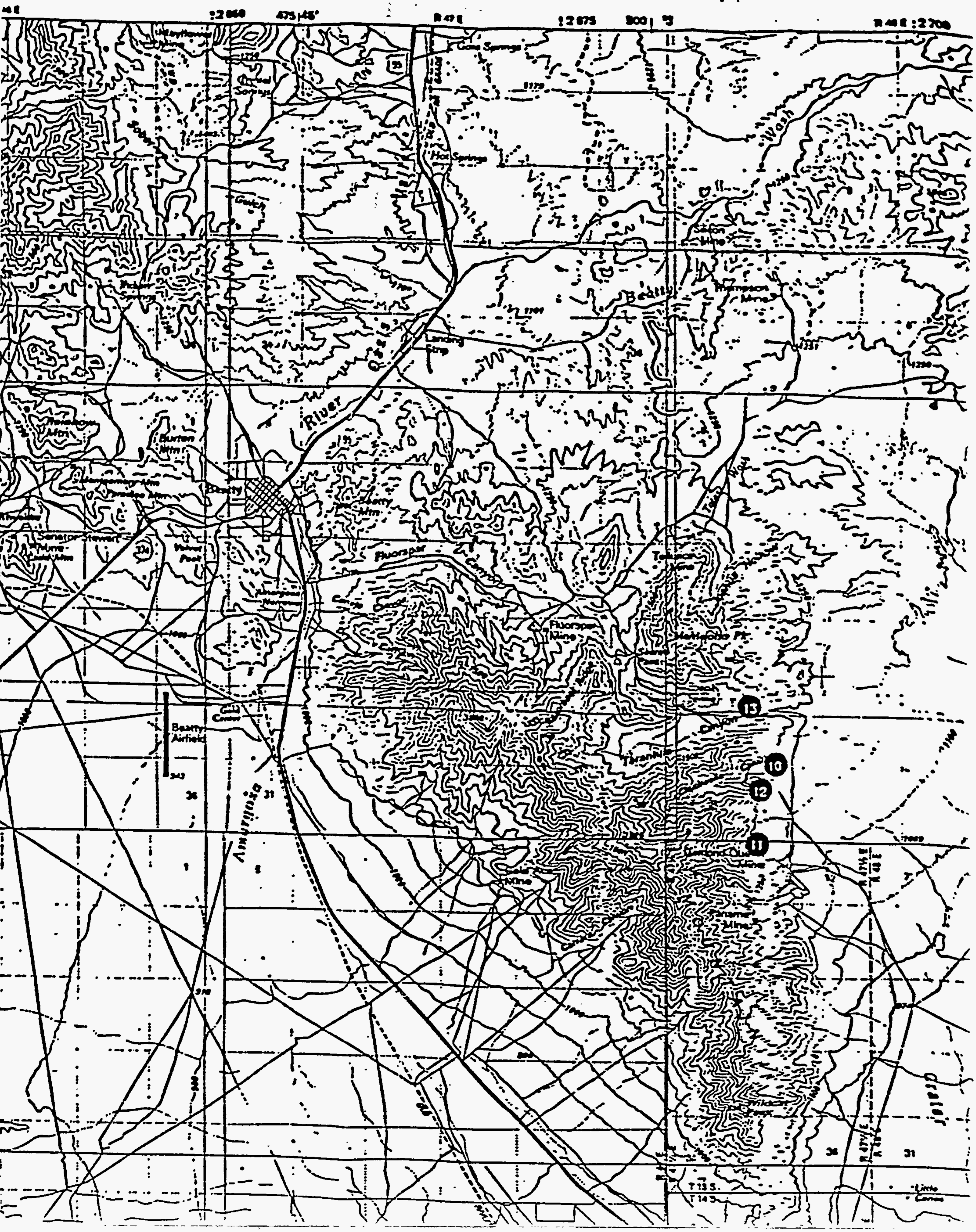
FIGURES

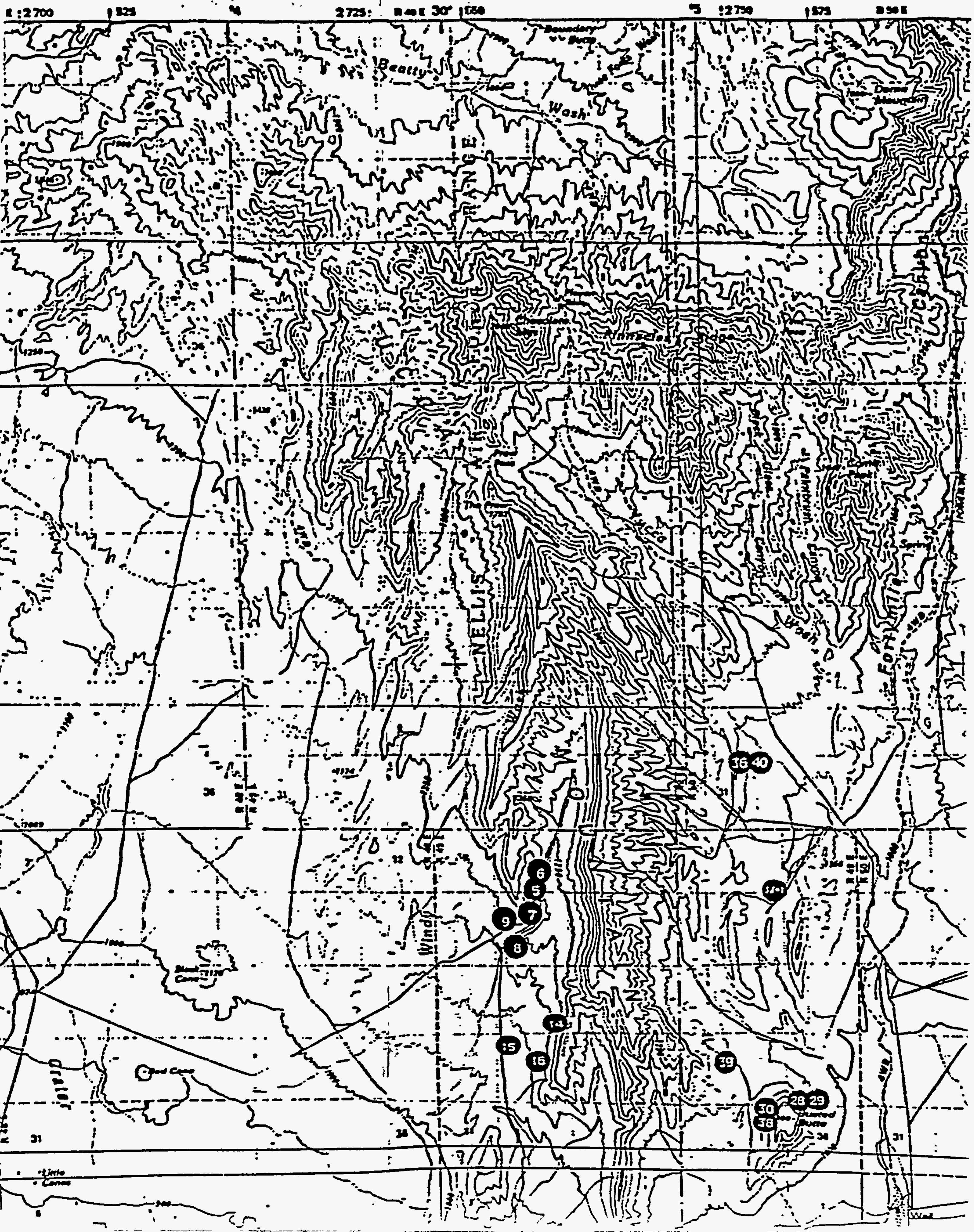
Figure 1. Locations of Stops are located on the map. Please see Appendix 1 for a detailed list of samples collected at each stop.

Map: USGS--Beatty (Nevada-California), No. 36116-E1-TM-100 (1986)

BEATTY, NEVADA—CALIFORNIA



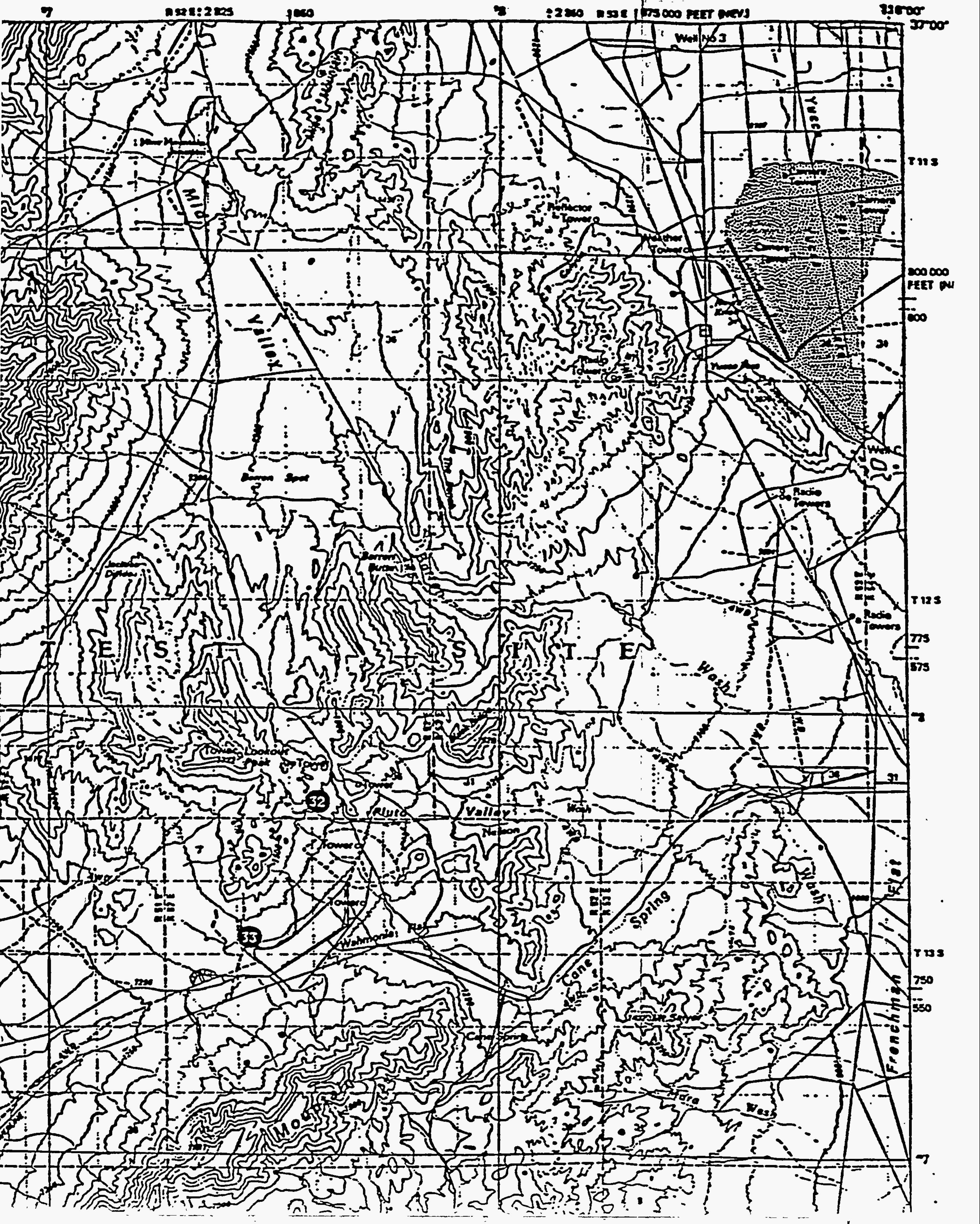

R 47 E
Gold Springs
Hot Springs
Gulch
Wash
Landing Strip
River
Burton Mtn
Beatty
Beatty Mtn
Senator Stewart
Fluorspar
Canyon
Fluorspar Mine
Thompson Mine
Beatty Airfield
Amargosa
13
10
12
11
T 13 S
T 14 S
Little Cones

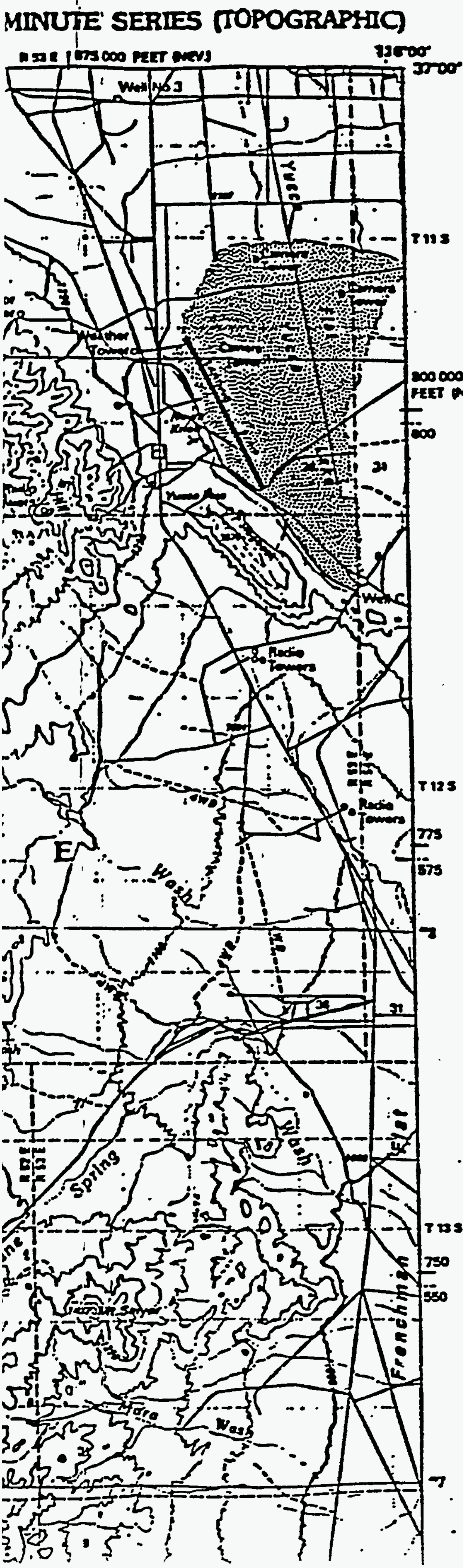


Beatty
Wash
NELLIS
Wind
36
40
6
5
7
9
8
15
16
39
28
29
30
38

2775
2800
15'
Water Pipe Butte
N E V A D A
T E S
Hills
34
35
Lookout
Weather Tower
Tonopah
J A C K A S S
F L A T S
Landing Field

30X60 MINUTE SERIES (TOPOGRAPHIC)





Beatty

NEVADA—CALIFORNIA

1:100 000-scale *metric* topographic map

30 X 60 MINUTE QUADRANGLE SHOWING

- Contours and elevations in meters
- Highways, roads and other manmade structures
- Water features
- Woodland areas
- Geographic names

