DOE/NV/10461--T57

TRAC *Technology and Resource Assessment Corporation*

3800 Arapahoe Avenue, Suite 225
Boulder, Colorado 80303
(303) 443-3700 FAX No. (303) 443-8626

FIELD TRIP REPORT: OBSERVATIONS MADE AT YUCCA MOUNTAIN, NYE COUNTY, NEVADA

SPECIAL REPORT No. 2
CONTRACT No. 92/94.0004

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

March, 1993

Authored by:

Carol A. Hill

travertine deposits (Machette, 1985), it is often interpreted to be strictly pedogenic in origin. The use of the term "travertine" will avoid this confusion.

The following observations were made concerning the travertine deposits in the Yucca Mountain region:

1. Calcite/opal travertine is localized along faults or fault zones. Faults were detectable by offset beds (e.g., Harper Valley), well-exposed and slickensided surfaces (e.g., Wailing Wall), or by brecciated and mineralized zones (e.g., Calico Hills and 2 km north of Mercury). In places where faults are well-exposed, the calcite/opal mineralization occurs primarily as seams or veins along or near the fault plane and dies out away from the fault (e.g., Wailing Wall). A number of the travertine deposits are located along major faults (e.g., the Bow Ridge Fault, Trench 14 calcite/opal and the Paintbrush Fault, Busted Butte calcite/opal). The nearly universal association of calcite/opal with faults implies that the travertine has a fault-related origin. If the calcite/opal were pedogenic in origin it should occur universally around Yucca Mountain and not be localized along fault zones.

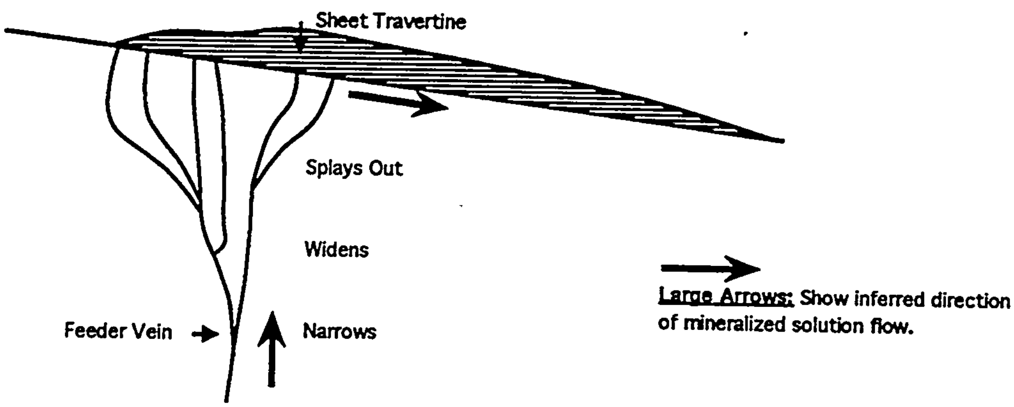
2. Calcite/opal does not occur in soil horizons between fault zones. In an exposed soil horizon at the Highway 95 gate-gravel pit (shown on the map of Swadley and Carr, 1987) the soil contains no calcite-caliche whereas less than a kilometer north from the gate along this same road calcite mound deposits are locally abundant.

3. The calcite/opal does not occur within specific stratigraphic units or rock types. Travertine was observed along fault zones in Paleozoic limestone (e.g., Bonanza King Limestone, Pull Apart Fault), in rhyolite tuffs (e.g., Bedded member of Paintbrush Tuff, Busted Butte), in basalts (e.g., Basalts Miocene, Tb_2, west of Mercury, Stop 27), and even in unconsolidated sand (e.g., Busted Butte sand ramps). That is, the source of calcium does not appear to be related to the amount of calcium in the host rock but to a subsurface travel route wherein calcium has been gained somewhere between recharge and discharge. It is suspected that the Bonanza King Limestone is the primary subsurface calcium source for the calcite/opal travertine as it is the most karstified unit in the region. Caves can be seen in the Bonanza King Formation along Highway 95 southwest of Mercury; also, regional discharge is at Ash Meadows and Devil's Hole in the cavernous Bonanza King.

4. In some cases calcite/opal travertine occurs in conjunction with an aquiclude; that is, a competent unit where carbonate-rich water has emerged as springs along the base of the unit. This can be observed on the western side of Busted Butte where the base of the Tiva Canyon member has acted as the aquiclude and where travertine occurs at the base of the Tiva but not in the stratigraphic units above the Tiva, at least in this location.

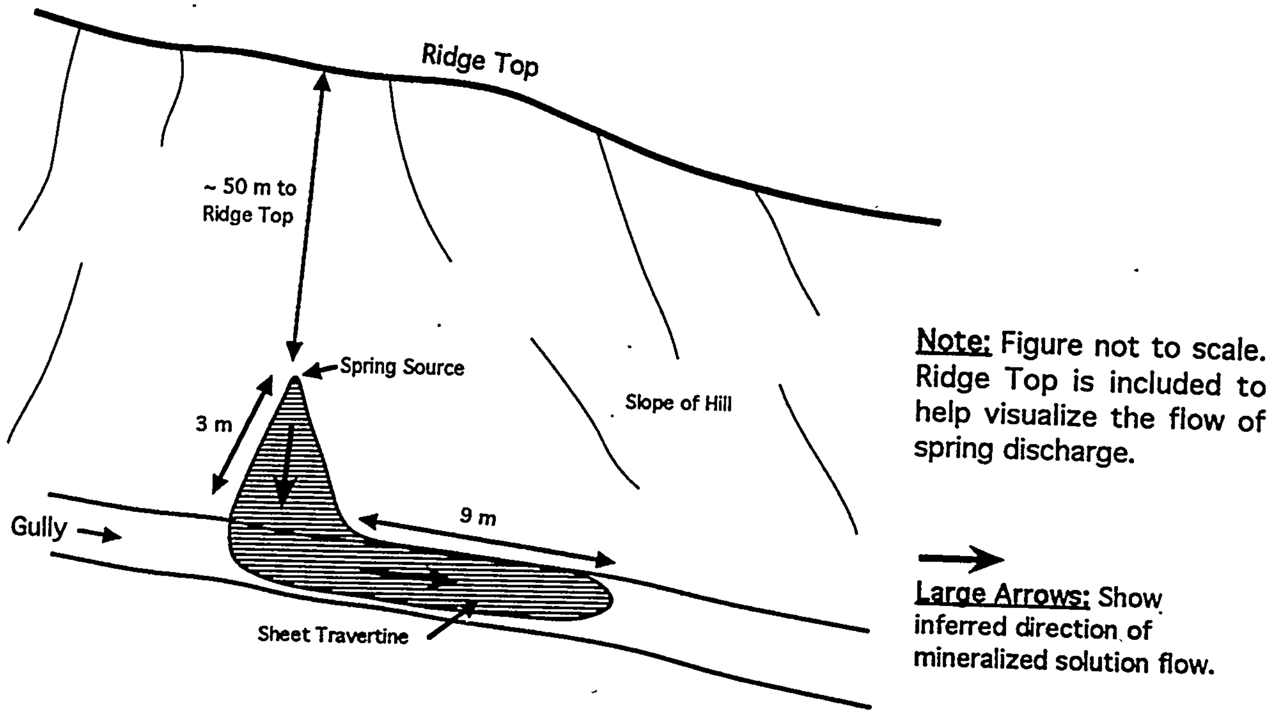
5. Calcite/opal travertine deposits are often associated with "feeder veins" where they have been vertically exposed by trenching or by valley downcutting. This

association can be seen at Trench 14 and at the fault scarp exposed at site 106 F, and is most dramatic on the west and east sides of Busted Butte where valley erosion has dissected sand ramps. As exposed in the sand ramps the veins narrow toward the base but thicken and splay out into multiple veins near (within a few meters of) the sand-ramp ground surface. Travertine continues along the surface downslope from these feeder veins:



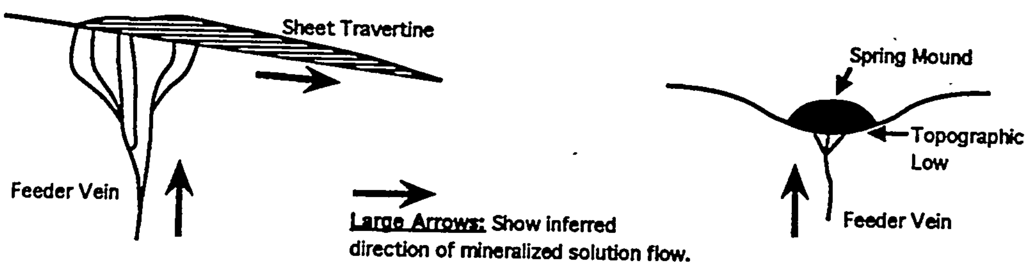
The direct correspondence in space between the feeder veins and the travertine downslope from the feeder veins is strong evidence that the veins were the source of mineralizing solutions from which the travertine deposited.

