Department of Energy
Washington, DC 20585

JUN 05 1991

Mr. John J. Linehan
Director
Division of High-Level
Waste Management
Office of Nuclear Material
Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Mr. Linehan:

The U.S. Department of Energy (DOE) has previously agreed with the U.S. Nuclear Regulatory Commission (NRC) (December 15, 1988, Study Plan Agreement) to submit "not readily available" references cited in study plans at the time of transmittal to NRC. This letter addresses two subjects relevant to the agreement: (1) DOE's definition of "not readily available" references and (2) fulfillment of DOE's response to NRC Comment 4 (DOE letter dated December 19, 1990; Desell to Linehan) on Study Plan 8.3.1.5.2.1, Revision 0, "Characterization of the Quaternary Regional Hydrology."

"Not readily available" references should be defined as those references that are not available through the open literature, published symposia proceedings, or the standard channels for distribution of government reports through the National Technical Information Service located in Springfield, Virginia. Enclosure 1 identifies more specifically examples of references that fall within the category of "not readily available"; DOE will supply NRC such references with each approved study plan.

Enclosure 2 contains a summary of the "unpublished data" requested in NRC Comment 4 on the subject study plan. Enclosures 3-13 provide the other documentation requested. Items referenced in the Study Plan as "written communications," or "oral/personal communications," and "in press/in review" are also provided. This information is being furnished because DOE had not previously identified to NRC what constituted a "not readily available" reference.

In the future, however, DOE does not plan to provide copies of "oral communications." In addition, DOE will not routinely provide documents that are in press (unless the published version will not be available). If the NRC believes it needs specific references to conduct its review, copies of the references at issue will be provided upon written request to the Office of

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Systems and Compliance. Citation of oral or personal communication is an accepted method in the scientific community and literature for giving credit to hypotheses or interpretations that were not developed by the author, but for which no written reference exists. DOE will, therefore, allow citation of oral or personal communications with no written documentation in study plans. Written communications, by definition, are documented and would be supplied. Documents, manuscripts, or reports that are "draft," "in press," or "in preparation" will be supplied if the eventual medium of publication falls into one of those items identified in Enclosure 1.

Should you have any questions, please contact Linda Desell of my office at (202) 586-1462.

Sincerely,

Dwight E. Shelor
Acting Associate Director for
Systems and Compliance
Office of Civilian Radioactive
Waste Management

13 Enclosures:

1. Definition of "Not Readily Available" References
2. Summary of "Unpublished Data" in Study Plan 8.3.1.5.2.1
3. J. P. Bradbury, 1985, "Oral Communication"
4. R. M. Forester and L. D. Delorme, "Unpublished Data"
5. D. Cowan, 1987, "Personal Communication"
6. R. M. Forester, 1985, "Written Communication"
7. Kolm and others, "In Review"
8. J. R. O'Neil, 1985, "Written Communication"
9. Sarna-Wojcicki, 1984, "Oral Communication"
10. E. M. Taylor, 1985, "Unpublished Data"
11. D. Vaniman and others, 1984, "Written Communication"
12. D. Vaniman and others, "In Press"
13. I. J. Winograd, "Personal Communication"

cc w/Enclosures 1 & 2 only:
C. Gertz, YMPO
R. Loux, State of Nevada
M. Baughman, Lincoln County, NV
D. Bechtel, Clark County, NV
S. Bradhurst, Nye County, NV
P. Niedzielski-Eichner, Nye County, NV

EXAMPLES OF "NOT READILY AVAILABLE" REFERENCES

1. Contractor and participant reports that will not be captured in the national data base for government-sponsored information (National Technical Information Service).

   Such items as USGS Open-File Reports, SAND Reports are not included

2. Foreign national journals and books that would not be expected to be found in a good research library (i.e., Library of Congress).

3. State publications

4. Symposium, meeting, and workshop abstracts and papers that are not published

5. Commercial and trade contract reports (e.g., EPRI)

6. Academic M.S. theses
   (Dissertations are not included because dissertations can be obtained from University Microfilms Inc., of Ann Arbor, MI).

7. Participant management plans, QA plans, etc.

8. Computer code manuals

9. Draft, unpublished, or "letter" reports and documents

10. Personal communications (written only)
    (Oral or personal communications are not included)

11. Manuscripts of "in press," "in review," or "in preparation" works are included only if the publications outlet is defined in this list

12. Monograph reports and handbooks from Federal agencies
    (e.g., local USDA soil reports)

ENCLOSURE 1

"UNPUBLISHED" REFERENCES

These citations represent "unpublished data" requested from the Principal Investigator for 8.3.1.5.2.1 (Characterization of Quaternary Regional Hydrology). Page numbers refer to pages in Revision 0 where citation occurred.

1) J. P. Bradbury, 1985, "oral communication", p. 3.5-10
2) R. M. Forester and L. D. Delorme, "unpublished data", p. 3.3-19

ORAL COMMUNICATION (BRADBURY) IS REPRESENTED BY A NOTE FROM RICK FORESTER APPENDED TO A FOSSIL REPORT. SOME OF FORESTER'S COMMENTS WERE BASED ON CONVERSATIONS WITH J.P. BRADBURY (WHO'S INITIALS APPEAR IN THE SAMPLE IDENTIFIERS IN THE FORMAL REPORT, (NOT ATTACHED))

3) D. Cowan, 1987, "personal communication", p.3.5-25

DOCUMENTATION PROVIDED

4) R. M. Forester, 1985, "written communication", p. 3.5-10

DOCUMENTATION PROVIDED

5) Kolm and others, "in review", p. 3.3-27

AUTHORSHIP CHANGED TO WEEKS, GUTENTAG, AND KOLM, DRAFT ATTACHED

6) J. R. O'Neil, 1985, "written communication", p. 3.5-10

DOCUMENTATION PROVIDED

7) Sarana-Wojcicki, 1984, "oral communication", p. 7.1.3

SEE 2/4/91 MEMO; TAYLOR TO STUCKLESS

8) E. M. Taylor, 1985, "unpublished data", p. 3.5-10

SEE 2 PAGES OF DATA FROM DRAFT COPY OF USGS BULLETIN

9) D. Vaniman and others, 1984, "written communication", p. 3.5.10

SEE NOVEMBER 1984 PROGRESS REPORT

10) D. Vaniman and others, "in press", p. 3.5-20

SEE DRAFT COPY OF TWS-ESS-1-11/86-4

11) I. J. Winograd, "personal communication", p. 3.3-24

SEE TWO PAGES FROM DRAFT COPY OF USGS BULLETIN BY SZABO AND WINOGRAD

ENCLOSURE 2

Nov. 11, 1987

TO: John Stuckless

FROM: Rick Forester

SUBJECT: Ostracode environmental data base

I spent the past month at the Canadian Centre of Inland Waters working with L. Denis Delorme. We used his extensive combined hydrochemical and ostracode data set to examine basic ostracode distributions as a function of major dissolved ion composition and concentration. We discovered what may be a relationship that couples ostracodes to the climate mediated aspect of lake hydrochemistry. A similar relationship may exist for ostracodes from springs, but in that case the hydrochemistry would more likely be controlled by rock water reactions and thus length of the flow path.

These results may be important to the test site studies, because most of the ostracodes Denis and I used in our study are common in the U.S. and if in fact this relationship is general it should apply to all taxa. In the latter instance we would only need to collect modern springs from a wide geographic area in order to define particular species hydrochemical habitat.

ENCLOSURE 3+4

Read and understood. 8 Jan 87
Robert Raymond, Jr

1/12/87 Phone conversation w. Julie Canepa (NP). Study plan input covers all work, incl ESTP. She needs input ~ end of February. Will talk again

[initials]

1/13/87 Called by Julie Orcutt, ASE-1. Main tunnel of U12t.02 is accessible, radiation level low. Area of interest is between gas seal door & gas seal plug(?). Transport by train available or could walk in. Should be no problem sampling & shouldn't interfere with other work in progress

[initials]

1/14/87 Meeting in Albuquerque with Dave Cowan, U. Missouri

Reference for inter lab comparison on ESR dating of carbonates

Dr. G. J. Hennig
Nieder sächsisches Landesamt für Bodenforschung
Alfred-Benz-Haus
Stilleweg 2, D-3000 Hannover 51
F R Germany,

Geyh & Grühn, "The first inter-laboratory ESR comparison project Phase II: Evaluation of equivalent doses (ED) of calcites"
Nuclear Tracks, v.10 no 4-6 p945-952 (1985) (Pergamon)

Sample TR14-7-9: heat-annealed sample has been subjected to γ radiation equivalent to 50,000 years (5000 Rad at assumed dose of 0.1 rad/yr). This dose did not produce any signal (from defects - peroxy centers) ∴ therefore the observed pre-annealing signals cannot be result of 50,000 yrs of γ radiation. Next step will be 50,000 rad.

Signal from peroxy centers is not completely annealed out at 500°C

Signal reproduction on annealed sample will be attempted by fast neutron bombardment. It will be better to allow time for sample to become nonradioactive after each bombardment, to avoid accountability paperwork for radioactive material.

Discussion on desirability of ESR dating material previously dated by

[redacted]

ENCLOSURE 5

1/14/87 another technique. Possibility would be quartz from New Mexico volcanics which have K/Ar dates

3/5/87 Rewrite of study plan - Calcite-Silica studies SAIC

1) write para. on silica (incl. silica-cemented breccia) for intro. feed something into purpose & scope. A: calcite-silica B: silica

2) p. 9 - work out applications of fluid inclusions to calc/silica & silica & reword as needed.

Get rewrite to Stuckless by early next wk.

3) Peer Review Committee

5 members from diff. specialties
Try for wk. of May 4 for peer review

Read and understood. March 27, 1987.

REPORT ON REFERRED FOSSILS

STRATIGRAPHIC RANGE	not determined	SHIPMENT NUMBER	WR-85-1D
GENERAL LOCALITY	Nevada	REGION	
QUADRANGLE OR AREA	Test Site	DATE RECEIVED	09 85
KINDS OF FOSSILS	Charophytes	STATUS OF WORK	Complete
REFERRED BY	Joe Downey	DATE REPORTED	10 85
REPORT PREPARED BY	Richard M. Forester		

This report deals with three (3) samples from a Quaternary Spring deposit that were examined for ostracodes and charophytes. The samples contained the following organisms and chemical sediments.

Sample TR14 NW 0.25 m below surface - JPB smpl. A
- Barren ostracodes
- *Chara* sp with organic lining in gyrogonite

Also
- massive laminated carbonate
- porous white carbonate
- root and or plant stem carbonate tubes
- root and or stem cuticle preserved as carbonate casts
- silica clastics coated with carbonate
- rare volcanic glass

Sample TR14 SW 0.25 m below surface - JPB smpl. B
- Barren ostracodes
- *Chara* sp with organic lining in gyrogonite

Also
- massive laminated carbonate
- porous carbonate
- root and or plant stem carbonate tubes
- silica clastic aggregates cemented by carbonates
- silica clastics coated by carbonate
- volcanic glass

Sample P1 2.4 m below surface - JPB smpl. C
- Barren calcareous microfossils (BCM)

Also
- silica clastics coated by carbonate
- massive laminated carbonate
- porous carbonate
- root and or plant stem carbonate tubes
- root and or plant cuticle carbonate casts
- rare white and amber colored volcanic glass

ENCLOSURE 6

The general absence of ostracodes could, of course, be either a preservational or environmental problem, however, the presence of charophytes and the carbonate suggests the absence of ostracodes is environmental. The most probable environmental problem in this setting is that the length of time when water is present, either at the surface or subsurface, is too short for an ostracode to complete its life cycle. The presence of charophytes, which depending on species may be very short lived, and plant-root casts may suggest these samples are from the edge of an otherwise more permanent aquatic system. If you have samples from sediments that may have accumulated in a pool including pools within carbonate, that might be the best place to look for ostracodes.

Charophytes are not known ecologically as well as ostracodes. Their presence, in a general ecologic sense, implies fresh or saline water having a pH generally above 7.5, moderate to high water clarity, typically low eutrophic to oligotrophic trophic status and an ephemeral or permanent water body receiving at least perched groundwater discharge. Charophytes live in the littoral areas of lakes as well as in the array of groundwater discharge environments including streams or other environments having a flow component. As complex algae, charophytes must live within the photic zone, but some species are adapted to low light levels. Studies in progress suggest that charophytes, if studied in the same manner as ostracodes, could provide similar sorts of environmental data.

Rick

Richard M. Forester

DRAFT

EVALUATING VERTICAL VARIABILITY OF AQUIFER PARAMETERS

By

JOHN B. WEEKS

U.S. Geological Survey, Denver, Colorado

EDWIN D. GUTENTAG

U.S. Geological Survey, Denver, Colorado

KENNETH E. KOLM

Colorado School of Mines, Golden, Colorado

ENCLOSURE 7

EVALUATING VERTICAL VARIABILITY OF AQUIFER PARAMETERS

By John B. Weeks[1], Edwin D. Gutentag[1], and Kenneth E. Kolm[2]

ABSTRACT

Vertical variability in fluvially derived aquifer systems is caused by layering of clay, silt, sand, and gravel deposited by aggrading streams. The method of moments was used to evaluate this vertical variability using estimates of hydraulic conductivity, specific yield, bed thickness, and saturated thickness obtained from drillers' lithologic logs. The method can be used to aid in the interpretation of the vertical and areal distribution of aquifer properties. The method was applied to more than 3,000 drillers' logs from the High Plains aquifer to help decide whether the aquifer could be modeled as a two-dimensional flow system.