GEOLOGICAL SURVE

1986

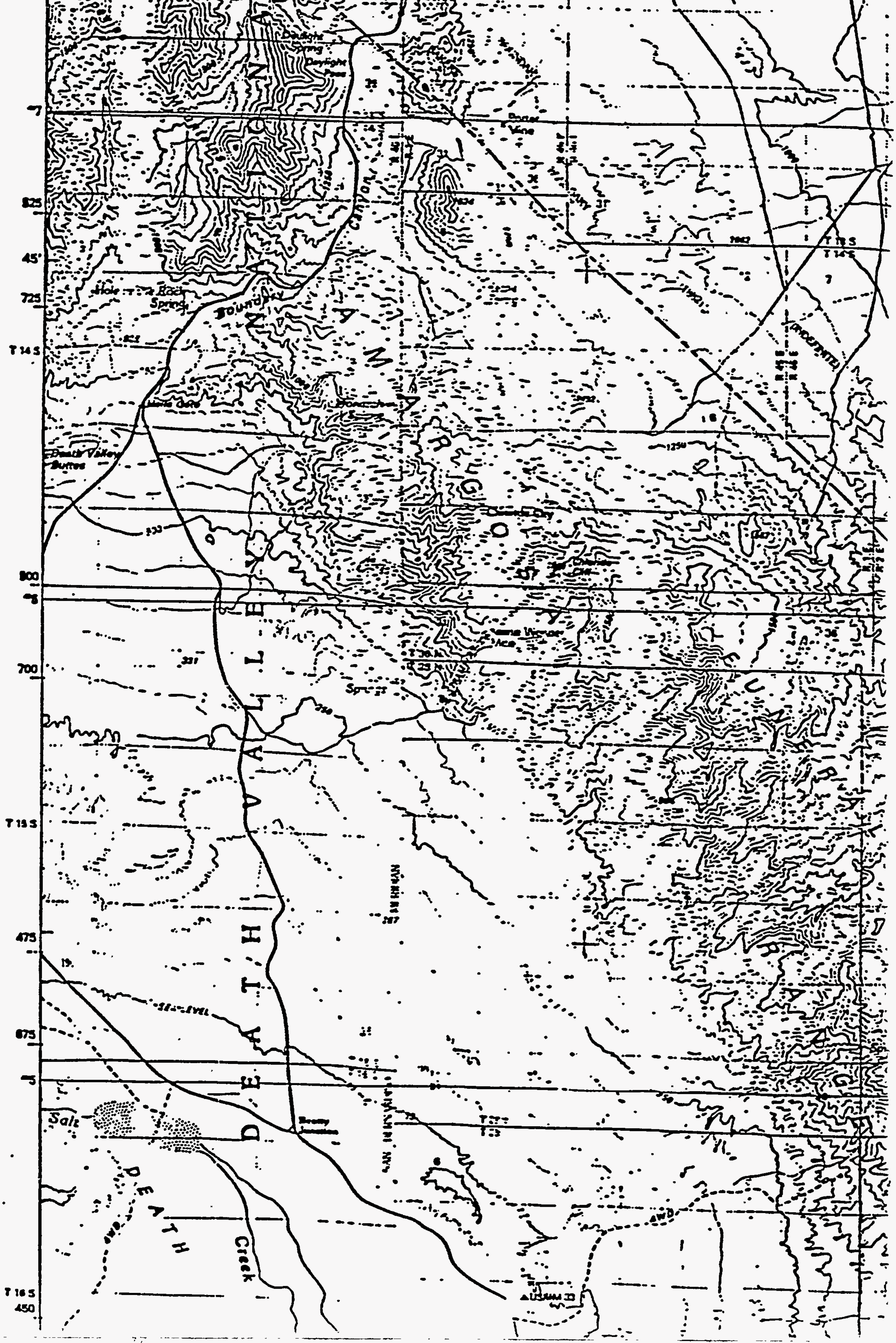
Produced by the United States Geological Survey

Compiled from USGS 1:24 000 and 1:62 500-scale topographic maps dated 1952-1984. Planimetry revised from aerial photographs taken 1983 and other source data. Revised information not field checked. Map edited 1986

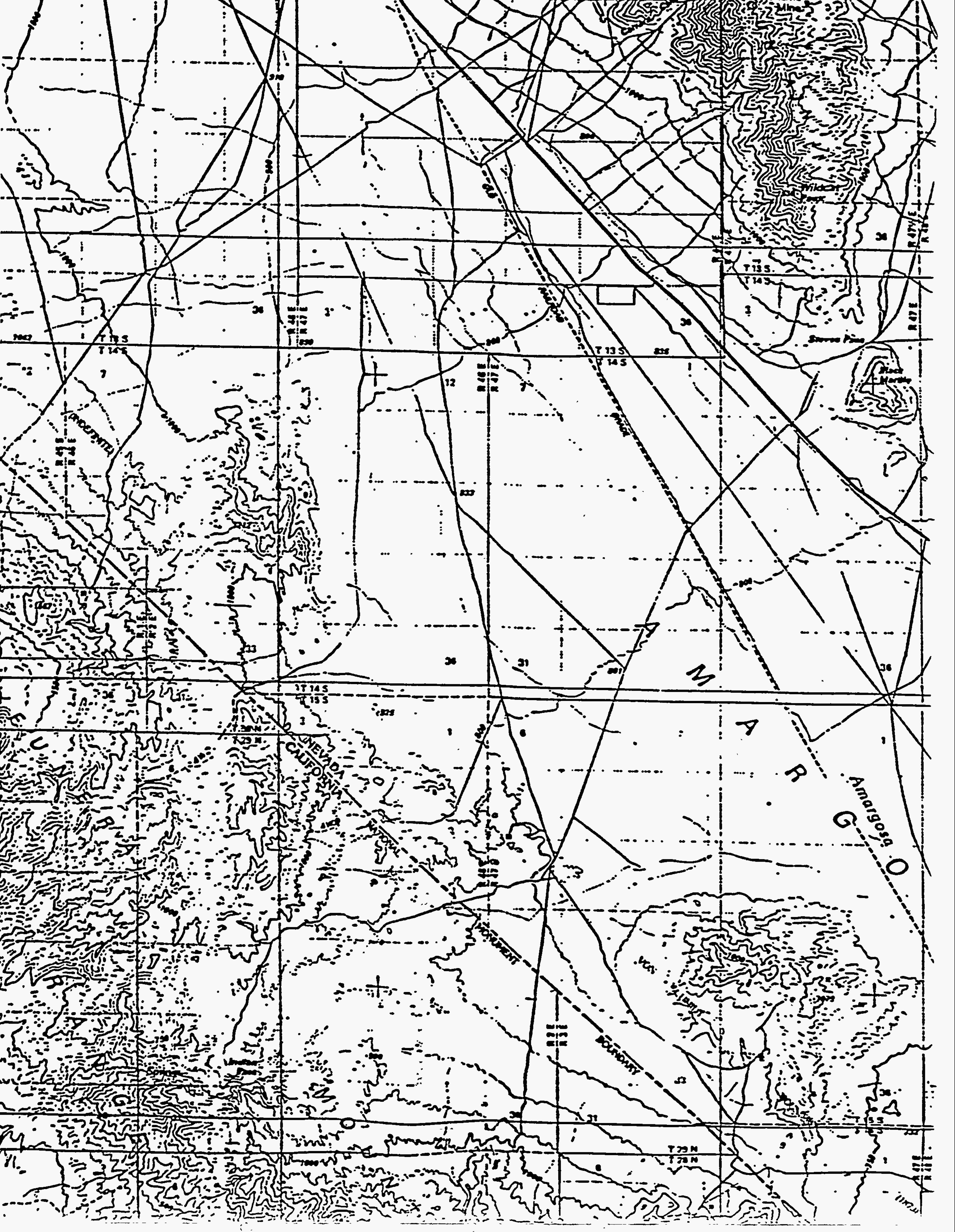
Projection and 10 000-meter grid, zone 11.
Universal Transverse Mercator
25 000-foot grid ticks based on Nevada coordinate system, central zone and California coordinate system, zone 4
1927 North American Datum
To place on the predicted North American Datum 1983 move the projection lines 8 meters north and 79 meters east

There may be private inholdings within the boundaries of the National or State reservations shown on this map

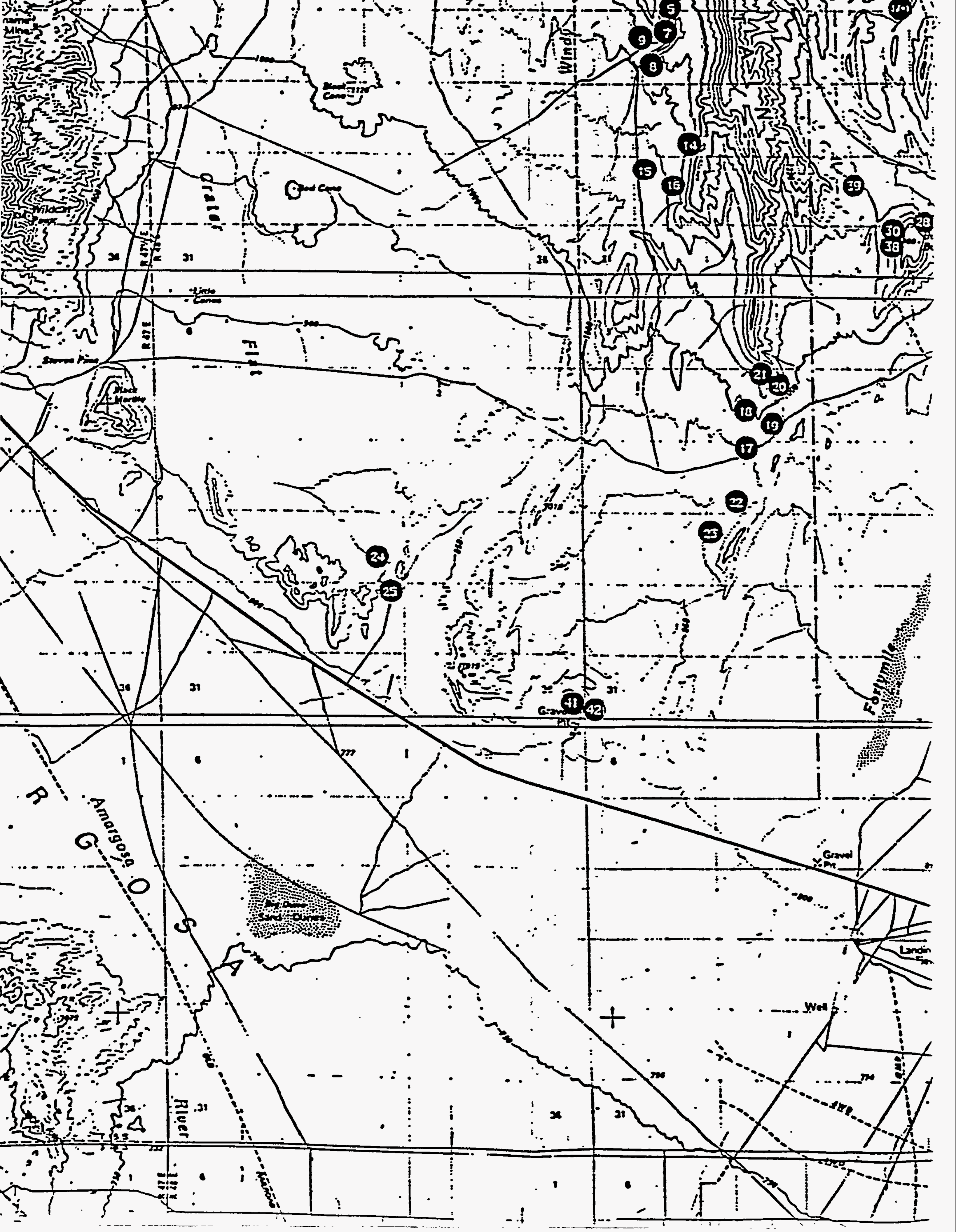
CONTOUR INTERVAL 50 METERS
NATIONAL GEODETIC VERTICAL DATUM OF 1929



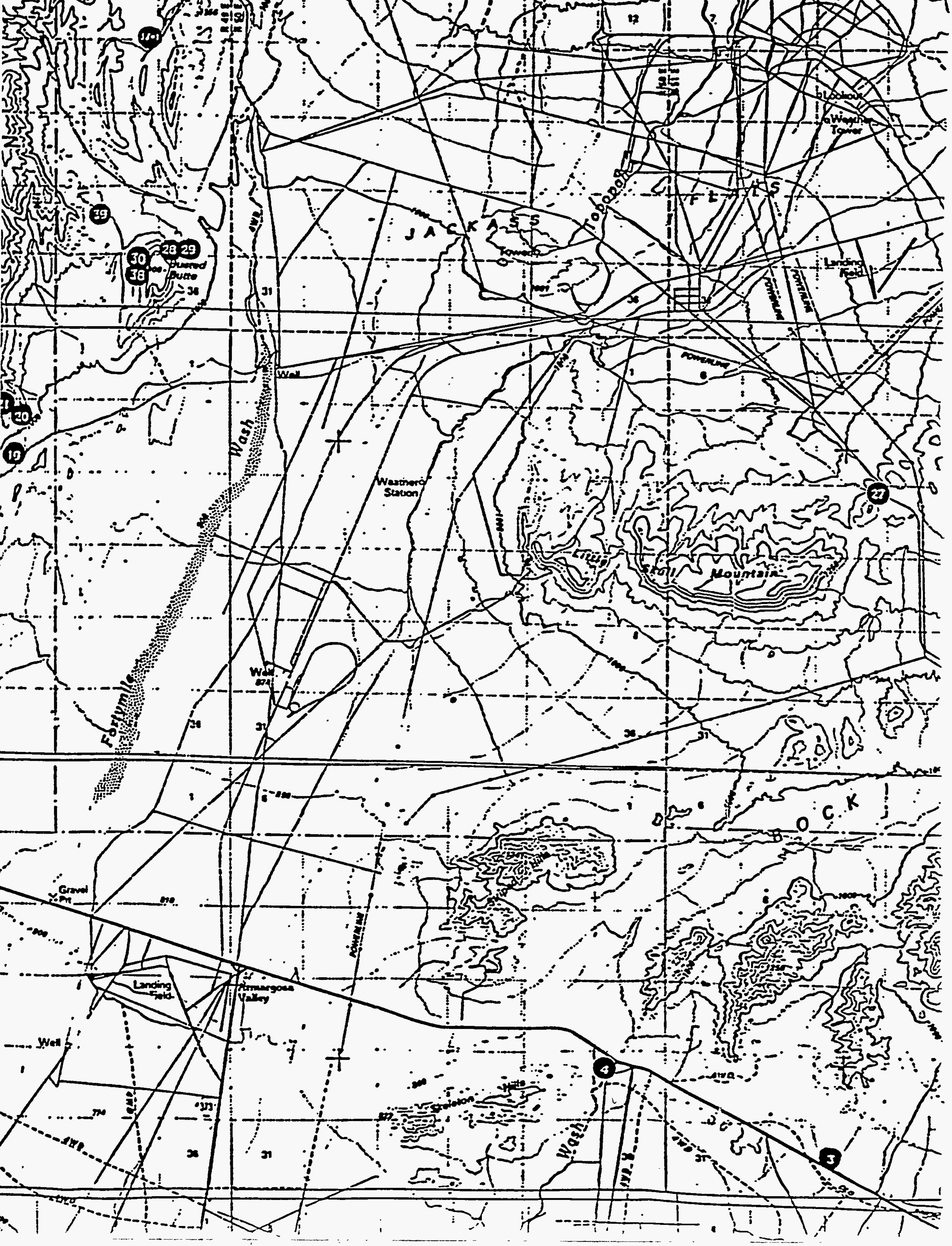
T 14 S
T 15 S
T 16 S
825
45'
725
800
700
475
675
450
Death Valley Buttes
Salt
Creek
DEATH
Beatty Junction
Boundary
Canyon
Daylight Pass