6. <u>Calcite/opal deposits which have not been vertically exposed also sometimes have topologies that suggest a point-source spring origin.</u> An excellent example of this can be seen in Harper Valley where carbonate-saturated water appears to have issued forth from a spring orifice, flowed downslope for 3 m before encountering a gully perpendicular to slope, and then continued down-gradient along the gully for another 9 m, all the while depositing a thin layer of carbonate travertine along its course:



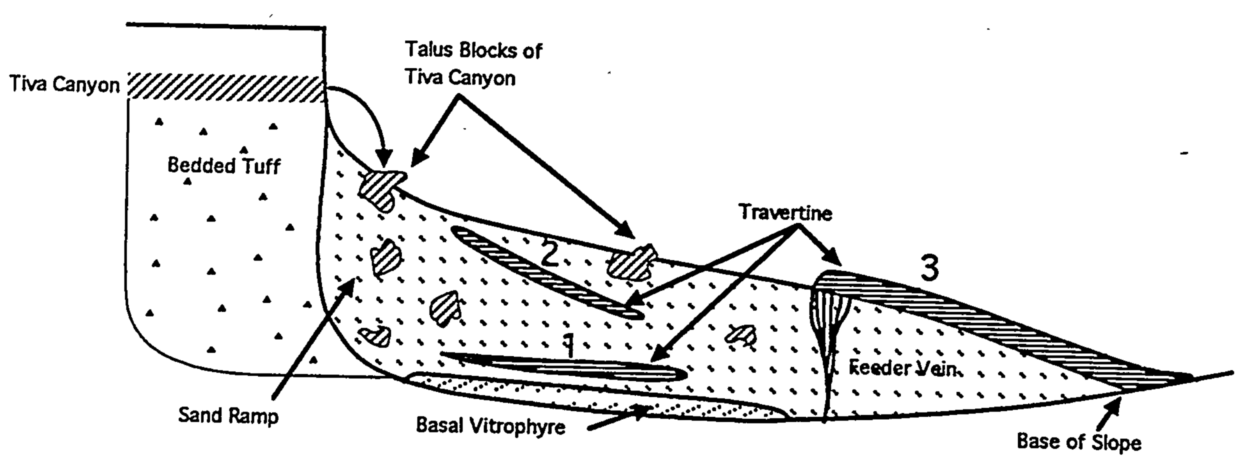
7. <u>Calcite/opal occurs as vein and fracture fillings, as material cementing breccia fragments, as matrix-supporting material cementing alluvium</u> (e.g., Site 106 F) or colluvium/talus (e.g. Plug Hill), and as spring mounds (e.g., Site 199). The type of deposit can change over short distances (e.g., calcite/opal veins are exposed in Trench 14 whereas possible mound material is exposed in South Trench 14 located some 60 m or so south of Trench 14).

8. <u>Spring mound-type travertine appears to have accumulated in topographic lows</u> as compared to travertine which formed as sheet deposits downslope from feeder veins:



Mound-type deposits are composed of massive, unlayered, unconsolidated, chalk-like calcite in comparison to layered calcite/opal sequences such as characterize sheet travertine and vein material. Spring mound deposits on the present-day erosion surface are known to be young (e.g.,~30 Ka, Site 199; diatomaceous earth along Highway 95 which has camel, horse, and mammoth bones in it). Spring mounds overlain by later soil material are probably older than this (e.g., the massive calcite exposed in South Trench 14 and in the North and South Stagecoach trenches). The Stagecoach mound material may represent a time when Crater Flat was at a higher erosional level than it is today (i.e., it is an earlier equivalent of Site 199). The South Trench 14 mound material may have formed in a local topographic low associated with spring activity in nearby Trench 14.

9. <u>Calcite/opal travertine deposition was both episodic and of varying intensity.</u> Various travertine episodes can be observed at Busted Butte where a number of travertine layers occur one above the other, separated by intervals of sand:



These travertine layers appear to have: (a) formed at different times (layer 1 being the oldest and layer 3 the youngest) and (b) represent different former ground-surface levels of the sand ramp. This is indicated by the presence of calcified root casts (and rare animal burrows) in all of the layers (1, 2, and 3). The calcite travertine layers of the sand ramps are oriented at different angles from the horizontal (from ~10-20°), which angles represent different angles of repose of the sand ramps at the time of each travertine event. Varying intensity of spring activity is indicated by some travertine layers extending all the way to the base of slope of the sand ramps and beyond (3); other travertine layers extend only part way down a former slope (1,2).

10. Calcite/opal deposits can increase in thickness and mass downslope. This can be observed on the hill just west of WT-7. Uphill the calcite/opal occurs as fracture fillings in the rock, but downhill the calcite/opal becomes a thin (a few cm or less) surface layer of travertine, and even further downslope along the road the travertine thickness increases to 15-30 cm.

11. Calcite/opal deposits display a variety of textures (e.g., laminated, vesicular, massive, etc.). A detailed description of these textures and field relationships between textural types will be provided in a separate report.

12. Calcite/opal deposits are microcrystalline which suggests rapid cooling and/or rapid degassing. This is in contrast to pedogenic carbonates which nearly always are "aggregates of silt-sized calcite crystals...the microcrystalline forms are readily

identified by optical microscope, either in thin section or grain mount" (Dixon and Weed, 1989, p. 281).

13. Density of calcite/opal travertine sheet deposits varies from a harder, more dense and shiny upper surface to a more porous, lower surface (e.g., Busted Butte, Trench 8). The travertine is often composed of an interwoven mass of root casts and sometimes displays algal- or pisolitic-like structures (e.g., Wailing Wall at the mouth of Red Cliff Gulch).

14. Some of the calcite/opal travertine must be relatively young since the deposits overlie and conform to present -day valley and gully slopes (e.g., Harper Valley)

SILICA TYPES

Five different types of opal (silica) were encountered during the course of this field trip. These five types display different textural relationships but they do not necessarily represent different episodes of mineralization. Four of the five silica types can occur with each other and these have been found in deposits of all ages (from ~30,000 ybp at the Wailing Wall to >400,000 ypb at Trench 14).

1. Opalite. "Opalite" is composed of a transparent to pearly opal (hyalite) which always fluoresces a brilliant green (i.e., it is an "uraniferous opal" such as described by Szabo and Kyser, 1985; U = 15-57 ppm). A number of specimens of opalite were collected from a number of different localities on this trip, but especially spectacular specimens were found at Harper Valley, on the hill above Trench 14, and at drill site

UE25p#1 (Stop 37-1). The Harper Valley opalite is translucent to white, opalescent, and botryoidal. It litters the hillsides and valleys of Harper Valley and has its source in the Tiva Canyon member where it occurs as veins filling fractures in the rock. The UE25p#1 opalite is massive, opaque, and displays conchoidal fracture and an opalescent sheen. This opalite occurs as veins in the bedrock (Topopah Spring member) and also crosscuts a soil horizon.

2. Silicified Breccia. Silicified breccia consists of breccia pieces floating in an opal matrix. This matrix is tan, opaque, hard (does not scratch with a knife) and dense, but it is not a pure opal as it contains variable amounts of intermixed calcite (it fizzes somewhat in acid). No samples of silicified breccia were observed to fluoresce. Silicified breccia was found at WT-7, Trench 14, and Harper Valley. At WT-7 the opal fills the spaces between fractured and brecciated rock. The silicified breccia at Trench 14 occurs as dikes and veins cut across by later calcite/opal veins. In both the WT-7 and Trench 14 occurrences, the silicified breccia appears to represent an early phase of brecciation and mineralization. The WT-7 opal has a U-series date of >300 Ka (R. Harmon, personal communication, 1992) and the Trench 14 silicified breccia is the first of five episodes recorded in the trench (Figure 3). In Harper Valley the silicified breccia occurs as a breccia dike which cross-cuts the Bedded Tuff member but which stops at the base of the more competent Tiva Canyon member.

3. Opal/Calcite Travertine. Opal exists interlayered or interlaminated with calcite in

many of the localities visited on the field trip. This opal is the same type as the opal in the matrix of the silicified breccia; it is tan, opaque, dense, hard, is intermixed with calcite, and never fluoresces. Particularly good exposures of opal/calcite exist at Trench 14 and Busted Butte. The laminations of opal and calcite are vertically oriented within feeder veins (e.g., Trench 14, Busted Butte), or they can be oriented near-horizontally within travertine sheet deposits downslope from feeder veins (e.g., Busted Butte). The opal laminations are distinguishable from interlaminated calcite by color (the opal is tan and the calcite white) and by hardness. Opal layers often stand out in relief between the more-porous and -powdery, less-hard layers of calcite.