[1]U.S. Geological Survey, Denver, Colorado, U.S.A.

[2]Colorado School of Mines, Golden, Colorado, U.S.A.

INTRODUCTION

Fluvially derived aquifer systems, composed of interbedded clay, silt, sand, and gravel (consolidated or unconsolidated), may have considerable vertical and areal variability in saturated thickness, hydraulic conductivity, specific yield, and bed thickness. Commonly, hydraulic data from aquifer tests are not readily available, whereas lithologic and grain-size information from drillers' logs is generally abundant. Therefore, a method was devised to evaluate the variability of aquifer properties that uses estimates of saturated thickness, hydraulic conductivity, specific yield, and bed thickness, for individual lithologic units based on drillers' lithologic logs.

The purpose of this paper is to demonstrate the use of the method of moments for evaluating the variability of estimated aquifer properties. Specifically, this method was applied to the hydraulic-conductivity and specific-yield values estimated from drillers' logs from the High Plains aquifer in the west-central United States to determine the vertical and areal variability of these values.

PREVIOUS STUDIES

Originally, the method of moments was applied to sand thicknesses estimated from lithologic logs. Krumbein and Libby (1957) applied a method of moments to prepare maps showing values of the center of gravity and standard deviation of the thicknesses of specific lithologic rock units. Meyboom (1960) applied the method of moments to determine the vertical variability of sandstone-bed thickness within a given stratigraphic section. Domenico and Stephenson (1964) applied quantitative geologic-mapping techniques that used the method of moments to determine thickness data for use in a hydrologic computer model of the Las Vegas Valley, Nevada. Winter (1975) applied the method of moments to the thickness of sand and gravel units in glacial-drift deposits in northwestern Minnesota.

In this study, the method of moments was used to evaluate the vertical variability of aquifer parameters. The method described in this paper has been applied by Ashworth (1980) to the High Plains aquifer in Texas, by Bryn (1984) to the High Plains aquifer in northeastern Colorado, by Kolm and Case (1983) to the High Plains aquifer in South Dakota, and by Gutentag and others (1984) to the entire High Plains aquifer.

METHOD OF MOMENTS

Before a computer model of ground-water flow can be constucted, the vertical and areal distribution of lithologic types and associated hydraulic properties within the aquifer need to be determined. If all lithologies are equally likely to be present at any position in the vertical section, the aquifer can be modeled in two dimensions using vertically averaged hydraulic-conductivity and specific-yield values. If one lithology is more likely to be present at a particular position in the vertical section than any other lithologic type, it may be necessary to model the aquifer by developing relations between vertical position and each aquifer property using a three-dimensional model.

The method of moments can be used to evaluate the vertical variability of aquifer properties by calculating the first moment or center of gravity (COG) of the vertical distribution of aquifer properties estimated from lithologic logs. The COG of the distribution of any property (P) can be calculated from the following equation:

$$COG(P) = \sum_{i=1}^{n} P_i M_i \Big/ \sum_{i=1}^{n} P_i \,, \qquad (1)$$

where the moment arm (M_i) is the distance from a reference plane (the base of aquifer is convenient to use) to the midpoint of the ith lithologic unit that has a value P_i of the aquifer property.

The COG has the dimension of length and can be made dimensionless by dividing it by the saturated thickness of the aquifer. This number is referred to as the relative COG (RCOG) and is calculated by the following equation:

$$RCOG(P) = COG(P) \Big/ \sum_{i=1}^{n} t_i , \qquad (2)$$

where t_i is the thickness of the ith lithologic unit. To use equations 1 and 2, a lithologic log is divided into n lithologic units and a value of the aquifer property is assigned to each unit.

The RCOG indicates the position of the centroid of the parameter distribution within the lithologic section at the site of the log. Thus, an RCOG of 0.5 indicates that the parameter is equally distributed about the middle of the lithologic section at that location. RCOG values determined from a number of lithologic logs can be statistically analyzed to gain information on the vertical variability of the parameter. Also, RCOG values of various parameters can be mapped to show their areal distribution and variability. Interpretation of the maps can aid in the identification of paleo-geomorphic features and geologic structures.

A driller's log from the High Plains aquifer is presented in table 1 to illustrate the computation of RCOG. Values of thickness (t_i), hydraulic conductivity (K_i), and specific yield (S_i) assigned to each unit, and the moment arm (M_i) for each unit are listed in the table. Specific-yield values for various fluvial materials, which were tested in the laboratory by the U.S. Geological Survey (Johnson, 1967), were modified for use in this study. Average hydraulic conductivity was estimated from the grain-size description by using the values modified from Reed and Piskin (Lappala, 1978) by Gutentag and others (1984, table 5).

TABLE 1.--NEAR HERE

The COG of transmissivity was calculated by substituting the product of hydraulic conductivity and thickness (K_it_i) for P_i in equation 1, which results in COG(T) = 64.0 feet and, from equation 2, RCOG(T) = 0.45. The RCOG of 0.45 indicates that the lower one-half of the section is somewhat more transmissive than the upper one-half.

Similarly, the COG of storage depth (the product of S_i and t_i) can be calculated by substituting (S_it_i) for P_i in equation 1, which results in COG(St) = 65.8 feet, and from equation 2, RCOG(St) = 0.47. The RCOG indicates that the storage properties in the lower one-half of the section are slightly larger than the upper one-half.

DISCUSSION

The RCOG provides a means of quantifying observations concerning the vertical distribution of sediments indicated by lithologic logs. For example, an analyst examines a driller's log and observes that most of the coarse sediments are located in the lower (deeper) part of the log.

Because hydraulic conductivity is typically larger for coarse sediments, the RCOG of transmissivity calculated for that log would be less than 0.5. The smaller the value of the RCOG, the greater the preponderance of coarse material in the lower (deeper) part of the log. After the analyst has examined numerous drillers' logs from the study area, it may not be apparent how the course material is distributed. Statistical analysis of the RCOG values calculated from the drillers' logs will enable the analyst to quantify the vertical variability of various parameters within the study area. Plotting the RCOG values on a map will enable an analyst to observe the areal variation and draw conclusions on the vertical and areal variability of particular aquifer parameters.

For example, Gutentag and others (1984) were concerned that a basal gravel may occur throughout large areas of the High Plains and make it necessary to model hydraulic conductivity as a function of saturated thickness. If so, the mean of the values of the RCOG of transmissivity computed from a large number of drillers' logs should be significantly smaller than 0.5.

Gutentag and others (1984, p. 23–26) analyzed 3,076 drillers' logs from the High Plains aquifer using the methods described here. Values for hydraulic conductivity and specific yield were assigned to each lithologic interval described on each log. A computer program was written and used to calculate the COG and RCOG values for selected aquifer properties from the logs. The results of these analyses indicated that the mean of the RCOG values for transmissivity was 0.48 (standard deviation = 0.10) and for storage depth was 0.49 (standard deviation = 0.07). Gutentag and others (1984, p. 23) concluded that vertically averaged values of hydraulic conductivity and specific yield could be used to model the aquifer without causing substantial errors in projected drawdown. The results of this analysis provided justification for Luckey and others (1986, 1988) to model the High Plains aquifer as a one–layer, two–dimensional system. The geohydrology of the High Plains aquifer and the simulated effects of pumpage on the aquifer are summarized by Weeks and others (1988).

The RCOG values also were interpreted to support hypotheses about the geomorphology of the High Plains aquifer. Gutentag and others (1984, p. 23) determined from statistical analysis of RCOG values based on drillers' logs that all lithologic types that compose the aquifer are equally likely to occur at any position in the vertical section. They concluded that the dominant mode of deposition of the aquifer was probably by braided streams because braided-stream deposits are characterized by both coarsening-upward and fining-upward sequences of sediment types that result in a random distribution of sediment types in the vertical section. Kolm and Case (1983) determined, from the areal distribution of vertically averaged values of hydraulic conductivity computed using these methods, the location of highly transmissive paleochannels in the South Dakota part of the High Plains aquifer.

CONCLUSIONS

The method of moments was used to evaluate the variability of aquifer properties using estimates of hydraulic conductivity, specific yield, unit-bed thickness, and saturated thickness obtained from drillers' lithologic logs. The results of this method provide (1) a means of quantifying observations concerning the vertical distribution of sediments, (2) information on the vertical and areal variability of particular aquifer parameters, and (3) data to support hypotheses about geomorphic constraints on the aquifer framework and related hydrologic properties.

REFERENCES

Ashworth, Jr., J.B., 1980, Evaluating the ground-water resources of the High Plains of Texas, results of test hole drilling: Texas Department of Water Resources Report LP-129, 41 p.

Bryn, S.M., 1984, Determination and distribution of the hydraulic conductivity and specific yield of the Ogallala aquifer in the Northern High Plains of Colorado: Master of Science Thesis T-2899, Colorado School of Mines, 123 p.

Domenico, P., and Stephenson, D., 1964, Application of quantitative mapping techniques to aid in hydrologic systems analysis of alluvial aquifers: Journal of Hydrology, v. 2, p. 164-181.

Gutentag, E.D., Heimes, F.J., Krothe, N.C., Luckey, R.R., and Weeks, J.B., 1984, Geohydrology of the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Professional Paper 1400-B, 63 p.

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Kolm, K.E., and Case III, H.L., 1983, A two-dimensional, finite-difference model of the High Plains aquifer in southern South Dakota: U.S. Geological Survey Water-Resources Investigations Report 83-4175, 34 p.

Krumbein, W.C., and Libby, W.G., 1957, Application of moments to vertical variability maps of stratigraphic units: Bulletin of the American Association of Petroleum Geologists, v. 41, no. 2, p. 197-211.

Lappala, E.C., 1978, Quantitative hydrogeology of the Upper Republican Natural Resources District, southwest Nebraska: U.S. Geological Survey Water-Resources Investigations 78-38, 200 p.

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Meyboom, P., 1960, Geology and ground-water resources of the Milk River sandstone in southern Alberta: Research Council of Alberta, Memoir 2, 84 p.

Weeks, J.B., Gutentag, E.D., Heimes, F.J., and Luckey, R.R., 1988, Summary of the High Plains regional aquifer-system analysis in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Professional Paper 1400-A, 30 p.

Winter, T.C., 1975, Delineation of buried glacial-drift aquifers: U.S. Geological Survey, Journal of Research, v. 3, no. 2, p. 137-148.

Table 1.—Values of thickness (t_i), hydraulic conductivity (K_i), specific yield (S_i), and moment arm (M_i), for i number of lithologic units for a driller's lithologic log from the High Plains aquifer in Hamilton County, Kansas

i	Lithologic unit	t_i (feet)	K_i feet per day	S_i (percent)	M_i (feet)
Bottom					
1	Sand and gravel, poorly sorted	13	160	25	6.5
2	Sandy clay	3	10	5	14.5
3	Hard clay	14	5	3	23.0
4	Sand and gravel, fine to medium	6	160	25	33.0
5	Sandy clay	10	10	5	41.0
6	Sand and gravel, poorly sorted	63	160	25	77.5
7	Sandy clay	32	10	5	125.0
Top					

United States Department of the Interior

GEOLOGICAL SURVEY

Branch of Isotope Geology (MS 937)
345 Middlefield Road
Menlo Park, California 94025
U.S.A.

April 29, 1985

Dr. Schon S. Levy
ESS-1 Geology and Geochemistry
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Dear Schon:

The stable isotope analyses and oxygen isotope "temperatures" of the most recent suite of samples you sent are given in the table.

Sample	Description	^{18}O (SMOW)	^{13}C (PDB)	T(°C)	T*(°C)
TR-14-3a-q	drusy quartz	22.1		145	50
TR-14-3a-w	calcite in WR	20.3	-7.5	90	5
YF-4-q	drusy quartz	17.8		190	70
YW-4-q	botryoidal quartz	13.1		255	100
VH-2-3545-q	quartz fracture filling	13.0		225	100
VH-2-3565-q	quartz fracture filling (impure)	11.9		--	

Temperatures given in the first T column were calculated assuming that the filling temperature of 145°C is a correct temperature of formation for quartz in TR-24-3a-q and that the other minerals were precipitated from a fluid with the same isotopic composition. Using the quartz-water fractionation curve of Bottinga and Javoy (1973) this fluid would have had a ^{18}O value of + 2.0 °/oo. Such a value, if correct, would be characteristic of a formation water or brine that may have originated as ocean water (^{18}O = 0 °/oo). If the fractionation curve of Clayton et al (1972) is used, a water with an unusually high ^{18}O value of +5.3 °/oo is implied. My initial reaction is that such waters were not involved in the growth of this quartz and that there is something wrong with the filling-temperature measurements. I can check this possibly by crushing the quartz and analyzing the deuterium content of the fluid inclsions. Under "normal" circumstances where ground water of meteoric origin is involved in the growth of these minerals, a high ^{18}O value such as 22.1 implies that the quartz formed at relatively low temperatues.

ENCLOSURE 8

In general, the lower the temperature, the larger the fractionation factor and the higher is the $\delta^{18}O$ value of a mineral. Igneous quartz has typical $\delta^{18}O$ values of 7 to 10, medium-rank metamorphic quartz has $\delta^{18}O$ values of 12 to 18, and low-temperature quartz has higher values up to +36 for authigenic quartz forming on the ocean floor.

The temperatures given in the second T* column were calculated with the Bottinga-Javoy equation assuming a $\delta^{18}O$ value of $-13.0\,^{o}/oo$ for local ground water. If this value were shifted to higher (more positive) values by exchange with ^{18}O-rich wall rocks before quartz was deposited in the fissures (and this is likely), the temperatures would be higher but much closer to those in the second column than to those in the first.