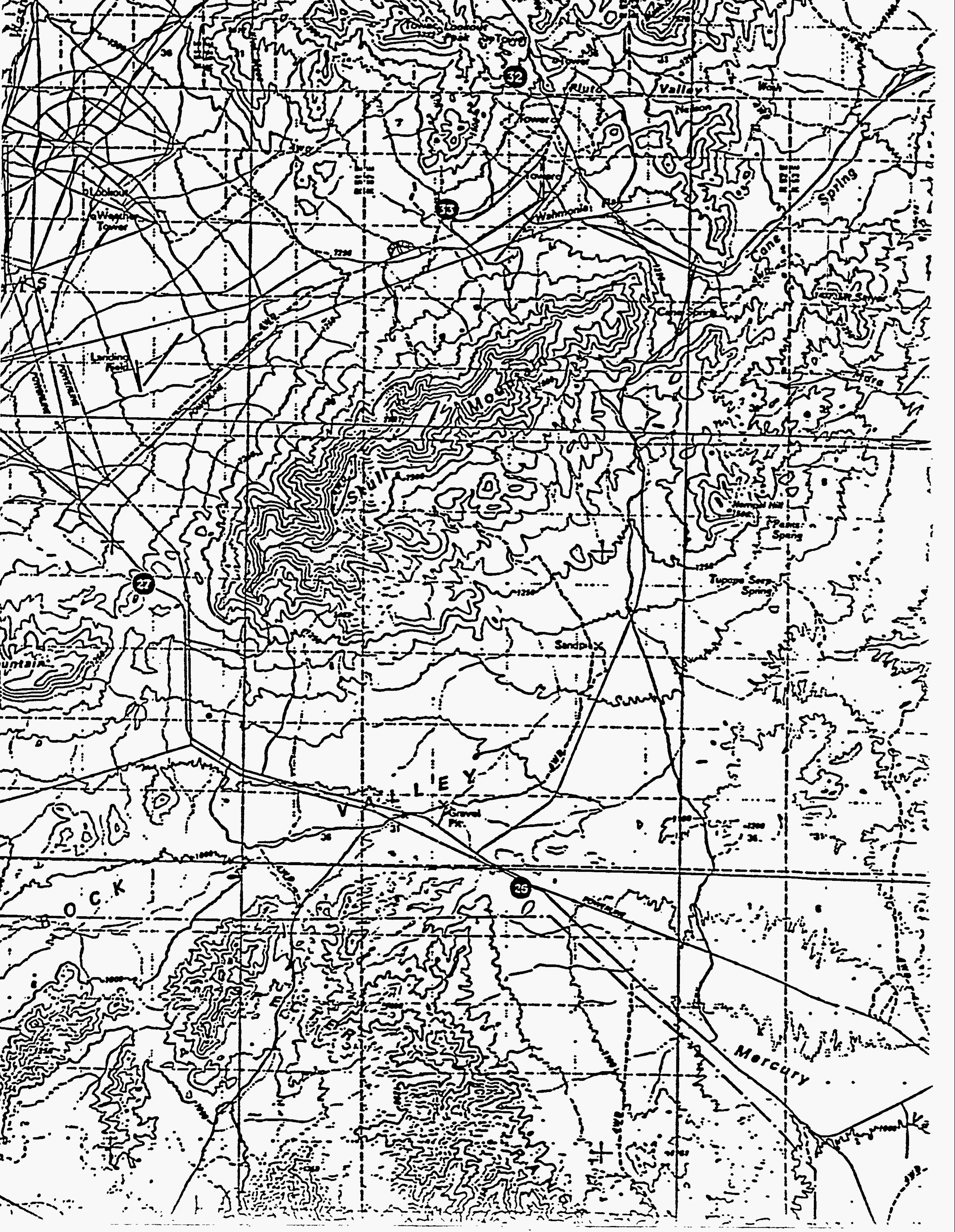
T 13 S
T 14 S
T 15 S
T 29 N
T 28 N
A M A R G O
Amargosa
NEVADA
CALIFORNIA
NATIONAL
MONUMENT
BOUNDARY
Black Marble

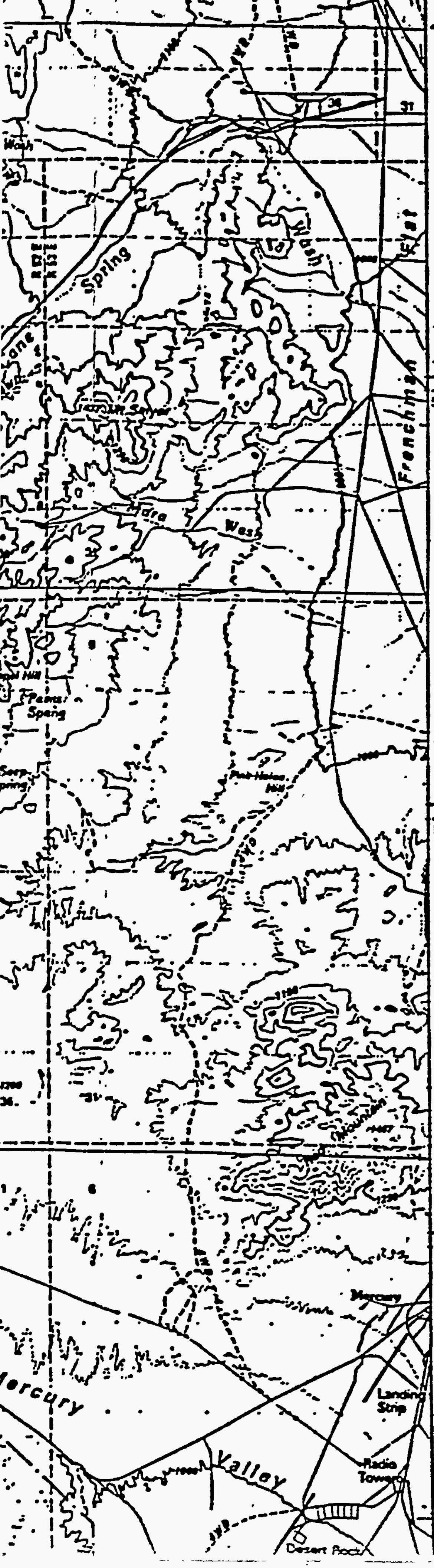


Wildcat Peak
Crater
Flat
Little Cones
Red Cone
Black Cone
Steves Pass
Black Marble
R 47 E
R 48 E
Amargosa
River
R
G
O
S
A
Big Dune
Sand Dunes
Gravel Pit
Well
Fortymile
5
7
9
8
14
15
16
39
30
28
38
21
20
18
19
17
22
23
24
25
41
42



JACKASS
FLATS
Lookout
Weather Tower
Landing Field
Well
Fortymile Wash
Weather Station
Little Skull Mountain
Busted Butte
ROCK
Gravel Pit
Landing Field
Amargosa Valley
Skeleton Hills
Wash
POWERLINE


32
Valley
Nelson
Wash
33
Wahmonie
Lookout
Weather Tower
Landing Field
Cane Spring
Spring
Skull
Mou
Sandpit
Tupapa Seep Spring
27
L E Y
V A
Gravel Pit
O C K
25
Mercury



GEOLOGICAL SURVE

1986

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CONTOUR INTERVAL 50 METERS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS

BOULDER MAP GALLERY

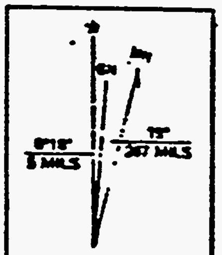
CONVERSION TABLE

Meters	Feet
1	3.2808
2	6.5617
3	9.8425
4	13.1234
5	16.4042
6	19.6850
7	22.9659
8	26.2467
9	29.5276
10	32.8084

To convert meters to feet multiply by 3.2808

To convert feet to meters multiply by 0.3048

DECLINATION DIAGRAM



UTM grid convergence (GN) and 1986 magnetic declination (MN) at center of map
Diagram is approximate

ADJOINING MAPS

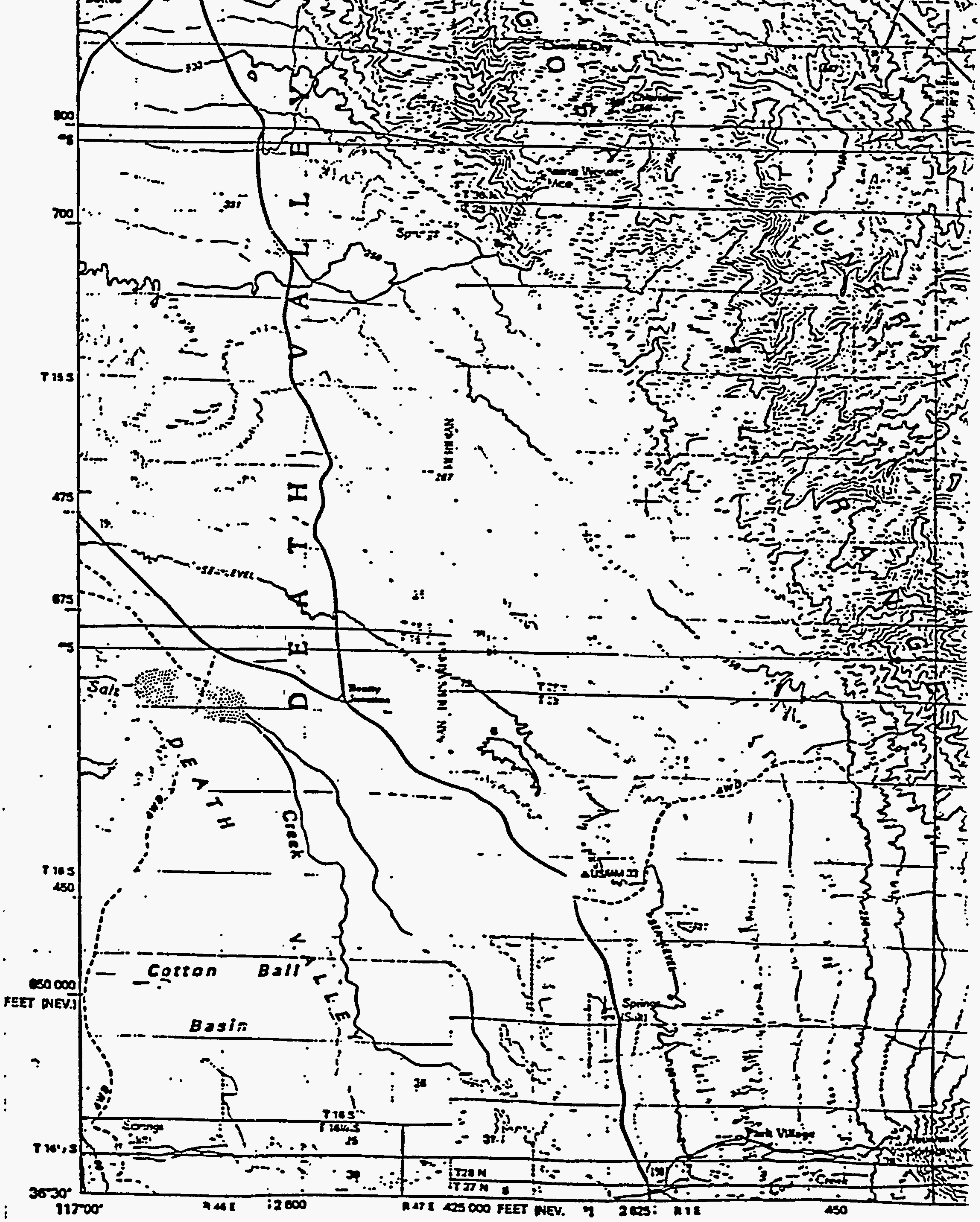
1	2	3
4		5
6	7	8

1 Last Chance Range
2 Pahute Mesa
3 Pahranagat Range
4 Saline Valley
5 Indian Springs
6 Darwin Hills
7 Death Valley Junc.
8 Las Vegas

FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225
OR RESTON, VIRGINIA 22092

Topographic Map Symbols

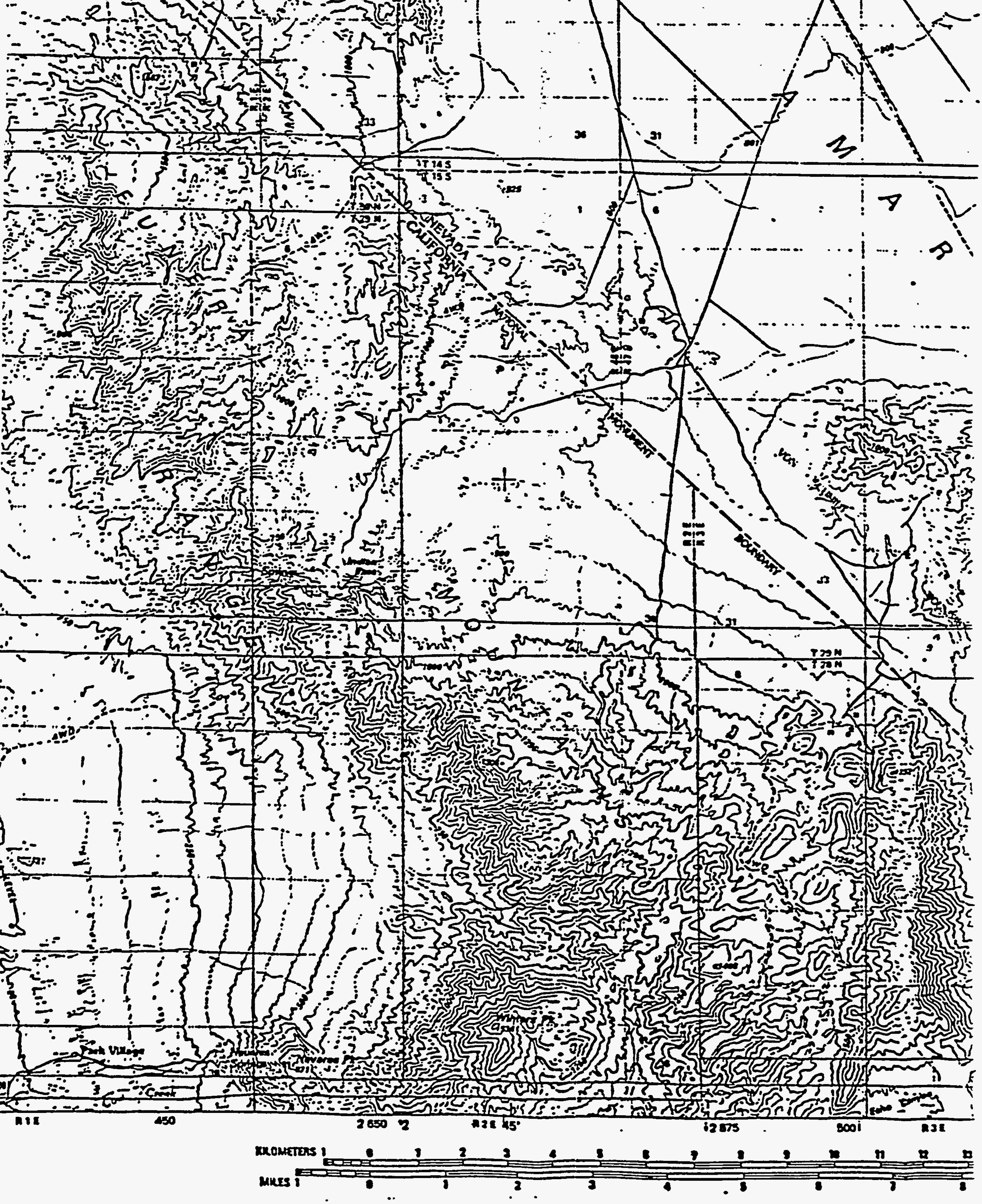
Primary highway, hard surface
Secondary highway, hard surface
Light-duty road, principal street, hard or improved surface



