Addressing Coupled THC Processes Using High Performance, Massively Parallel Computers

Nuclear Waste Technical Review Board
Carson City, Nevada

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Principal Investigator
August 1, 2000

Development of a reactive transport simulator at LLNL leverages existing strengths

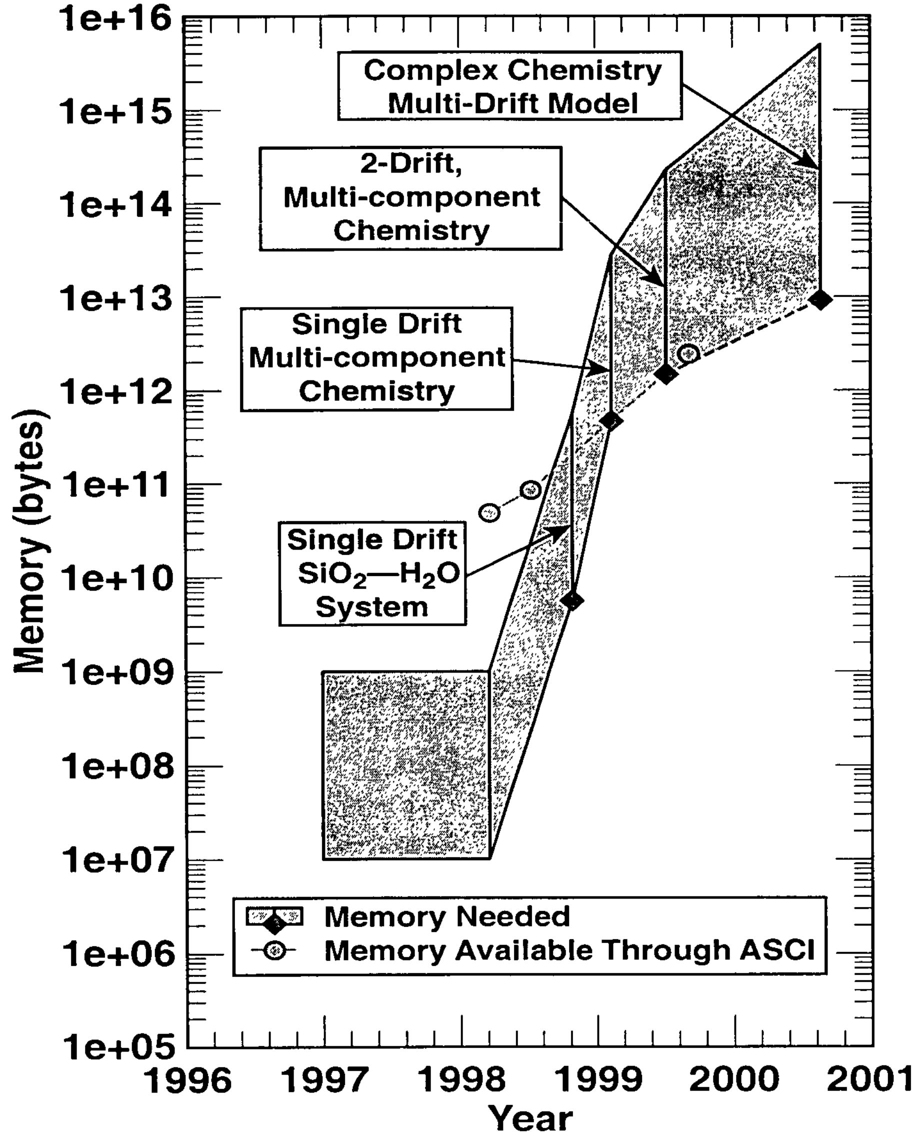
Extensive expertise in subsurface issues

Fault sealing behavior, fluid migration (oil and gas) in sedimentary basins, groundwater remediation, groundwater resource management, subsurface carbon sequestration, nuclear waste repositories

Long history of development, use and application of state-of-the-art high performance computational platforms

Stockpile stewardship, climate modeling, environmental restoration, magnetic fusion energy.

Expanding computational power allows development of ever more realistic models



Current efforts are focused on understanding the expression of coupled effects, and uncertainty

Three simultaneous efforts are underway

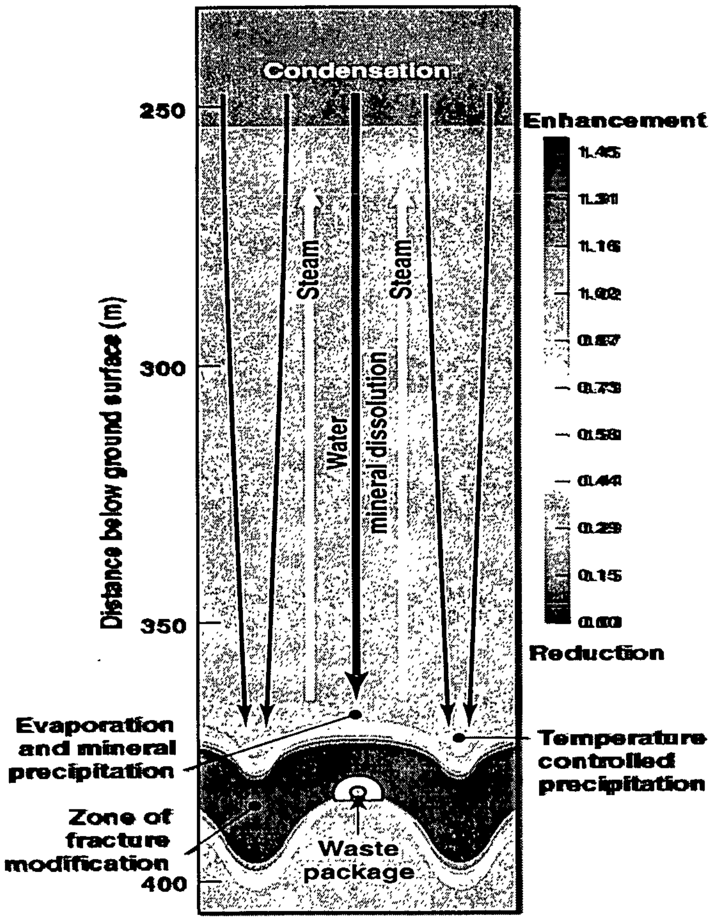
Determine how specific properties, assumptions or features contribute to uncertainty.

Conduct large scale 3D simulations to "reconnoiter" the frontier.

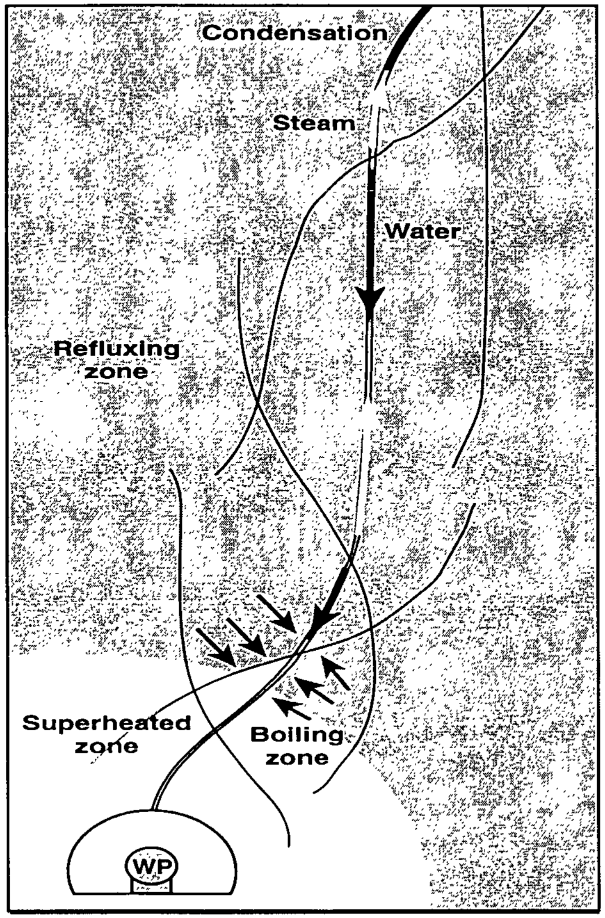
Develop a knowledge base useful for performance confirmation.

What to measure, where to measure, what values to expect

Application to EBS and Performance Confirmation: the processes of interest and sources of uncertainty



Color scale represents relative change in fracture porosity



Continuous refluxing of steam and water in the fracture-matrix system

Uncertainty from:

Measurement error

Model fidelity

Natural system heterogeneity

JN_WP_endview

Summary and Conclusion

High performance reactive transport simulations provide a unique capability to understand uncertainty associated with the response of geological materials to complex, coupled processes.

An example application highlights useful parameters for measurement in a performance confirmation program.

Use of such a code can bring more robust conclusions to research and design questions that derive from uncertainty associated with measurement error, fidelity of mineral models, and natural system heterogeneity.

Natural Hydrogeochemical and Whole-Rock Lead and Mercury Baseline Values for Use in Scoping Experiments for Alloy C-22 Corrosion Studies.

Maury Morgenstein and Don Shettel
Geosciences Management Institute, Inc.

Task:

To obtain a range of natural whole-rock and ground-water values for trace elements in and near Yucca Mountain.

Natural Data Sources for Scoping Studies:

- Perfect, D. L., C. C. Faunt, W. C. Steinkampf and A. K. Turner, 1995. Hydrochemical Data Base for the Death Valley Region, California and Nevada. *USGS Open-File Report* 94-305.

- Weiss, S. I., D. C. Noble, and L.T. Larson, 1994. Task 3: Evaluation of Mineral Resource Potential, Caldera Geology, and Volcano-Tectonic Framework at and near Yucca Mountain. Part II, Major and Trace-element Geochemical Data. In: *Evaluation of the Geologic Relations and Seismotectonic Stability of the Yucca Mountain Area Nevada Nuclear Waste Site Investigation (NNWSI) – Progress Report,* 30 September 1994. Center for Neotectonic Studies Mackay School of Mines, University of Nevada, Reno. (Also: Weiss, et al., 1996. Hydrothermal Origin and Significance of Pyrite in Ash-Flow Tuffs at Yucca Mountain, Nevada. *Economic Geology*, v. 90, pp. 2081-2090.)

- Castor, S. B., J. V. Tingley, and H. F. Bonham, Jr., 1994. Pyritic Ash-Flow Tuff, Yucca Mountain, Nevada. *Economic Geology*, v. 89, pp. 401-407.

Summary of Hydrogeochemical Values (from Perfect et al., 1995):

- Lead values range from below detection limit (mg/L) to 3.1ppm.

Some natural lead values to look at are:
J-11 (Jackass Flat) ------------ 0.3000 ppm
J-12 (Busted Butte) ----------- 0.0160 ppm
Devils Hole -------------------- 0.1000 ppm
Amargosa Flat ----------------- 0.1000 ppm
Yucca Lake (Yucca Flat) ---- 0.0260 ppm
Yucca Flat, well A ------------ 0.0560 ppm
Fallout Hills NW -- 2.9000 to 3.1000 ppm
(Fallout Hills, Obsidian Butte is on Pahute Mesa)

- Mercury values are either zero or below detection limits.

Summary of Natural Whole-Rock Values (from Weiss et al., 1994):

- Lead values (Table II-6) from selected drill hole samples within the Yucca Mountain controlled area boundary range from 1.9 to 22.6 ppm except for one pyrite + fluorite sample from UE25P1 which has very high values.

- Lead values (Table II-14) from Trench 14 Bow Ridge fault and vicinity range from 2.93 to 154 ppm.

- Mercury values (Table II-6) from the same Yucca Mountain drill hole samples range from <0.02 to 0.815 ppm.

- Mercury concentrations (Table II-14) from Trench 14 Bow Ridge fault and vicinity range from <0.050 to 3.08 ppm.

Summary of Natural Whole-Rock Values (from Castor et al., 1994, Table 1):

- Non-pyritic tuff (other volcanic rock) values: 0.9 to 97.0 ppm Pb and <0.10 to 0.38 ppm Hg.