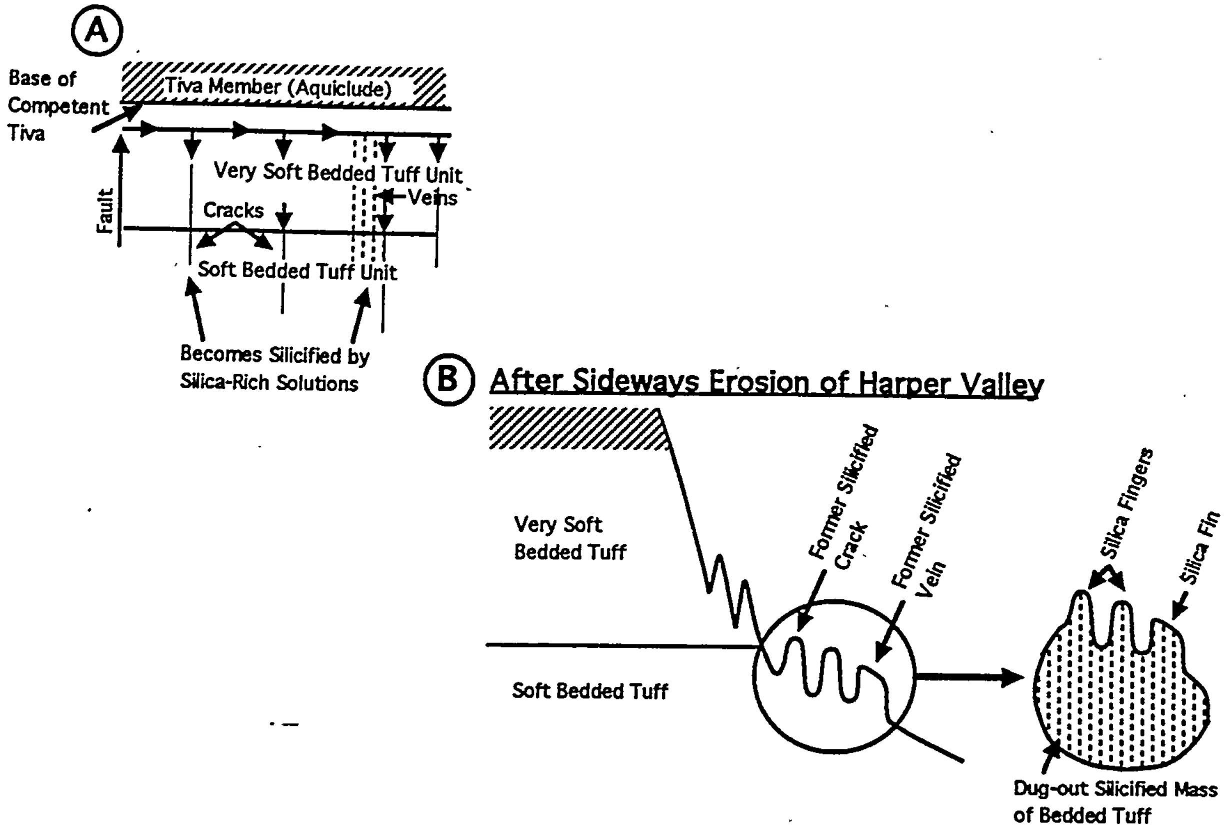
4. Powdery Opal. Powdery opal is a white, massive opal with a powdery-like texture and appearance. This type of opal was identified in samples collected from Trench 14, and while this type of opal was not positively identified in any other samples, it seems entirely possible that powdery opal may exist intermixed with powdery calcite in these layers.

5. Diatomaceous Earth (diatomite). Diatomaceous earth occurs along Highway 95 just northwest of the dirt road taking off to Site 199. This site was not visited on the field trip but reportedly the earth is siliceous rather than calcitic (J. Frazier, personal communication, 1992). This is the only silica type of the five listed that is not known to occur with the other types. The diatomaceous earth along Highway 95 contains camel, horse, and mammoth bones so it must be fairly young (25-30 Ka?).

SILICA FINGERS

Some unusual forms exist in the soft Bedded Tuff member, along the fault in Harper Valley. These are finger-like projections of silicified tuff a few centimeters or so high and wide which have been informally been given the name "silica fingers." Hill (1992) mistakenly thought that these forms might be miniature "tent rocks" which were perhaps syngenetic with deuteric gas activity. During this field trip two other silica-finger localities were examined. The silica fingers are actually erosional remnants of more extensive blocks of silicified tuff which, in addition to the finger shapes, display fin-like shapes where the tuff became silicified along cracks.

The author now believes that the silica fingers in Harper Valley formed in a manner analogous to "sand stalagmites" in caves except that sand stalagmites are cemented with calcite brought in by dripping water whereas the silica fingers are cemented with silica brought in by silica-rich water ascending from below. Sand stalagmites and compound sand-stalagmite forms are caused by calcite-saturated water seeping preferentially through vertical and horizontal porous zones in sand on the cave floor (Hill and Forti, 1986). The calcite cements the porous zones causing them to become harder than the surrounding sand and to better resist subsequent erosion. When the uncemented sand becomes eroded away, the harder cemented portions of sand are left in relief. In an analogous manner the silica fingers in Harper's Valley are believed to have formed as follows:



Contrary to speculation that silica fingers may represent late-stage degassing (deuteric) at Yucca Mountain, the silica fingers are actually part of a consistent story of epithermal (epigenetic) mineralization along fault zones. The silica fingers formed by silica-bearing solutions ascending along the Harper Valley fault zone, which solutions then permeated into cracks within the Bedded Tuff. As the valley walls eroded away, the harder silica fingers and fins were left in relief, becoming eroded on the very top into rounded "finger" shapes.

WAHMONIE TRAVERTINE/GYPSITE MOUND

This site was specifically visited because of reports of "crystalline-gypsum beehive-shaped mounds" in the Wahmonie Hills. The Wahmonie mound is a travertine/gypsite block ~6 m long, 4 m wide, and 2 m high composed of ~70-80%

calcite and ~20-30% gypsum (5 samples tested). Rather than being crystalline in character the mound is massive and contains a somewhat harder, more-dense exterior and a softer, more-porous, friable interior. Thin (1-3 mm) botryoidal crusts of gypsum line the travertine/gypsite block in places where cavities in the block have not been exposed to weathering. These crusts represent diffusion of the more soluble gypsum component toward the outside of the block caused by evaporation of solutions at the air/block surface. Sepiolite has been reported as being present in the mound (Vaniman et al., 1988 and Somerville et al., 1992), but was not observed.

The Wahmonie travertine/gypsite mound is also not indicative of special processes occurring at Yucca Mountain but is consistent with the concept of region-wide epithermal (epigenetic) mineralization along fault zones. The only difference between this site and other mounds in the Yucca Mountain area is that the Wahmonie mound is composed partially of gypsum. The reason for this variation in mineralogy is because the Wahmonie mound is located within the Wahmonie Mining District, directly overlying a prominent N30°E- trending fault. Quade and Tingley (1983) reported both sulfide and gypsum mineralization in the Wahmonie Mining District and it seems logical that hydrothermal solutions ascending from depth through sulfide-rich intrusives along the fault picked up sulfate and deposited it in the Wahmonie travertine/gypsite spring-mound.

Because the Wahmonie mound is composed partially of gypsum and because it is extremely friable, it is believed to be very young (<30,000 years?). The Wahmonie mound is especially important because it demonstrates the principle: "What's on top reflects what's below." The gypsum mound on the surface reflects the presence of a sulfide-rich intrusive body below, and this, in turn, implies ascending water along a fault rather than sulfate carried in by descending water (i.e., the gypsite is not of pedogenic origin). **Editorial Note by J. S. Szymanski:** By itself, the Wahmonie mound seems to successfully challenge the notion of a quiescent steady-state description of the local hydrologic system. This mound occurs at an attitude of about 4,700 ft above mean sea level, in an area where the contemporary water table is very deep. In two wells the water table was found at altitudes 2,784 ft (to the east) and 3,755 ft (upstream) (Winograd and Thordarson, 1975). In this setting, the young and unequivocally hypogene mound cannot be dismissed without recognizing that, for one reason or another, the local hydrologic system can exhibit diverse behavior, including discharge of mineralized and deep-seated solutions at the topographic surface.

TRENCH 14

Trench 14 was mapped in some detail (Figure 2 & 3) and a number of samples (36a to 36z) were collected at this site. Trench 14 is located directly along the Bow Ridge Fault, a normal fault which trends north-south along the eastern flank of Yucca Mountain. At Trench 14 the Rainer Mesa member of the Timber Mountain Tuff has been downfaulted against the Tiva Canyon member of the Paintbrush Tuff (Figure 3). A complex sequence of crosscutting veins filled with calcite/opal has been exposed by the trench.

At least five crosscutting episodes of epithermal mineralization are exposed in Trench 14. The first episode (1, Figure 3) is represented by the silicified breccia which has been crosscut by later calcite opal veins. Pieces of silicified breccia have been sheared off by later movement along the fault and incorporated as "float" into calcite/opal which was injected during that movement (sbf = silicified breccia float in Figure 3). The remaining four episodes are represented by calcite/opal veins which consecutively crosscut each other (2, 3, 4, 5; Figure 3). During the last episode (5) mineralizing solutions appear to have used the same vein conduits as during episodes 2, 3 and 4 but mineralization extended farther to the surface, crosscutting everything else. Following the five mineralization episodes was a later period of extension during which the veins were opened a centimeter or more causing cavities to form in the mass (cav = cavities in Figure 3). In some of these cavities tiny (a few mm in diameter) calcite "popcorn" nodules have formed as crustal linings.

Veins 2, 3, 4, and 5 consist of alternating laminae of calcite and opal. The calcite is the lighter-colored, more friable component of the couplets and the opal is the tannish-colored, denser, chert-like component of the couplets. Individual laminae vary substantially in width but the opal layers on the average are thinner (~a few mm) than the calcite layers (~1 cm). However, opal layers up to 2-3 cm thick and calcite layers as narrow as a few mm were noted. The intimately-laminated sequences of calcite/opal do <u>not</u> resemble textures which could have been caused by all of the opal forming first and all of the calcite last. The calcite/opal sequences within each episode (e.g., 2-4) may represent sub-episodes of opal and then calcite precipitation, but the textures more readily suggest that the opal and calcite laminae within the veins precipitated nearly simultaneously for each episode of crosscutting.