In any event, if similar waters were involved in the formation of the various samples of quartz, a variety of formation temperatures is implied. The relative temperatures are more meaningful than the absolute temperatures. The amorphous silica sent in the first batch has a very high $\delta^{18}O$ value of $27.2\,^{o}/oo$ and I am <u>certain</u> that it was formed at or near suface temperatures from ground water.

If I get further involved in extracting fluid inclusions to check this all out, I shall need some financial support. Please call me if you need further explanations of the limitations of the isotopic data and how they were manipulated.

Regards,

James R. O'Neil

cc: J. Rosholt
D. Vaniman

United States Department of the Interior

GEOLOGICAL SURVEY
BOX 25046 M.S. ______
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DENVER, COLORADO 80225

TAKE PRIDE IN AMERICA

IN REPLY REFER TO:

2-4-91

John Stuckless
USGS MS 913
Box 25046
Denver CO 80225

John,

I have enclosed two pages of data that include depth distributions of secondary carbonate exposed in the slope-wash alluvium in trench 14. These data will be included in the paper: Taylor, E.M., in press, A discussion on the origin of secondary carbonate and opaline silica exposed in trench 14, Yucca Mountain, Nevada, USGS Bulletin, Proposed title "USGS Earth-Science Studies for the Yucca Mountain Project--Selected Papers."

In regards to your second question, I spoke with Andrei Sarna-Wojcicki in September of 1984 and he identified the unique dark detrital material that fills fractures in places in trench 14 as a magnetic black ash.

Emily M. Taylor

Emily M. Taylor

#210-A

ENCLOSURE 9

TABLE 1--Field description of a characteristic soil exposed in the slope-wash alluvium in trench 14

	HORIZON	DEPTH(cm) TOP	BASE	BND[1]	<----- COLOR ------> DRY	MOIST	TEXTURE[2]	STRUCTURE[3]	CONSISTENCE DRY[4]	WET[5]	<----- $CaCO_3$ ------> MATRIX[6]	GRAVEL[7]	% GRAVEL VOLUME	SiO_2[8]
UNIT 1[9]	Av	0	9	as	10YR 6/3	10YR 4/3	SL	3 co sbk	so	ss,ps	0	0	10	0
UNIT 1	Btk	9	20	aw	10YR 6/3	10YR 4/3	SL	2 co sbk	so	ss+,ps	es	I	25	0
UNIT 2[10]	2Btj	20	50	cw	10YR 5.5/4	10YR 3.5/4	SL	2-3 m-co pr, 2 co sbk	h	s,ps	e-es	I	5	0
UNIT 2	2B+K	50	61	as	10YR 6/3.5	10YR 6/3.5	SL	2 m sbk	sh	ss,ps	es, ev in K		5-20	0
UNIT 3[11]	3Kmq1	61	77	aw	10YR 8/0	10YR 8/2	LS	3 vco pl	eh	so,po		IV	5	4
UNIT 3	3Kmq2	77	119	aw	10YR 8/2	10YR 8/3	LS	3 vco pl, m	eh	so,po	ev	IV, 50 percent ooids	10	4 (<5mm) 10YR 7/3(d),7/4(m)
UNIT 3	3Kq	119	138	as	10YR 8/0	10YR 8/2	SL	m	eh	so,po	ev	III	5	3, 4 in places
UNIT 3	3Bkq1	138	202	aw	10YR 8/2	10YR 5/3	LS	2 co abk, m-sg	so	so,po	ev	II dense, III lenses, ooid lenses,	25	2, 3-4 in places
UNIT 3	3Bkq2	202	247	--	10YR 7.5/2	10YR 5/3	LS	m-sg	so	so,po	ev	II, III lenses, ooid lenses	10	2-3

1 Horizon boundaries--aw, abrupt wavy; as, abrupt smooth; cw, clear smooth; and --, no data.
2 Textural classes are based on grain size analyses, SL, sandy loam; LS, loamy sand.
3 Structure--(1) Grade--2, moderate; 3, strong; m, massive; sg, single grain; m-sg, massive to single;
(2) Strength--m, medium; co, coarse; vco, very coarse; and
(3) Kind--sbk, subangular blocky; pr, prismatic; pl, platy; abk, angular blocky.
4 Dry consistence--so, soft; sh, slightly hard; h, hard; eh, extremely hard.
5 Wet consistence--so, nonsticky; ss, slightly sticky; s, sticky; po, nonplastic; ps, slightly plastic.
6 Carbonate matrix--e, slightly effervescent; es, strongly effervescent; ev, violently effervescent.
7 Gile and others (1966)
8 Taylor (1986)
9 Parent material is slope-wash alluvium and fine-grained eolian material.
10 Parent material is slope-wash alluvium with 5 percent K plates derived from Unit 3.
11 Parent material is fine-grained slope-wash alluvium

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TABLE 2.--Selected grain-size data, bulk density, and calcium carbonate content from a characteristic soil exposed in the slope-wash alluvium in trench 14

	Soil	Depth cm		<---------------- % SAND [1,2]				---------------->	<-------- % SILT [1,2]		----->	<-- % CLAY [1,2]	-->	<-------- TOTAL		-------->	Density	
	Horizon	top	base	vco	co	med	fi	vfi	co	m + fi	vfi	co + m	fi	% SAND	% SILT	% CLAY	gm/cc	% $CaCO_3$
UNIT 1	Av	0	9	2.45	2.94	6.09	42.45	18.85	5.77	8.84	5.41	4.51	2.71	72.77	20.01	7.21	1.63	0.46
UNIT 1	Btk	9	20	2.34	2.45	4.90	33.71	19.99	9.56	9.56	4.78	8.64	4.05	63.40	23.91	12.69	1.69	1.22
UNIT 2	2Btj	20	50	1.54	1.96	5.45	38.08	17.74	8.40	11.80	5.54	6.79	2.68	64.77	25.75	9.48	1.67	0.34
UNIT 2	2B+K (B)	50	61	1.75	2.07	5.85	39.99	17.65	8.08	11.32	4.49	5.92	2.87	67.32	23.89	8.80	1.65	2.37
	(K)			28.13	15.71	11.34	16.92	6.72	3.85	4.92	3.42	4.49	4.49	78.82	12.20	8.98	1.34	33.05
UNIT 3	3Kmq1	61	77	13.21	10.41	11.57	32.69	9.92	4.11	6.99	3.29	3.91	3.91	77.80	14.38	7.81	1.62	40.12
UNIT 3	3Kmq2	77	119	13.76	12.03	14.51	32.67	9.67	4.18	5.23	3.14	0.63	4.18	82.63	12.56	4.82	1.66	45.92
UNIT 3	3Kq	119	138	12.46	11.78	14.96	28.10	9.14	4.35	7.09	3.66	2.74	5.72	76.45	15.09	8.46	1.46	56.14
UNIT 3	3Bkq1	138	202	4.66	4.24	9.44	44.87	16.01	5.85	5.85	2.42	3.63	3.03	79.22	14.12	6.66	1.73	26.81
UNIT 3	3Bkq2	202	247	6.37	4.86	7.94	49.02	14.14	3.64	5.47	2.55	4.01	2.00	82.32	11.67	6.01	1.55	23.56
	Carbonate fracture fill from bedrock																	
				26.88	16.55	11.59	12.77	7.73	4.26	8.25	2.92	1.33	7.72	75.52	15.43	9.05		69.41
	Material from vein III which contain the black ash (D15S)																	
				2.60	3.99	11.89	60.40	11.15	2.20	1.32	2.20	1.90	2.34	90.03	5.72	4.25		23.69

[1] Values for sand, silt, and clay are based on sieve and pipette analyses. Particle-size limits are: sand 2-0.05 mm; silt, 0.05-0.002 mm; clay, less than 0.002 mm.

[2] Textural classes are subdivided: vco, very coarse; co, coarse; med, medium; fi, fine; vfi, very fine.

DRAFT

Progress Report: Studies on the origins of soil and fault-related mineralogy in the vicinity of Yucca Mountain.

D. Vaniman, D. Bish, and S. Levy

I. Introduction

Studies of soil and fault-related samples around Yucca Mountain, particularly in relation to faults exposed in trenches, were begun in late September at the request of NNWSI Management. Concern was expressed that some of the mineral deposits associated with faults may be the products of deep-seated springs. Any future activity of deep-seated springs could compromise a repository at Yucca Mountain by providing aqueous transport of waste upward to the surface.

The mineralogy of these soil and fault-related samples is being studied with four possible origins in mind:

(1) The deposits may be pedogenic, reflecting only local dissolution and reprecipitation of material from the soil zone. This would be a local, low-temperature origin.

(2) The deposits may have formed from a low-temperature spring. Such springs could be either perched or deep-seated.

(3) The deposits may have formed from a high-temperature spring, with a deep-seated origin.

(4) The deposits may include material that originated from early high-temperature alteration along with early faulting soon after tuff emplacement.

More than one of these hypotheses may be necessary to explain the full variety of minerals found in these faults, in the altered tuff cut by the faults, and in the nearby soils.

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This is a multi-disciplinary study because of the large variety of data relevant to the resolution of an origin for these deposits. Also for this reason, the studies are spread jointly between researchers at LANL and in the USGS. At this time, J. O'Neil of the USGS is analyzing oxygen and carbon isotopes in samples from this collection.

No active springs of deep-seated origin have been observed at Yucca Mountain or vicinity. However, spring deposits of 30,000 yr age occur in southern Crater Flat, and a 78,000-yr old spring deposit may occur at the southern end of Yucca Mountain (Szabo et al., 1981). It is certainly possible that other springs may have occurred with activity so old or rare as not to have been observed in surface mapping. Such springs could be recognized by study of mineral deposits or alteration in trenches. The descriptions below concentrate on what is at present our best known suite of samples, from Trench 14 on the eastern side of Yucca Mountain.

II. Field relations

Trench 14 was excavated across a north-south trending fault on the west side of Exile Hill. From east to west, the trench exposes volcanic bedrock, bedrock with overlying alluvial cover, and alluvium. There is considerable calcite and silica accumulation within the alluvium. Several fault traces are exposed at the east end and central part of the trench; faults and associated fractures are coated with carbonate and silica.

Preliminary study suggests that there is a close textural and mineralogical similarity between the pedogenic material in weathered alluvium and the material deposited along faults within the weathered alluvium. Pedogenic calcite is transported in soils by downward-moving surface water and deposited from solution. Continuing deposition and recrystallization force the non-carbonate soil particles apart, leading to the formation of laminated, nearly pure carbonate horizons (ref. Birkeland, 1974). For carbonate deposition in a fracture, however, the geometry and permeability of the depositional environment are different. In addition, because tectonic fractures can conduct water well below the root zone, carbonate deposition may be less affected by plant CO_2 in such fractures than in the soil horizons. Nevertheless, the basic depositional processes are much the same. The material deposited along fractures may be nonpedogenic mainly in the sense that it transgresses soil horizons. The apparent greater abundance of coarse sparry calcite in fractured tuff and in caliche near the fault, compared to horizontal K-horizon caliche, may result from locally increased permeability along fractures and from possible fluid composition differences. Lattman and Simonberg (1971) showed that infiltration of rainwater into carbonate alluvium in southern Nevada was sufficient to cause local solution and reprecipitation of fine-grained carbonate as sparry cement to depths of more than 10 ft (3 m). Therefore, no additional source of water (e.g., a spring) is required to account for the sparry calcite. It is in this pedogenic association that sepiolite is also found.

In contrast, the altered tuff also contains drusy quartz that could be the product of moderate temperature hydrothermal alteration. If this is true (see fluid inclusion studies, below), it would be important to establish the time of alteration and the relationship, if any, between alteration and fluid movement along faults. Further field study will determine the distribution of alteration within tuff and its relationship to the exposed faults.

III. Mineralogy

X-ray diffraction analysis of bulk samples of both soil- and fault-filling materials revealed the presence of major calcite and minor amorphous silica or opal CT. However, the 10% HCl-insoluble residue of the carbonate rocks contained major sepiolite and/or opal CT and lesser amounts of palygorskite(?) and quartz. The presence of sepiolite and palygorskite, magnesium silicates with chain-like structures, is noteworthy because these minerals are thought to form at low temperatures. These two minerals are very common in calcic soils, pedogenic calcretes, and other surficial carbonates, such as paludal or lacustrine deposits, in the semiarid southwestern U.S. In fact, their presence in calcic horizons of the surficial deposits of the NTS area has been noted by Jones (1983).

Lacking strong evidence for a hydrothermal origin for the deposits in Trench 14, we suggest that these deposits represent low-temperature pedogenic calcretes, similar to those documented in the NTS area. Khoury et al. (1982) showed that these Mg-silicates can form under ambient conditions simply through the evaporation of surface water equilibrated with atmospheric CO_2.

IV. Fluid inclusions

Multiple thin sections through soil and fault-filling samples have shown no fluid inclusions large enough to analyze for temperature of homogenization. The largest inclusions found are less than 2 μm in size, or occur as fracture-related secondary inclusions in opaline silica. However the intergrowth of these carbonate-rich samples with sepiolite is strong evidence of low-temperature origin. Moreover, although the inclusions found are very small, examination at high magniication reveals no bubbles that would be expected from formation at higher temperatures.

The drusy quartz crystals that occur in altered tuff also are poor in large inclusions, but the small inclusions which occur in abundance contain visible bubbles. The largest inclusion found so far (8 μm) yielded a homogenization temperature of 145°C. Further serial sections are being obtained to confirm this temperature. This preliminary datum plus the textural evidence for early growth of the drusy quartz suggest that some form of hydrothermal event preceded the calcite - opal CT - sepiolite - palygorskite (?) - amorphous silica crystallization along the fault.