SiteName	date	Cl	SO4	Pb	Hg	Name7.5quad
[illegible]005E02ES1S SARATOGA SPRING	820423	700.0	1000.0	0.0300	-99998.0	(Not entered yet)
022N007E30ES1S	820425	150.0	250.0	0.0300	-99998.0	(Not entered yet)
212 S22 E62 01DBCD1	860503	1900.0	2500.0	0.1000	-99998.0	Las Vegas SE
212 S21 E62 26DBA 2	820825	1525.0	2370.0	0.0320	-99998.0	Las Vegas SE
212 S21 E61 17BADD1	820823	240.0	1600.0	0.0460	-99998.0	Las Vegas NW
DESERT INN ESTATES S21 E62 17AAB1	820824	350.0	2400.0	0.0480	-99998.0	Las Vegas NE
212 S20 E61 36DDD 1	820825	3.7	1540.0	0.0400	-99998.0	Las Vegas NE
WHITEROCK SPRING	910731	19.0	190.0	0.0200	-99998.0	(Not entered yet)
212 S20 E61 27BDAA1	820823	252.0	119.0	0.0360	-99998.0	Las Vegas NW
212 S20 E62 21AAC 1	820825	230.0	1220.0	0.0120	-99998.0	Las Vegas NE
CRAIG AND I15 S20 E61 01ACCD1	820823	3.0	25.0	0.0120	-99998.0	Las Vegas NE
212 S19 E60 25CCC 1	820823	6.0	10.0	0.0110	-99998.0	Gass Peak SW
WHEELER WELL SWNWNE 20-18S-55E CLARK CO	641029	-99998.0	-99998.0	0.0120	-99998.0	Wheeler Well
230 S18 E51 19ACB 1 BIG SPRING	900822	28.0	120.0	0.1000	0.0	Devils Hole
230 S18 E51 19ACB 1 BIG SPRING	910827	27.0	110.0	0.1000	0.0	Devils Hole
NAVEL SPRING 026N002E13F	900823	75.0	110.0	0.1000	0.0	(Not entered yet)
[illegible]NT OF ROCK SPR (SMALL) NWSE 7-18S-51E	641026	-99998.0	-99998.0	0.0120	-99998.0	Devils Hole
[illegible]30 S18 E50 03ADBA1	900825	23.0	81.0	0.1000	0.0	Devils Hole
230 S18 E50 03ADBA1	910905	22.0	89.0	0.1000	0.0	Devils Hole
DEVILS HOLE SWSWSE 36-17S-50E NYE CO	661209	-99998.0	-99998.0	0.0260	-99998.0	Devils Hole
DEVILS HOLE SWSWSE 36-17S-50E NYE CO	900822	24.0	87.0	0.1000	0.0	Devils Hole
DEVILS HOLE SWSWSE 36-17S-50E NYE CO	910827	24.0	83.0	0.1000	0.0	Devils Hole
230 S17 E50 33CAAB1	900827	97.0	230.0	0.1000	0.0	Devils Hole
230 S17 E50 33CAAB1	910831	500.0	1400.0	0.1000	0 0	Devils Hole
027N001E26BS1S TRAVERTINE SPRING	820422	40.0	160.0	0.0300	-99998.0	(Not entered yet)
027N001E23BS1S TEXAS SPRING	820422	37.0	170.0	0.0300	-99998.0	(Not entered yet)
027N001E23BS1S TEXAS SPRING	900823	36.0	150.0	0.1000	0.0	(Not entered yet)
230 S17 E50 23BBCA1	900824	21.0	77.0	0.1000	0.0	Devils Hole
230 S17 E50 23BBCA1	920428	26.0	85.0	0.1000	0.0	Devils Hole
LONGSTREET SPRING NENWNE 22-17S-50E NYE	661118	-99998.0	-99998.0	0.0180	-99998.0	Devils Hole
230 S17 E50 09AD 1	900821	21.0	79.0	0.1000	0.0	Devils Hole
230 S17 E50 09AD 1	910826	23.0	82.0	0.1000	0.0	Devils Hole
230 S17 E52 08CDB 1	900824	130.0	500.0	0.1000	0.0	Amargosa Flat
[illegible]0 S17 E52 08CDB 1	910905	130.0	540.0	0.1000	0.0	Amargosa Flat

Data values in ppm, from Perfect et al. (1995, USGS OFR 94-305)

SiteName	date	Cl	SO4	Pb	Hg	Name7.5quad
S17 E52 08CDB 1	920324	130.0	480.0	0.1000	0.0	Amargosa Flat
028N001E36GS1S NEVARES SPRING	820422	38.0	170.0	0.0300	-99998.0	(Not entered yet)
INDIAN SPRINGS NWNW 14-16S-56E CLARK CO	641023	-99998.0	-99998.0	0.0120	-99998.0	Indian Springs
230 S16 E50 07CABB1	900825	27.0	150.0	0.1000	0.0	South of
WELL N670000 E755000	620913	8.0	6.6	0.0200	-99998.0	Mercury SE
TEST WELL 10 N671051 E739075 AURORA SITE	640628	-99998.0	-99998.0	0.0170	-99998.0	Mercury SE
S16 E53 05ADAD1 Army 1 WW	911218	17.0	50.0	0.1000	0.0	Point of Rocks
015S046E01RS1M	820423	550.0	740.0	0.0300	-99998.0	(Not entered yet)
S13 E50 34BCCB1 J-12 WW	680815	-99998.0	-99998.0	0.0160	-99998.0	Busted Butte
J-11 N738968 E611764 JACKASS FLATS	611221	18.0	435.0	0.3000	-99998.0	Jackass Flat
WELL C-1 N790011 E692132 YUCCA FLAT	640614	-99998.0	-99998.0	0.0280	-99998.0	Yucca Lake
WELL C-1 N790011 E692132 YUCCA FLAT	661208	-99998.0	-99998.0	0.0260	-99998.0	Yucca Lake
S11 E61 DESERT (DRY LAKE) VALLEY WELL	870318	8.9	48.0	0.1600	-99998.0	Mule Deer Ridge
228 S11 E47 21 1 BURREL HOT SPRING	740205	44.0	121.0	0.0200	0.0	Beatty Mountain
011S043E18ES1M	820420	50.0	97.0	0.0300	-99998.0	Scottys Castle
011S042E10BS1M	820419	67.0	130.0	0.0300	-99998.0	Ubehebe Crater
1S043E05ES1M	820420	42.0	90.0	0.0300	-99998.0	Scottys Castle
ELL A N833000 E684000 YUCCA FLAT	640613	-99998.0	-99998.0	0.0560	-99998.0	Yucca Flat
S10 E53 21CABB1 U-3cn POSTSHOT 2	650708	-99998.0	-99998.0	0.0110	-99998.0	Yucca Flat
OBSIDIAN BUTTE BRINE POND SITE NO. 2 S BANK	781214	-99998.0	-99998.0	3.1000	-99998.0	Fallout Hills NW
TEST WELL 8 N879468 E609999 NYE CO	0	10.0	17.7	0.0480	-99998.0	Ammonia Tanks
WELL 2 N880000 E668720 YUCCA FLAT	630923	7.2	21.0	0.0200	-99998.0	Oak Spring
WELL 2 N880000 E668720 YUCCA FLAT	630923	7.2	21.0	0.0200	-99998.0	Oak Spring
OBSIDIAN BUTTE BRINE POND	781214	-99998.0	-99998.0	2.9000	-99998.0	Fallout Hills NW
U20a-2 N907395 E571439 PAHUTE MESA	0	18.0	19.3	0.1600	-99998.0	Scrugham Peak
UE20d N909200 E554300 PAHUTE MESA	660727	-99998.0	-99998.0	0.0120	-99998.0	Scrugham Peak
WATERTOWN No. 3 N914990 E742272	611116	10.0	0.0	0.1600	-99998.0	Groom Mine
WATERTOWN No. 3 N914990 E742272	611214	8.0	9.9	0.1800	-99998.0	Groom Mine
WATERTOWN No. 3 N914990 E742272	630925	6.4	19.0	0.0500	-99998.0	Groom Mine
UE20h N918015 E567747 PAHUTE MESA	650826	-99998.0	-99998.0	0.0150	-99998.0	Silent Butte
U19as N919248 E586326 PAHUTE MESA	650607	-99998.0	-99998.0	0.0170	-99998.0	Dead Horse Flat
U20i? ZONE 7 PAHUTE MESA NTS NYE CO	670902	-99998.0	-99998.0	0.0300	-99998.0	Silent Butte
Ue 20J N928306 E538537 NYE CO	641021	-99998.0	-99998.0	0.1400	-99998.0	Trail Ridge
S05 E60 36D 1 LITTLE ASH	740204	21.0	34.1	0.0200	0.0	Ash Springs

Data values in ppm, from Perfect et al. (1995, USGS OFR 94-305)

SiteName	date	Cl	SO4	Pb	Hg	Name7.5quad
MILE WASH AT J-12	840814	2.00	6.30	-99998.00	-99998.0	Busted Butte
3 E50 34BCCB1 J-12 WW	571106	12.00	17.70	-99998.00	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	571106	14.00	16.50	-99998.00	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	580425	7.00	24.00	-99998.00	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	580425	7.00	24.00	-99998.00	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	590219	8.00	24.00	-99998.00	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	590219	8.00	24.00	-99998.00	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	590219	8.00	24.00	-99998.00	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	601220	14.00	23.50	-99998.00	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	601220	16.00	182.30	-99998.00	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	620331	8.80	19.00	-99998.00	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	620807	11.00	8.20	-0.0040	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	640526	7.40	21.00	-99998.00	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	661100	8.30	22.00	-99998.00	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	670104	8.30	22.00	-99998.00	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	670104	8.30	22.00	-99998.00	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	680815	54.00	24.00	-99998.00	-99998.0	Busted Butte
E50 34BCCB1 J-12 WW	690421	6.50	22.00	-99998.00	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	700608	8.80	22.00	-99998.00	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	710326	7.44	22.09	-99998.00	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	710326	7.30	22.00	-99998.00	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	740501	7.70	23.00	-99998.00	-99998.0	Busted Butte
S13 E50 34BCCB1 J-12 WW	740501	7.70	23.00	-99998.00	-99998.0	Busted Butte
AMARGOSA DESERT 14S/50-6a1	580425	7.00	24.00	-99998.00	-99998.0	Busted Butte
BUSTED BUTTE WASH	840814	1.70	7.90	-99998.00	-99998.0	Busted Butte
WELL J-13 N749209 E579651 JACKASS FLATS	630101	8.40	25.00	-99998.00	-99998.0	Busted Butte
WELL J-13 N749209 E579651 JACKASS FLATS	630101	8.40	25.00	-99998.00	-99998.0	Busted Butte
WELL J-13 N749209 E579651 JACKASS FLATS	640525	7.40	23.00	-99998.00	-99998.0	Busted Butte
WELL J-13 N749209 E579651 JACKASS FLATS	661100	7.20	18.00	-99998.00	-99998.0	Busted Butte
WELL J-13 N749209 E579651 JACKASS FLATS	670104	7.20	18.00	-99998.00	-99998.0	Busted Butte
WELL J-13 N749209 E579651 JACKASS FLATS	690421	5.40	18.00	-99998.00	-99998.0	Busted Butte
WELL J-13 N749209 E579651 JACKASS FLATS	710326	7.10	17.00	-99998.00	-99998.0	Busted Butte
40-MILE WASH AT ROAD 'H'	840815	1.40	10.00	-99998.00	-99998.0	Busted Butte
40-MILE WASH ABOVE DRILL HOLE WASH	840814	1.30	6.20	-99998.00	-99998.0	Busted Butte

ata from Perfect et al. (1995, USGS OFR 94-305)

SiteName	date	Cl	SO4	Pb	Hg	Name7.5quad
LL HOLE WASH AT MOUTH	840814	2.20	12.00	-99998.00	-99998.0	Busted Butte
25P-1 YUCCA MTN	830211	26.00	78.00	-99998.00	-99998.0	Busted Butte
UE-25P-1 YUCCA MTN	830512	28.00	160.00	-99998.00	-99998.0	Busted Butte
S13 E49 02DDCC0 USW H-3 HTH YUCCA MTN	840314	9.50	31.00	-99998.00	-99998.0	Busted Butte
UE-25c#2 YUCCA MTN	840313	7.10	22.00	-99998.00	-99998.0	Busted Butte
S13 E50 06DDDB1 UE-25c 2 HTH YUCCA MTN	840313	7.00	22.00	-99998.00	-99998.0	Busted Butte
S13 E50 06DDDB1 UE-25c 1 HTH YUCCA MTN	830927	7.80	23.00	-99998.00	-99998.0	Busted Butte
S13 E50 06DDDB1 UE-25c 1 HTH YUCCA MTN	830928	7.50	21.00	-99998.00	-99998.0	Busted Butte
S13 E50 06DDDB1 UE-25c 1 HTH YUCCA MTN	830930	7.40	23.00	-99998.00	-99998.0	Busted Butte
S13 E50 06DDDB1 UE-25c 1 HTH YUCCA MTN	830930	7.20	20.00	-99998.00	-99998.0	Busted Butte
S13 E50 06DDDB1 UE-25c 3 HTH YUCCA MTN	840509	7.20	22.00	-99998.00	-99998.0	Busted Butte
S13 E50 06DDDB1 UE-25c 3 HTH YUCCA MTN	840509	7.20	22.00	-99998.00	-99998.0	Busted Butte
USW H-4 YUCCA MTN	820517	6.90	26.00	-99998.00	-99998.0	Busted Butte
S12 E49 34DADB0 USW H-6 HTH	821016	7.60	29.00	-99998.00	-99998.0	Busted Butte
USW H-6	840620	7.20	25.00	-99998.00	-99998.0	Busted Butte
USW H-6	840706	7.40	32.00	-99998.00	-99998.0	Busted Butte
S12 E50 31BDBC1 UE-25b 1 HTH	810807	13.00	24.00	-99998.00	-99998.0	Busted Butte
E50 31BDBC1 UE-25b 1 HTH	810807	30.00	24.00	-99998.00	-99998.0	Busted Butte
S12 E50 31BDBC1 UE-25b 1 HTH	810901	8.50	22.00	-99998.00	-99998.0	Busted Butte
S12 E50 31BDBC1 UE-25b 1 HTH	820720	7.50	21.00	-99998.00	-99998.0	Busted Butte
USW G-4	801020	5.90	19.00	-99998.00	-99998.0	Busted Butte
USW G-4	821209	5.90	19.00	-99998.00	-99998.0	Busted Butte
USW H-5 YUCCA MTN	820703	6.10	16.00	-99998.00	-99998.0	Busted Butte
USW H-5 YUCCA MTN	820726	6.10	16.00	-99998.00	-99998.0	Busted Butte
USW H-1 YUCCA MTN	801001	5.67	18.25	-99998.00	-99998.0	Busted Butte
USW H-1 YUCCA MTN	801208	5.80	19.00	-99998.00	-99998.0	Busted Butte
USW H-1 YUCCA MTN	821209	5.70	18.00	-99998.00	-99998.0	Busted Butte