The Trench 14 calcite/opal veins are interpreted by the author to be feeder veins for ascending mineralized solutions. Morphologically they are identical to the feeder veins observed at Busted Butte, only they are larger and more complexly-episodic. Like the veins at Busted Butte the Trench 14 veins narrow (but do not pinch out) toward the base and splay outward near the ground surface. Also, travertine material (~0.5 m thick) is present downslope from the feeder veins at Trench 14 as is the case for the Busted Butte veins. The morphology of the veins at Trench 14 is consistent with the concept of ascending mineralized solutions which become injected into cracks along the unloaded ground-surface zone (hence the splaying out of the veins near the surface).

The author does not interpret the vein material at Trench 14 to be of pedogenic origin, despite numerous reports to the contrary (e.g., Quade and Cerling, 1990). Objections to a pedogenic model are:

1. The veins and localized travertine at Trench 14 do not look like caliche/pedogenic-calcrete deposits. Calcic soils are those that contain a significant amount of secondary carbonate in the form of horizontal or nearly-horizontal layers (i.e.; see the figures of Wiede, 1985, which show calcic soil horizons in desert climates).

2. The author cannot visualize how pedogenic processes could have produced the cross-cutting vein morphology at Trench 14 or how the vertical laminations of calcite and opal could have been produced by soil-forming processes.

3. If the calcite/opal were pedogenic then calcrete/caliche-type mineralization should not be localized as vein deposits but should occur everywhere in the vicinity of Trench 14.

4. Sepiolite has been reported as occurring at Trench 14 (Vaniman et al., 1988 and Levy and Naeser, 1991). It has been argued that this sepiolite may have a pedogenic origin as is supposed for the sepiolite playa deposits south of Yucca Mountain (The "Amargosa Sepiolite Mine"). However, a pedogenic origin for these playa deposits is not supported by the evidence. Rather, this sepiolite occurs with opal CT in areas of spring discharge along faults in the Amargosa Valley. (A discussion of sepiolite occurrences in the Basin and Range will be provided in a separate report.)

5. Finally, a pedogenic model does not adequately provide for the source of calcium for the calcic veins at Trench 14. There are no wind-blown dust accumulations in the immediate area of Trench 14 nor are there large windblown deposits anywhere at Yucca Mountain (see the following discussion on the origin of the so-called "eolian" sand ramps).

SAND RAMPS

Sand ramps were observed at Busted Butte, Fran Ridge, and Harper Valley. Sand ramps are long (500 m or so) and thick (50-90 m or so) masses of sand which slope away from the sides of valleys, ridges, or buttes. Sand ramps have been commonly thought to be eolian in origin (e.g., Whitney et al., 1985; Vaniman et al., 1988). In turn, windblown "dust" has been deemed the source of calcium for the "pedogenic calcite/opal calcretes" in otherwise calcium-poor volcanic rock (Stuckless et al., 1991, 1992).

<u>The sand ramps at Busted Butte are interpreted by the author to be apron debris.</u> This interpretation is based on the following observations:

1. The sand ramps go all the way around Busted Butte. They have not piled up in a consistent prevailing-wind direction. This is in contrast to uncontroversial sand dune deposits (e.g., the Lathrop Wells Cone dunes which have accumulated only along the eastern side of the cone).

2. The sand ramps all emanate from approximately the same level on Busted Butte; that is, from the Bedded Tuff member of the Paintbrush Tuff. Burchfiel (1966, p. 4) described this stratigraphic unit as "approximately 45 feet of yellow-brown pumiceous airfall tuff and tuffaceous sandstone. The pumice fragments in the tuff are about 1 inch in diameter and may form as much as 80 percent of the rock...Most of the tuff is friable and weathers into low relief between the more resistant welded tuffs of the Topopah Spring and Tiva Canyon Members."

3. The sand ramps contain large talus clasts from the competent Tiva Canyon member of the Paintbrush Tuff but no talus pieces from the incompetent Bedded Tuff member (See Figure on p. 7). Therefore, the sand must represent the erosion of this soft member.

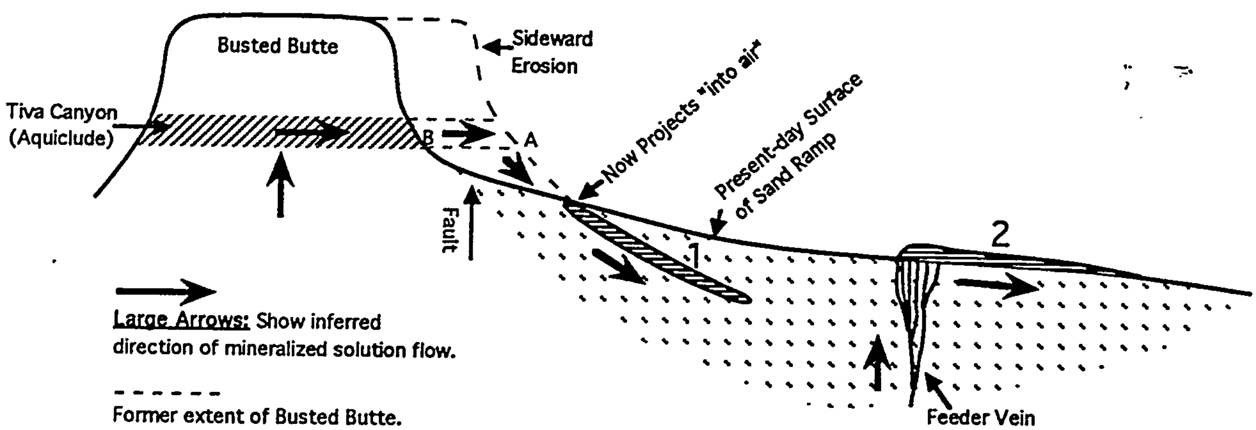
4. The sand ramps can be traced directly to their source; that is, to the very soft, pumice-rich, Bedded Tuff member. The Bedded Tuff member is so unconsolidated that wind pockets (up to a meter high and several meters wide) have formed in this unit (seen in Harper Valley and at Busted Butte). In-situ wind erosion of the unwelded Bedded Tuff has helped to produce the apron-debris sand of the ramps -- this "in situ" wind erosion should not be confused with an "eolian" origin for the sand where sand particles have been transported for great distances. This point is of extreme importance because in the case of apron-debris (in-situ sand) there is no source of calcium brought into the system, whereas in the case of an eolian origin calcium could be brought from a distant carbonate source.

5. The sand ramps have few characteristics of wind-blown deposits. There are no characteristic dune shapes and no cross-bedded sequences. The angle of repose of the sand ramps is ~15-20° and does not approach the 34° angle reached by sand dunes. Talus pieces of all sizes occur in the ramps and the sand is not well sorted as is characteristic of wind-blown deposits. In addition, the color of the sand ramps matches (or is slightly darker than) the Bedded Tuff member and is not light-colored as are the other known sand dunes in the area (e.g., the Lathrop Wells Cone sand dunes). Wind has no doubt played a minor role in the formation of the sand ramps,

with the wind reworking the sand and piling up small dunes <1 m in height (as seen on the western side of Busted Butte), but in the author's estimation probably less than 1% of the sand of the ramps had a wind-blown, eolian origin where wind has transported material for great distances. It is also possible that reworking by wind may have been partly responsible for creating higher-angled ramps on the eastern side of the butte than on the western side.

The sand ramps are interpreted to be apron deposits which have been dissected by valley erosion. Where crosscut by faults, the dissecting valleys make a jog along the fault (e.g., on the eastern side of Busted Butte). <u>The origin of the sand ramps and associated calcite/opal vein and travertine deposits is proposed as follows:</u>

1. Earthquake activity and faulting along the Paintbrush Fault caused mineralized water to rise along the fault.



2. The base of the Tiva Canyon member acted as an aquiclude for epithermal solutions ascending along the Paintbrush Fault. Springs issued forth along the base of the Tiva Canyon and flowed downhill. Progressive sideward erosion of Busted

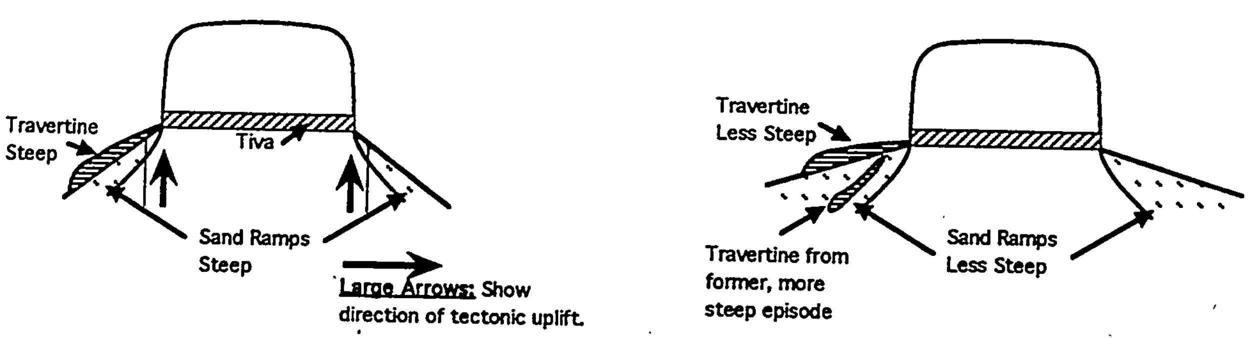
Butte caused past travertine flows to project "into the air" (i.e., when Busted Butte was at A, the #1 travertine flow issued forth from the base of the Tiva Canyon aquiclude).