V. Isotopic studies

Samples of pedogenic K-horizon carbonate, of fault-filling carbonate, and of amorphous silica from one of the trenched faults are being analyzed for carbon and oxygen isotopes by J. O'Neil of the USGS. A sample of the early-formed drusy quartz from altered tuff along the fault will also be analyzed. These data will be compared with those compiled for Yucca Mountain drill-hole carbonates by Scott et al. (1984). Analysis of the drusy quartz will be particularly useful for comparison with the high temperature (145°C) so far indicated by fluid inclusion studies, and may help to distinguish between a high-temperature spring origin or an origin during early high-temperature tuff alteration.

VI. Preliminary interpretations and future work

Of the four possible interpretations for the origin of fault-related minerals stated in the introduction, none can yet be explicitly ruled out. We can however state that more than one episode of alteration is recorded in these samples. An early episode of high-temperature quartz growth (either during early cooling of the tuff or by high-temperature spring activity) was followed by an episode of low-temperature sepiolite-carbonate-silica-palygorskite (?) alteration (through either pedogenic or low-temperature spring activity). The problem remains of uniquely determining whether or not spring activity was involved in either the high-temperature or low-temperature stages of alteration. Our preliminary data lead us to suggest that a combined field and laboratory study will provide the answers to these questions by (1) comparing the formation conditions, including direct or indirect radiometric dating if possible, of early drusy quartz in Yucca Mountain faults with the formation conditions of similar silica alteration that occurs elsewhere at Yucca Mountain, and by (2) comparing the later low-temperature alteration in the faults with the known spring deposit at Crater Flat and with the suspected spring deposits of southern Yucca Mountain.

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A PRELIMINARY COMPARISON OF MINERAL DEPOSITS IN FAULTS NEAR YUCCA MOUNTAIN, NEVADA, WITH POSSIBLE ANALOGS

by

D. T. Vaniman, D. L. Bish, and S. Chipera

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FIGURES

A PRELIMINARY COMPARISON OF MINERAL DEPOSITS IN FAULTS NEAR YUCCA MOUNTAIN, NEVADA, WITH POSSIBLE ANALOGS

by

D. T. Vaniman, D. L. Bish, and S. Chipera

ABSTRACT

Several faults near Yucca Mountain, Nevada, contain abundant calcite and opal-CT, with lesser amounts of opal-A and sepiolite or smectite. These secondary minerals are being studied to determine the directions, amounts, and timing of transport involved in their formation. Such information is important for evaluating the future performance of a potential high-level nuclear waste repository beneath Yucca Mountain. This report is a preliminary assessment of how those minerals were formed. Possible analog deposits from known hydrothermal veins, warm springs, cold springs or seeps, soils and aeolian sands were studied by petrographic and x-ray diffraction methods for comparison with the minerals deposited in the faults; there are major mineralogic differences in all of these environments except in the aeolian sands and in some cold seeps. Preliminary conclusions are that the deposits in the faults and in the sand ramps are closely related, and that the process of deposition did not require upward transport from depth.

I. INTRODUCTION

Yucca Mountain, near the southwestern boundary of the Nevada Test Site (Figures 1A, B, and C), is being studied to determine its suitability to host a mined geologic repository for high-level radioactive waste. Research at Yucca Mountain, sponsored by the US Department of Energy and managed by its Waste Management Project Office at the Nevada Office of Operations, must address the question of seismic stability through the study of past fault movements near Yucca Mountain. Trenches have been excavated across faults near Yucca Mountain, Nevada, in order to assess the extent of Quaternary fault movement. In addition to fault displacements, these trenches revealed calcite and silica deposited in several of the faults. Figure 2 shows an example of

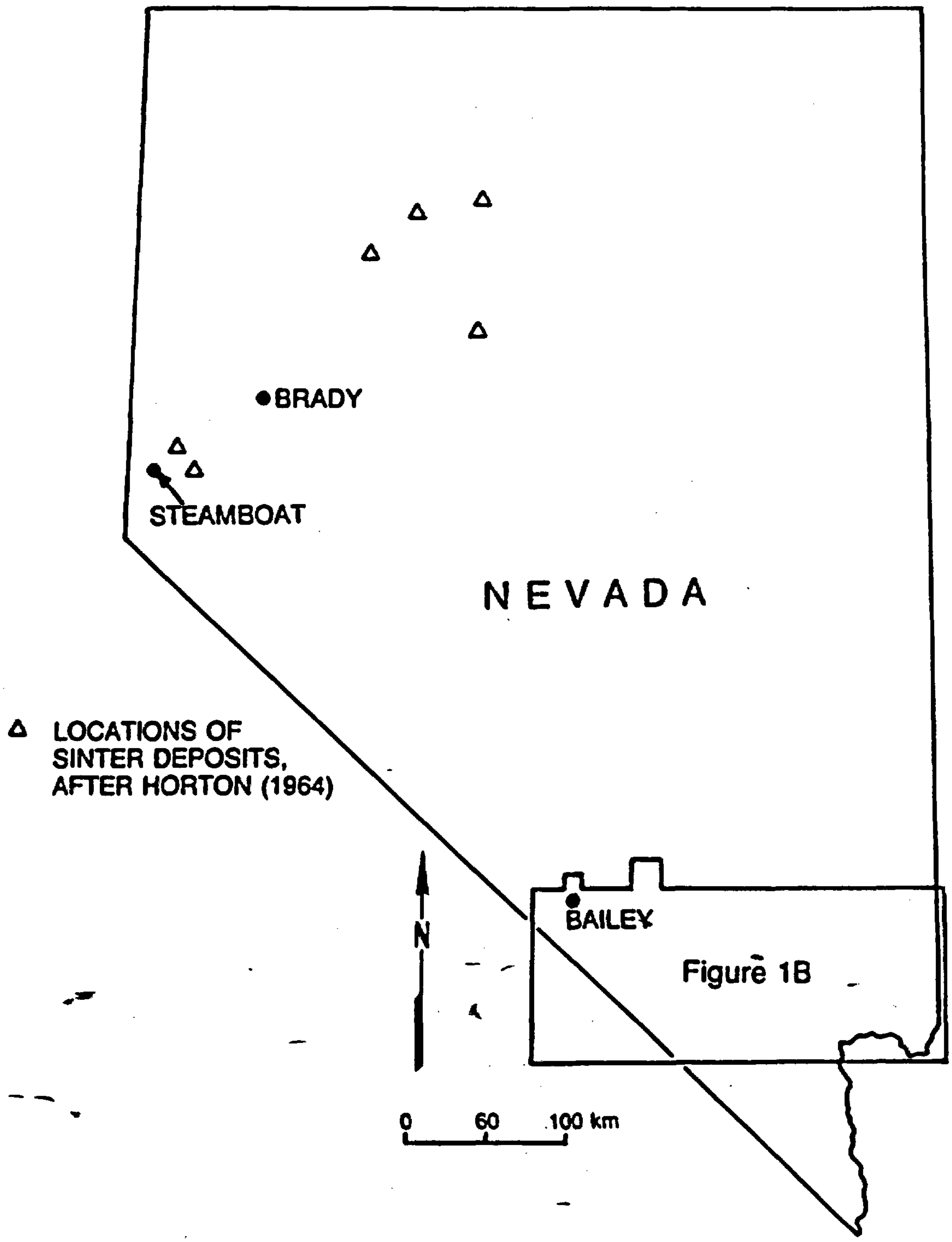


Fig. 1A.
Locations of warm springs and of warm spring sinter deposits in northern Nevada. The inset rectangle shows the area detailed in Figure 1B.

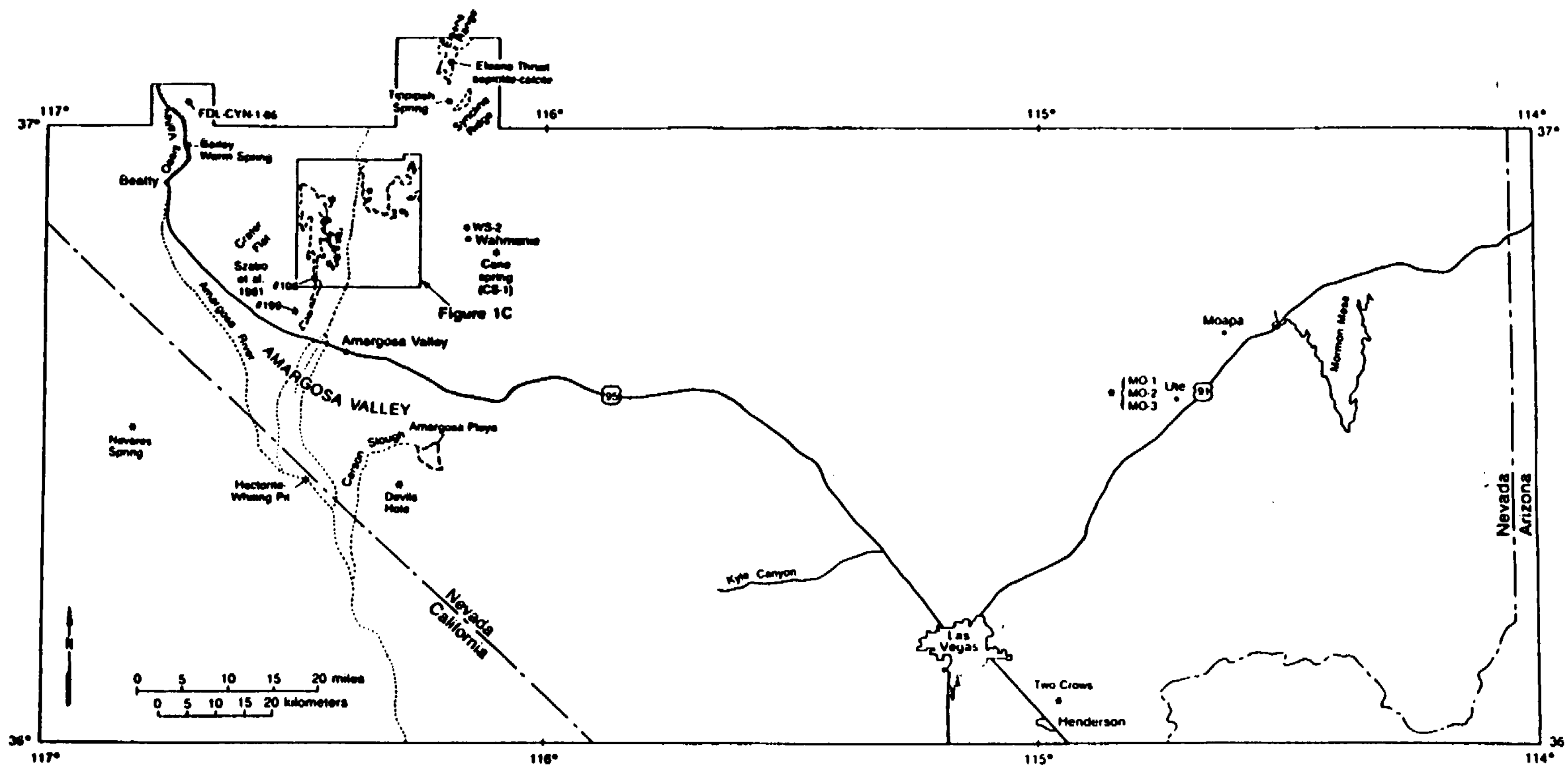


Fig. 1B.
Positions of localities mentioned in the text, other than those in northern Nevada (Fig. 1A), and near Yucca Mountain (Fig. 1C).