SiteName	date	Cl	SO4	Pb	Hg	Name7.5quad
N01 E53 07AD	680913	-99998.0	-99998.0	0.0120	-99998.0	Freds Well

a from Perfect et al. (1995, USGS OFR 94-305)

Weiss et al. (1992)

Precious Metals and Indicator-Element Abundances in Core and Rotary Cuttings Samples from the Subsurface of Yucca Mountain
Ag and Au values given in ppb, all others given in ppm

Hole #	SMF ID#	Ag	Au	As	Bi	Cd	Hg	HgAA	Sb	Se	Te	Cu	Mo	Pb	Zn	Tl
UE25B-1H	16854	38.0	0.492	4.2	0.451	0.202	0.066	0.023	<0.05	0.355	0.208	2.8	0.38	13.5	37.4	<0.492
UE25B-1H	16855	34.5	0.233	4.8	0.554	0.132	0.063	0.022	0.22	0.456	0.413	3.3	0.47	17.0	37.0	<0.500
UE25B-1H	16856	37.9	<0.200	7.8	0.442	0.118	0.068	0.037	0.23	0.416	0.428	3.5	0.33	15.8	38.4	<0.500
UE25B-1H	16857	33.7	0.230	5.2	0.450	0.196	0.078	0.021	<0.05	0.556	0.268	3.2	0.69	14.1	38.2	<0.493
UE25B-1H	16859	34.1	0.596	7.9	0.445	0.118	0.080	0.024	<0.05	0.464	0.202	3.1	0.27	16.5	39.7	<0.496
UE25B-1H	16860	33.3	0.324	0.7	0.182	0.324	0.153	0.106	<0.05	<0.243	<0.049	5.8	0.23	7.7	54.1	<0.486
	YMX-2	40.1	1.10	<0.75	0.167	0.355	0.142	nd	<0.15	<0.753	<0.151	6.5	0.41	7.9	53.2	<1.51
UE25B-1H	16861	28.6	<0.200	0.5	0.183	0.082	0.060	0.040	0.14	<0.250	0.112	2.4	0.23	8.7	41.4	<0.500
UE25B-1H	16862	33.6	0.230	0.3	0.057	0.037	<0.020	<0.010	<0.05	<0.246	<0.049	0.9	<0.02	8.0	36.4	<0.493
UE25 P1	16954	41.1	0.360	5.2	0.156	0.320	0.140	0.120	<0.07	<0.338	<0.068	1.7	1.18	14.9	30.8	<0.675
UE25 P1	16955	27.1	<0.198	2.7	0.154	0.089	0.053	0.038	0.42	<0.248	0.085	2.6	0.79	22.6	125	<0.495
UE25 P1	16956	29.6	<0.197	3.4	0.105	0.082	0.039	0.022	0.52	<0.247	0.062	1.7	0.62	14.1	21	<0.493
UE25 P1	16958	54.0	0.519	47.8	0.123	0.127	0.092	0.061	1.84	<0.243	0.055	1.6	2.86	11.7	29.4	<0.487
UE25 P1	16959	93.0	2.13	63.2	0.051	0.253	0.129	0.136	0.39	<0.242	<0.048	1.4	1.32	5.6	42.5	<0.484
UE25 P1	16960	29.8	<0.198	14.3	0.164	0.107	0.060	0.027	1.14	<0.247	0.157	1.4	0.82	13.0	21.5	<0.494
UE25 P1	16961	91.3	0.794	9.7	<0.050	0.035	0.056	0.046	1.35	0.268	<0.050	1.1	2.19	1.9	12.8	<0.496
UE25 P1	16962	51.3	<0.196	3.7	<0.049	0.030	0.025	0.031	0.77	0.363	<0.049	0.8	1.92	2.3	11.7	<0.489
	YMH-X5	54.7	<0.199	3.9	<0.050	0.031	0.031	nd	0.86	0.318	0.065	0.9	1.78	2.3	11.8	<0.498
UE25 P1	16963	139.0	4.83	25.9	1.92	0.469	0.585	nd	12.7	0.687	0.091	38.6	208	900	227	2.44
	16963B*	173.0	7	38.2	1.65	0.208	0.815	0.714	20.1	1.38	<0.526	64.9	286	1358	304	3.05
UE25 P1	16964	49.2	0.328	4.5	0.053	0.037	0.051	0.051	1.23	<0.246	<0.049	1.6	16.2	9.7	15	<0.492
USW G1	16904	41.8	<0.196	8.0	0.340	0.079	0.073	0.023	0.15	0.404	0.439	4.3	0.37	16.1	21.2	<0.491
USW G1	16905	39.1	2.72	6.8	0.427	0.173	0.070	0.023	<0.05	0.526	0.206	3.9	0.64	18.3	37.9	<0.486
USW G1	16907	36.7	0.396	8.4	0.381	0.224	0.069	0.016	<0.05	0.687	0.325	4.7	0.68	15.0	37.4	<0.495
USW G1	16914	33.3	0.327	2.6	0.070	0.045	0.054	<0.010	<0.05	<0.245	<0.049	2.0	<0.02	10.1	57.3	<0.490
USW G2	16871	14.8	1.47	18	<0.049	0.416	0.649	0.786	5.31	<0.246	<0.049	1.7	0.46	9.5	36.8	<0.491
	16871							0.681								
USW G2	16887	28.4	0.332	68.8	<0.050	0.100	0.192	0.118	<0.05	<0.249	<0.050	3.9	0.59	12.1	50.1	<0.498
USW G2	16888	26.2	<0.197	85.2	0.064	0.119	0.220	0.152	0.40	<0.247	0.073	3.5	1.16	17.2	81.9	<0.493
USW G2	16889	28.7	0.232	47.1	0.081	0.126	0.220	0.123	<0.05	<0.248	<0.050	3.1	2.05	16.9	52	<0.497
	YMX-1	34.9	1.14	50	<0.132	0.132	0.188	nd	<0.132	<0.66	<0.132	3.5	2.2	16.5	51.8	<1.32
USW G2	16890	27.9	<0.198	38.6	<0.050	0.163	0.081	0.037	0.34	<0.248	0.067	3.7	0.18	22.3	86.8	<0.496
USW G2	16895	43.0	0.360	1.6	<0.049	0.092	0.061	0.016	0.17	<0.246	0.067	12.6	0.18	9.3	76.8	<0.491
USW G2	16896	38.6	<0.197	0.5	<0.049	0.100	0.178	0.021	<0.25	<0.246	<0.049	11.2	<0.02	7.2	78.8	<0.492
USW G3	16932	36.7	<0.198	1.5	0.196	0.153	0.078	0.046	<0.05	<0.248	<0.050	1.8	0.13	9.3	12.7	<0.496
	X-1							0.050								
USW G3	16933	36.7	<0.194	1.3	0.152	0.071	0.091	0.063	0.11	<0.243	0.130	1.0	0.30	10.5	32.8	<0.486
USW G3	16934	40.2	0.328	1.2	0.268	0.215	0.110	0.079	<0.05	<0.246	<0.049	1.7	0.15	10.6	31.7	<0.492
USW G3	16935	41.3	0.329	1.1	0.177	0.144	0.111	0.066	<0.05	<0.247	<0.049	1.6	0.12	10.8	29.8	<0.493
USW G3	16936	34.4	<0.199	1.1	0.179	0.077	0.053	0.046	0.24	<0.249	0.115	1.7	0.29	14.8	27.7	<0.498
UE25 C1	20064	8.5	<0.198	18.1	0.106	0.119	0.042	0.033	15.1	<0.247	<0.049	0.8	1.25	9.9	40.6	<0.494
UE25 C2	20065	6.5	0.295	5.5	1.110	0.050	<0.020	0.017	<0.05	<0.246	0.083	0.5	<0.02	13.9	17.0	<0.491
UE25 C2	20066	12.4	<0.225	22.4	0.122	0.057	0.026	0.018	3.72	<0.282	<0.056	0.6	8.83	6.2	9.3	<0.563

UE25 C2	20067	10.1	0.276	20.4	0.277	0.120	0.050	0.021	0.47	<0.345	<0.069	0.8	12.5	6.5	27.3	<0.689
UE25 C3	20068	12.5	0.328	77.4	0.163	0.292	0.075	0.062	1.49	<0.246	<0.049	0.6	0.98	10.9	39.1	<0.491
UE25 C3	20069	21.1	0.395	34.3	1.970	0.083	0.153	0.045	3.37	<0.247	0.134	0.5	193	11.1	20.8	<0.494
	20069R	10.0	<0.199	37.7	1.240	0.092	0.113	0.045	3.67	<0.249	0.188	0.7	207	11.3	23.6	<0.499
	X-2							0.050								
	20069B	9.9	<0.199	23	0.674	0.067	0.065	0.030	2.35	<0.248	0.090	0.4	110	9.2	19.3	<0.497
	YMH-X4	10.4	<0.198	22.7	0.744	0.066	0.064	0.045	2.3	<0.248	0.107	0.6	109	9.0	19.1	<0.496
UE25 C3	20070	4.5	0.261	35.3	<0.049	0.063	0.041	0.058	4.67	<0.244	<0.049	0.7	0.29	2.8	12.8	<0.489
	Fresh tuff reference samples															
BMCF-D		10.1	<0.199	5.3	<0.050	0.062	0.024	0.013	0.26	<0.249	0.055	1.0	1.36	2.0	47.9	<0.497
3SW-589		9.7	0.265	2.7	<0.050	0.037	<0.020	0.015	<0.05	<0.249	<0.050	1.4	0.89	4.9	49.0	<0.497
YMH-X3		13.1	<0.198	2.6	<0.049	0.044	0.023	0.014	0.12	<0.247	0.053	1.2	0.64	4.5	50.5	<0.495
X-3								0.012								

SMF ID # denotes sample identification assigned to each interval by staff of Sample Management Facility, Area 25, Nevada Test Site; ID numbers beginning with YM and X were assigned by Task 3 to denote blind duplicates. nd = not determined.

py = pyrite, fluor = fluorite; cal = calcite; qtz = quartz; vns = veins, alt = altered, mod = moderately, dissem = disseminated.

Srm = Roberts Mountain Formation, Slm = Lone Mountain Dolomite; Tot = pre-Lithic Ridge sequence of ash-flow and bedded tuffs, Tr1 = pre-Lithic Ridge silicic lavas, Tlr = Lithic Ridge Tuff; Tct, Tcb and Tcp = Tram, Bullfrog, and Prow Pass members of the Crater Flat Tuff, respectively; Tc = Crater Flat Tuff undivided; Tpc = Tiva Canyon Member of the Paintbrush Tuff.