DEATH VALLEY
DEATH
Salt
Creek
Cotton Ball Basin
VALLEY
Beatty Junction
Springs (Salt)
Park Village
Springs
SEA LEVEL
Creek
T 15 S
T 16 S
T 16 S
T 16½ S
T 28 N
T 27 N
800
700
475
675
450
850 000 FEET (NEV.)
36°30'
117°00'
R 46 E
R 47 E
425 000 FEET (NEV.
2 625
450

KILOM

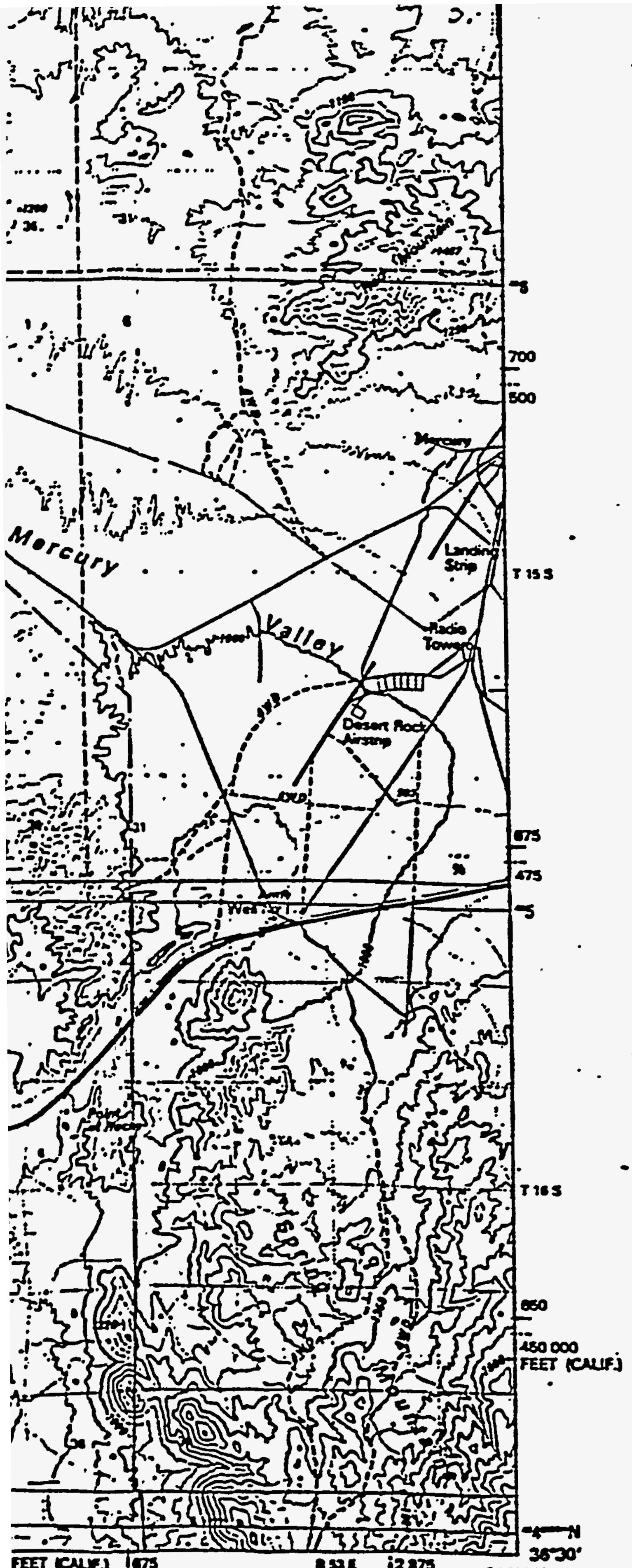
MILE:


T 14 S
T 15 S
NEVADA
CALIFORNIA
NATIONAL
MONUMENT
BOUNDARY
M
A
R
Park Village
Creek
R 1 E
450
R 2 E
R 3 E
KILOMETERS
MILES

Amargosa
River
Gravel Pit
Well
Wells
NYE CO
INYO CO
T 28 N
T 27 N
R 3 E
R 4 E
SCALE 1:100 000
1 CENTIMETER ON THE MAP REPRESENTS 1 KILOMETER ON THE GROUND
CONTOUR INTERVAL 50 METERS

Fortymile
Well
Gravel Pit
Landing Field
Amargosa Valley
Well
Skeleton Hills
Wash
Landing Strip
Rock Valley
Wells
Substa
Well
Nine
POWERLINE
4WD
R 49 E
R 50 E
15'
IN THE GROUND

V A L L E Y
R O C K
Gravel Pit
Mercury
Wells
Nine
25
3
2
1
4WD
15'
R 51 E
R 52 E
2 850 000 FEET (CALIF.)
15 000
20 000 METERS
20 000 FEET
BEATTY



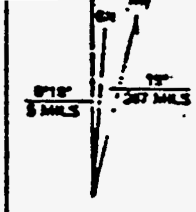
BEATTY, NEVADA—CALIFORNIA
36116–E1–TM–100

1986

1	3.2808
2	6.5617
3	9.8425
4	13.1234
5	16.4042
6	19.6850
7	22.9659
8	26.2467
9	29.5276
10	32.8084

To convert meters to feet multiply by 3.2808

To convert feet to meters multiply by 0.3048



UTM grid convergence (GN) and 1986 magnetic declination (MN) at center of map
Diagram is approximate

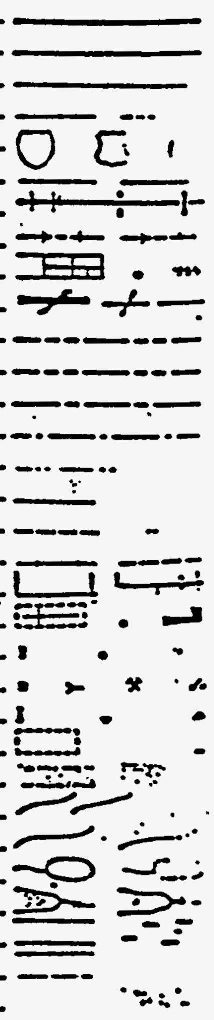
4		5
6	7	8

1 Last Chance Range
2 Pahute Mesa
3 Pahranagat Range
4 Saline Valley
5 Indian Springs
6 Darwin Hills
7 Death Valley Junc.
8 Las Vegas

FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225 OR RESTON, VIRGINIA 22092

Topographic Map Symbols

- Primary highway, hard surface
- Secondary highway, hard surface
- Light duty road, principal street, hard or improved surface
- Other road or street; trail
- Route marker: Interstate; U. S.; State
- Railroad: standard gage; narrow gage
- Bridge; overpass; underpass
- Tunnel: road; railroad
- Built up area; locality; elevation
- Airport; landing field; landing strip
- National boundary
- State boundary
- County boundary
- National or State reservation boundary
- Land grant boundary
- U. S. public lands survey: range, township; section
- Range, township; section line: protracted
- Power transmission line; pipeline
- Dam; dam with lock
- Cemetery; building
- Windmill; water well; spring
- Mine shaft; adit or cave; mine, quarry; gravel pit
- Campground; picnic area; U. S. location monument
- Ruins; cliff dwelling
- Distorted surface: strip mine, lava; sand
- Contours: index; intermediate; supplementary
- Bathymetric contours: index; intermediate
- Stream, lake: perennial; intermittent
- Rapids, large and small; falls, large and small
- Area to be submerged; marsh, swamp
- Land subject to controlled inundation; woodland
- Scrub; mangrove
- Orchard; vineyard



A pamphlet describing topographic maps is available on request

A)

B)

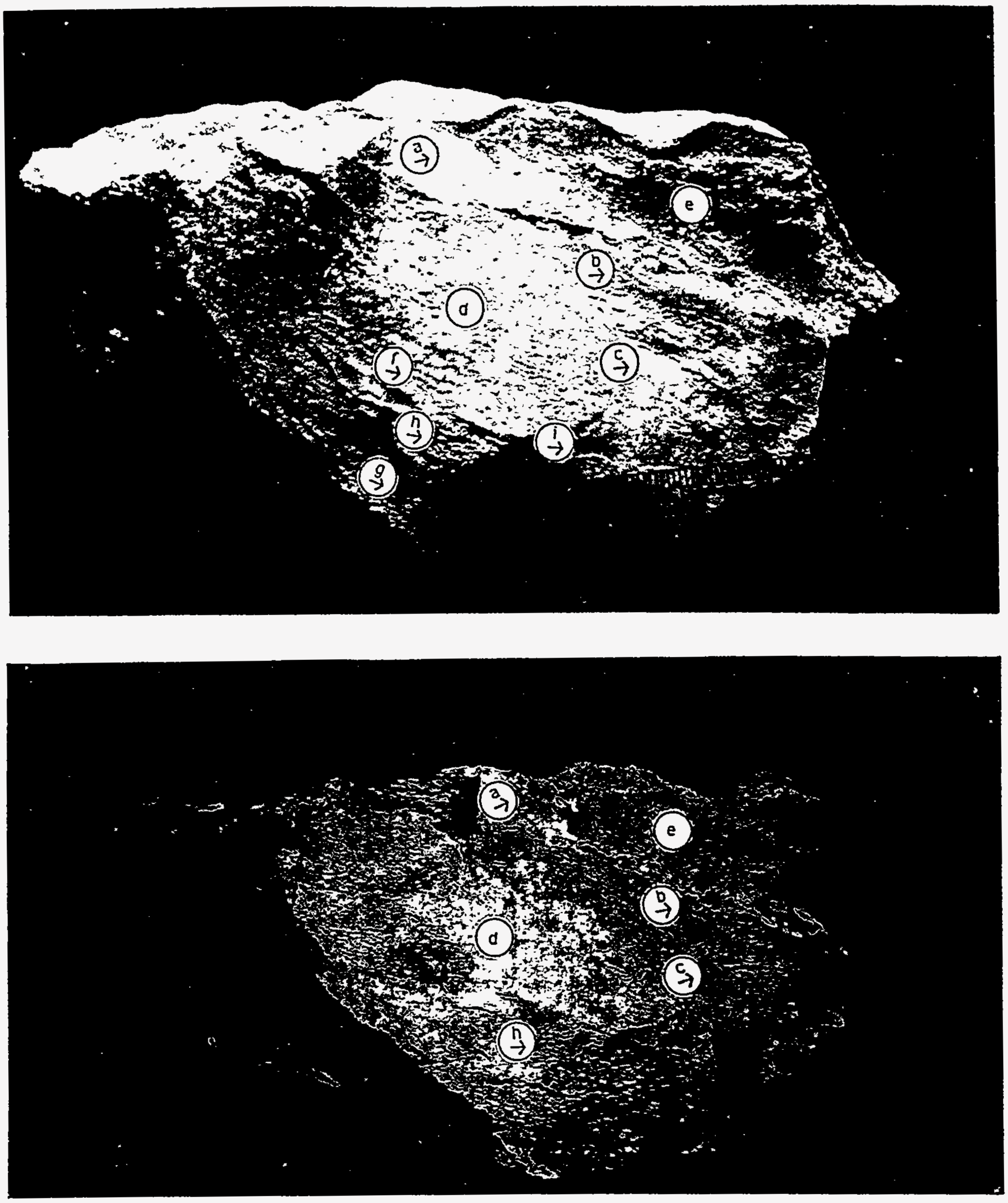


Figure 2. (A) Pods and seams of pure-texture, pearly opal (a, b, c) in a matrix of dense, buff-colored, mixed-textured calcite/opal (d). Lighter-colored sections are very soft and porous (easily scratched), massive-textured calcite/opal (e). Note the holes (vesicular/phenocrystic texture) throughout the mass, especially in the dense, buff-colored calcite/opal (f, g), but also in the massive-textured calcite/opal (h). Also note how the vesicles seem to line up in bands (i and elsewhere). (B) Using a UVG-54 Mineralight, this photo (same position as A) illustrates bands of pure opal fluorescing a brilliant green (a, b, c) in the mixed-textured calcite/opal which does not fluoresce (d, e, h). Photos by Christine Schluter; Sample 36b, Trench 14).

A)

B)

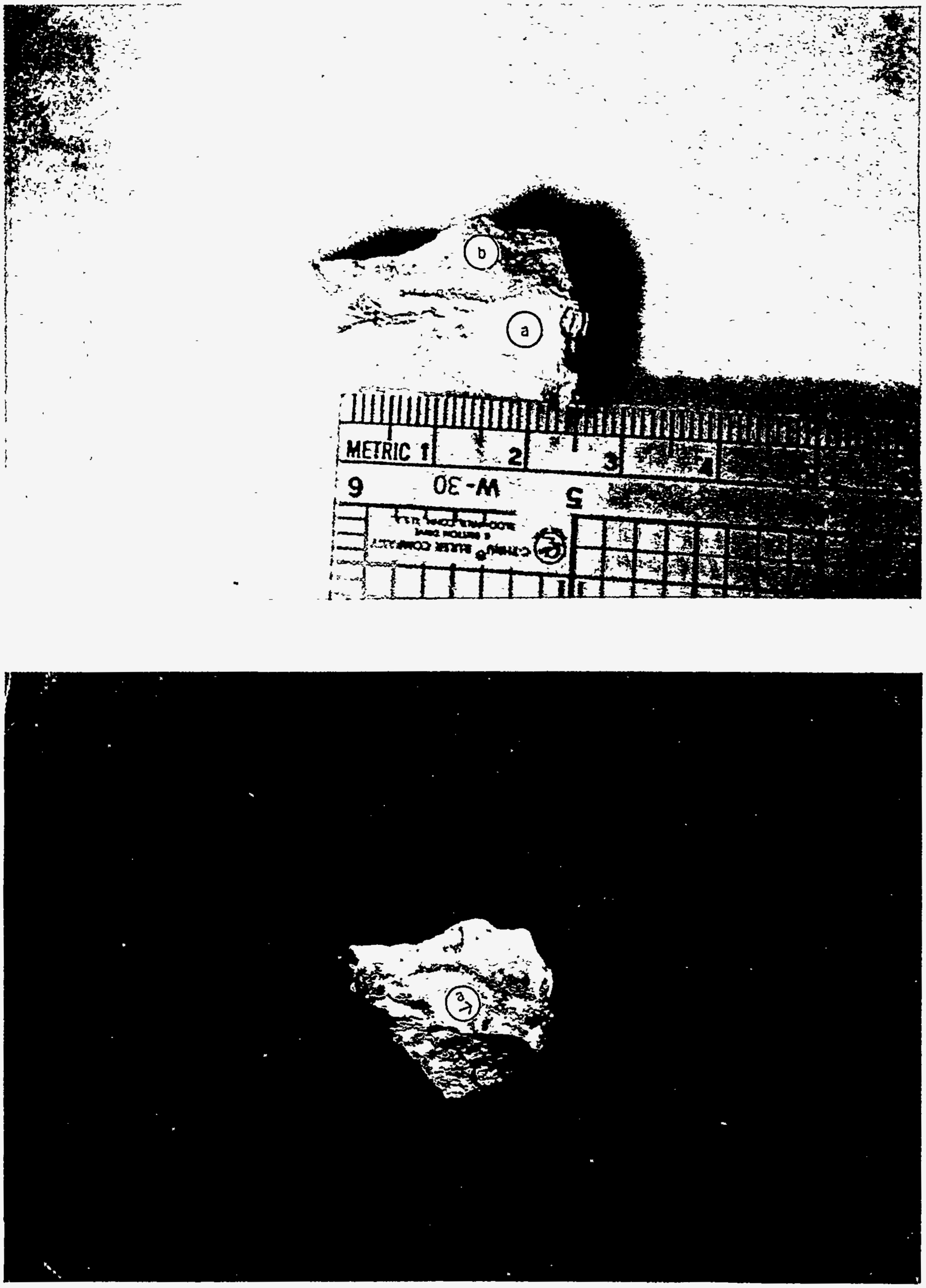


Figure 3. (A) Close-up of pearly, pure-textured opal (a) in a dense, buff-colored, mixed-texture matrix (b). (B) The same sample using a UVG-54 Mineralight, which illuminates the bands of pure opal (a). Photos: Christine Schluter; Sample 36j, Trench 14.