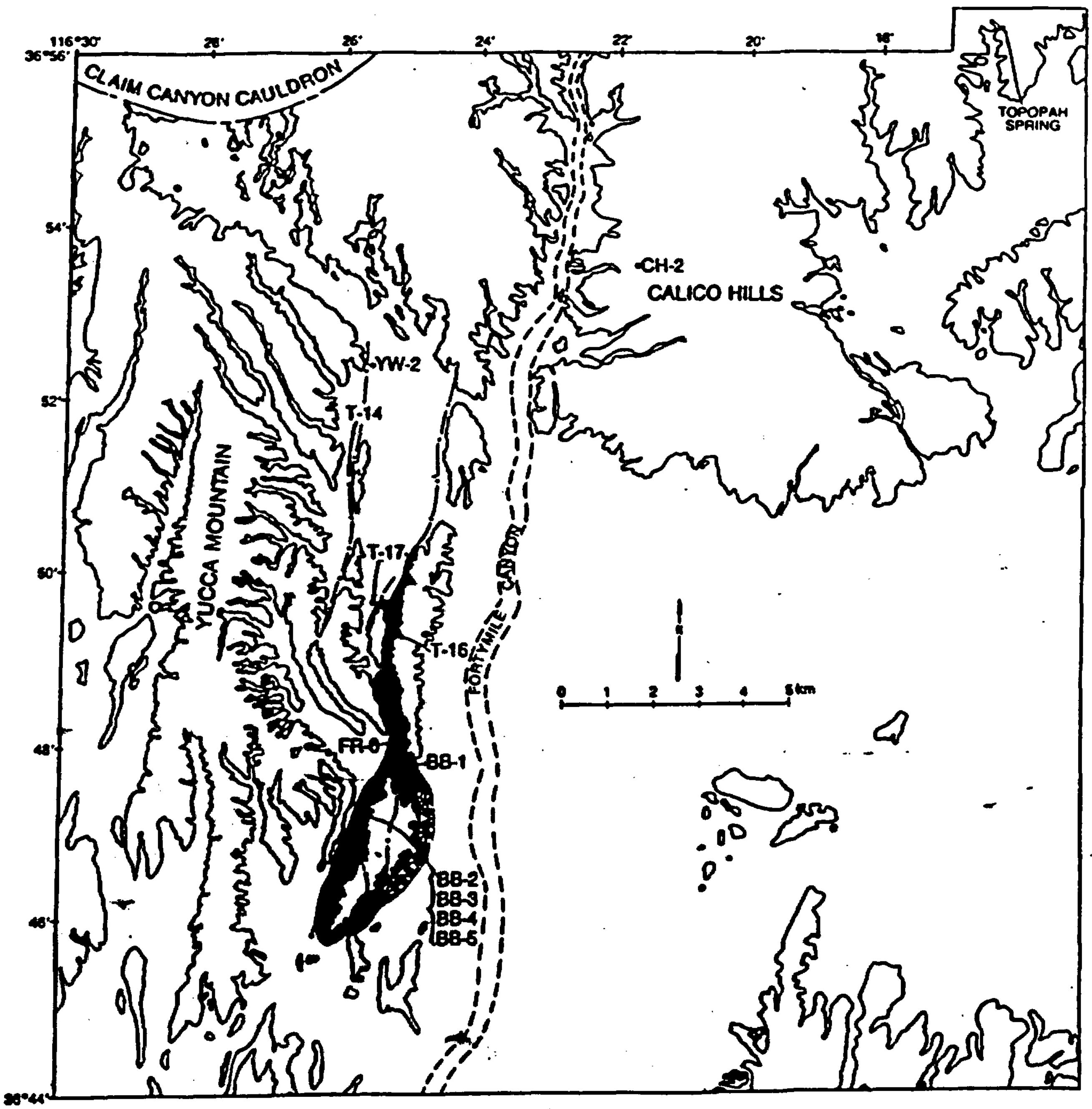


Fig. 1C.
Sample localities near Yucca Mountain.

Fig. 2.
Photograph of the southern wall of Trench 14 with sample localities mentioned in the text. The notebook placed on the wall of the trench is 21 cm (8.5 inches) long.

one of the widest of these deposits, exposed in the south wall of Trench 14 (Fig. 1C). The extent of those deposits of secondary minerals and the associated alteration of the tuff wall rocks were not expected. Subsequently, the origin of the deposits was questioned and a variety of depositional environments have been suggested.

Some studies of the secondary calcite and opal within trenched faults conclude that the depositional environment was limited to near-surface soil-zone transport and that the calcite and opal are mostly neoformed (Swadley and Hoover 1983; Taylor and Huckins 1986). However, Szabo et al. (1981) refer to similar materials as seep or spring deposits; these deposits have not been fully characterized (localities 106 and 199 in Fig. 1B). Workshops held on these deposits have led to informal suggestions that the secondary minerals in the faults might be attributed to deep-seated hydrothermal or warm-spring activity. These suggestions of conflicting origin are difficult to evaluate because of an absence of full geological characterization of the secondary calcite-silica at Yucca Mountain. Furthermore, some mineralogic data are lacking for secondary minerals of known origin that might be used for comparison with the fault fillings at Yucca Mountain. In this paper we provide a preliminary mineralogic comparison between the fault-filling minerals at Yucca Mountain and possible analogs of known origin.

Five types of possible analogs for the Yucca Mountain fault fillings are described in this paper. The selection of analog types was based on consideration of a wide variety of fault- and fracture-related secondary calcite and silica in the area around Yucca Mountain. The five analog types are (1) near-surface exposures of hydrothermal vein deposits, (2) warm spring or hot spring deposits, (3) cold spring or seep deposits, (4) soil deposits, and (5) aeolian "sand ramp" deposits. In terms of possible impact on an unsaturated repository beneath Yucca Mountain, the first two possible analogs have the strongest negative impact because they imply that deep, hot waters have risen upwards past the potential repository horizon. If the fault fillings are young, then such origins would be a serious concern. The third possible analog is of lesser concern, particularly if the possible spring or seep sources were perched rather than deep-seated. Nevertheless, a spring or seep discharge from presently dry faults would require a re-evaluation of the presently assumed recharge rate of less than 0.5 to 4.5 mm/yr for Yucca

Mountain (Montazer and Wilson 1984). The last two possible analogs impute a soil-development origin that requires no major deviations from the presently observed arid processes at Yucca Mountain, with the possible exception of intermittent saturations during heavy rainfall accumulations. These soil-like origins would have no serious impact on an underlying repository. On the other hand, if the fault fillings have a seep or soil origin, then they might be useful to help calibrate the extent of near-surface transport along hydraulically conductive faults.

II. ANALYTICAL METHODS

Petrographic studies were made using polished thin sections in both transmitted and reflected light, at magnifications up to 500x. Electron microprobe analyses of calcite were made using a Cameca model CAMEBAX microprobe operated at 15 Kv accelerating potential with a sample current of 5 nanoamperes. A ZAF data reduction routine was used which assumed a fixed proportion of CO_2 in stoichiometric MCO_3 ($MO.CO_2$).

X-ray diffraction (XRD) studies were made on rock powders using the bulk-sample methods of Bish (1981) and the clay mineral separation techniques described in Bish (1986). For analysis of calcite-rich samples, the calcite in a few samples was removed by dissolution in a bath of cold 10% HCl. Other analyses used the buffered pH5 sodium acetate - glacial acetic acid dissolution as described by Jackson (1969). Clay minerals were separated by centrifugation or sedimentation. Because a variety of preparation methods was used on the samples described in this report, ranging from no treatment to acid dissolution and clay mineral separation, the preparation history of each sample is summarized in Table I.

III. RESULTS

The XRD data are summarized in Table II. Several of the minerals listed in Table II are not evident in the bulk samples analyzed but were found after the calcite fraction was removed, when the <2 µm fraction was extracted, or when both treatments had been used. It is important to note that the minerals marked with circles in Table II are detrital or relic fragments that were not co-precipitated with the host deposit; the detrital or relic nature of these minerals was determined by petrographic analysis.

TABLE I

PREPARATION PROCEDURES USED FOR SAMPLES DESCRIBED IN THE TEXT

Brady Spring tufa (RMV-201-82): crushed only.
Busted Butte north side surface (BB-1): crushed only.
Busted Butte west side surface (BB-3): crushed only.
Busted Butte west side fault filling (BB-2): crushed only.
Busted Butte west side fault filling (BB-2 2-5 μm acid): crushed, washed twice in pH 5 acetate buffer with Na-acetate rinses, rinsed in ethyl alcohol, treated in ultrasonic bath, sampled from precipitate after overnight settling.
Busted Butte west side surface (BB-3 2-5 μm acid): crushed, washed twice in pH 5 acetate buffer with Na-acetate rinses, washed in ethyl alcohol, treated in ultrasonic bath, sampled from precipitate after overnight settling.
Busted Butte west side surface (BB-3 1 day): sediment from supernatant over sample "BB-3 2-5 m acid" after 24 hours settling time.
Busted Butte west side buried sand (BB-4 <2 μm): crushed, treated in ultrasonic bath, set aside overnight to allow settling of >2 μm fraction, collection from supernatant following evaporation.
Busted Butte west side surface sand (BB-5 <2 μm): crushed, treated in ultrasonic bath, set aside overnight to allow settling of >2 μm fraction, collected from supernatant after evaporation.
Busted Butte west side surface sand (BB-5 oriented-EG): XRD of sample BB-5 <2 μm following preparation of oriented mount with ethylene glycol saturation.
Calico Hills (CH-2): crushed only.
Cane Spring (CS-1 white): crushed only.
Fleur de Lis Canyon (FDL-CYN-1-86): crushed only.
Fran Ridge (FR6): crushed only.
Moapa spring mound (MO-1): crushed only.
Moapa spring mound (MO-1 acidified): crushed, washed four times in pH 5 acetate buffer with Na-acetate rinses, rinsed in ethyl alcohol, sampled from precipitate after centrifuging thirty minutes at 9,000 rpm.
Moapa spring mound (MO-1 <2 μm acid): sampled from residue left after evaporation of supernatant from sample "MO-1 acidified".
Moapa outflow at 3 ft depth (MO-2): crushed only.
Moapa outflow at 3 ft depth (MO-2 acidified): crushed, washed four times in pH 5 acetate buffer with Na-acetate rinses, washed in ethyl alcohol, sampled from precipitate after centrifuging thirty minutes at 9,000 rpm.
Moapa outflow at 3 ft depth (MO-2 <2 μm acid): sampled from residue left after evaporation of supernatant from sample "MO-2 acidified".
Moapa outflow surface (MO-3): crushed only.
Moapa outflow surface (MO-3 acidified): crushed, washed four times in pH 5 acetate buffer with Na-acetate rinses, washed in ethyl alcohol, sampled from precipitate after centrifuging thirty minutes at 9,000 rpm.
Moapa outflow surface (MO-3 <2 μm acid): Sampled from residue left after evaporation of supernatant over sample MO-3 acidified.
Moapa outflow surface (MO-3 <2 μm oriented): XRD of oriented mount made from sample MO-3 <2 μm acid.
Moapa outflow surface (MO-3 <2 μm ori/eg): XRD of glycolated mount MO-3 <2 μm oriented.

TABLE I (cont)

Navares Spring (Navares): crushed only.
Steamboat Spring altered rock (RMV-205-A): crushed only.
Steamboat Spring tufa (RMV-205-D): crushed only.
Trench 14 silica band in fault (T14-FA silica): crushed only.
Trench 14 fault (T14-FA,R): crushed only.
Trench 14 fault (T14-FA,R acidified): crushed, washed twice in pH5 acetate buffer, rinsed in sodium acetate, rinsed in deionized water, sampled from residue.
Trench 14 fault (T14-FB calcite): crushed only.
Trench 14 fault (T14-FB insoluble): crushed, insoluble residue sampled after treatment in cold 10% HCl and NaOH neutralization.
Trench 14 fault (T14-FB >2 μm insoluble): neutralized supernatant collected over sample T14-FB insoluble, sample collected after sedimentation overnight.
Trench 14 fault (T14-FB >2 μm glyc.): XRD of oriented and glycolated mount prepared from sample "T14-FB >2 μm insoluble".
Trench 14 fault (T14-FB <2 μm-ins.): crushed, dissolved in cold 10% HCl, neutralized in NaOH, ultrasonic bath followed by separation of <2 μm fraction through gravitational settling.
Trench 14 fault (T14-FB <2 μm glyc.): XRD of oriented and glycolated mount prepared from sample "T14-FB <2 μm-ins".
Trench 14 fault center (T14-11 white): crushed only.
Trench 14 fault center (T14-11 brown): crushed only.
Trench 14 wall (T14-10 gdms): crushed only.
Trench 14 wall (T14-10 gdms <2 μm acid): crushed, washed twice in pH 5 acetate buffer with sodium acetate rinses, rinsed in ethyl alcohol, centrifuged at 9000 rpm for 20 minutes, sample taken from supernatant after evaporation.
Trench 14 wall (T14-10 acidified): precipitate from final centrifugation of sample "T14-10 gdms <2 μm acid".
Trench 14 wall contact (T14-10 vein): crushed only.
Trench 14 wall contact (T14-vein acidified): crushed, washed in cold 10% HCl, neutralized in NaOH, sampled from precipitate.
Trench 16 root (T16-1 rim): crushed only.
Trench 16 root: (T16-1 core): crushed only.
Trench 17 fault (T17-1): crushed only.
Trench 17 fault (T17-1 acid residue): crushed, insoluble residue sampled after treatment in cold 10% HCL and NaOH neutralization.
Wahmonie deposit (WS-2 bulk): crushed only.
Wahmonie deposit (WS-2 acid floculant): crushed, washed in cold 10% HCl for thirty minutes, neutralized in NaOH, sample taken from residue left after evaporation of supernatant.
Yucca Wash (YW-2): crushed only.
Yucca Wash (YW-2 acidified): crushed, washed four times in pH 5 acetate buffer with Na-acetate rinses, rinsed in ethyl alcohol, sampled from precipitate after centrifuging for thirty minutes at 9000 rpm.
Yucca Wash (YW-2 <2 μm acid): sampled from residue after evaporation of supernatant from sample "YW-2 acidified".
Yucca Wash (YW-2,R): crushed only.
Yucca Wash (YW-2,R acidified): crushed, washed twice in pH5 acetate buffer, rinsed in sodium acetate, rinsed in deionized water, sampled from residue.

TABLE II

X-RAY DIFFRACTION DATA*

	Calcite	Opal-A	Opal-CT	Opal-C	Quartz	Clay	Cryptomelane	Gypsum	Halite	Burkeite	Trona	Feldspar	Mica
Yucca Mountain Faults													
T14-FA	X	X	X										
T14-FA,R	X	X											
T14-FB	X		X		0	S							
T14-10 gdms	X		X		0	X						0	
T14-10 vein	X		X		0								
T14-11	X		X										
TR17	X		X		0	X							
Hydrothermal Vein													
CH-2				X	X		X						
Warm Spring Deposits													
RMV-201-82		X											
FDL-CYN-1-86									X	X	X		
RMV-205-A		X											
WS-2	X					X		X				0	
Cold Springs and Seeps													
CS-1	X				0							0	
MO-1	X												
MO-2	X				0	X							
MO-3	X				0	X							
Navares	X												0
Soil													
YW-2 and 2,R	X	X	X		0	X						0	0
Sand Ramps													
BB-1	X		X		0	X						0	
BB-2	X		X		0	X						0	
BB-3	X		X		0	X						0	
**BB-4						X							
**BB-5						X							
FR6	X		X		0	X							
T16-1 Rim		X											
T16-1 Core			X										

* X = Authigenic; 0 = relic or detrital based on optical examination; S = positive sepiolite identification.