3. Other springs occurred along faults after the Tiva Canyon had eroded past their extent; in these cases the feeder veins extended directly to the surface and travertine-precipitating flows occurred downslope from the veins (2).

4. All of the travertines (1,2) formed as spring deposits at the surface of the sand ramps. This is indicated by the presence of root casts in all of the travertine, whether in the older units which formerly deposited on a past surface of the sand ramps (1), or younger surficial units now at the surface of the sand ramps (2).

5. The differently angled travertine represents the slope of the sand ramps at the time the travertine formed. The different angles may relate to differential displacement along the Paintbrush Fault, minor eolian activity, or both. During times of tectonic displacement the sand ramps (and travertine formed on the surface of the ramps) would have become steeper sloped and during times of tectonic quiescence the sand ramps would have been less steep.

A. Tectonic Uplift **B. Tectonic Quiescence**



6. The calcite/opal filling the feeder veins in the sand ramps are not considered to be "of pedogenic, infilling origin along faults" as specified by Stuckless and Whitney (1990, p. 25). Why would the so-called "wind-blown" sand of the sand ramps not have infilled fault openings? Why would they have remained open to become filled with slowly-accumulating, pedogenic calcite and opal instead of with sand? The calcite/opal of the veins and downslope sheet deposits contain sand in places where they contact the sand (i.e., at the base of the sheets and sides of the veins), but they are relatively sand-poor where they have not come into direct contact with pre-existent sand.

7. The age of the sand ramps/travertine is not known with certainty, but Whitney et al. (1985) and Stuckless and Whitney (1990) reported that the ~740 Ka Bishop Ash appears near the base of the sand ramps at Busted Butte and so the overlying travertine layers must be younger than this.

SITE 199

Site 199 was the most puzzling stop of the field trip. Calcite spring mounds exist at the site along with rock of the very-brecciated, Cambrian Bonanza King and Carrera Formations. Swadley and Carr (1987), Swadley and Parrish 1988), and Frizzel et al. (1990) portrayed these Paleozoic units to be landslide deposits (T_{ls}) and they may be. However, it seems suspicious that only a few kilometers to the northeast are the thrust faults of the Bare Mountain. On the Bare Mountain Quadrangle the Bonanza King Formation is shown thrust to the south and the east, in the direction of the so-called Paleozoic "landslide deposits" overlying Tertiary rock (the Ammonia Tank member, ~11 Ma). Could local thrust faulting possibly have happened as late as the Miocene? Might thrust faulting have caused the shattering of the brecciated Bonanza King and Carrera Formations at Site 199? Could the presence of the calcareous and diatomaceous spring mound deposits in the immediate vicinity of these "landslide" deposits be related to late-stage (Quaternary) solutions moving up along these Tertiary thrust faults?

Another problem related to Site 199 is the nearby presence of Pliocene/Pleistocene lake deposits. Might the springs at Site 199 (and along the road between the gate and Site 199) have fed the lake with water? Might the high mark of this lake be correlative with higher water input along the fault plus higher runoff during the Wisconsin glacial?

Site 199 is most curious and may be a key that helps unlock some of the geologic history of the Yucca Mountain area.

ORE MINERALIZATION/ALTERATION

There is evidence of ore mineralization and alteration in the Yucca Mountain region: to the west in the Bare Mountain Mining District, to the east in the Wahmonie Mining District, to the northeast in the Calico Hills, and at Yucca Mountain.

1. Yucca Mountain. Not only is calcite/opal travertine localized along fault zones at Yucca Mountain, but also alteration of bedrock has been localized along these same fault zones. Alteration in the Yucca Mountain area seems to consist primarily of iron

which colored the tuffaceous rock honey yellow to orange to bright red. Such iron enrichment can be seen in the Bedded Tuff member at Busted Butte and in Harper Valley. In Harper Valley the altered areas contain elevated levels of iron (1.45%) and manganese (130 ppm) and also elevated levels of lead and zinc (Pb = 34 ppm; Zn = 20 ppm).

2. Calico Hills. The Calico Hills area has been especially subject to alteration by silicification, alunitization, and kaolitization. Cubic hematite (after pyrite) and reniform hematite was found in the Calico Hills; hematite and disseminated iron cause the entire Calico Hills to be colored various shades of red, orange, and tan (like calico). Along the fault zone (at the site visited) the Topopah Spring member of the Paintbrush Tuff is so silicified and hardened by silica that it resembles quartzite more than it does tuff.

3. Bare Mountain Mining District. Mineralization also occurs along Tertiary intrusive rhyolite dikes and faults in the Bare Mountains located about 15 km west of Yucca Mountain. The Diamond Queen Mine is located at a thrust-fault contact between the Precambrian Johnnie Formation and the Cambrian Nopa Formation. Mineralization seen at the Diamond Queen Mine and vicinity includes fluorite, calcite, opal, and kaolinite. In places the calcite occurs as large bladed sheaths or Iceland spar and the opal occurs as rounded nodules. In other places (at "Slide mine", just north of the Diamond Queen Mine) calcite/opal textures closely resemble those found at Yucca Mountain.

Breccia dikes were also found in the Bare Mountain Mining District. These are most likely explosion breccias as they are heterogeneous in breccia-fragment type (i.e., material has come from different stratigraphic units) and heterogeneous in shape (some of the fragments are rounded, some are angular). These breccias differ from the silicified breccias at Yucca Mountain which are much more homogeneous with respect to composition, size, and shape of the breccia fragments (i.e., the breccias are typically in place or have not been carried far from a host bedrock source).

4. Wahmonie Mining District. In the Wahmonie Mining District quartz is plentiful and calcite and fluorite are rare. A small amount of an opaque mineral was observed with the quartz; this may be either a sulfide mineral or cerargyite.

RECOMMENDATIONS

The following recommendations are made pertaining to the analysis of samples for the purpose of using such information in forthcoming publications:

1. $^{87}Sr/^{86}Sr$. Perform strontium analyses on all 18 of the collected Precambian, Paleozoic, and Tertiary rock samples. Perform strontium analyses on at least some of the calcite/opal deposits collected at key spots at Yucca Mountain and compare these values with bedrock values in order to determine the provenance of the strontium. Also compare these with calcite/opal deposits already analyzed for $^{87}Sr/^{86}Sr$.

2. U-Series dates. It is recommended that as much dating as possible be done on the samples collected. Dating of a number of samples would allow one to determine: (a) if some of the calcite is very young, (b) if there is a clustering of ages around discrete hydrothermal events, and (c) if the dates on calcite and opal couplets are equivalent. This would require a great deal of money but would provide important, even definitive, information.

3. Fluid inclusions. From the analyses done so far on the WT-7 and Wailing Wall opal, the fluid inclusion method does not appear promising in establishing a hypogene origin for the calcite/opal. However, only the opal has been tested and perhaps some of the calcite filling cavities in the opal can be analyzed for fluid inclusions. It is worth some effort to do this because not only must it be proved that the calcite/opal is young, it must also be proved that the deposits are hypogene (i.e.,

of deep-seated origin).

4. Trace element analyses. Trace element analyses may also be a way to show that the calcite/opal travertine is hypogene. High amounts of metals (Hg, Mo, etc.) in the travertine would tie it to the ore deposits of the surrounding region (e.g., the Bare Mountains). Trace element analyses are not that expensive: a 32 element package costs $5.50/sample.

5. Carbon-oxygen isotope analyses. Carbon-oxygen isotope analyses need to be done on the calcite of both the Wahmonie mound and the Bare Mountain Mining District where the calcite is known to be hydrothermal; these deposits can then be compared to the controversial vein deposits at Yucca Mountain. Also, carbon-oxygen isotope analyses should be performed on different types of travertine deposits (feeder vein, sheet, mound deposits, etc.) in order to compare the isotopic signatures of these different morphological types. In addition, known pedogenic crusts coating volcanic clasts in Lathrop Wells Cone should be isotopically compared with respect to the so-called "pedogenic" deposits at Trench 14, Busted Butte, etc.

REFERENCES

Burchfiel, B.C., 1966. *Reconnaissance geologic map of the Lathrop Wells 15-minute quadrangle, Nye County, Nevada.* U. S. Geological Survey Miscellaneous Geologic Investigations Map I-474, scale 1:62,500. Six pages of accompanying notes.

Dixon, J. B., and S. B. Weed, 1989. *Minerals in soil environments.* Soil Science of America. Madison, Wisconsin, 1244 pp.

Frizzel, V. A., and J. Shulters, 1990. *Geologic map of the Nevada Test Site.* U. S. Geological Survey Miscellaneous Investigation Series, Map I-2046, scale 1:100,000.

Hill, C. A., 1992. *Report of field trip of 2-27 and 2-28, 1992.* Unpublished report to Technology and Research Assessment Corporation, 10 pp.

Hill, C. A., and P. Forti, 1986. *Cave minerals of the world.* National Speleological Society. Huntsville, Alabama, 238 pp.

Levy, S., and C. Naeser, 1991. *Bedrock breccias along fault zone near Yucca Mountain, Nevada.* Draft Los Alamos-USGS paper.