Hole #	SMF ID#	Unit	Py?	Vns?	Comments
UE25B-1H	16854	Tct	Y	N	lithology similar to Round Mountain type II ore
UE25B-1H	16855	Tct	Y	N	
UE25B-1H	16856	Tct	Y	Y	cal vns
UE25B-1H	16857	Tct	Y	Y	cal vns; dissem py in groundmass and in lithics; minor py in cal vn.
UE25B-1H	16859	Tct	Y	Y	cal + green to clr fluor?? vein, possible fluid inclusions.
UE25B-1H	16860	Tct?	N	Y	cal + green phase in vn; no py seen
	YMX-2				(blind duplicate 16860)
UE25B-1H	16861	Tlr	?	N	
UE25B-1H	16862	Tlr	N	Y	cal vn
UE25 P1	16954	Tot	N	?	
UE25 P1	16955	Tot	Y	?	alt volc frags, some w/py
UE25 P1	16956	Tot	N	?	alt Tot, no py seen, contains drill tool fragments
UE25 P1	16958	Tot	Y	?	mixed Tot/Slm
UE25 P1	16959	fault?	?	?	
UE25 P1	16960	Tot/Slm	Y	?	mixed Tot/Slm, 90% Tot fragments contain sparse py
UE25 P1	16961	Slm	N	Y	cal + fluor? vns
UE25 P1	16962	Srm	N	Y	cal+fluor?+qtz? vn frags
	YMH-X5				(blind dup. 16962)
UE25 P1	16963	Srm	Y	Y	contains drill tool fragments; py and fluor vn or vug fragments
	16963B*				(powder from 2nd split of chips; 5 gram GXPL)
UE25 P1	16964	Srm	Y	Y	qtz, py, fluor? vns + dissem py in some fr, contains drill tool fragments;
USW G1	16904	Tct	Y	N	
USW G1	16905	Tct	Y	Y	clear qtz vn; pyritic lithics and groundmass.
USW G1	16907	Tct	Y	N	pyritic lithics and groundmass.
USW G1	16914	Tot	N	N	xtal-rich, milky fldsp phenocrysts

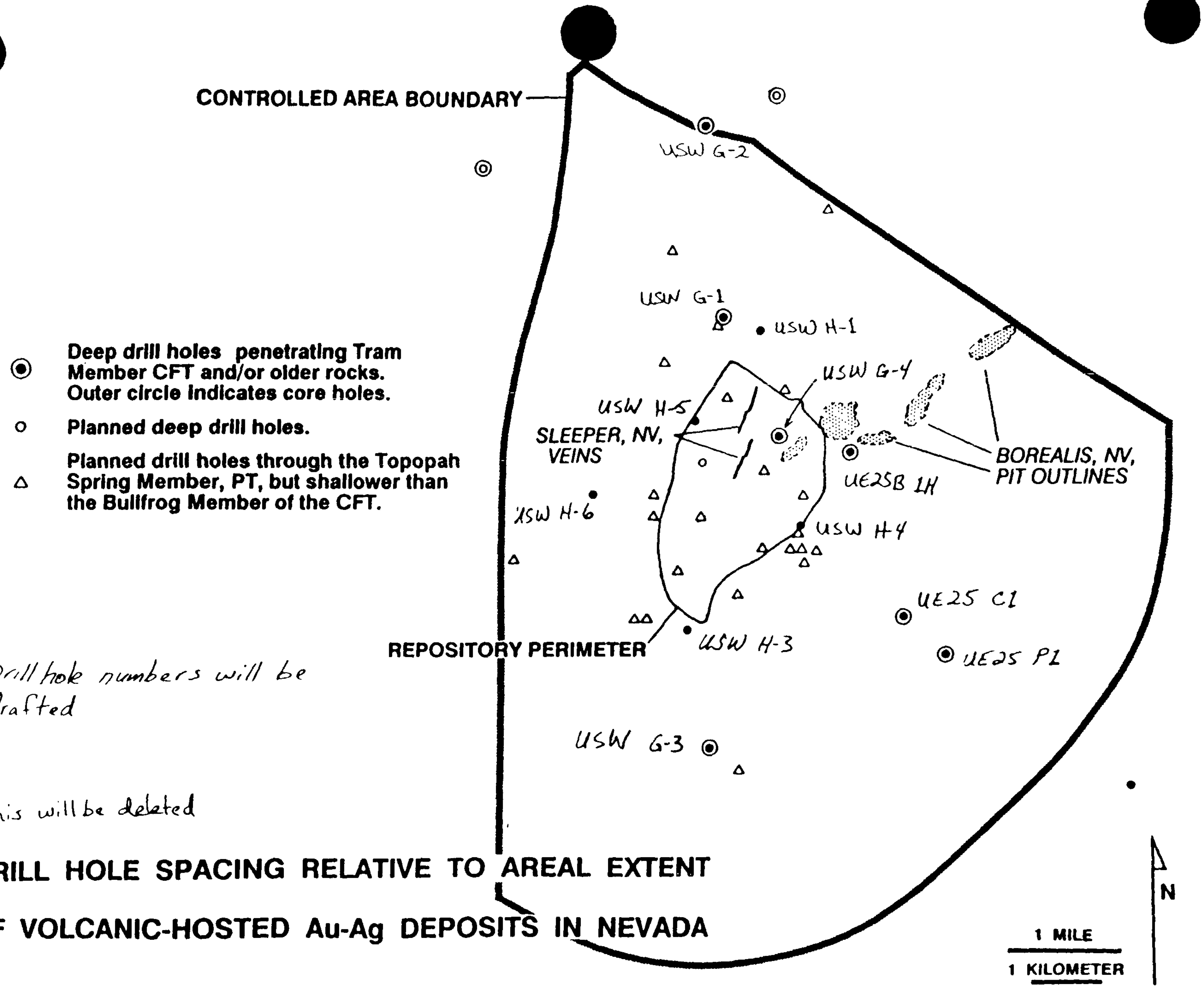
USW G2	16871	Tcb	N	Y	Mn-ox filled fracture.
	16871				(second split of original powder)
USW G2	16887	Trl	Y	Y	propylitic alt, cal-chlor-silica vns., albitized feldspar phenos
USW G2	16888	Trl	N	Y	as above
USW G2	16889	Trl	Y	Y	propylitic alt, cal-chlor-silica vns., albitized feldspar phenos
	YMX-1				(blind dup. 16889)
USW G2	16890	Trl	N	Y	fault surfaces, sheared cal+green clay? vn
USW G2	16895	Trl	N	Y	cal vns
USW G2	16896	Trl	N	Y	cal vns
USW G3	16932	Tlr	Y	N	py in lithics and groundmass
	X-1				X-1 (blind dup. 16932 for Hg by AA)
USW G3	16933	Tlr	Y	N	very sparse py in few lithics; lithology similar to Round Mtn type II
USW G3	16934	Tlr	Y	N	v. sparse py in few lithics; good match for RM typeII ore
USW G3	16935	Tlr	Y	N	v. sparse py in few lithics; good match for RM typeII ore
USW G3	16936	Tlr	?	N	
UE25 C1	20064	Tc	N	Y	rubble zone frags w/breccia veins
UE25 C2	20065	Tc	N	N	strong reddish Feox stain
UE25 C2	20066	Tc	N	Y	bleached, Feox breccia vns
UE25 C2	20067	Tc	N	Y	breccia veins as in 20064; bleached, biotite fresh
UE25 C3	20068	Tc	N	Y	breccia veins, clear calcite+dark grey calcite veins
UE25 C3	20069	Tc	N	Y	breccia vns; fluor+ montmorill. in cavities; vfg qtz+fluor? vns, no ca
	20069R				(2nd analysis of powder from original split of 20069)
	X-2				(blind dup. 20069 for Hg by AA)
	20069B				(powder from second split of 20069 excluding cut surfaces)
	YMH-X4				(blind dup. 20069B)
UE25 C3	20070	Tc	N	N	bleached to mustard color
BMCF-D		Tcb			mod. welded, devit; S end Yucca Mtn NW of Lathrop Wells cinder cone
3SW-589		Tpc			fresh, dense, devit, minor caliche in lithophys.; Exile Hill
YMH-X3					(blind dup. 3SW-589)
X-3					(blind duplicate 3SW-589 for Hg by AA)

Analyses by MB Associates, North Highland, CA, using inductively-coupled plasma emission spectrography for all elements except Au which was carried out by graphite furnace - atomic absorption spectrometry; * = 5 gram digestion, all other analyses used 15 gram digestion. Values as reported by MB Associates except Ag rounded to nearest ppb, As, Sb and Cu rounded to nearest 0.1 ppm, and Mo to nearest 0.01 ppm. Number of significant figure does not indicate precision or accuracy of analyses.

HgAA = analyses carried out by the Nevada Mining Analytical Laboratory using hydride-generator type atomic absorption methods, M. O. Desilets, analyst.

nd = not determined.

Fig. 4



DRILL HOLE SPACING RELATIVE TO AREAL EXTENT OF VOLCANIC-HOSTED Au-Ag DEPOSITS IN NEVADA

PRECIOUS METALS AND INDICATOR-ELEMENT ABUNDANCES IN ROCK-CHIP SAMPLES FROM TRENCH 14 AND VICINITY

(expressed in parts per million)

	Ag	As	Au	Cu	Hg	Mo	Pb	Sb	Tl	Zn	Bi	Ga	Se	Te
1)	0.423	110	0.005	27.9	0.799	65.3	154	24.6	<0.49	33.2	<0.249	1.90	<0.995	<0.497
1a)	0.129	10.0	0.002	6.49	0.202	1.11	15.0	0.763	<0.487	44.6	<0.243	1.15	<0.973	<0.487
1b)	-	-	-	-	0.036	-	-	-	-	-	-	-	-	-
2)	0.048	15.6	0.004	11.1	0.373	1.23	16.4	10.1	<0.488	90.8	<0.244	<0.488	<0.977	<0.488
2a)	-	-	-	-	0.085	-	-	-	-	-	-	-	-	-
3)	<0.015	5.89	0.001	2.71	0.349	1.80	10.7	2.90	<0.498	147	<0.249	<0.498	<0.996	<0.498
3a)	-	-	-	-	0.012	-	-	-	-	-	-	-	-	-
4)	0.048	11.2	0.001	4.11	0.553	2.29	14.8	6.36	<0.492	75.5	<0.246	<0.492	<0.984	<0.492
4a)	-	-	-	-	0.048	-	-	-	-	-	-	-	-	-
5)	0.049	11.2	0.002	2.95	2.02	1.58	46.6	2.89	<0.492	892	<0.246	<0.492	<0.983	<0.492
5a)	-	-	-	-	0.012	-	-	-	-	-	-	-	-	-
6)	0.141	14.1	0.001	14.4	3.08	2.54	78.6	8.69	<0.487	344	<0.244	<0.487	<0.975	<0.487
6a)	-	-	-	-	0.024	-	-	-	-	-	-	-	-	-
7)	0.054	1.77	0.001	2.35	0.160	0.759	3.27	<0.247	<0.494	50.0	<0.247	0.845	<0.987	<0.494
7a)	0.054	1.83	<0.0005	3.11	0.185	0.686	3.49	<0.245	<0.49	46.3	<0.245	0.799	<0.979	<0.49
7b)	0.049	1.57	0.001	1.68	0.170	0.637	2.93	<0.25	<0.5	49.4	<0.25	0.576	<0.999	<0.5
7c)	-	-	-	-	<0.050	-	-	-	-	-	-	-	-	-
8)	0.04	3.09	<0.0005	1.28	0.214	0.688	4.02	<0.245	<0.49	41.1	<0.245	0.606	<0.979	<0.49
8a)	0.055	3.05	<0.0005	1.31	0.184	0.712	4.02	<0.248	0.523	44.0	<0.248	0.684	<0.992	<0.496
8b)	0.053	3.51	0.001	1.57	0.177	0.883	4.31	<0.245	<0.491	44.7	<0.245	0.650	<0.982	<0.491
8c)	-	-	-	-	<0.050	-	-	-	-	-	-	-	-	-
9)	0.048	4.34	<0.0005	1.23	0.154	0.703	3.68	<0.247	<0.494	43.1	<0.247	0.535	<0.989	<0.494
9a)	0.051	3.84	<0.0005	1.17	0.178	0.698	3.60	<0.244	<0.488	38.8	<0.244	0.524	<0.976	<0.488
9b)	0.047	4.09	<0.0005	1.16	0.171	0.680	3.49	<0.246	<0.491	41.1	<0.246	0.559	<0.982	<0.491
9c)	-	-	-	-	<0.050	-	-	-	-	-	-	-	-	-

1) [x]3SW195B: north wall, fractured Tiva Canyon Member with weak silicification, ± drusy quartz in lithophysae, analysis from Weiss et al. (1989) **

1a) Split of hand-sample remaining from 3SW-195B. **

1b) [z] Later split of hand-sample remaining from 3SW-195B.

2) [x]3SW329: south wall, siliceous buff to white carbonate vein filling. *

2a) [z]Split of hand-sample remaining from 3SW329.

3) [x]3SW331: south wall, dark purplish, silicified breccia of Tiva Canyon Member between calcareous veins. *

3a) [z]Split of hand-sample remaining from 3SW331.