** Only the <2 μm fraction was x-rayed in BB-4 and BB-5.

Several comparative petrographic features are listed in Table III. The term "ooids" is used throughout this paper to describe any pelletal or spherical forms smaller than 2 mm; these features may be massive but are typically formed of distinct concentric growth layers, and they may or may mot have foreign nuclei of rock, mineral, or glass fragments. Where opal is visible, a distinction is made between a single opal type or multiple types, based on variations in color, relief, birefringence, or growth forms. Any remains of fossil vascular plants either in thin section or in outcrop are noted. The term "geopetal opal" is used to describe distinct opal concentrations on the undersides of pebbles. Deposits which are layered on a millimeter-scale are said to have laminae, and cross-cutting laminae representing disruption between depositional series are noted. Occurrence of quartz formed in-situ rather than by accidental inclusion is also noted. The preservation of accidental pumice fragments is recorded. Finally, the occurrence of discharge flow-tube structures in spring mounds is recorded. Each sample studied is variable and often complex beyond the simple categorization of Table III; therefore this table is only a summary of some of the most prominent features. Electron microprobe data for calcite were obtained only where crystals coarser than micrite were found (Table IV). Many of the petrographic details are discussed along with the corresponding XRD data for each sample in the section that follows, and electron microprobe data are discussed where appropriate.

IV. DISCUSSION

Our discussion of the XRD and petrographic data is organized to follow the six types of localities listed along the left sides of Tables II and III. First, the samples analyzed from the faults around Yucca Mountain are discussed. Then the samples from the five possible analogs (hydrothermal veins, warm spring deposits, cold spring and seep deposits, soils, and sand ramps) are discussed. As part of the discussion, published studies and personal communications are cited where they are relevant to the minerals in faults and to the possible analogs. Much work has already been done in southern Nevada on many of these mineral associations, and these previous studies are important to the interpretations and conclusions made in this paper.

TABLE III

PETROGRAPHIC DATA

	Ooids	Single Opal Type	Multiple Opal Types	Fossil Vascular Plants	Geopetal Opal	Laminae	Cross-Cutting Laminae	Co-Deposit of Euhedral Quartz	Pumice Fragments	Flow Tube Structure
Yucca Mountain Faults										
T14-FA	X		X	X			X			
T-14-FA,R	X	X		X						
T14-FB	X		X			X				
*T14-8	X	X							X	
T14-10	X		X			X				
T14-11	X		X			poor				
T17-1	?		X				X			
Hydrothermal Vein										
CH-2		X						X		
Warm Springs										
RMV?		X				X				
San Ignacio			X	X						
Cold Springs/Seeps										
MO-1	X			X		X				X
MO-1	X					X				
MO-3	X					X				
Navares Soils										
YW-2 and 2,R	X		X		X	X				
Sand Ramps										
BB-2	?		X			X			?	
BB-3	?		X	X		poor			X	
FR-6	X		X	X		X			?	
**T16-1			X	X					X	

* T14-8 is a sample of loose volcanic ash and detrital fragments, with incipient ooidal rinds of calcite and opal-CT.

** T16-1 is a root cast and opal infilling (cf. Figure 22).

TABLE IV

ELECTRON MICROPROBE ANALYSES OF CALCITES

	Navares	Moapa MO-1	Moapa MO-2	Trench 14 wall (T14-10 qdms)
wt.% oxide				
CaO	53.5	54.8	54.5	55.9
MgO	2.20	0.82	1.20	0.55
FeO	0.06	0.00	0.00	0.04
MnO	0.00	0.03	0.00	0.02
SrO	0.21	0.01	0.00	0.08
BaO	0.00	0.13	0.03	0.00
CO_2[a]	44.1	44.2	44.3	43.4
Total	100.1	100.0	100.0	100.0
cations/3 oxygens				
Ca	0.949	0.975	0.967	1.002
Mg	0.054	0.020	0.030	0.013
Fe	0.001	0.000	0.000	0.000
Mn	0.000	0.000	0.000	0.000
Sr	0.002	0.000	0.000	0.001
Ba	0.000	0.001	0.000	0.000
C[a]	0.997	1.002	1.001	0.991
Total	2.003	1.998	1.998	2.007

[a]CO_2 calculated by difference from 100 wt.%.

(A) DEPOSITS WITHIN FAULTS NEAR YUCCA MOUNTAIN

Several faults have been exposed by trenching and mapped around Yucca Mountain (Swadley and Hoover 1983; Szabo and O'Malley 1985), and several of these faults contain deposits of calcite, silica, and clay minerals. These deposits consist of many small depositional bands, some of which are cross-cutting. The banded nature indicates that the minerals were probably deposited by a process that was repetitive and persisted over a long timespan. Alteration of the tuff wall rock to calcite, silica, and clay minerals is also found; this alteration is evaluated in the discussion of sample T14-10. The descriptions below concentrate on two of the faults in which these mineral deposits and the alteration effects in the wall rock are most extensive. The faults studied are those exposed in Trenches 14 and 17 (Fig. 1C).

Samples from Trench 14

The largest of the deposits studied is exposed in Trench 14 (Fig. 2). Samples T14-F and T14-11 were collected within the banded central regions of two of the fault splays exposed in the southern wall of Trench 14. Sample T14-10 was collected a few feet east of the other samples and includes the contact between minerals deposited along the fault and the altered wall rock. The wall rock at this point is the densely-welded and devitrified Tiva Canyon Member of the Paintbrush Tuff.

Sample T14-F

Interpretations of the banded sample T14-F indicates that there were at least two episodes of deposition, as illustrated in Fig. 3. The earlier episode is represented by very complex layering of patchy, mineral-clast rich, fragmental, and ooidal layers. These layers are, individually, 1 mm to 1 cm thick; the thicker layers are themselves formed of fragmental clasts up to a few millimeters long, indicating that even earlier deposition has occurred followed by brecciation and recementation. Ooids are 0.1 to 0.4 mm in diameter with few detrital nuclei (see Hay and Wiggins 1980, for a discussion of ooidal textures). The abundant mineral clasts that occur in some layers are widely varied but include fragments of quartz, potassium feldspar, plagioclase feldspar, amphibole, olivine, clinopyroxene, and both clear and colored volcanic glasses. The later episode of deposition was much simpler and consists of almost pure laminated opal, which cut across the earlier layering.

Fig. 3.
Photomicrograph of sample T14-FA. The clear band of opal-A overlies earlier layers of calcite with opal-CT.

The younger deposit appears to have begun with a minor amount of microcrystalline calcite (crystals smaller than 0.1 mm), but is dominated by almost pure opal layers. X-ray diffraction analysis (Fig. 4) shows that this opal is amorphous (opal-A in the nomenclature of Jones and Segnit, 1971), and differs markedly from the calcite-rich ooidal layers of the earlier depositional episode.

The nature of opal structural types is an important parameter in describing the deposits in faults, hydrothermal veins, warm springs, soils, and sand ramps. Opal XRD data will be compared throughout this paper. Three opal structural types are commonly identified based on the work by Jones and Segnit (1971); these three types range from amorphous (opal-A) to opal with short-range tridymite and cristobalite-type stacking (opal-CT) to opal with more extensive domains of cristobalite-type stacking (opal-C). XRD patterns of these three opal structural types are illustrated in Fig. 5 for comparison with XRD patterns used in this paper.

The youngest depositional episode in sample T14-F consists of opal-A. Another split from this youngest layer (sample T14-FA,R) was analyzed to confirm the identification of opal-A. Aside from being somewhat more

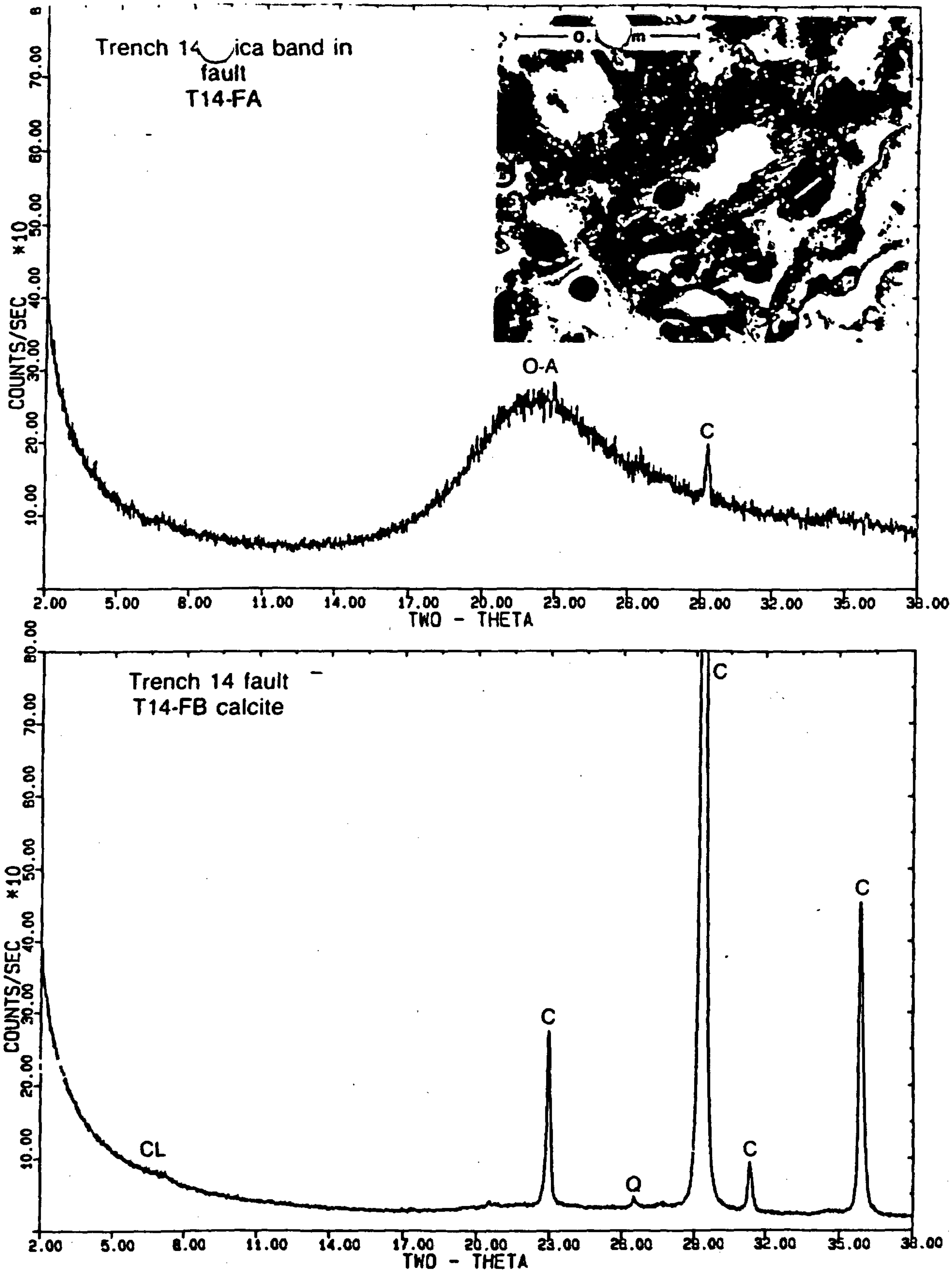


Fig. 4.