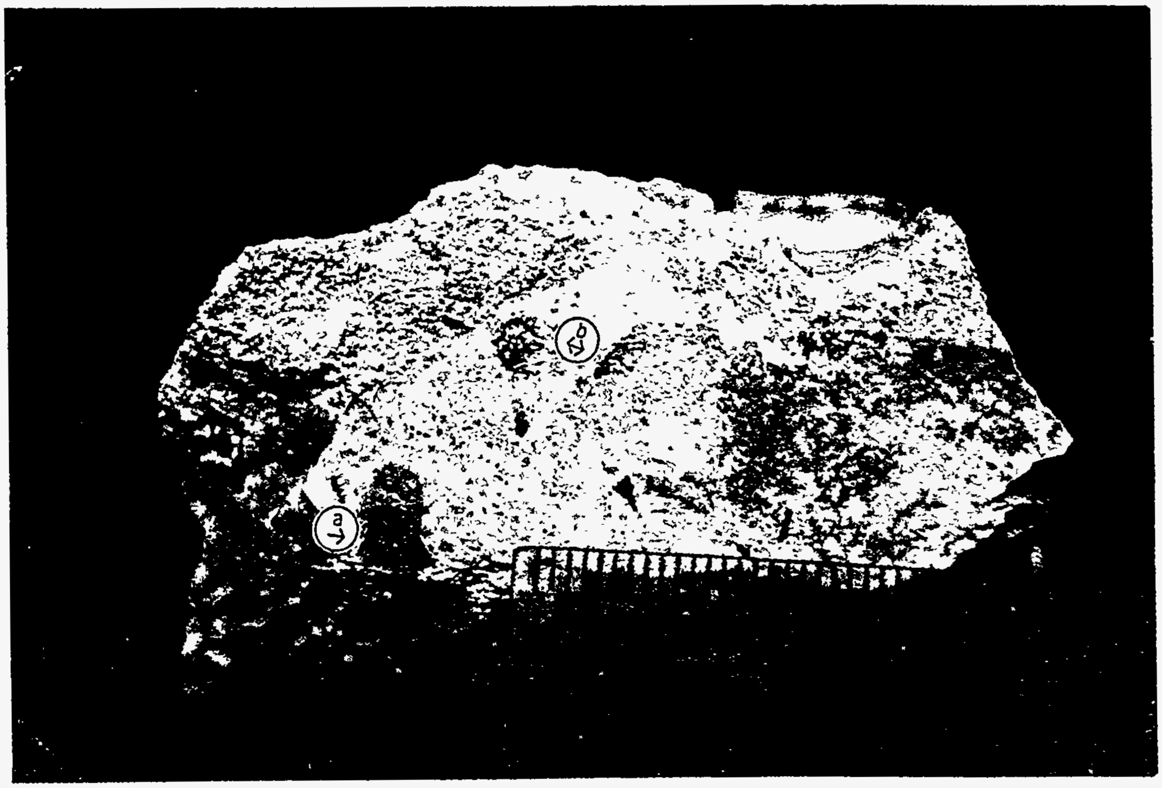


Figure 4. This sample is an example of both mixed texture and floating-brecciated texture. The buff-colored matrix contains varying amounts of calcite and opal; the lighter-colored upper part contains relatively more calcite, and the darker-colored lower part contains relatively more opal. Note the tuffaceous foreign clasts (a, b) which seemingly "float" in the mixed-textured matrix. Photo by Christine Schluter; Sample 7a, downhill from WT-7.

A)

B)

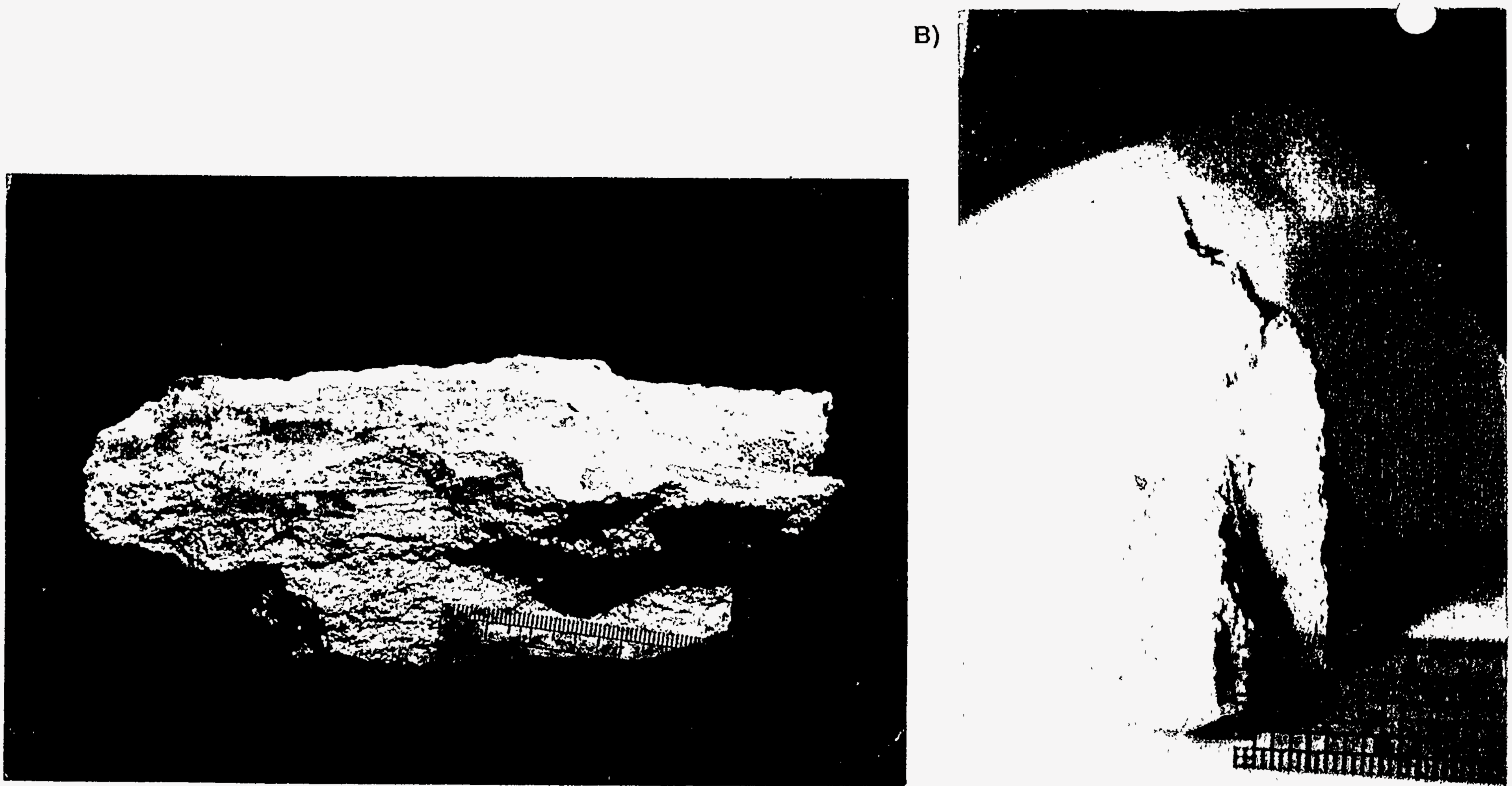


Figure 5 - Banding in a mixed-textured calcite/opal matrix. Banding represents different mixtures of calcite and opal. (A) Horizontal banding, Sample 5d, WT-7 drill pad, and (B) vertical banding, Sample 28d, from east side of Busted Butte. Photos by Christine Schluter.

A)

B)

<u>Figure 6.</u> Two more examples of banded/laminated texture. (A) Laminated texture where the individual layers are narrow (a few millimeters). This sample also displays flow texture, where darker and lighter bands exhibit a marbly or wavy pattern. Note the dark reaction rim at the edge of the Tiva Canyon tuff where it comes in contact with the calcite/opal matrix. Under thin section this rim does not appear to have been altered or invaded by calcite/opal; rather, it appears to be a "baked" rim possibly caused by hot calcite/opal solutions. (B) Two banded textures from the Wailing Wall. Photos by Christine Schluter; (A) = 5a; (B) = 19a.

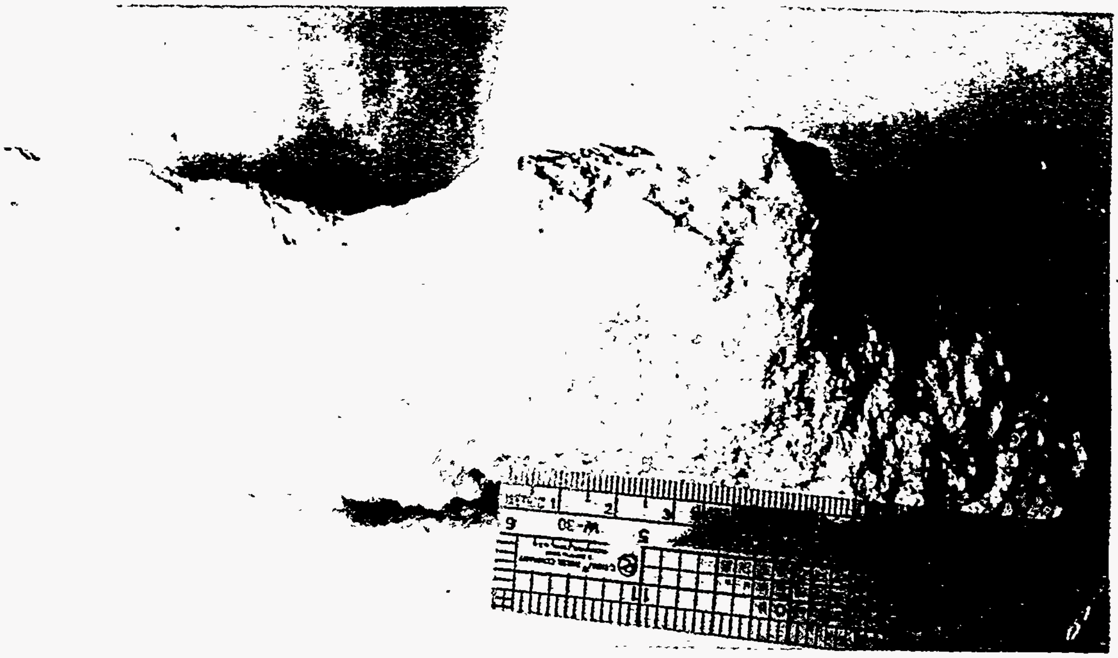


Figure 7. Massive texture showing porous, unlayered to roughly-layered, calcite/gypsum. This sample (32a) was collected from the Wahmonie travertine/gypsite mound and consists of about 70-80% calcite and 20-30% gypsum. Photo: Christine Schluter.

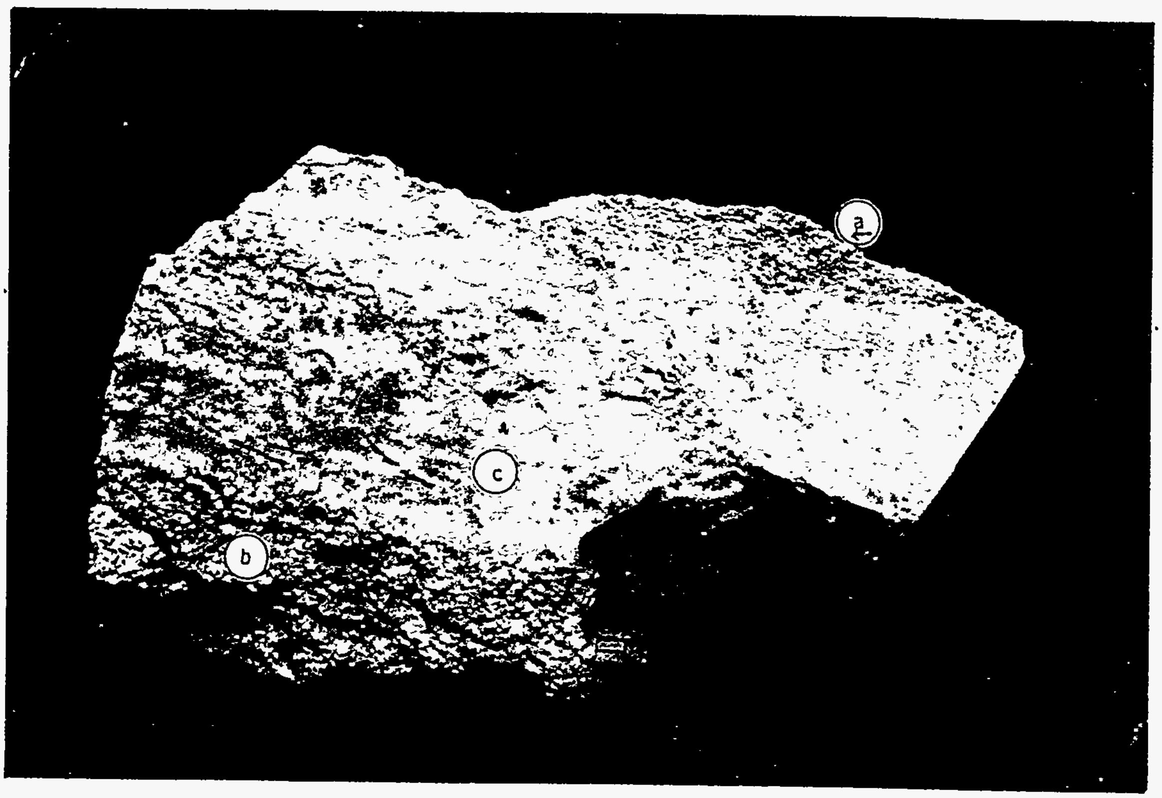


Figure 8. Powdery-textured calcitic layers (a, b) interbedded with dense, buff-colored, mixed-textured calcite/opal (c). This sample (10e) was collected from the Bare Mountain mining district west of Yucca Mountain, yet it displays identical textures to samples collected at Yucca Mountain. Photo: Christine Schluter.