4) [x]3SW333: south wall, siliceous margin of 1-2 cm thick white calcareous vein. Margin is composed of buff to light brown silica vein material containing small, dark colored, silica-replaced fragments of Tiva Canyon Member. *

4a) [z]Split of hand-sample remaining from 3SW333.

5) [x]3SW335: north wall, silicified breccia of Tiva Canyon Member with bleached groundmass surrounding drusy quartz-lined lithophysal cavities, ~ 2 meters east of thick, white, calcareous vein. *

5a) [z]Split of hand-sample remaining from 3SW335.

6) [x]3LT029: south wall, silicified breccia of Tiva Canyon Member, purplish rock fragments in buff siliceous matrix. *

6a) [z]Split of hand-sample remaining from 3LT029.

7) 3SW433; dense, lithophysal Tiva Canyon Member, east side of Exile Hill. **

7a) Duplicate split of 3SW433. **

7b) Triplicate split of 3SW433. **

7c) [z]Split of hand-sample remaining from 3SW433.

8) 3SW435; dense, lithophysal Tiva Canyon Member, east side of Exile Hill. **

8a) Duplicate split of 3SW435. **

8b) Triplicate splite of 3SW435. **

8c) ^{z}Split of hand-sample remaining from 3SW435.
9) 3SW437; dense, lithophysal Tiva Canyon Member, east side of Exile Hill. **
9a) Duplicate split of 3SW437. **
9b) Triplicate splite of 3SW437. **
9c) ^{z}Split of hand-sample remaining from 3SW437.

Except as noted, analyses by Geochemical Services Inc., using inductively-coupled plasma emission spectrography; * = 10 gram digestion; ** = 15 gram digestion; k = x103. Values as reported by G.S.I.; number of significant figures does not indicate precision or accuracy of analyses.

^{x} denotes analyses from Weiss et al. (1989b).

^{z} denotes mercury analyses by the Nevada Mining and Analytical Laboratory, Nevada Bureau of Mines and Geology, using atomic absorption methods.

Precious Metals and Indicator-Element Concentrations in Rocks from Northwestern Yucca Mountain and Bare Mountain, Nevada
(Ag and Au values given in ppb, all others in ppm)

Sample Id	comments	Ag	Au	As	Bi	Cd	Hg	Sb	Se	Te	Cu	Mo	Pb	Zn	Ga	Tl
	Northwestern Yucca Mtn															
3SW-394A	brep675; opal-qtz vn w/Feox	13.7	0.459	12.7	0.154	0.183	0.677	2.72	-0.246	-0.049	5.58	3.4	8.74	10.6	0.849	1.03
3SW-394B	brep681B; Hbx vn of feox+silica	9.03	-0.198	139	0.293	0.562	0.18	8.9	-0.248	-0.05	9.05	1.8	44.8	29.6	2.69	-0.495
3SW-394C	brep681C; Hbx vn of feox+silica	8.22	-0.196	36.2	0.187	0.246	0.099	3.39	-0.245	-0.049	4.02	1.69	23.6	17.6	1.88	1.93
3SW-394D	brep685; silicif siltst, upper ledge	8.5	-0.2	6.59	0.07	0.625	0.233	1.27	-0.25	-0.05	5.16	3.33	4.54	14.3	0.343	4.95
3SW-394E	brep693; "sinter" lower ledge	12.8	-0.198	2.35	0.184	0.132	0.1	0.753	-0.248	-0.05	8.36	4.99	7.8	6.79	0.35	-0.495
3SW-394F	brep697; silicif siltst, upper ledge	7.04	-0.195	5.7	0.256	0.173	0.217	2.05	-0.244	0.057	6.36	8.11	51.9	104	0.329	0.637
X94A	bdup394F(697)	8.18	-0.199	5.5	0.261	0.172	0.229	1.89	-0.248	-0.05	6.09	7.92	50.7	102	0.104	0.667
NEEBM16	Tct w/qtz-opal vnlts	22.6	-0.196	40	0.096	0.135	0.041	3.89	-0.245	-0.049	14	2.27	16.1	35	1.63	0.829
3SW-717	Tct w/qtz-opal vnlts; bleached	18.5	-2.34	8.01	-0.049	0.063	-0.02	0.584	-0.247	-0.049	8.16	1.21	14	17.8	0.818	-0.494
3SW-719	Silica-Feox Hbx vns in Tct	19.7	-0.198	89	0.068	0.215	0.299	6.4	-0.247	-0.049	11.8	1.64	15	42	1.88	-0.495
3SW-721P	silicif silst +opal, upper ledge	8.06	-0.195	4.51	0.091	0.407	0.153	1.12	-0.243	-0.049	1.91	0.959	3.33	13.7	-0.097	1.67
X94C	bdup721S; silicif sltst, upper ledge	13.1	-0.199	5.64	0.13	0.428	0.15	1.32	-0.249	-0.05	12.5	4.45	4.36	22	0.353	1.83
3SW-723P	silicif silst +opal, upper ledge	10.2	0.291	7.63	0.144	0.192	0.091	0.4	-0.242	-0.048	1.73	0.614	22.5	88.5	0.196	1.05
X94D	bdup723S; silicif sltst, upper ledge	13.4	0.26	6.92	0.195	0.199	0.108	0.564	-0.244	-0.049	10.6	2.86	42.8	104	0.277	1.2
X94E	bdup723S; silicif sltst, upper ledge	14.1	0.23	6.79	0.2	0.192	0.107	0.586	-0.246	-0.049	10.5	2.78	41.5	105	0.289	1.18
3SW-725	alt. Tct	20.2	10.5	33.3	0.063	0.076	0.481	2.28	-0.25	-0.05	10.8	1.54	12	27.8	0.841	-0.5
3SW-121	Feox+silica hbx vns in Tc; Windy Wash	22.9	-0.2	5.53	0.088	0.075	0.065	2.14	-0.25	-0.05	8.61	1.25	9.11	22.9	0.793	-0.5
3MJ-184A	arg alt Tcp, head of Windy Wash	-2.93	-0.195	18	0.05	0.133	0.234	2.41	-0.244	-0.049	10.9	1.54	8.79	26	1.21	-0.488
3MJ-188	Feox-rich porous tuff	-2.91	-0.194	1.89	0.176	0.059	0.1	1.23	-0.243	-0.049	9.44	1.25	13.9	17.4	0.705	-0.485
	Bare Mountain															
3SW-633	arg alt Tip dike, Tungsten Canyon	11.1	1.06	2.34	-0.05	0.06	0.081	0.639	-0.248	-0.05	7.47	0.833	7.71	45.4	2.18	-0.495
3SW-641	alt Tip dike, Tarantula Canyon	11.8	0.265	2.41	-0.05	-0.02	0.037	0.08	-0.248	-0.05	8.54	1.09	3.48	11.1	0.531	-0.497
3SW-705	Dev ls wallrock <1 m from 641 dike	47.1	1.34	18.1	0.114	0.195	0.251	1.15	0.371	0.056	8.74	14.8	5.22	117	0.193	-0.49
3SW-645	alt Tip dike, Tarantula Canyon	41	-0.197	192	0.245	4.16	0.124	8.99	3.57	-0.049	15.2	14.8	14.6	84.6	1.17	-0.491
3SW-649	alt Tip dike N of Tarantula Canyon	11.1	0.398	55.3	0.074	-0.02	-0.02	0.17	-0.249	-0.05	8.04	2.15	4.18	7.55	0.941	-0.497
3SW-655A	hbx, margin of dike	24118	1603	163	0.153	0.044	5.22	22.4	-0.245	3.56	29.3	11.1	11.5	15.7	0.635	-0.49

3S[illegible]	hbx, margin of dike	10488	1381	166	0.096	0.08[illegible]	[illegible]4	20.7	-0.247	2.09	29.1	9.62	16	34	0.241	0.537
872111	fluoritized brecciated Nopah, N pit	2.96	1158	65.8	0.854	0.028	1.5	53.4	-0.247	0.097	4.76	118	5.65	16.6	3.12	1.55
SJH-2	Hbx dike, volc frags, in Pz carbs	164	1.87	4.59	0.134	0.193	0.322	2.76	-0.246	0.336	13.7	5.33	19.7	7.73	0.252	-0.491
SJH-3	Hbx dike, volc frags, in Pz carbs	49.3	0.96	1.24	-0.05	0.041	0.064	0.267	-0.248	-0.05	10.7	3.35	15.3	5.84	0.414	-0.497
TIPWW	alt Tjp, W wall ML pit, fresh bio	17.8	-0.199	4.02	-0.05	0.034	-0.02	-0.05	-0.249	-0.05	9.16	0.553	12.7	60.6	2.59	-0.497
3SW-659	alt Tjp, Joshua Hollow	21.9	-0.199	0.684	-0.05	0.068	-0.02	-0.05	-0.249	-0.05	5.96	0.843	12.6	52.8	4.29	-0.497
3SW-707	Sr ls wallrock <0.5 m W from dike	7.47	2.44	37.2	0.062	0.182	-0.02	1.13	-0.247	-0.049	9.87	1.3	4.53	24.7	0.1	0.543
3SW-709	Sr dolo ~350' W of 707	11.8	-0.197	17.4	-0.049	0.405	0.026	1.27	-0.246	-0.049	4.57	1.66	3.2	32.6	-0.098	-0.492
3SW-711A	brecc'd Sr dolo 0.5m W of dike	12.3	1.01	20	-0.049	0.359	-0.019	0.723	-0.244	-0.049	7.23	0.352	3.54	37.4	0.156	-0.487
3SW-711B	silicified Sr ~150' from 711A	36.4	0.365	25	0.073	0.073	0.037	1.38	-0.249	-0.05	10.3	2.45	2.96	22.4	-0.1	-0.498
3SW-713	cherty dolo w/fluor? near dike	246	0.627	84	0.208	1.4	0.569	11.3	2.56	0.081	40.9	23.8	4.84	117	0.276	-0.495
3MJ-160A	Gold Ace, Au-bearing Wood Canyon Fm	33010	110151	8.34	0.324	0.039	0.343	7.27	-0.249	0.069	14.5	9.75	12.3	25.8	-0.1	0.499
	"Blank" of fresh Tiva Canyon Mbr															
3SW-589p	new split prep'd in steel pulverizer	83.8	-0.194	1.99	-0.049	0.031	-0.019	-0.049	-0.243	-0.049	1.65	0.445	33.4	44.6	0.534	-0.485
X94B	new split prep'd in shatterbox	20.9	-0.195	1.93	-0.049	0.038	-0.02	-0.049	-0.244	-0.049	7.86	1.02	7.36	51.2	0.569	-0.488

brep= blind repeat analysis
bdup= blind duplicate analysis
hbx= hydrothermal breccia
vn= vein
Pz= Paleozoic
qtz= quartz
siltst= siltstone
vnlts= veinlets
alt= altered
ls= limestone
Sr= Roberts Mountain Formation
"p" following sample number denotes preparation in rotary pulverisor with steel plates; "s" denotes preparation in shatterbox with carbon-steel rings.
Tct= Tram Member of the Crater Flat Tuff
Tcp= Prow Pass Member of the Crater Flat Tuff
Tip and Tjp = porphyry dikes of Bare Mountain

Analyses by U. S. Mineral Laboratories, Inc., North Highlands, CA, using 15 gram digestions, organic liquid separation and inductively- coupled plasma-emission spectrography, except for Au which was determined by graphite-furnace atomic-absorption spectrometry. Values as reported by U. S. Mineral Laboratories. Number of significant figures does not indicate precision or accuracy of analyses.
"-" = less than.
Detection limits as quoted by U. S. Mineral Laboratories at 3 sigma confidence level:

Ag= 3 ppb
Au= 0.2 ppb
Tl= 0.5 ppm
As= 0.25 ppm
Se= 0.25 ppm
Zn= 0.25 ppm
Cu= 0.010 ppm
Bi= 0.050 ppm
Sb= 0.050 ppm
Te= 0.050 ppm
Pb= 0.050 ppm
Cd= 0.020 ppm
Hg= 0.020 ppm
Mo= 0.020 ppm

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HYDROTHERMAL ORIGIN AND SIGNIFICANCE OF PYRITE IN ASH-FLOW TUFFS AT YUCCA MOUNTAIN, NEVADA

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Introduction

Yucca Mountain, Nevada, the only site presently being considered for the construction of a national site for the disposal of high-level nuclear waste, is situated between areas of hydrothermally altered rocks peripheral to the Timber Mountain caldera complex of the middle Miocene southwestern Nevada volcanic field (Noble et al., 1991; Castor and Weiss, 1992; Castor et al., 1994; Weiss et al., 1995; Fig. 1). Areas of altered and mineralized rocks in southwestern Nevada include precious metal deposits hosted by the same ash-flow units that comprise Yucca Mountain (Weiss et al., 1994; 1995). These areas have been the sites of current and historic mining and mineral exploration. The possible presence of mineral and hydrocarbon resources in the vicinity of Yucca Mountain has raised concerns that exploration in the distant future could disrupt the nuclear waste, resulting in the release of radionuclides to the environment (Johnson and Hummel, 1991). The nature of past fluid flow and water-rock interactions at Yucca Mountain are important factors in assessing the potential for undiscovered mineral resources in the area of the proposed high-level nuclear waste repository. Ample well-documented textural and mineralogic evidence exists for at least one episode of widespread hydrothermal alteration of volcanic rocks deep within Yucca Mountain based on detailed studies of core and cuttings from deep drill holes (e.g., Broxton et al., 1982; Caporusio et al., 1982; Scott and Castellanos, 1984; Vaniman et al., 1984; Warren et al., 1984; Bish, 1987; Bish and Aronson, 1993). The presence of pyrite in major ash-flow units, and to a lesser extent, in altered silicic lava flows locally present between the ash-flow units, was documented.