Machette, M. N., 1985. *Calcic soils of the southwestern United States.* In Weide, D. L., Soils and Quaternary geology of the southwestern United States, pp. 1-21.

Quade, J., and T. E. Cerling, 1990. *Stable isotopic evidence for a pedogenic origin of carbonates in Trench 14 near Yucca Mountain, Nevada.* Science. v. 250, pp. 1549-1552.

Quade, J., and J. V. Tingley, 1983. *A mineral inventory of the Nevada Test Site and portions of the Nellis Bombing and Gunnery Range, southern Nye County, Nevada.* Department of Energy Report, DOE/NV/10295-1.

Somerville, M. R., J. S. Szymanski, G. A. Frazier, C. B. Archambeau, C. M. Schluter, and D. E. Livingston, 1992. *Critical review of the National Research Council report: groundwater and Yucca Mountain: how high can it rise?* Quarterly Report prepared by TRAC for the Nuclear Waste Project Office, State of Nevada.

Stuckless, J. S., Z. E. Peterman, and D. R. Muhs, 1991. *U and Sr isotopes in ground water and calcite, Yucca Mountain, Nevada: evidence against upwelling water.* Science. v. 254, pp. 551-554.

Stuckless, J. S., Z. E. Peterman, R. L. Forester, J. F. Whelan, D. T. Vaniman, B. D. Marshall, and E. M. Taylor, 1992. *Characterization of fault-filling deposits in the vicinity of Yucca Mountain, Nevada.* Proceedings of Waste Management '92. Tucson, Arizona, March 1-5. Rough draft.

Stuckless, J. S., and J. Whitney, 1990. *Field trip to Yucca Mountain and surrounding region for the National Academy of Sciences Panel on coupled processes.* October 18-20, pp. 25-26.

Swadley, W. C., and W. J. Carr, 1987. *Geologic map of the Quaternary and Tertiary deposits of the Big Dune Quadrangle, Nye County, Nevada, and Inyo County, California.* U.S. Geological Survey Miscellaneous Investigations Map I-1762, scale I:48,000.

Swadley, W. C., and L. D. Parrish, 1988. *Surficial geologic map of the Bare Mountain Quadrangle, Nye County, Nevada.* U.S. Geological Survey Miscellaneous Investigations Map I-1826, scale 1:48,000.

Szabo, B. J., and T. K. Kyser, 1985. *Uranium, thorium isotopic analyses and uranium-series ages of calcite and opal, and stable isotopic compositions of calcite from drill cores UE25a#1, USW G-2, and USWG-3/GU-3, Yucca Mountain, Nevada.* U. S. Geological Survey, Open File Report 85-224, 25 pp.

Vaniman, D. T., D. L. Bish, and S. Chipera, 1988. *A preliminary comparison of mineral deposits in faults near Yucca Mountain, Nevada, with possible analogs.* Los Alamos National Laborary, Report LA-11289-MS, 54 pp.

Weide, D. L., 1985. *Soils and Quaternary geology of the southwestern United States.* Geological Society of America, Special Paper 203, 150 pp.

Whitney, J. W., W. C. Swadley, and R. R. Shroba, 1985. *Middle Quaternary sand ramps in the southern Great Basin, California and Nevada.* Geological Society of America. Abstracts with Programs, v. 17,. p. 750.

Winograd, I. J., and W. Thordarson, 1975. *Hydrogeologic and hydrochemical framework, South-Central Great Basin, Nevada-California, with special reference to the Nevada Test Site.* USGS Professional Paper 712-C. Washington, D. C. pp. C1-C126.

APPENDIX 1

Detailed List of Samples Collected

Note: Appendix 1 is a detailed list of the samples collected at each stop. (Provided by C. M. Schlüter) An "X" in the column identifies the samples selected for analyses. All Trace Element and REE analyses have been completed.

		STATUS:	To Do	To Do	To Do	Done	To Do	Done
	SAMPLE	TYPE	87Sr/86Sr	U-series	Fluid Inclusions	Trace element	Carbon-oxygen	REE
STOP #1	US 95 mile 10							
1a	dolomite	Nopah Fromation	X					
1b	silica	breccia zone						
1c	calcite							
1d	dolomite	organic lithofacies						
1e	silica	vein						
1f	calcite	vein						
1g	calcite							
STOP #2	US 95 mile 12.47							
2a	quartzite (clean)	Stirling Quartzite	X					
2b	quartzite (dirty)	Stirling Quartzite	X					
2c	epidote	vein						
2d	calcite	vein						
STOP #3	US 95 mile 18.8							
3a	dolomite/lmst		X					
STOP #4	Pull Apart Fault							
4a	limestone	fault related alteration	X			X	X	
4b	calcite	coating						
4c	calcite-opal-breccia					X		
4d	calcite-opal	bulk samples	X				X	
4e	opal breccia							
4f	calcite	riverbed						
4g	carb.-coated rock							
STOP #5	WT - 7							
5a	calcrete-coated rock							
5b	calcite-opal	surficial deposit						
5c	opaline layer	on breccia	X				X	
5d	calcite-silica					X		X
5e	calcite	fracture fill						
5f	breccia							
5g	breccia							
5h	calcium crystals	Carol's sample			X			
STOP #6	USW H - 6							
6a	carbonate crust	surficial coating						
STOP #7	roadside (WT-7)							
7a	calcite	caliche?/calcrete						
7b	silica-calcite							
7c	opal							
7d	indurated layer	coating on surface roc[k]						
STOP #8	Plug Hill							
8a	carbonate	coating on colluvium						

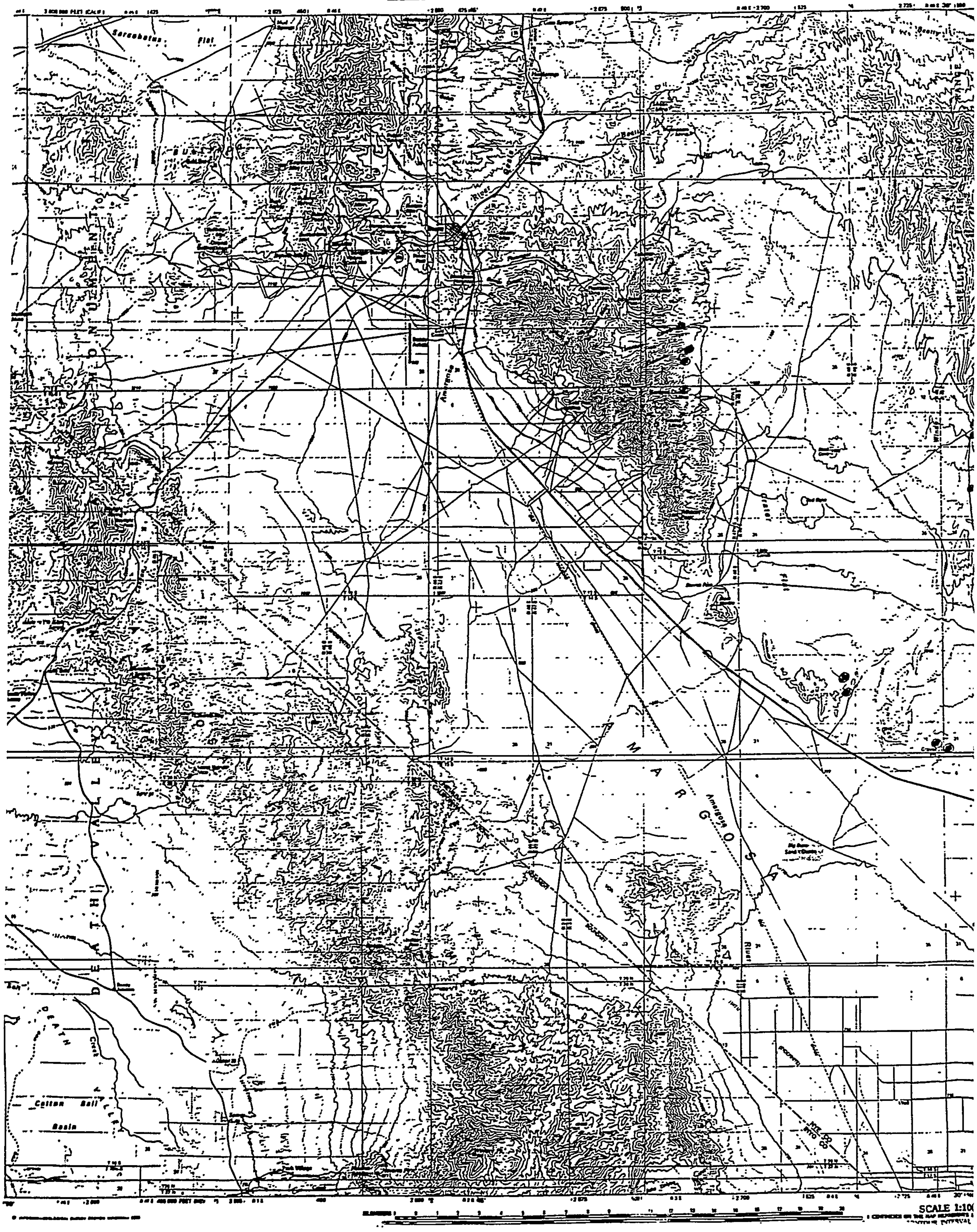
STOP #	SAMPLE	TYPE	87Sr/86Sr	U-series	Fluid Inclusions	Trace element	Carbon-oxygen	REE
STOP #9	roadside (WT-7)							
9a	calcite	coating						
STOP #10	Bare Mountain							
10a	calcite-opal	loose material	X			X	X	
10b	lmst/opal	brecciated, cemented						
10c	calcite-lmst					X		
10d	limestone	Ely Springs	X					
10e	opal	siliceous						
10f	carbonate	in stream bed						
STOP #11	Diamond Queen M.							
11a	white mineral	filling, metamorphose						
11b	calcite	float sample						
11c	phyllite	Johnnie Formation	X					
11d	carbonate	incrustations						
11e	Nopah formation		X					
11f	Iceland spar	massive					X	
11g	calcite	vein						
11h	quartz							
11j	fluorite							
11k	fluorite							
11m a	calcite	coating						
11m b								
11n	calcite	crust						
11o	kaolinite clay	from breccia pipe						
11p	chert nodule	in fluorite breccia						
11q	porphyry	volcanic breccia						
11r	fluorite breccia							
11s	chert nodule							
STOP #12	Chuckwalla Canyon							
12a	Iceland spar	massive					X	
12b	opal-calcite	inter-layers						
12c	carbonate	white & black mineral						
12d	dolomite	Lone Mt.	X					
12e	calcite							
12f	calcite	fracture filling						
12g	calcite	columnar crystals						
STOP #13	Tarantula Canyon							
13a	limestone	Meiklejohn	X					
13b	rhyolite							
STOP #14	Trench 8							
14a	calcite	root casts						
14b	ash							
14c	calcite-opal-silica							
14d	clacite-opal	fault infilling						
14e	black glassy materia	in altered vitrophyre						