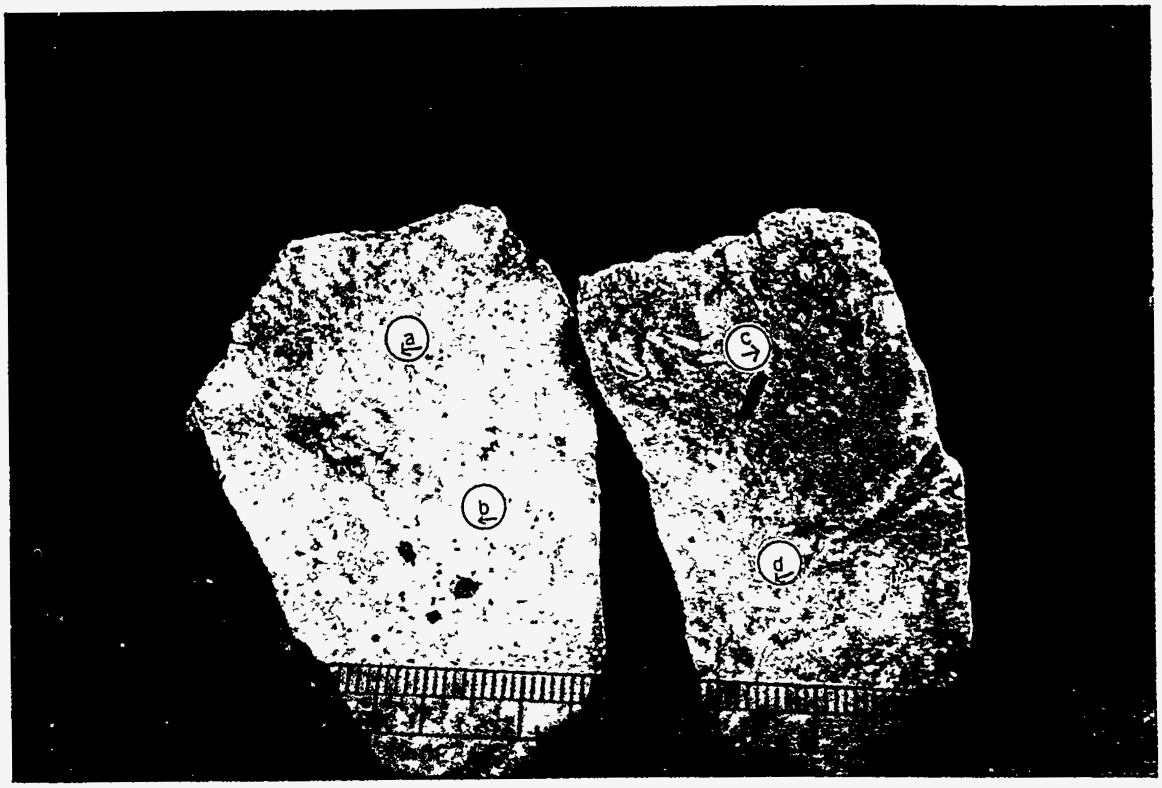


Figure 9. Patchy texture contains clasts of calcite/opal (a, b, c, d) within a mixed-textured calcite/opal matrix. The clasts (both rounded and angular) of calcite/opal must have been at least partially-hardened and brecciated before a later engulfment by the calcite/opal matrix. Photo: Christine Schluter; Sample 4d, Pull Apart Fault.

A)

B)

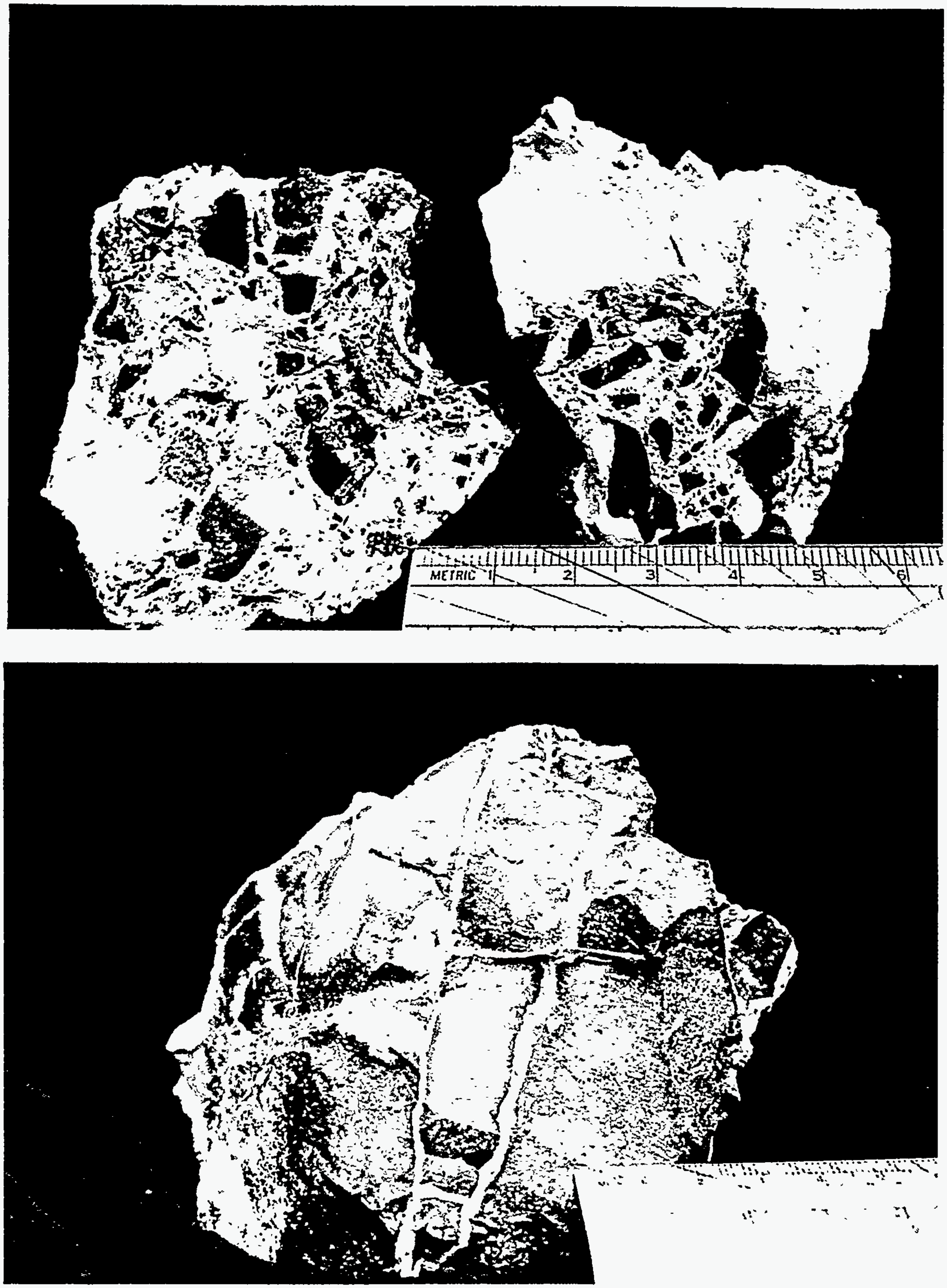


Figure 10. Brecciated texture: (A) Floating-brecciated texture where the Tiva Canyon clasts seem to "float" in a calcite/opal matrix, and (B) Mosaic-brecciated texture where the Tiva Canyon has become fractured and filled with (and wedged apart by?) calcite/opal. Both (A) and (B) are part of Sample 5g, WT-7 drill site, showing that floating- and mosaic-brecciated texture can occur together. Photos by Christine Schluter.

Figure 11. Mosaic-brecciated texture, WT-7 drill pad, Sample WT-7 (3). Note how many of the clasts can be "fitted back together" like the pieces of a puzzle. This type of breccia has alternately been considered to be an "explosion breccia" or the result of "chemical brecciation." Photo: Carol Hill.

A)

B)

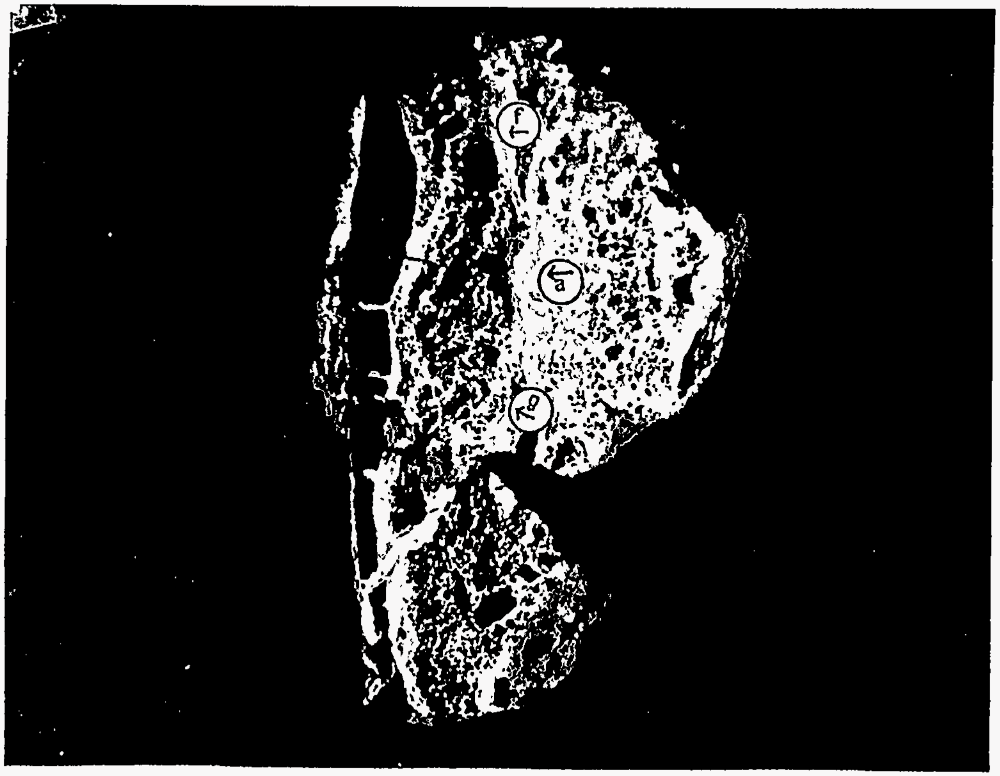


Figure 12. (A) This sample displays many textural types: pure texture (the seams of pearly opal; a), mixed texture (the buff-colored matrix material; b), floating-breccia texture (c), mosaic - breccia texture (d), and flow texture (e). Note how in the flow texture the calcite/opal appears to have "flowed" conformable to the Tiva Canyon breccia clast to the left of it. Note also the seam of pearly opal (follow seam from f to g). This piece is part of an almost-vertical dike cutting the Tiva Canyon at Trench 14 (Sample 36z). (B) Using a UVG-54 Mineralight, this fluorescent photo illustrates flow texture; where bands of pure opal (a, f, g) exhibit a wavy pattern. Photos: Christine Schluter.

A)

B)

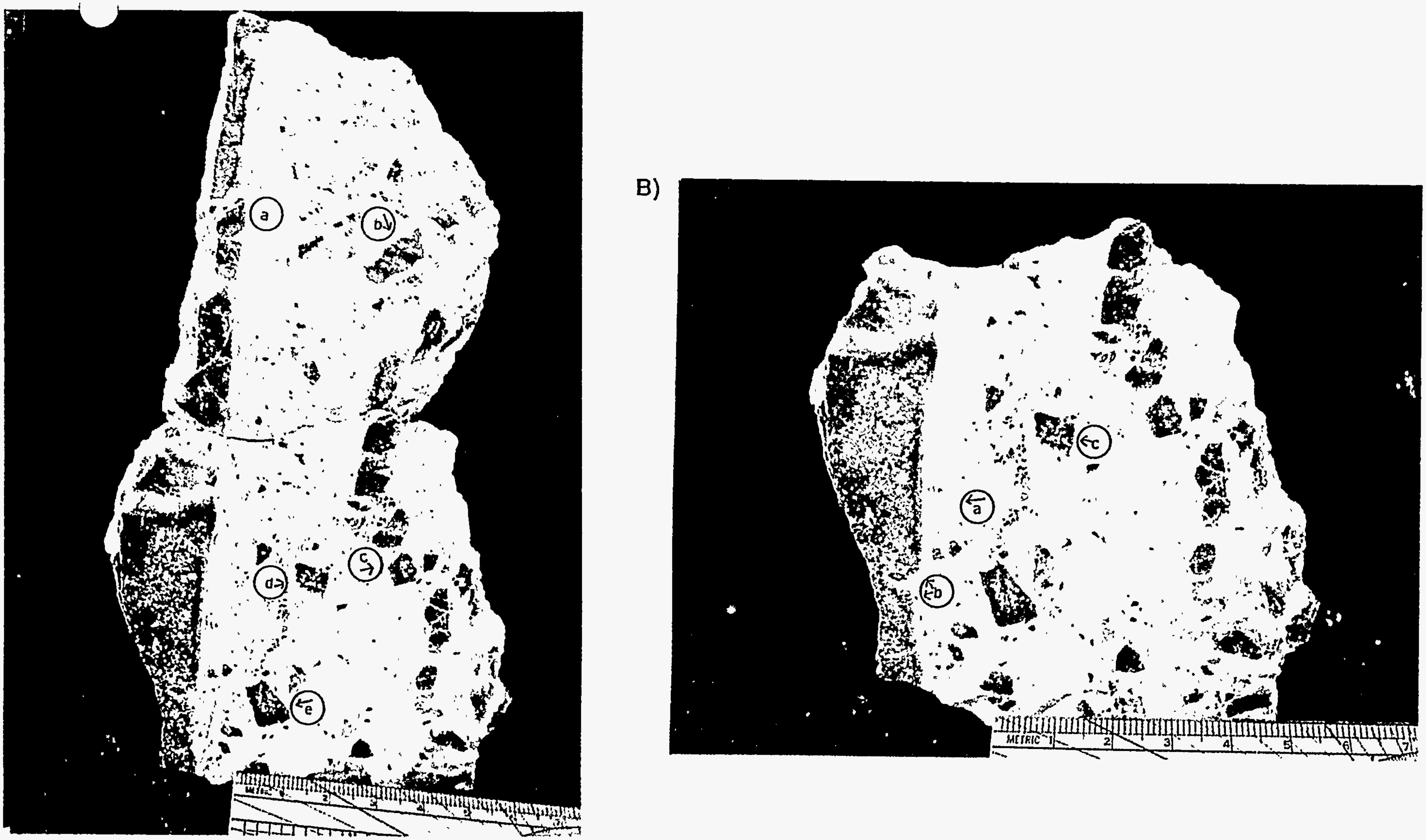
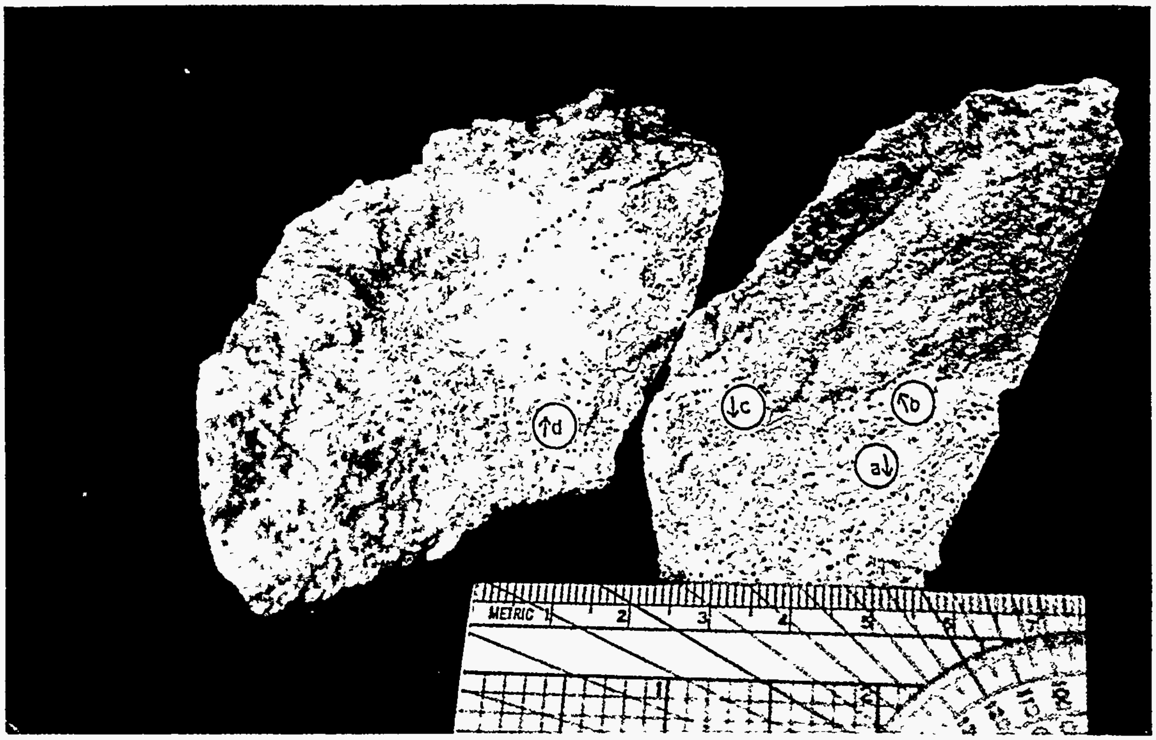