Based on studies of selected core from 4 of the 13 deep drill holes, Castor et al. (1994) contend that most of the pyrite found in tuffs at Yucca Mountain was introduced as foreign lithic fragments incorporated during eruption of the tuffs rather than having been formed in place by hydrothermal activity. This conclusion appears to be based largely on their assertion that most of the pyrite resides in unaltered to variably altered and veined foreign lithic fragments, whereas pyrite-bearing veins are absent in the tuff matrix, titanomagnetite and mafic phenocrysts in the matrix are generally not replaced by pyrite, and feldspar phenocrysts in the pyritic tuffs are generally unaltered. Castor et al. (1994) regarded the much smaller quantities of pyrite disseminated in the tuff matrix, including relatively rare pyritized hornblende and biotite grains, as xenolithic as well.

We have studied core and cuttings from the same drill holes studied by Castor et al. (1994) as well as from eight additional drill holes in Yucca Mountain. The tuffs that contain pyrite mainly belong to large-volume, subalkaline (metaluminous) rhyolite ash-flow units of middle Miocene age, including the Lithic Ridge Tuff and units of the Crater Flat Group (ca. >150–250 km^3 each; Carr et al., 1986; Sawyer et al., 1994), which we have examined in numerous outcrops in surrounding areas of the southwestern Nevada volcanic field. These units lie stratigraphically below the ash-flow sheets of the Paintbrush Group and underlie the site of the proposed repository. The lithic origin of the pyrite of Castor et al. (1994) is not consistent with the temperature, f_{O_2} and f_{S_2} of major ash-flow eruptions. It is our contention that inconsistent lateral and stratigraphic distribution of the pyrite, textural features of the pyrite, and phase stability considerations are incompatible with the lithic origin and are more reasonably explained by in situ formation from hydrothermal fluids containing low, but geochemically significant, concentrations of reduced sulfur. Such fluids would have been capable of transporting and depositing precious metals and should be a factor considered in assessing the potential for buried mineral resources.

Textural and Stratigraphic Evidence for In situ Hydrothermal Origin of Pyrite

The disseminated pyrite in lithic fragments and in the groundmass of the ash-flow units in Yucca Mountain consists of anhedral to subhedral, generally pitted and wormy to sieved, or skeletal(?), individual crystals and granular aggregates of from <5 μm to ~0.5 mm in maximum dimension (Fig. 2). In some grains, pits and poikilitic texture appear to result from the presence of numerous inclusions of altered groundmass, whereas other grains, mainly those smaller than about 10 μm in diameter, are commonly subhedral and free of pits and inclusions. Propylitically altered silicic lava in drill hole USW G-2 contains disseminated pyrite grains having textures and morphology indistinguishable from those of the pyrite in the tuffs (Fig. 3). Fractures are occasionally present in pyrite grains in the altered lava, as well as in granular pyrite in the tuffs. The pyrite in the lava is not lithic material, demonstrating that fragmentation and degassing processes of ash-flow eruptions are not neccessarily responsible for the textures and morphology of the pyrite in the tuffs. Instead, as is clearly the case in the altered lavas, the observed textures of pyrite in the tuffs more likely resulted from in situ nucleation and growth from hydrothermal solutions, perhaps followed by partial dissolution.

In Yucca Mountain drill hole USW G-2 (Fig. 4) small amounts of pyrite are disseminated in the altered dacitic lava and associated tuff that lies between the Lithic Ridge Tuff and the overlying Tram Tuff of the Crater Flat Group at depths of between 4,072 to 4,149 ft. Between 3,457 and 3,544 ft partially to densely welded ash-flow tuff of the Bullfrog Tuff of the Crater Flat Group contains small amounts (<1%) of pyrite disseminated in the groundmass, in altered pumice fragments (see below), in sparse lithic fragments, and in and near thin quartz and quartz + calcite veinlets (Fig. 5). A steeply dipping, drusy quartz vein cutting the Bullfrog Member, although largely oxidized, contains traces of filmy pyrite

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Vol. 89, 1994, pp. 401-407

PYRITIC ASH-FLOW TUFF, YUCCA MOUNTAIN, NEVADA

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Introduction

Yucca Mountain, Nevada, is a proposed repository site for high-level nuclear waste. Because such waste may constitute an environmental threat for 10,000 years or more, long-term potential for human intrusion will be considered during evaluation of this site.

The Yucca Mountain site is underlain by a 1,500-m-thick Miocene volcanic sequence that comprises part of the southwestern Nevada volcanic field (Fig. 1). Rocks of this sequence, which consists mainly of ash-flow tuff sheets with minor flows and bedded tuff, host precious metal mineralization in several areas as near as 10 km from the site (Fig. 1). In two such areas, the Bullfrog and Bare Mountain mining districts, production and reserves total over 60 t gold and 150 t silver (Castor and Weiss, 1992). Evidence of similar precious metal mineralization at the Yucca Mountain site may lead to mining or exploratory drilling in the future, compromising the security of the repository (Johnson and Hummel, 1991).

Pyrite, a common associate of precious metal deposits, occurs in samples from drill holes adjacent to the proposed repository site (Spengler et al., 1981; Caporuscio et al., 1982; Scott and Castellanos, 1984). Silicification and propylitic alteration were reported for some drilled intervals (Caporuscio et al., 1982), and such alteration is typical of areas containing volcanic-hosted precious metal deposits (Bonham, 1988). Veins containing quartz, carbonate, fluorite, and barite were reported in drill core from the Yucca Mountain site (Caporuscio et al., 1982), and similar vein assemblages are commonly present in volcanic rock-hosted precious metal deposits (Bonham, 1988). The presence of pyrite, in conjunction with the alteration and vein assemblages, has led to speculation that the Yucca Mountain site has potential for mineral resources (Caporuscio et al., 1982; Larson et al., 1988).

We believe that most of the pyrite encountered by drilling at Yucca Mountain was introduced as pyroclastic ejecta, rather than by in situ hydrothermal activity. Pyritic ejecta in ash-flow tuff are not reported in the literature, but there is no reason to believe that the Yucca Mountain occurrence is unique. The pyritic ejecta are considered by us to be part of a preexisting hydrothermal system that was partially or wholly destroyed during eruption of the tuff units. Because it was introduced as ejecta in tuff units that occur at depths of about 1,000 m, such pyrite does not constitute evidence of shallow mineralization at the proposed repository site; however, the pyrite may be evidence for mineralization deep beneath Yucca Mountain or as much as tens of kilometers from it.

Methods

Data presented below are mainly based on lithologic logging and microscopic examination of core. Trace element contents were determined for about 200 samples using an organic extraction technique and inductively coupled plasma emission spectroscopy by M B Associates, North Highlands, California. Gold was determined using graphite furnace atomic absorption by M B Associates and replicate analyses were done using a highly sensitive combined neutron activation and fire assay method by XRAL Activation Services, Ann Arbor, Michigan. Iron was analyzed as part of a multielement instrumental neutron activation analysis package by XRAL Activation Services.

Pyrite Occurrences

Pyrite occurs in lithic-rich ash-flow tuff in the lower part of the Tram Member of the Crater Flat Tuff from below depths of 984, 1,122, and 1,024 m in drill holes G-1, G-3, and 25b, respectively (Fig. 2). This pyritic ash-flow tuff ranges in thickness from 60 m in hole G-3 to 164 m in hole 25b. We found very little pyrite in the Tram Member from hole G-2, and sulfide was not reported in Tram Member cuttings from hole 25p (M. D. Carr et al., 1986). Pyrite occurs in the upper 8 m of bedded tuff (air-fall ± surge ± water-worked ± ash-flow tuff) beneath the Tram Member in holes G-3 and 25b but is absent in correlative bedded tuff from hole G-1. Pyrite also occurs in the basal 38 m of the Lithic Ridge Tuff in hole G-3.

Pyrite mainly occurs in accidental lithic fragments in the pyritic tuff (as noted by Spengler et al., 1981, in a log of hole G-1). It also occurs as small, commonly rounded grains in the tuff matrix (Fig. 3), but we have not seen it in pumice fragments. Quartz + calcite veins that do not contain pyrite cut part of the pyritic interval in hole 25b, but veins are rare or absent in pyritic tuff in holes G-1 and G-3 (Fig. 2). Pyrite grains in the matrix rarely have oxidized rims, but the upper 4 m of pyritic tuff in hole G-3 includes pyritic fragments with white rinds from which the sulfide seems to have been removed.

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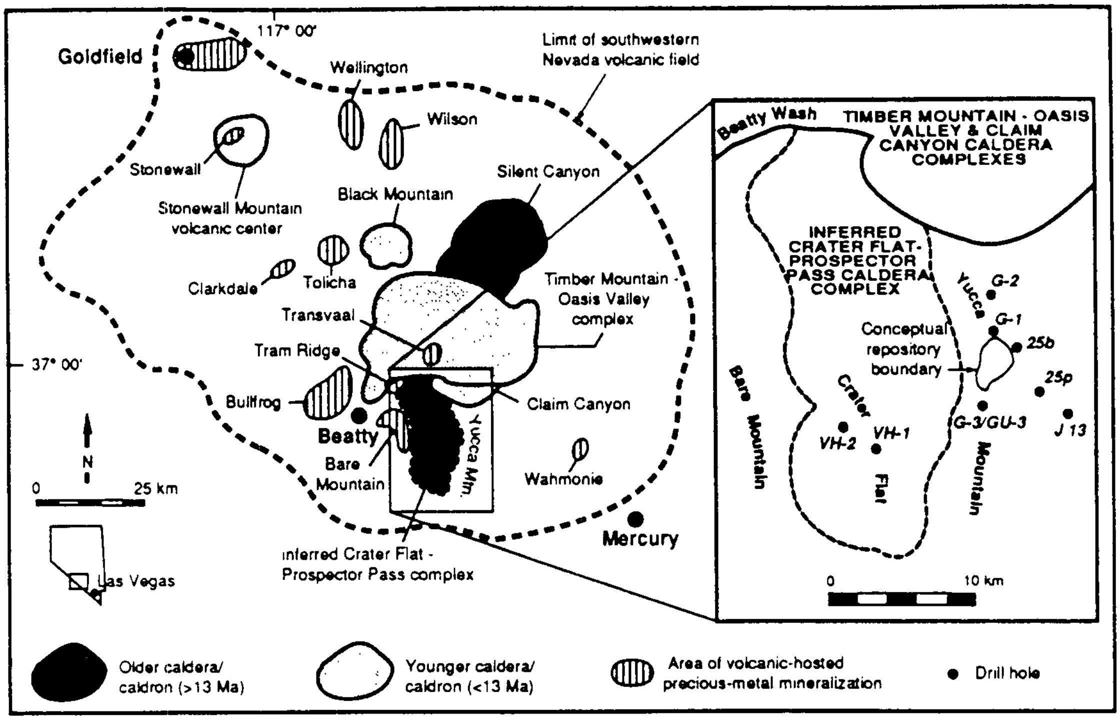

FIG. 1 Location map showing caldera complexes and areas of volcanic rock-hosted precious metal mineralization in rocks of the southwestern Nevada volcanic field. Inset shows drill holes in the Yucca Mountain area. Caldera complex margins are from W. J. Carr et al. (1986) and Byers et al. (1989).

Based on modal analyses, pyrite comprises 0.4 to 2.8 percent of pyritic ash-flow tuff in the Tram Member. We estimate that lithic fragments make up 20 percent by volume of this rock and that at least 50 percent of these fragments contain pyrite. Therefore, pyrite-bearing fragments comprise at least 10 percent by volume of the pyritic portion of the Tram Member. Bedded tuff beneath the Tram Member generally contains only traces of pyrite, but more than 1 percent pyrite was found in a thin bed of fine, well-sorted tuff in hole 25b.