XRD patterns of T14-FA and T14-FB compared. The peaks labeled are calcite (C), opal-A (O-A), Quartz (Q), and clay (CL). The inset photomicrograph shows remnant organic structure within the opal-A of T14-FA; all structures shown consist of opal.

transparent than the other relatively pure opal zones in Trench 14, the opal-A in sample T14-F differs in having remnants of organic structures (note inset photomicrograph in Fig. 4). Remnants of small root cases can be seen in hand-samples of the opal-A. The earlier episode of complex layered deposition

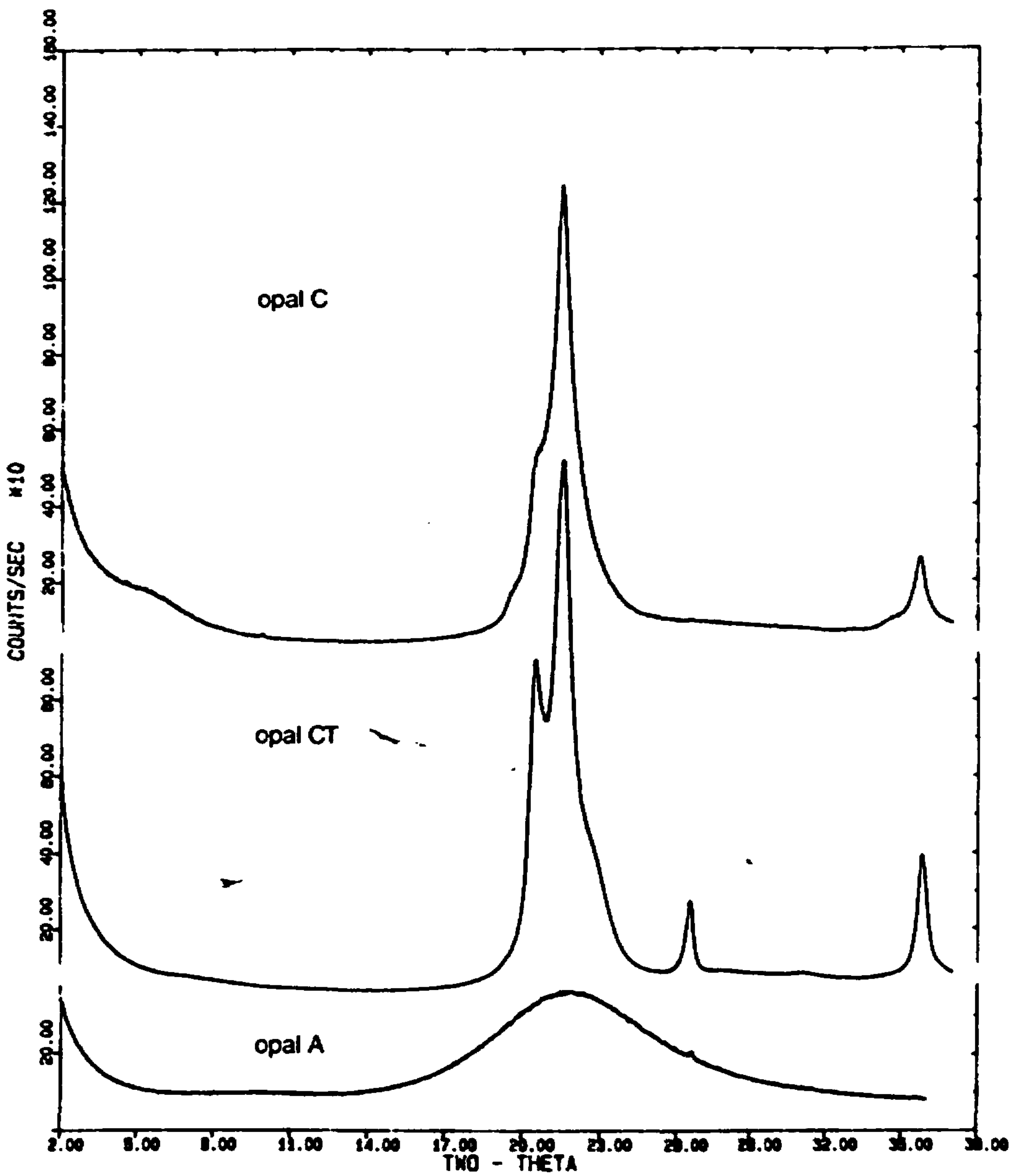


Fig. 5.
Comparative XRD patterns of opal-A, opal-CT, and opal-C.

in T14-F and in all other calcite-silica banding found in the faults is opal-CT, and does not preserve any organic structures of hand-sample or thin-section scale.

Figure 6 is the XRD pattern of the less-than-2 µm-size fraction separated from the earlier-episode layers of T14-F. This pattern shows the presence of the mineral sepiolite. Coarsely crystalline sepiolite can form in hydrothermal environments as fibrous crystals up to 5 cm long (Imai and Otsuka 1984). Post (1978) described a nearly pure vein filling of sepiolite at Two Crows, east of Henderson, Nevada (Fig. 1B) and suggested an origin by direct precipitation from deep water sources; he did not rule out a hydrothermal origin for this deposit. However, Post also contrasted the pure sepiolite at Two Crows with a sepiolite-dolomite duripan in North Las Vegas and, closer to

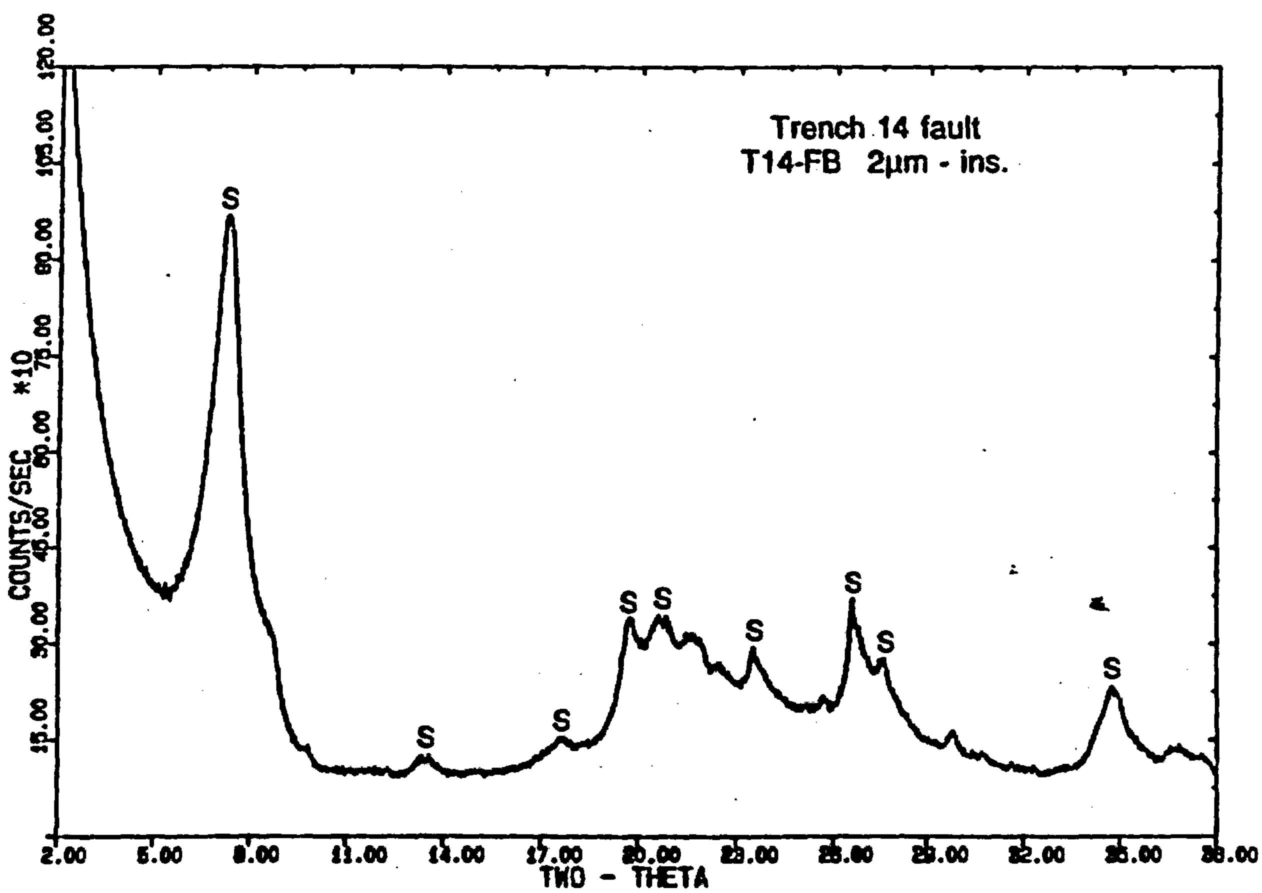


Fig. 6.
XRD pattern of sepiolite (S) in the less-than-2 micron size fraction of sample T14-FB.

Yucca Mountain, a sepiolite-dolomite playa deposit in the Amargosa Valley (Fig. 1B). In these other localities Post suggested that the sepiolite precipitated directly from high-Mg, high-pH surface waters. Jones (1983) examined the distribution of sepiolite and smectite around Yucca Mountain and suggested that sepiolite can be formed by precipitation in playas, spring seeps, old soils, and faults (Fig. 7) but that it is also commonly redistributed by aeolian processes. Thus the occurrence of sepiolite is not definitive evidence of a particular origin, although the commonest occurrences of sepiolite in Southern Nevada appear to be either playa-formed or pedogenic. With further study the data on sepiolite abundance, size, form, composition and associated mineral assemblages may provide some constraints on origin.

Sample T14-11

The more typical banded deposits within the fault at Trench 14 consist of parallel layers of dense buff-colored calcite and opal-CT with minor concordant layers of white or colorless, relatively pure opal-CT. Sample T14-11 (Fig. 2) contains such layering, and the layers are compared in Fig. 8. The central calcite-silica band is about 1 centimeter wide, and the outer layers of relatively pure opal are 0.5 to 3 mm thick. Although the opal type in both the silica and calcite-silica layers is opal-CT, the major diffuse opal diffraction at 21.6° 2θ in the central calcite-silica layer is not as sharp as the comparable opal diffraction at 21.5° 2θ in the outer pure silica layers. It is possible that the outer opal layers have long-range order because they did not encounter growth interference from the simultaneous deposition of calcite, or a lower silica activity may have favored growth of more ordered opal-CT, or the outer silica layers may have matured to an opal-CT with improved crystallinity through surface exposure which the opal in the calcite-silica band did not have. This large number of possible explanations for the difference in opal-CT crystallinity indicates the complexity of genetic interpretation for this sample.

The outer layers of pure opal-CT in sample T14-11 were deposited after the calcite-silica layer; this is the same relative timing of deposition as was seen in sample T14-F (above) in which pure silica deposition is a relatively recent event, although in T14-11 the pure silica is opal-CT rather than opal-A. We can not rule out the possibility that the pure silica layers in T14-11 may have originally been formed as opal-A, possibly as organic structures as in samples T14-FA and T14-FA,R. The late deposition of

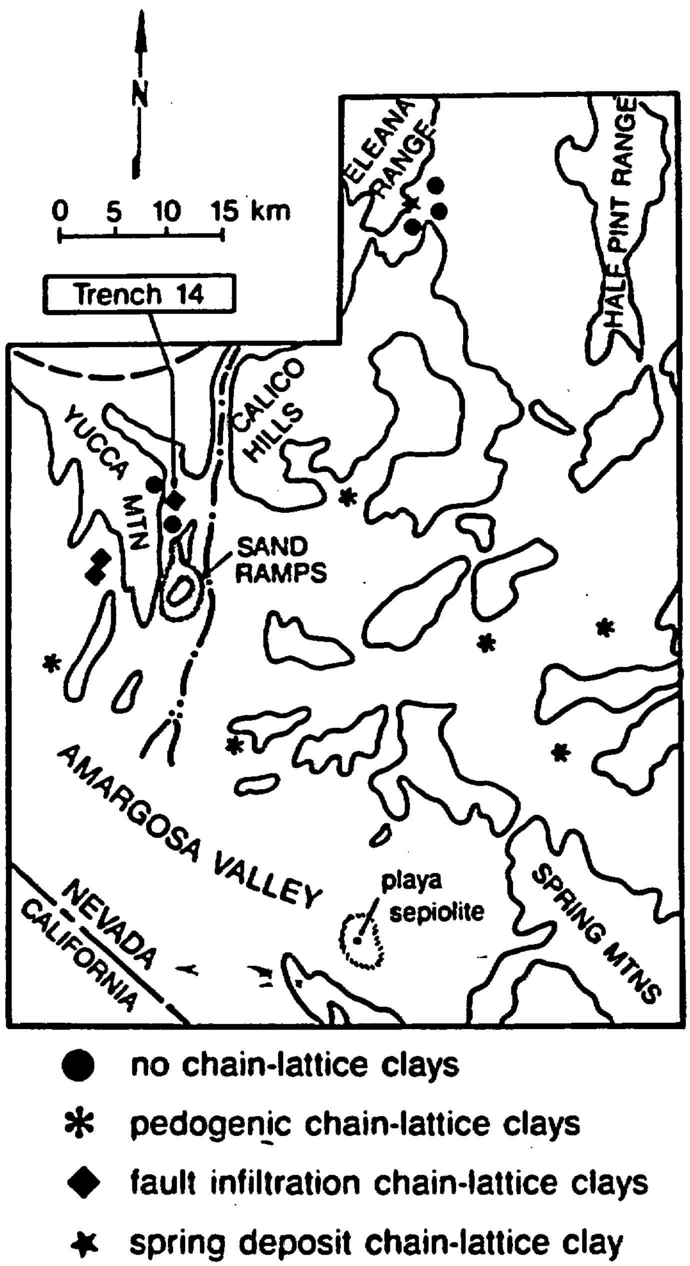


Fig. 7.
A map of chain-silicate clay (sepiolite) distributions in soils, faults, and a spring seep around Yucca Mountain (after Jones, 1983). The localities of Trenches 14 and 17, and of sand ramps south of these trenches, are also shown.