Figure 13. Mosaic- and floating-brecciated texture, Sample 36z, Trench 14. (A) Note the mosaic-brecciated texture on the left and how the clasts at (a) have been cross-cut by calcite/opal material and offset slightly to the right. Note also the mosaic- to floating-brecciated textures on the right; how the clast at (b) has been turned about 30° to the vertical and how the "line of clasts" veers to the right at (c). Clasts (d) and (e) may have been part of the "line" but were swept to the left. (B) Close-up of bottom part of (A) which shows the marbly flow-texture of the calcite/opal matrix (e.g., at a). Note the possible reaction (baked?) rims surrounding clasts (b) and (c). Photos: Christine Schluter.

A)



B)

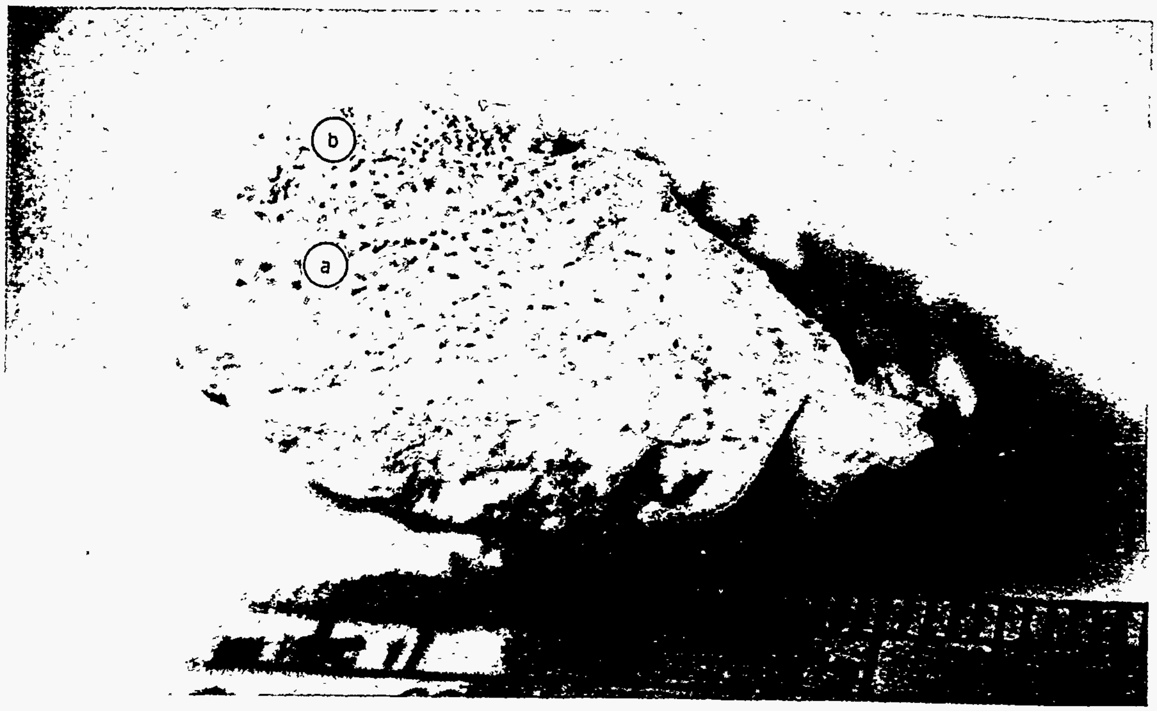


Figure 14. Vesicular/phenocrystic texture: (A) Note how the vesicles are aligned in rows along roughly-layered banded sequences; lighter bands (a), darker bands (b), or along wavy flow texture (c, d). This sample (10a) was collected from the Bare Mountain mining district west of Yucca Mountain. (B) Note how the vesicles occur in both the mixed-texture, buff-colored calcite/opal (a) and also across the boundary into the powdery-texture matrix (b). This sample (36h) was collected at Trench 14 and possibly indicates that the mixed and powdery textures formed penecontemporaneously, with degassing of solutions creating the vesicular texture. Photos: Christine Schluter.

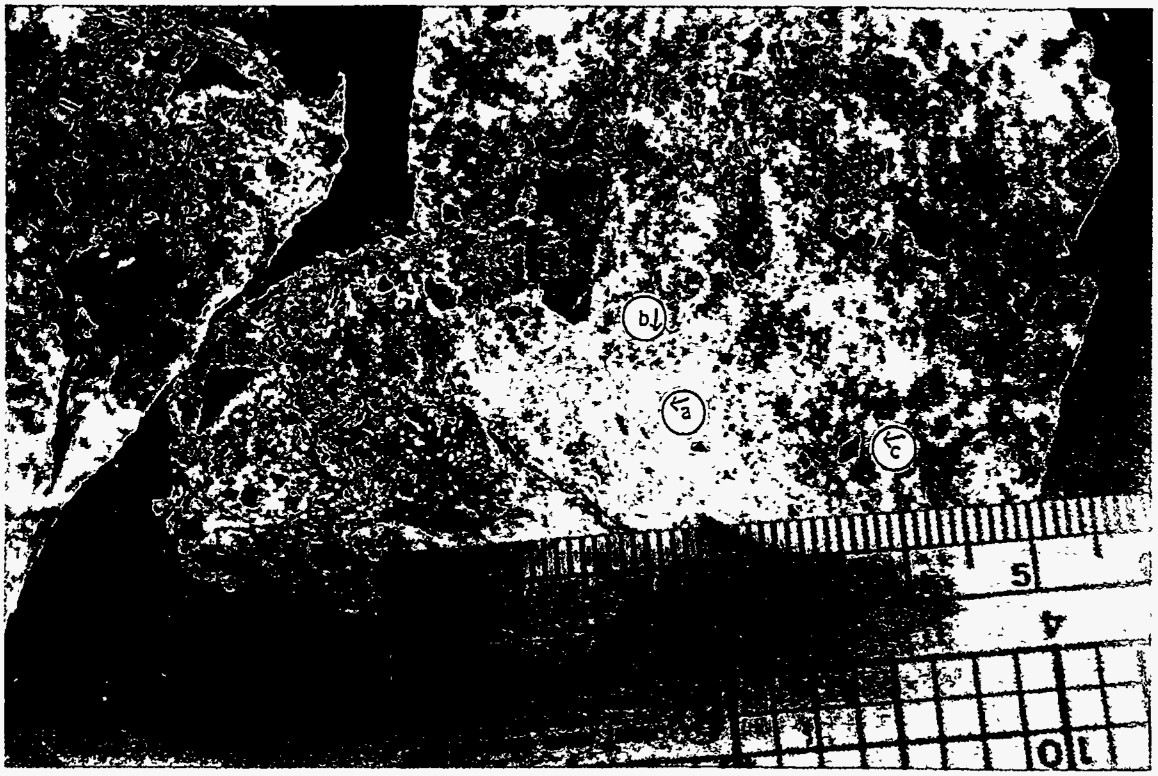


Figure 15. Veined texture where calcite/opal veins cross-cut calcite/opal matrix (a). This is also a good example of patchy texture (see calcite/opal clasts at b and elsewhere), and floating-brecciated texture (e.g., see foreign clasts at c). Sample 4e, Pull Apart Fault. Photo by Christine Schluter.

A)

B)

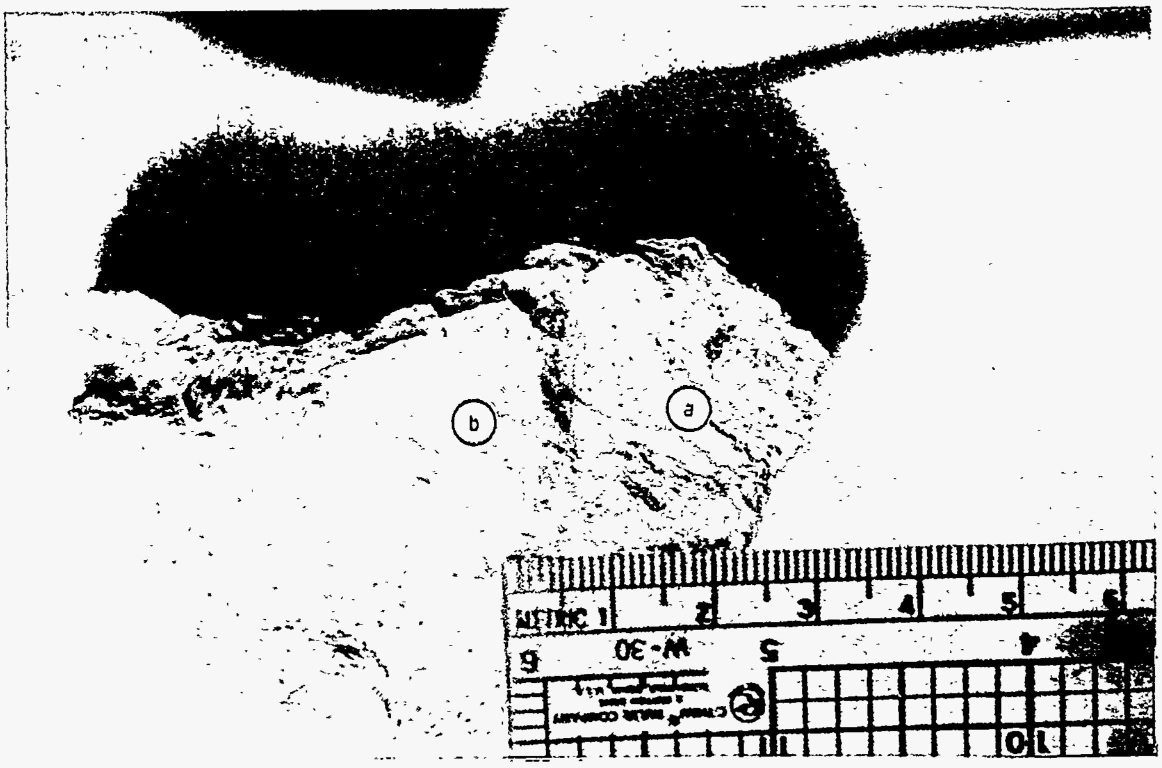
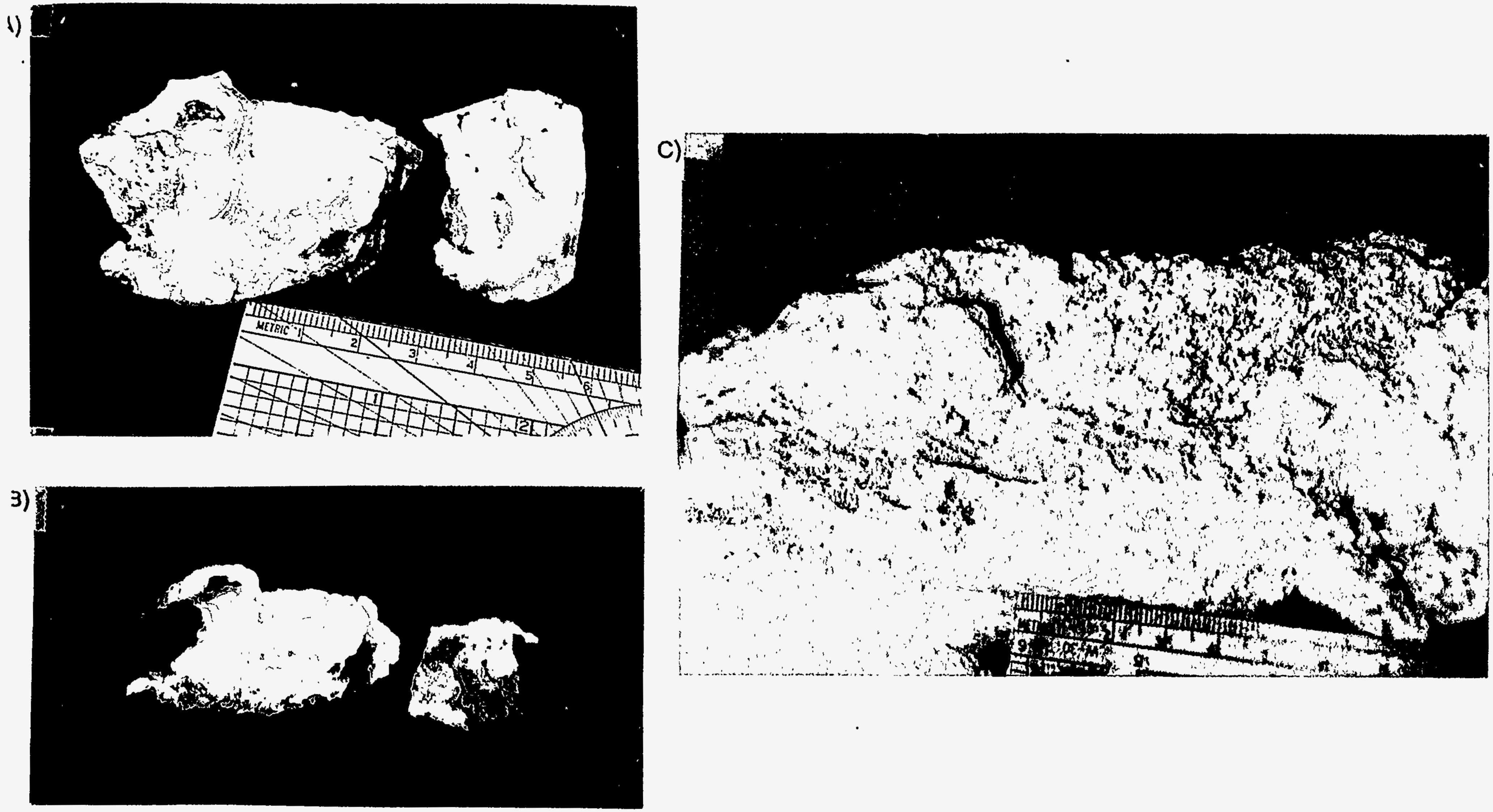


Figure 16. Two examples of invasive texture: (A) where dense, buff-colored, calcite/opal of mixed texture (a) has invaded a powdery-textured mass composed primarily of calcite (b), Sample 19b, Wailing Wall; (B) where a "blob" displaying powdery texture (a) has invaded a calcite/opal banded mass of mixed texture (b), Sample 7d, downhill from WT-7 drill site. Photos by Christine Schluter.