Most of the pyritic fragments are of mafic to intermediate volcanic or subvolcanic rocks that are unaltered or variably silicified, argillized, and propylitized. Pilotaxitic texture is common in these fragments, which contain plagioclase ± biotite ± amphibole ± pyroxene phenocrysts. Fragments of pyritized ash-flow tuff are rare. Most mafic phenocrysts in the pyritic lithic fragments are altered, and some are partially replaced by pyrite (Fig. 4A). Unaltered and nonpyritized biotite phenocrysts are common in the tuff; rare grains of altered and pyritized mafic minerals that occur in the tuff are considered to be xenocrysts. Similarly, primary titanomagnetite is partially replaced by pyrite in some lithic fragments, but in the matrix it is rarely pyritized. Plagioclase in pyritic fragments ranges from unaltered bytownite-labradorite to thoroughly argillized pseudomorphs. Plagioclase in the matrix, mainly oligoclase-andesine, is generally unaltered.

Pyrite in the lithic fragments occurs in veinlets (Fig. 4B) and as disseminated grains ranging from irregular anhedra to perfect cubes. It is commonly in, or associated with, quartz veinlets and also occurs lining chalcedony- and calcite-filled cavities in some fragments. Pyrite veinlets do not cut the matrix and are terminated at contacts between lithic fragments and the matrix (Fig. 4B). Pyrite forms skeletal masses surrounding shards in tuff matrix in a single sample of partially calcitized tuff from hole G-1, but similar occurrences were not noted in samples from holes 25b and G-3.

Pyritic ash-flow tuff in both the Tram Member and Lithic Ridge Tuff is unwelded. Although partially collapsed pumice fragments give some of the tuff a welded appearance, thin section examination showed no evidence of shard welding (Fig. 3 shows typical shard shapes).

We found pyrite in two other rock types in drill samples from Yucca Mountain, and both occurrences are in rocks older than the Lithic Ridge Tuff. Propylitized flow rock from 1,586- to 1,608-m depth in hole G-2 contains disseminated and vein pyrite, and cuttings from 1,204- to 1,710-m depth in hole 25p con-

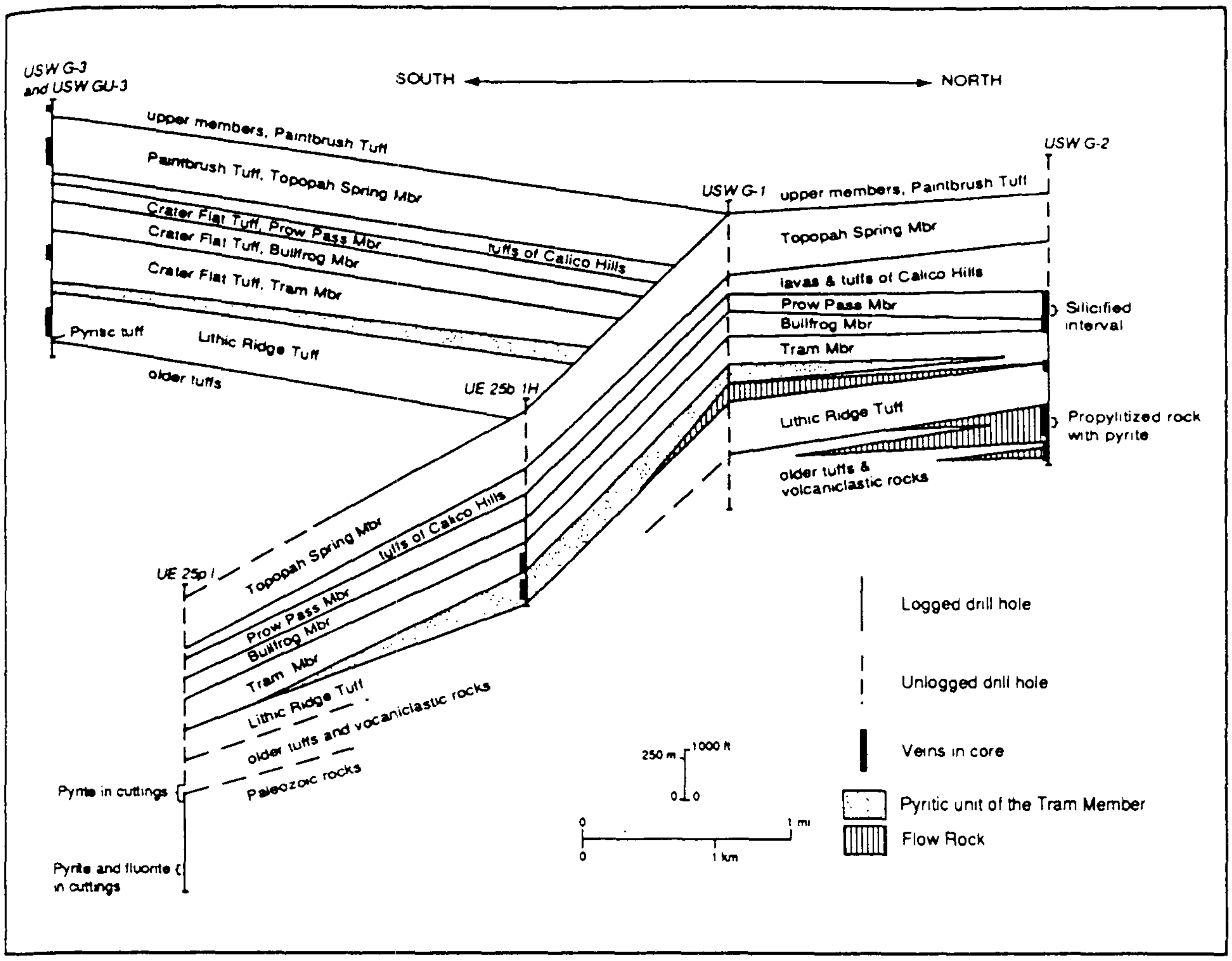

FIG. 2. Fence diagram showing stratigraphy, pyritic intervals, and veins intersected by drill holes USW G-1, USW G-2, USW GU-3/G-3, UE 25b 1H, and UE 25p 1. Veins may be present in unlogged intervals. Plan hole locations are at the top of the Topopah Spring Member of the Paintbrush Tuff.

tain pyrite in association with limestone, fluorite, and drusy quartz.

Minor Element Abundances

High contents of minor elements that are typically associated with volcanic rock-hosted precious metal deposits are rare in Yucca Mountain drill core sampled by us. A few samples containing quartz + manganese oxide veins from hole G-2 contain up to 142 ppm arsenic and 249 ppm antimony; altered rock from the same hole contains 438 ppm arsenic (Table 1). A sample of altered bedded tuff from a depth of 125 m in hole GU-3 contains 46.9 ppm bismuth.

Gold is not present in amounts higher than 2.5 ppb in any sample, and silver does not exceed 0.34 ppm. However, silver is slightly enriched in some samples, particularly in pyritic lithic fragments (Table 1) and is relatively high in the pyritic portions of the Tram Member and Lithic Ridge Tuff in holes GU-3/G-3 (Fig. 5). Although the pyritic tuff does not contain trace elements at levels expected in economic precious metal deposits, it contains anomalously high amounts of bismuth and tellurium when compared with unaltered samples of other volcanic units in Yucca Mountain. Pyritic lithic fragments of Tram Member ash-flow tuff are relatively enriched in bismuth and have the highest mercury, selenium, and tellurium contents of any drill hole samples (Table 1). Nonpyritic lithic tuff from the Tram Member in hole G-2 also contains elevated levels of tellurium (0.65–1.24 ppm), suggesting that it is correlative with the pyritic part of the member encountered in holes to the south. In holes GU-3/G-3, arsenic and antimony are present in amounts above background levels in the lithic-rich portion of the Tram Member and in the Lithic Ridge Tuff but seem to be most enriched in the nonpyritic portions of these units (Fig. 5). Base metal

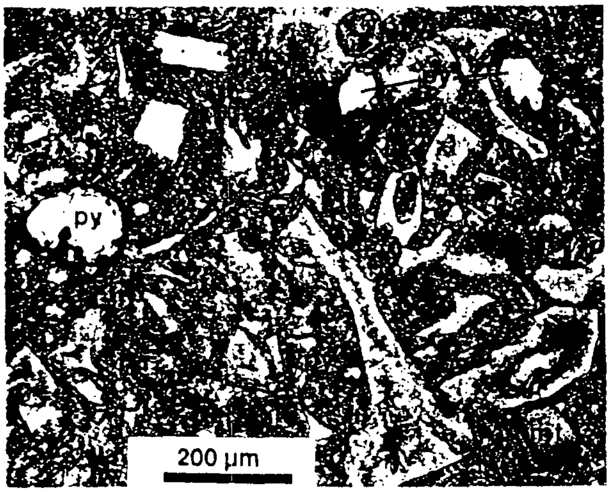

FIG. 3. Reflected and transmitted light photomicrograph of pyritic ash-flow tuff matrix, Tram Member of the Crater Flat Tuff, 1,172 m, hole G-3. Zeolitized shards (light gray), pyrite (py), and titanomagnetite (mt).

Note: *

contents in the pyritic tuff are not appreciably different from those of the other volcanic units sampled (Table 1), but the pyritic tuff in hole G-3 (Fig. 5) seems to be relatively enriched in copper, although this could be due to the presence of mafic lithic fragments.

Discussion

We believe that most of the pyrite in the Crater Flat and Lithic Ridge Tuffs at Yucca Mountain was introduced as ejecta rather than by in situ hydrothermal activity. Phenocryst alteration, pyrite veins, chalcedony, and silicification in lithic fragments, but not in the enclosing matrix, argue for such an origin. Pyrite in the matrix is thought mainly to be from pulverized ejecta and is commonly in rounded grains (Fig. 3), probably due to abrasion during pyroclastic transport. Minor amounts of pyrite in the tuff matrix at Yucca Mountain may have been introduced or remobilized during hydrothermal activity, but we found evidence for this in only a single sample. We consider sulfidation following ash-flow deposition to be an untenable alternative for the origin of most of the pyrite in the pyritic tuff at Yucca Mountain because mafic minerals and titanomagnetite are commonly replaced by pyrite in the lithic fragments but are rarely pyritized in the tuff matrix.

Pyritic ejecta in the Crater Flat and Lithic Ridge Tuffs must have come from a hydrothermal deposit that formed prior to their eruption. Initial dismantling of this pyrite deposit began during eruption of the Lithic Ridge Tuff, followed by considerably more destruction during eruption of the Crater Flat Tuff.

Although pyritic ejecta occur in air-fall tephra from modern phreatic or fumarolic eruptions (Heiken and Wohletz, 1985) and pyrrhotite occurs as inclusions in phenocrysts of ash-flow tuffs (Whitney and Stormer, 1983), we found no reports of pyritic ejecta in ash-flow tuff in the literature. However, we see no reason why the Yucca Mountain occurrence should be unique.

The pyritic ash-flow tuff was deposited at relatively low temperatures. The lack of shard deformation suggests depositional temperatures below 550°C (Fisher and Schmincke, 1984). The Tram Member pyritic tuff has relatively high magnetic susceptibilities, but remanent magnetism is very low for this rock (Rosenbaum and Snyder, 1985), which is consistent with deposition at temperatures below

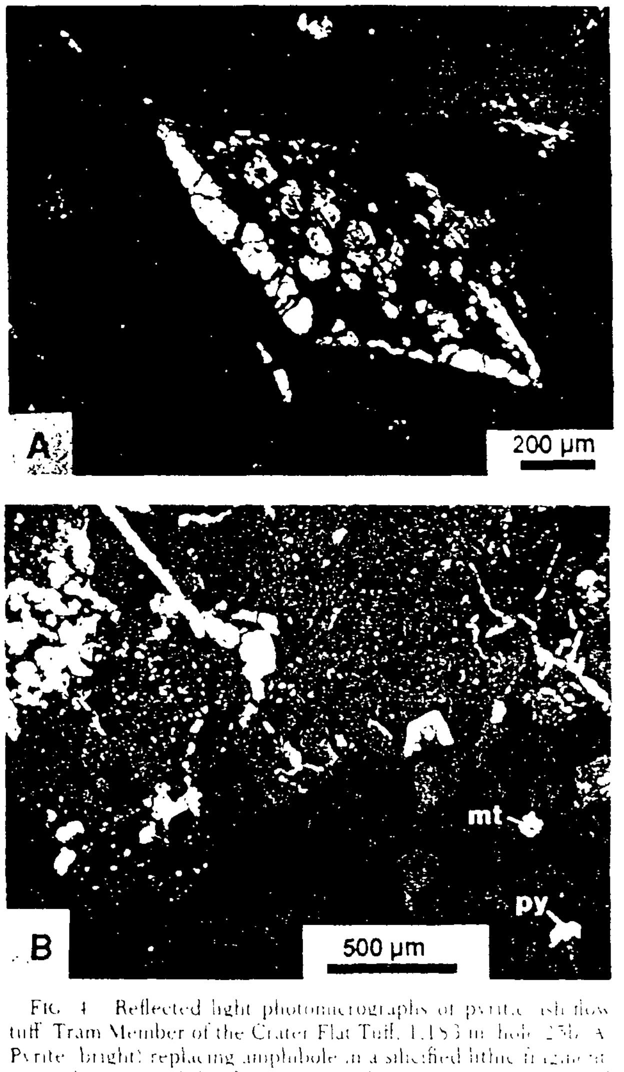

FIG. 4. Reflected light photomicrographs of pyritic ash-flow tuff, Tram Member of the Crater Flat Tuff, 1,183 m, hole 25b. A. Pyrite (bright) replacing amphibole in a silicified lithic fragment. B. Bright pyrite in lithic fragment (mostly gray) at contact with tuff matrix (mostly black) that contains pyrite (py) and titanomagnetite (mt) grains.