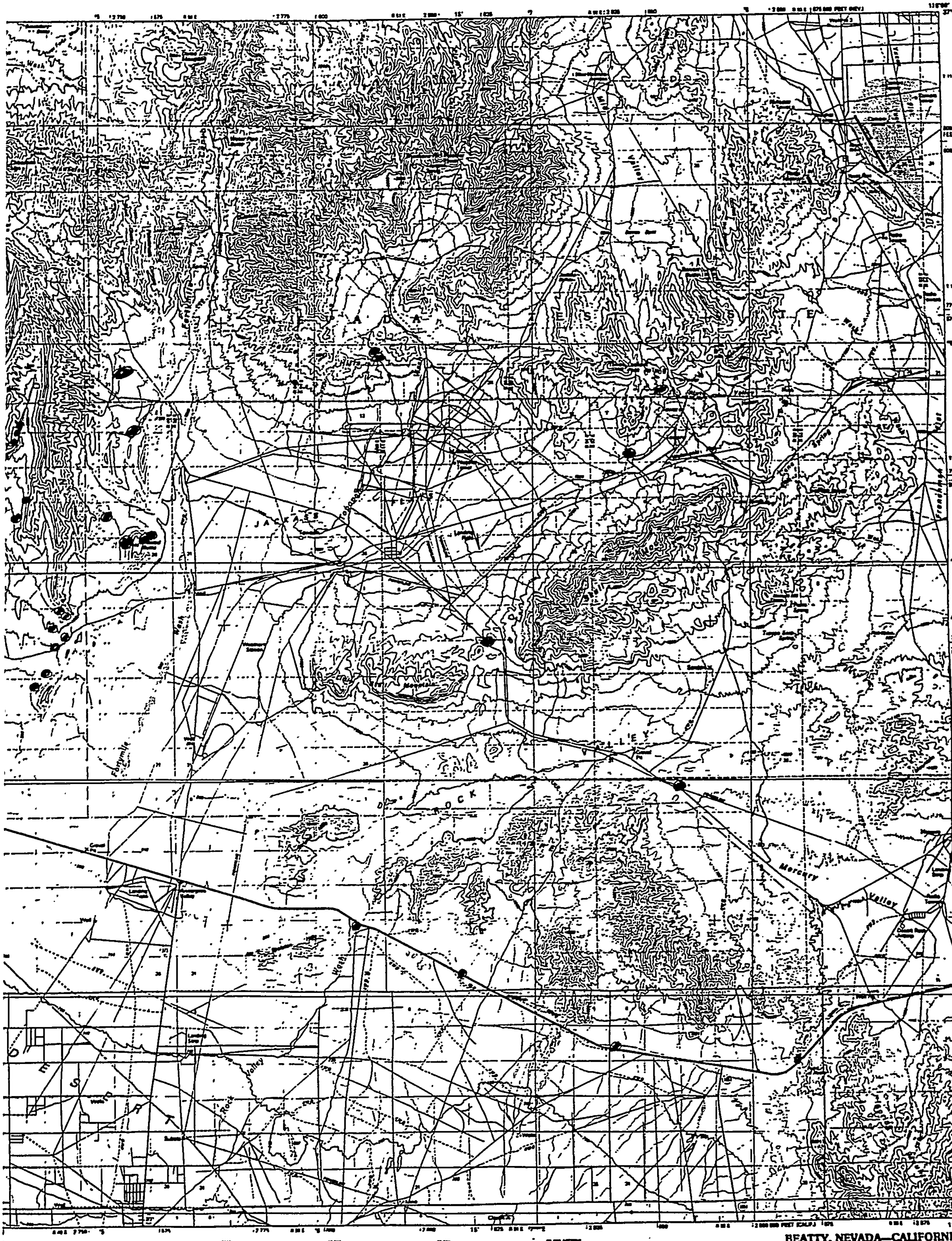
STOP #	SAMPLE	TYPE	87Sr/86Sr	U-series	Fluid Inclusions	Trace element	Carbon-oxygen	REE
STOP #14	Trench 8 (cont.)							
14f	carb., some silica	cement						
14g	silica-calcite	vein	X			X	X	
STOP #15	roadsie (trench 8)							
15a	carbonate	matrix						
STOP #16	New Trench							
16a	carbonate	vein						
16b	ash							
16c	carbonate	matrix	X			X	X	
STOP #17	Site 106							
17a	tufa	spring						
17b	carbonate	spring						
STOP #18	Livingston Scarp							
18a	carbonate	fracture fillings						
18b	opal-carbonate	vein	X			X	X	
STOP #19	Wailing Wall							
19a	opal-calcite	coating	X			X	X	
19b	carbonate	vein						
19c	carbonate	coating						
19d	algal?							
19e	opal-calcite	Carol's sample			X			
STOP #20	roadside ("scarp")							
20a	glass	volcanic	X			X		X
STOP #21	Red Cliff Gulch							
21a	carbonate	surface coatings				X		
STOP #22	Stagecoach Trench							
22a	carbonate	root casts				X		
22b	tuff	calcite overlies				X		
22c	quartz?	calcite overlies						
22d		full of clasts						
22e	carbonate	surficial						
STOP #23	Stagecoach Trench							
23a	carbonate	root casts						
23b	glass	vitrophyre						
STOP #24	Site 199							
24a	silicified material	some clasts						
24b	breccia (Carrera)	conglomerate	X				X	
24c	breccia	Bonanza King	X					
24d	tufa	some brecciated carb.	X			X	X	

STOP #	SAMPLE	TYPE	87Sr/86Sr	U-series	Fluid Inclusions	Trace element	Carbon-oxygen	REE
STOP #25	roadside (site 199)							
25a	carbonate	root casts (burrows?)						
25b	seds.	marsh/lake						
STOP #26	roadside (FOC)							
26a	lmst, dolomite	Bonanza King	X					
STOP #27	roadside (FOC)							
27a	calcite	secondary						
27b	carbonate? in basalt	cement filling						
27c	travertine	surficial cap				X		
STOP #28	East Busted Butte							
28a	silica	vein						
28b	sand							
28c	carbonate?	root casts						
28d	carbonate?	vert. vein	X	X ?		X	X	
28e	opaline-coral	slope deposit		X ?				
28f	travertine	upslope						
STOP #29	East Busted Butte							
29a	calcrete							
29b	rat midden							
29c	sheet deposit							
29d	vitrophyre		X					
29e	travertine, breccia	sheet deposit						
29f	carbonate?	root casts						
STOP #30	West Busted Butte							
30a	carbonate?	vert. vein		X ?				
30b	carbonate?	root casts						
30c	opal-calcite		X			X	X	
30d	carbonate?	vein						
30e	carbonate?	vein						
30f	calcite	vein						
30g	carbonate?	punchbowl						
30h	carbonate?	root casts						
STOP #31	roadside (Mercury)							
31a	calcite	coating						
STOP #32	Wahmonie Mounds							
32a	gypsum with calcite							
32b	carbonate							
32c	calcite-gypsum							
32d	calcite		X ?			X		
32e	gypsum	crust on carbonate						