<u>Figure 17.</u> Two examples of botryoidal texture: (A) Botryoidal opal that fills fractures in the Tiva Canyon tuff, Harper Valley (B) fluorescent photo of same sample (Sample 39b); (C) botryoidal gypsum crusts overlying the main mass of calcite/gypsum, Wahmonie travertine/gypsite mound (Sample 32a). Photos by Christine Schluter.

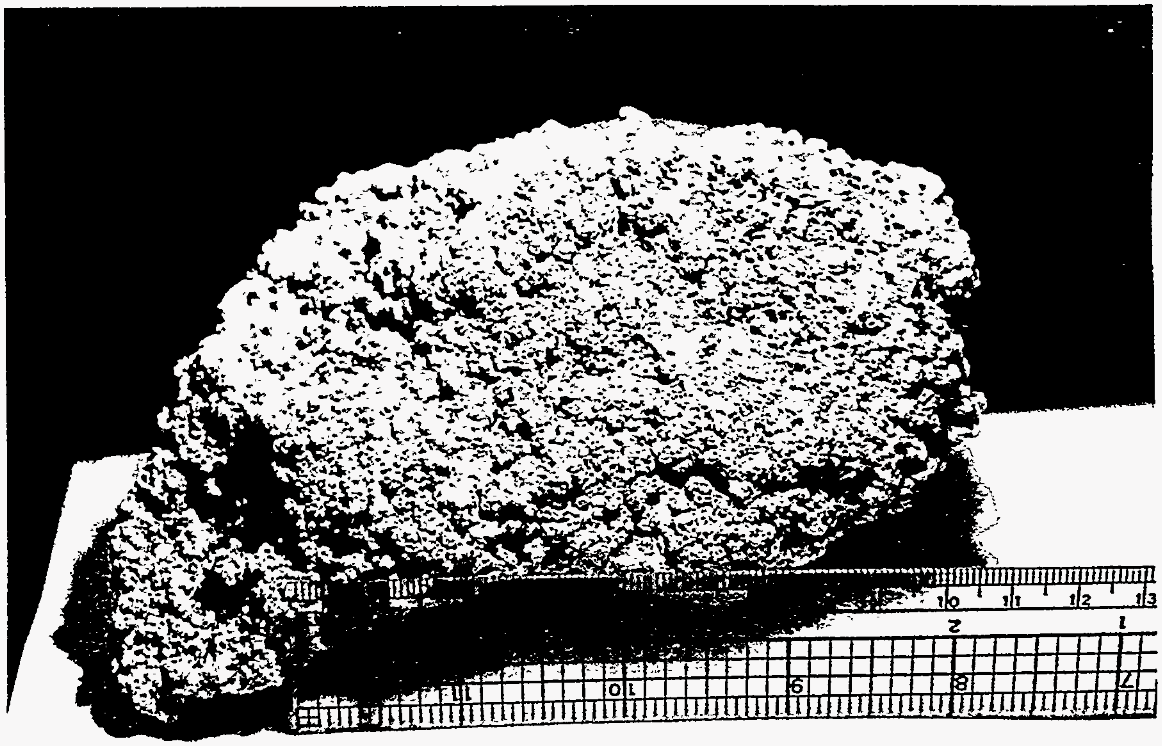


Figure 18. Algal-ooidal texture, Sample 19d, Wailing Wall. Sample may have precipitated from spring water in which algae were growing, much as the actively-growing spring travertine at Cane Springs (east of Yucca Mountain) has live algae in it today. Photo: Christine Schluter.

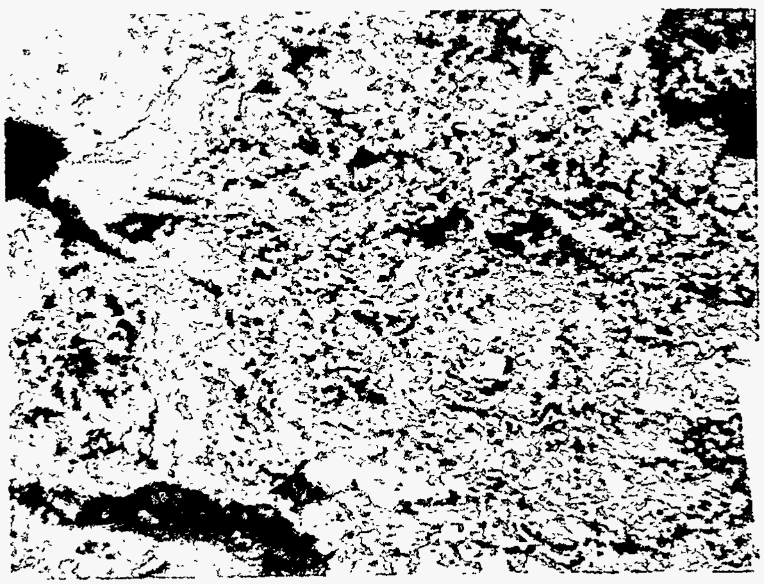


Figure 19. Root-cast texture in sheet travertine, West Busted Butte. Photo: from Johnson Control World Services (taken from a video).

A)

B)

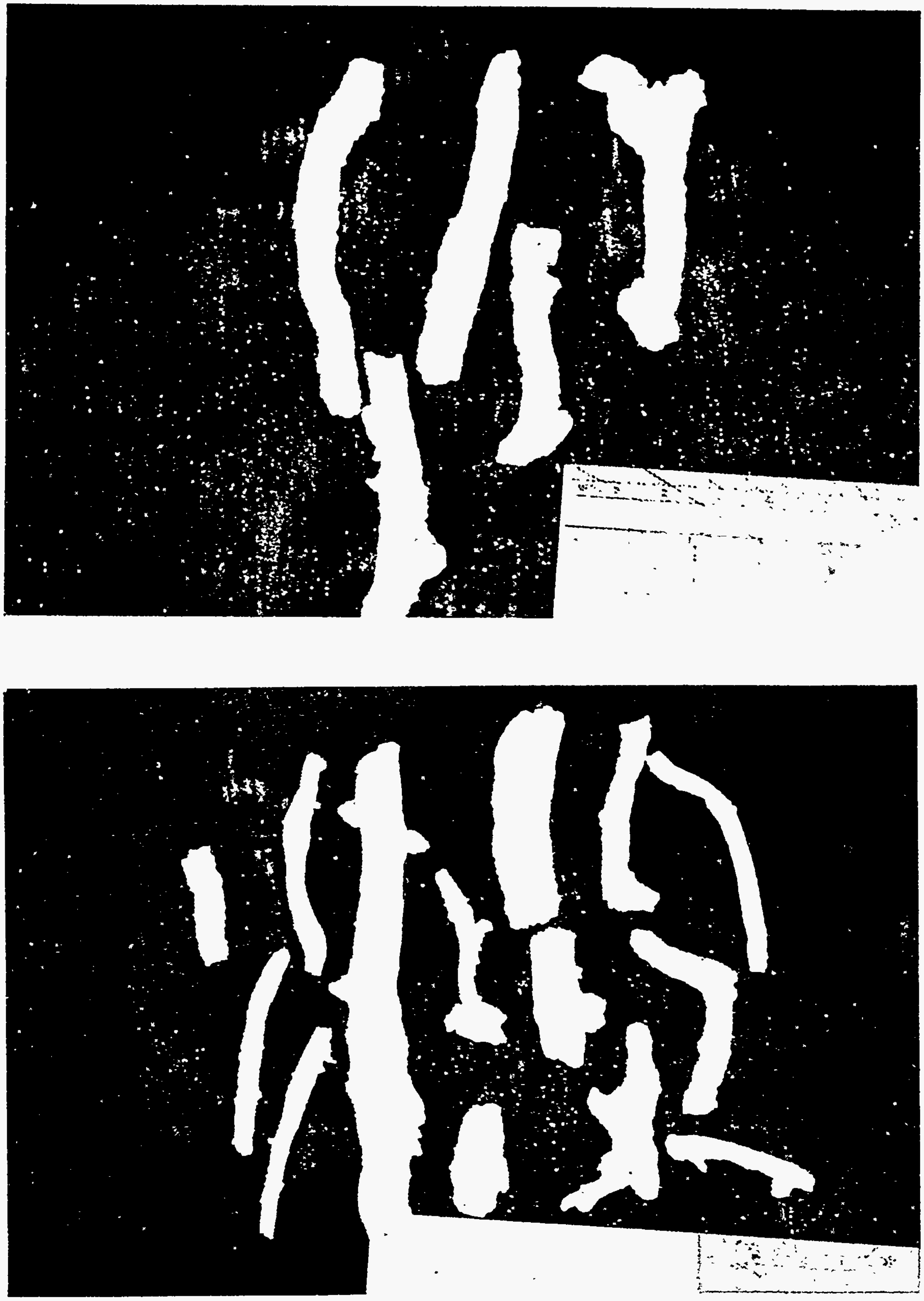
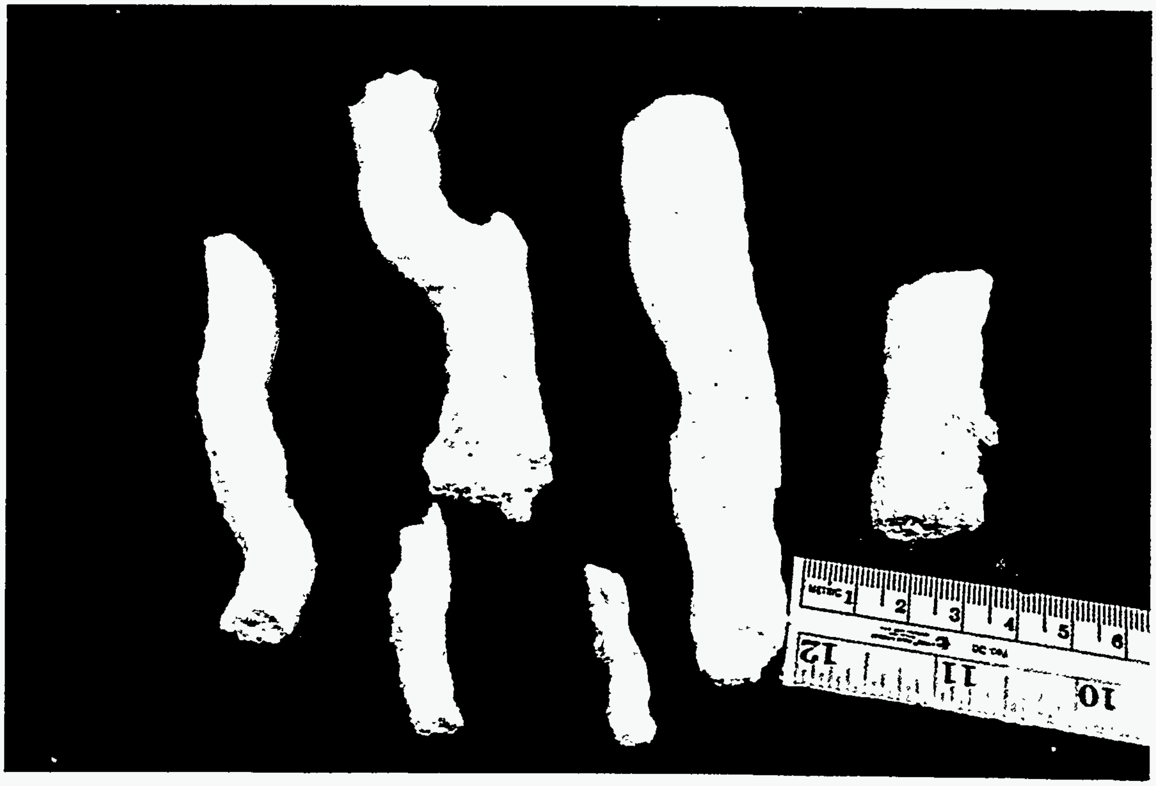


Figure 20. Root casts collected from a variety of locations, Yucca Mountain. (A) Sample 22a, Stagecoach Trench North, Trench A, (B) Sample 23a, Stagecoach Trench South, Trench A,

C)



D)

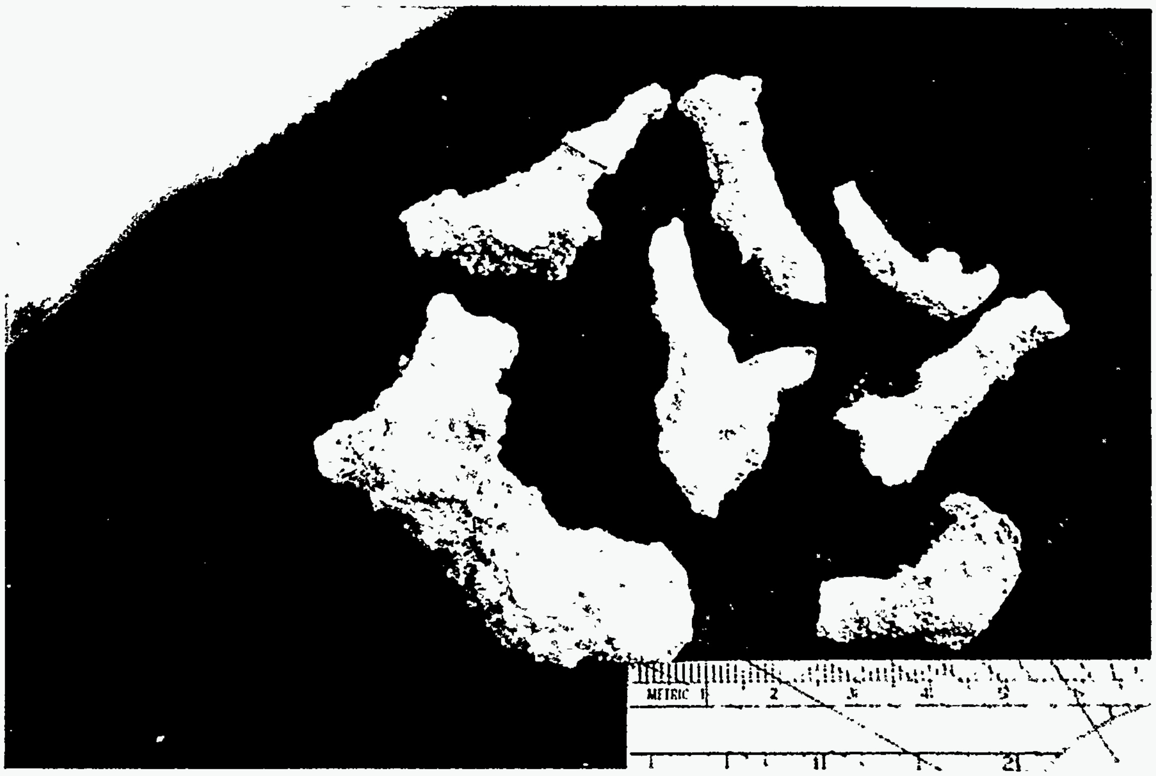


Figure 20. (C) Sample 28c, East side of Busted Butte, (D) Sample 30b, West side of Busted Butte. Photos by Christine Schluter.