TABLE 1. Comparison of Some Trace Element Contents of Unaltered and Altered Volcanic Rocks, Veins, Pyritic Tuff, and Lithic Fragments and Veins in Pyritic Tuff from Yucca Mountain Drill Core (data in ppm unless noted otherwise)

			Ag	As	Au (ppb)	Bi	Cu	Hg	Mo	Pb	Sb	Se	Te	Zn
Pyritic tuff (41 samples)	Max		0.104	24.2	2.5	1.72	8.9	0.72	18.0	35.6	1.45	2.86	3.39	120
	Min		0.024	1.9	0.2	<0.25	2.0	<0.10	0.43	6.9	<0.25	<1.00	<0.50	17.2
	Median		0.050	6.1	1.0	0.40	5.0	<0.10	1.21	16.9	0.33	<1.00	<0.50	43.8
Other volcanic rock (83 samples)	Max		0.110	44.7	2.0	0.75	17.6	0.38	4.22	97.0	2.36	1.57	0.86	133
	Min		0.014	<1.0	<0.1	<0.25	<0.1	<0.10	0.24	0.9	<0.25	<1.00	<0.50	8.8
	Median		0.031	3.1	1.0	<0.25	2.0	<0.10	0.92	10.8	0.37	<1.00	<0.50	42.9
Strongly altered volcanic rock (14 samples)	Max		0.070	438	2.0	46.9	12.2	0.43	14.50	57.2	2.84	<1.00	1.24	131
	Min		0.032	1.0	<0.1	<0.25	0.7	<0.10	0.41	5.3	<0.25	<1.00	<0.50	17.3
	Median		0.015	8.2	1.0	<0.25	2.6	<0.10	1.31	11 9	0.62	<1.00	<0.50	40.7
Veins (50 samples)	Max		0.125	142	2.0	1.42	17.9	0.99	6.00	48.8	249	<1.00	<0.50	211
	Min		0.014	<1.0	0.1	<0.25	0.4	<0.10	<0.10	1.6	<0.25	<1.00	<0.50	1.9
	Median		0.028	9.5	1.0	<0.25	2.4	<0.10	1.11	10.1	0.70	<1.00	<0.50	35.9
	Drill hole	Depth (m)												
Pyritic lithic fragments	G-1	1,007	0.054	27.7	<0.5	1.46	9.6	<0.10	3.10	22.7	0.45	1.28	6.75	27.0
	G-1	1,018	0.136	30.9	<0.5	<0.26	7.3	<0.10	2.06	12.7	0.45	1.46	2.97	31.2
	G-1	1,030	0.136	30.9	<0.5	4.90	8.7	<0.10	2.54	13.6	0.49	3.41	0.64	9.2
	25B	1,183	0.337	10.1	<0.5	0.51	11.0	2.35	2.34	64.2	0.94	1.21	1.61	44.4
Veins in pyritic tuff	25B	1,088	0.029	2.6	<0.5	0.51	1.8	<0.10	0.43	8.0	0.43	<1.00	<0.50	32.3
	25B	1,166	0.035	21.4	<0.5	0.33	1.0	<0.10	0.69	11.2	0.68	<1.00	<0.50	13.1

580°C (the Curie temperature for magnetite). In addition to the cooling effects of atmospheric admixture and adiabatic expansion of magmatic gas, incorporation of large amounts of lithic ejecta probably lowered the eruptive temperature of the pyritic tuff significantly. Preservation of pyrite in ash-flow tuff is consistant with eruption at temperatures below 742°C because thermal decomposition to pyrrhotite and sulfur takes place at that temperature (Kullerud and Yoder, 1959). If atmospheric admixture is assumed during deposition, the presence of unoxidized pyrite suggests even lower temperatures because partial oxidation of pyrite to hematite and iron sulfate takes place in minutes in air at 400° to 500°C (Schwab and Philinis, 1947).

Pyrite is restricted to the lower parts of the Lithic Ridge Tuff and Tram Member ash-flow tuffs. The eruption of both ash-flow units from a single vent area that included a pyritic deposit with intensely altered rock at depth and nearly unaltered near-surface rock seems the most plausible interpretation of our observations. Eruption of the lower part of both units from a vent area containing pyritized rock, followed by eruption of the upper part of the units from different nonpyritized vent areas seems to us to be an unlikely coincidence. Pyritic ejecta in the upper part of each ash-flow unit could have been oxidized during devitrification and vapor phase activity, or oxidation may have taken place following cooling. Pyritic fragments in the lower parts of each unit would remain unoxidized by virtue of location beneath the water table, which probably moved up section following each addition to the volcanic sequence.

The eruption that produced pyritic tuff at Yucca Mountain expelled a large amount of pyritic rock. In holes G-1, G-3, and 25b pyritic ash-flow tuff in the Tram Member has an average thickness of about 100 m over an area of at least 5 km^2. If this tuff contains 10 percent pyritic lithic fragments by volume, it includes 130 million metric tons of pyrite-bearing rock (at a conservative density of 2.6 t/m^3). This is a minimum tonnage that does not include pulverized ejecta in the ash-flow matrix, pyritic ejecta in the bedded tuff and Lithic Ridge Tuff, or extensions of pyritic tuff outside the triangle formed by holes G-1, G-3, and 25b. The amount of pyritized rock calculated for the Tram Member is comparable to that found in many ore deposits.

Although abundances were reduced by dilution, minor metal contents in the pyritic tuff suggest that the original deposit was largely barren of base and precious metals. However, low-level bismuth, tellurium, and silver anomalies do suggest chemical affinities with some types of epithermal precious metal deposits (Bonham, 1988) that may be associated with large volumes of relatively barren pyritic rock.

Exposed areas of hydrothermal activity in the Yucca Mountain region are probably too young to

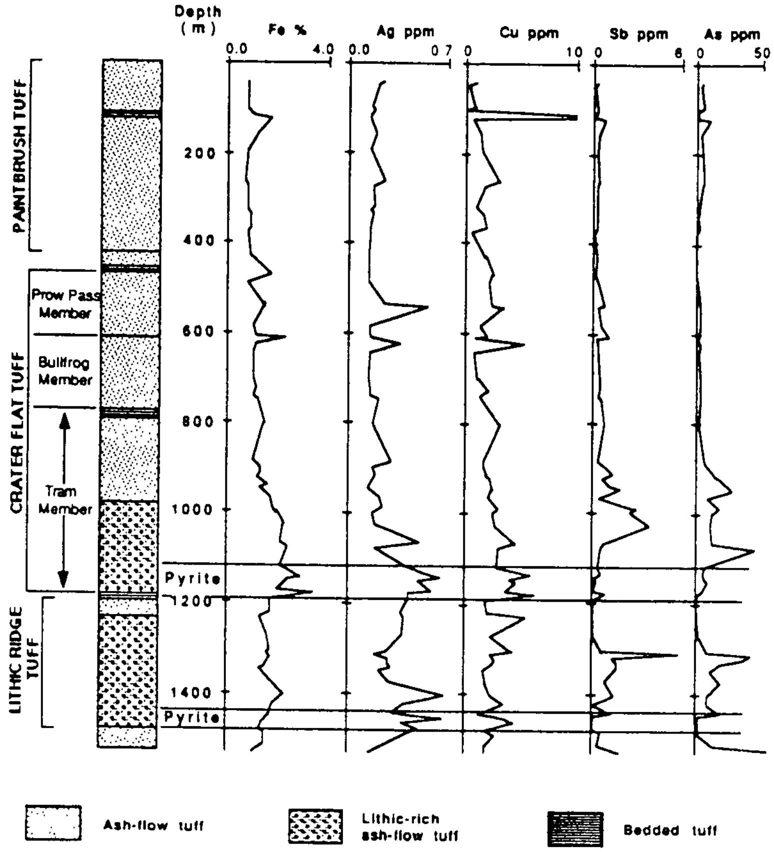

FIG. 5. Iron, silver, copper, antimony, and arsenic contents in core from drill holes GU-3 and G-3.

have been incorporated in the Lithic Ridge and Crater Flat Tuffs, which are 13.85 to 13.2 Ma (Sawyer et al., 1990; D. A. Sawyer, pers. commun., 1993). The oldest known volcanic-hosted hydrothermal activity near Yucca Mountain occurs about 10 km to the west on Bare Mountain and 25 km to the east at Wahmonie (Fig. 1). In both areas, precious metal deposits are associated with altered and pyritized volcanic rock and with elevated tellurium contents (Castor and Weiss, 1992). At Bare Mountain gold and fluorite mineralization occurs in 13.8 to 14.9 Ma felsic volcanics (Noble et al., 1991), but associated alunite has been dated at 12.9 Ma or less (Jackson, 1988). At Wahmonie silver telluride veins cut intermediate to felsic volcanic rocks (Castor and Weiss, 1992), but associated adularia has been dated at 12.9 Ma (Jackson, 1988). Although several precious metal mining districts in the north part of the southwestern Nevada volcanic field (Fig. 1) are in relatively old volcanic rocks, they are 50 km or more away from Yucca Mountain and are unlikely source areas for the pyritic tuff. Closer mineralized areas such as Tram Ridge and the Bullfrog and Tolicha districts (Fig. 1) are known, on the basis of host rock or hydrothermal mineral ages, to be considerably younger than the pyritic tuff at Yucca Mountain.

According to W. J. Carr et al. (1986), the Tram Member is mainly in a 60-km-long lobe extending southeast from Beatty Wash through hole G-3, and they speculated that its source was the northern part of the inferred Prospector Pass-Crater Flat caldera complex (Fig. 1); however, the existence of this complex has been questioned (e.g., Scott, 1986). We identified neither pyrite nor evidence of oxidized pyrite in exposures of the Tram Member mapped in the Bare Mountain and Beatty Wash areas adjacent to the inferred complex (W.J. Carr et al., 1986; Monsen et al., 1990). Another potential source is in the large Timber Mountain-Oasis Valley-Claim Canyon caldera complex area (Fig. 1), but 10.0 to 12.8 Ma volcanic events obscured evidence for older activity in this area. Eruptive activity at the Silent Canyon caldera (Fig. 1) predated deposition of the Lithic Ridge Tuff (Noble et al., 1991).

Tram Member pyritic tuff thins southward from holes 25b and G-1 to hole G-3 and does not appear to have been intersected by hole 25p to the southeast (Fig. 1). Trace element data suggest that a thin correlative interval in hole G-2 was oxidized following deposition. No sulfide was reported in core or cuttings from hole J-13 (Byers and Warren, 1983) east of Yucca Mountain, and holes to the west (VH-1 and VH-2) were not drilled deep enough to penetrate the lower part of the Tram Member. It is not possible, on the basis of such data, to determine a source direction for the pyritic tuff. The source vent, or vents, may have been under Yucca Mountain or some distance from it. Pyritic ejecta in the Lithic Ridge Tuff from hole G-3 suggest eruption from the same area as the Tram Member, and according to W. J. Carr et al. (1986), the distribution of these two ash-flow units is similar.

Although pyritic ejecta in the Tram Member and the Lithic Ridge Tuff were originally products of hydrothermal activity in the Yucca Mountain area, we do not believe that they provide evidence for mineral potential at shallow depths at or near the proposed repository site at Yucca Mountain. The pyritic tuff is 600 to 800 m below the proposed repository location near the base of the Paintbrush Tuff (Fig. 2), and the source of the pyritic ejecta must be stratigraphically lower. Uncertainty as to the source area for this tuff permits mineralization at Yucca Mountain well below the proposed repository level or elsewhere in the area.

Acknowledgments

This work was supported by Science Applications International, Inc., subcontract 39-920040-65, part of Prime Contract DE-AC08-87NV10576 issued by the U. S. Department of Energy. We thank Christopher Lewis and the rest of the Yucca Mountain Project Sample Management Facility staff for assistance during logging. F. J. Breit is acknowledged for help with sample preparation and petrographic examinations.

April 29, August 9, 1993

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