STOP #	SAMPLE	TYPE	87Sr/86Sr	U-series	Fluid Inclusions	Trace element	Carbon-oxygen	REE
STOP #33	Mines (Wahmonie)							
33a	carbonate?	vein						
33b	fluorite? in quartz					X		
33c	calcite crystal in qua							
STOP #34	Calico Hills							
34a	shale	Eleana	X					
34b	limestone	Eleana	X					
34c	pyrite	cubes						
34d	pumice and silicified	Calico Hills						
34e	kaolinitized clay							
34f	ironized tuff	Calico Hills				X		
34g	calcite	slslickenside	X			X	X	
34h	yellow hot rock							
STOP #35	Shoshone Mt. road							
35a	kaolinite							
35b	Topopah	red sample						
35c		cavity fillings						
STOP #36	Trench 14							
36a	carbonate							
36b	opaline							
36c	carbonate	finely laminated						
36d	carbonate	vein		X ?				
36e	silica	vein	X			X	X	
36f	carbonate	vein						
36g	carbonate	vein		X ?				
36h	silica	vein	X			X	X	X
36i	carbonate	vein						
36j	opal	vein						
36k	opal-breccia-carbona	finely laminated		X ?			X	
36m	calcite	vein	X			X	X	X
36n	carbonate	vein		X				
36o	carbonate	vein						
36p1	calcite-opal	vein						
36p2	calcite-opal	vein		X ?				
36r	carbonate	vein						
36s	opal	vein						
36t	carbonate	vein						
36v	carbonate	vein						
36w	opal	vein						
36x		Calico Hills?						
36y	breccia-calcite							
36z	breccia		X			X		
STOP #37-1	UE 25 p#1							
37-1a	opal	opaline	X			X	X	
37-1b	opal	Carol's sample						

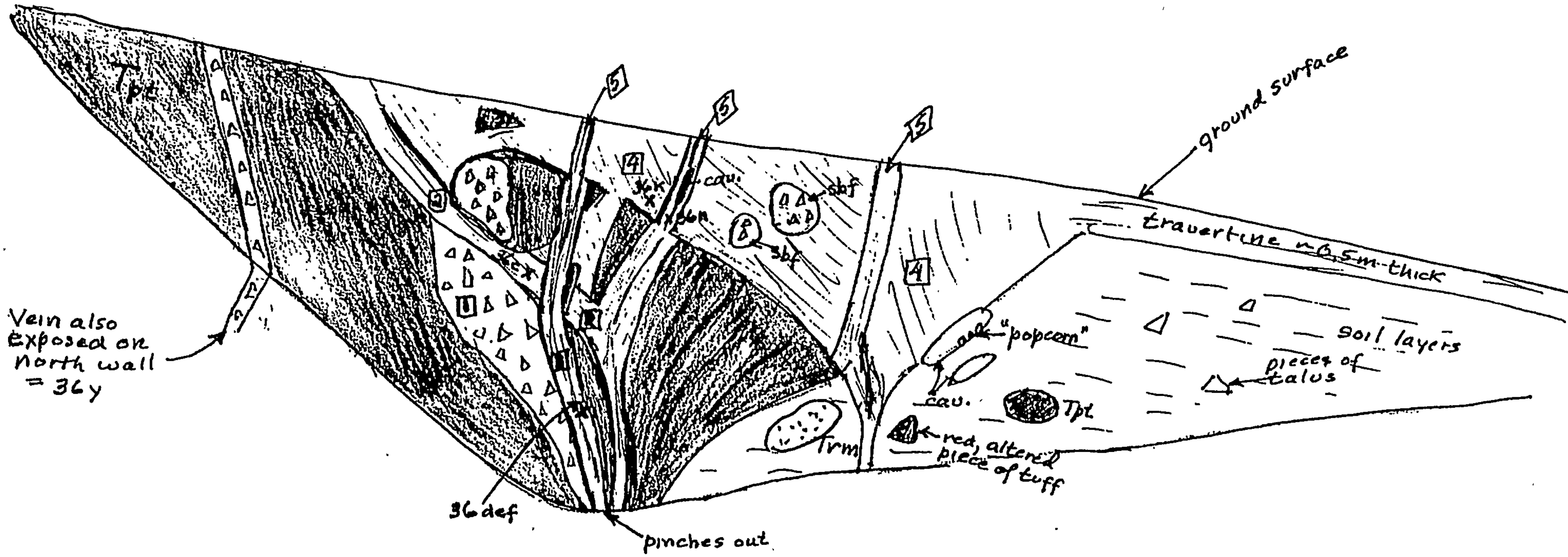
STOP #	SAMPLE	TYPE	87Sr/86Sr	U-series	Fluid Inclusions	Trace element	Carbon-oxygen	REE
STOP #37-2	Mercury							
37-2a	dolomite	fault zone	X					
37-2b	carbonate	vein						
37-2c	brecciated dolomite	red altered zone						
STOP #	SAMPLE	TYPE	87Sr/86Sr	U-series	Fluid Inclusions	Trace element	Carbon-oxygen	REE
STOP #38	West Busted Butte							
38a	sand	windblown						
38b	travertines							
38c	opal-calcite							
38d	pumice tuff	bedded tuff						
38e	tuff	red altered				X		X
38f	travertine		X			X	X	
38g	carbonate	caps tuff						
STOP #39	Harper Valley							
39a	carbonate	in streambed	X	X		X	X	
39b	silica	botryoidal (opalite)						
39c	Tiva	partially welded						
39d	flowstone	laminated						
39e	carbonate	vein filling						
39f	opal	botryoidal						
39g	calcite	vein						
39h	some opal	pinnacles						
39i	carb?-silica	"Z" veins						
39k	tuff	red altered						
39m	carbonate	vein						
39n	opal	Carol's sample						
STOP #40	Trench 14							
40a1	mostly carbonate	vein						
40a2	carbonate?	vein						
40a3	carbonate?	vein						
40b	calcite	vein	X			X	X	
40c	calcite	subsurface						
STOP #41	Lathrop Cone							
41a	sulfur or jarosite							
41b	carbonate	coatings	X				X	
41c	sulfur?							
STOP #42	Lathrop Cone							
42a	sand							


Sarcobatus Flat
River
Amargosa
A M A R G O S A
River
Cotton Ball
Basin
SCALE 1:10(



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

<u>Figure 2.</u> Actual photograph of the south wall of Trench 14 taken from an unclassified, United States Department of Energy negative — No. YM-284.



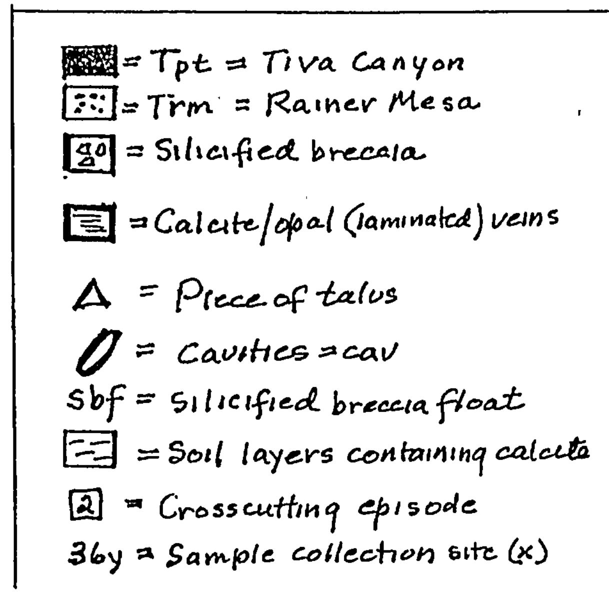


Figure 3. Field sketch of the south wall of Trench 14 showing a cross-section of at least five episodes of crosscutting mineralization. Red indicates the calcite/opal deposits, blue--the silicified breccia, and green--cavities within the mass. The boxed numbers 1, 2, 3, 4, and 5, represent the five episodes of crosscutting. The length of the trench in the diagram is approximately 40 m and the depth of the trench is approximately 7.5 m.

Field Trip Report: Observations Made at and Around Yucca Mountain, Nye County, Nevada

---

TABLE OF CONTENTS

INTRODUCTION	1
FIELD OBSERVATIONS	1
Calcite/Opal Travertine	1
Silica Types	8
Silica Fingers	11
Wahmonie Travertine/Gypsite Mound	12
Trench 14	14
Sand Ramps	18
Site 199	22
Ore Mineralization/Alteration	23
RECOMMENDATIONS	26
REFERENCES	28
APPENDIX 1 -- Detailed List of Samples Collected	30
FIGURES (1, 2, and 3)	37

INTRODUCTION

A field trip was made to the Yucca Mountain area on December 5-9, 1992 by Jerry Frazier, Don Livingston, Christine Schluter, Russell Harmon, and Carol Hill. Forty-three separate stops were made and 275 lbs. of rocks were collected during the five days of the field trip. Key localities visited were the Bare Mountains, Yucca Mountain, Calico Hills, Busted Butte, Harper Valley, Red Cliff Gulch, Wahmonie Hills, Crater Flat, and Lathrop Wells Cone. This report only describes field observations made by Carol Hill. Drawings are used rather than photographs because cameras were not permitted on the Nevada Test Site during this trip. Figure 1 shows the location of all the sites (stops) mentioned in the text.

FIELD OBSERVATIONS

During the field trip various observations were made. Taken collectively, these preliminary observations may be used to infer origin of various calcite-silica deposits, known from Yucca Mountain. A summary of observations made by C. A. Hill is presented below.

CALCITE/OPAL TRAVERTINE

Deposits of calcite/opal were collected from nearly all of the localities visited (i.e., from about 40 separate sites). These will herein be referred to as "travertine" rather than as "calcrete" since the deposits are believed to have a spring origin rather than a pedogenic (soil-related) origin (i.e., they are calcareous or siliceous sinters or tufas). Although "calcrete" is a non-genetic term which can include spring or