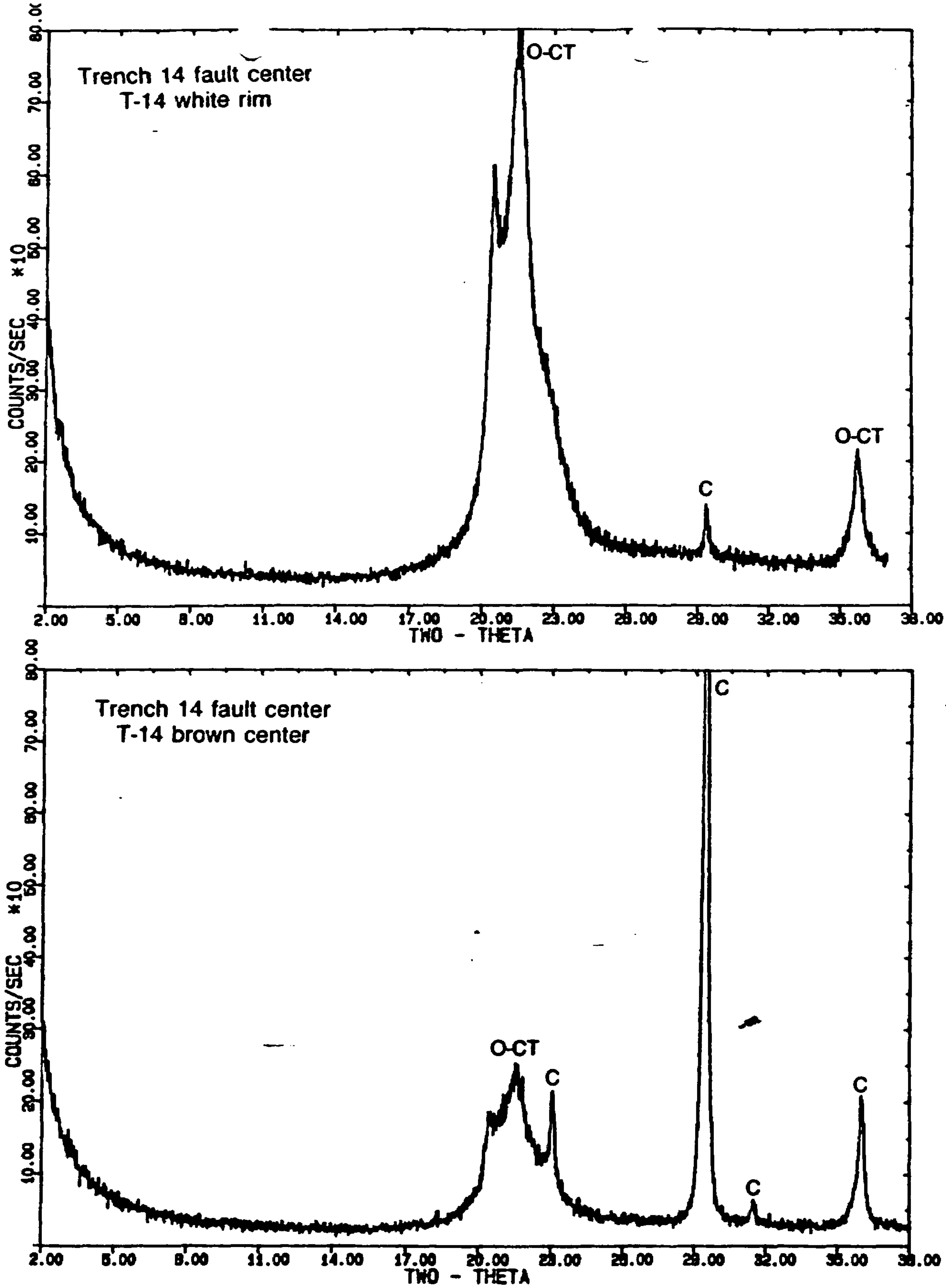


Fig. 8.

XRD patterns comparing the calcite (C) and opal-CT (O-CT) of a dense calcite-silica band (T14-11 brown) and its outer coating of laminated botryoidal opal-CT (T14-11 white).

relatively pure opal is seen throughout Trench 14, in other fault-related deposits in the sand ramps, and in the soils around Yucca Mountain. In contrast, pure opal deposition is an early and ongoing feature in sinter deposits from warm springs and does not appear to occur at all in cold spring or seep deposits. However, small amounts of euhedral quartz occur in the Hectorite-Whiting spring deposits of the Amargosa Valley (Fig. 1B; Khoury et al. 1982) and larger amounts of opal-CT, chalcedony, and quartz occur as a result of groundwater-caused silicification and replacement of playa carbonates and clays near Carson Slough in the Amargosa Valley (Fig. 1B; Hay et al. 1986).

Sample T14-10

Sample T14-10 provides an important comparison between layered silica-rich deposits along the wall of the fault and relatively calcite-rich alteration of the tuff wall rock (Fig. 9). The altered tuff consists of small brecciated tuff fragments (less than 0.5 cm in diameter) from the devitrified Tiva Canyon member, with matrix replacement by the coarsest calcite crystals (10 μm long) yet observed in Trench 14. The calcite crystals are also unique because of their euhedral habit (doubly-terminated spar). The coarse size of these calcite crystals has permitted electron microprobe analysis, and the results are tabulated in Table IV along with calcite analyses from two spring deposits. All are low-Mg or closely similar intermediate-Mg calcites, with no major differences in composition detectable by electron microprobe analysis. The fabric of calcite growth in the altered tuff suggests invasion along fractures between breccia fragments, although some replacement growth is suggested by calcite embayments in tuff fragments and by remnant phenocrysts surrounded by calcite crystals. Opal-CT occurs deposited along the walls of many of the voids between clusters of calcite crystals, although a final void filling of calcite in some cases suggests that calcite deposition occurred more than once. There are several opal morphologies, including colloform and massive birefringent forms. The variability in opal morphologies and optical properties suggests that the opal-CT seen in the XRD pattern is an averaged pattern representing several opal structural types. The broad diffraction maximum at 7.1° 2θ indicates relatively abundant clay, although study of the less than 2 μm fraction has not been able to resolve whether this is a chain-silicate clay such as sepiolite or a smectite.

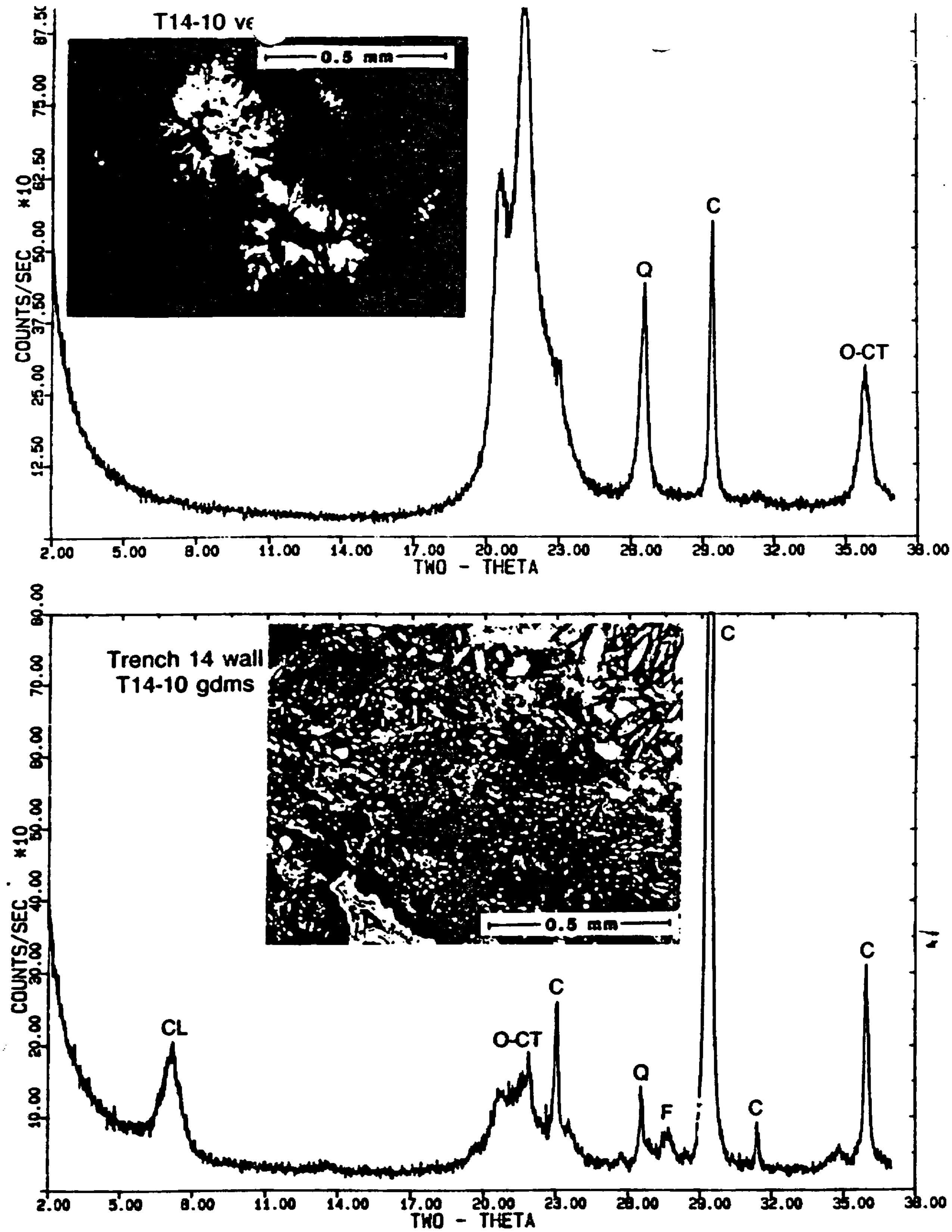


Figure 9
XRD patterns comparing the fault deposit (T14-10 vein) and the adjacent matrix of the altered tuff (T14-10 gdms) at a locality along the altered Tiva Canyon member in Trench 14 (Fig. 2). The minerals shown are calcite (C), opal-CT (O-CT), quartz (Q), and clay (CL). Inset photomicrographs show representative textures of the two samples. The photomicrograph of T14-10 vein shows both botryoidal and coarse birefringent opal. The photomicrograph of T14-10 gdms shows calcite crystals and late opal.

The layered silica deposited in contact along the wall of the altered tuff contains microcrystalline calcite-silica layers intercalated between relatively pure silica layers. The XRD pattern for this layered silica deposit shows a relatively sharp opal-CT diffraction band centered over 21.59° 2θ. As in the adjacent altered tuff, this opal diffraction pattern represents an average of more than one opal type. The inset photomicrograph of the layered silica deposit (T14-10 vein in Fig. 9) shows at least two types of opal on a microscopic scale, with massive or colloform colorless opal of moderate birefringence deposited on earlier brown colloform opal. A sharp quartz diffraction peak is also seen in this XRD pattern, but this peak is due to broken fragments of earlier drusy quartz that have been incorporated into the layered silica deposit.

Drusy Quartz in Trench 14

Euhedral quartz crystals form encrustations (i.e., drusy quartz) on many of the cavities in the Tiva Canyon Member exposed in Trench 14. The age of these relatively coarse (up to 0.5 cm) quartz crystals is of interest because their relation (if any) to the later opal deposition within the fault will have a bearing on the interpretation of the calcite-silica deposits. Drusy quartz crystals have been collected from Trench 14 for fluid inclusion and stable isotope studies and to attempt age determination by electron spin resonance. Preliminary data suggest a relatively high temperature of formation (D. Vaniman, letter of 7/85 to D. Vieth). The occurrence of a significant peroxy-defect electron spin resonance signal suggests that the drusy quartz is not young (S. Levy, pers. commun., 9/86). The distribution of drusy quartz in Trench 14A, just north of Trench 14, is revealing; here two different tuffs, the Tiva Canyon Member (12.4 My age) of the Paintbrush Tuff and the Rainier Mesa Member (10.4 My age) of the Timber Mountain Tuff occur on opposite sides of the fault. As in Trench 14, the drusy quartz is found in place in the Tiva Canyon wall rock and as broken fragments dragged into the fault along with the tuff. In Trench 14A, however, there is the added constraint that the drusy quartz is not found in the Rainier Mesa wall rock. These relations indicate that the drusy quartz predates most if not all of the calcite-silica deposits of the fault (in which it occurs only as accidental fragments) and predates the juxtaposition of Tiva Canyon and Rainier Mesa tuffs along the fault (S. Levy, pers. commun., 8/86). Actual dating and interpretation of the drusy quartz occurrence is of considerable interest because this material is widespread throughout the Tiva Canyon Member and near the base of the Topopah Spring Member at Yucca Mountain, but the evidence so far available indicates that it is a deposit considerably older than the calcite-silica and silica layering within the faults studied in trenches.

Sample from Trench 17

A sample from Trench 17 (Fig. 1C) is described here for comparison to the Trench 14 samples, to illustrate the lateral uniformity in mineral composition but variation in texture of the fault deposits along the flank of Yucca Mountain. Within the fault exposed in Trench 17 the total width of the calcite-silica deposit is less (about one meter), and small-scale banding of calcite-silica and silica depositional layers does not occur as in Trench 14. Instead, the fault-filling deposit is a single complex brecciated mass of opal-CT and calcite, with fragments of tuff and of drusy quartz crystals as described in Trench 14. Ooidal structures are almost completely absent, although many of the calcite-silica clasts incorporated in the deposit have an enigmatic structure of small (0.05 - 0.1 mm) aligned polygonal cells which are often curving or concentric (relict ooids?; see inset photomicrograph in Fig. 10). Despite the strikingly different texture, the mineralogy of the sample from Trench 17 is virtually identical to the predominant mineralogy (calcite, opal-CT, and minor clay) of Trench 14 (compare the upper part of Fig. 10 with the upper part of Fig. 9). Opal-A, however, has not been found in the fault deposit of Trench 17. Neither have organic structures been found in either hand sample or thin-section. The similarity in major mineralogy with Trench 14 indicates that although the calcite-silica deposits in the faults are texturally very complex and include a wide variety of brecciated and detrital rock and mineral fragments, the deposits that actually crystallized from solution within the faults are consistently composed of calcite and opal-CT with minor amounts of sepiolite or smectite and rare occurrences of opal-A. Opal-A appears to be restricted to young and fragile (unfaulted?) accumulations of organically-controlled silica deposition.

(B) HYDROTHERMAL VEIN DEPOSITS NEAR YUCCA MOUNTAIN

Hydrothermal vein deposits are abundant throughout the silicic volcanic rocks of Nevada, often with associated mineralization. Where these veins approach the surface they may merge into warm-spring type deposits (section C, below). Most descriptions of such systems emphasize the often associated

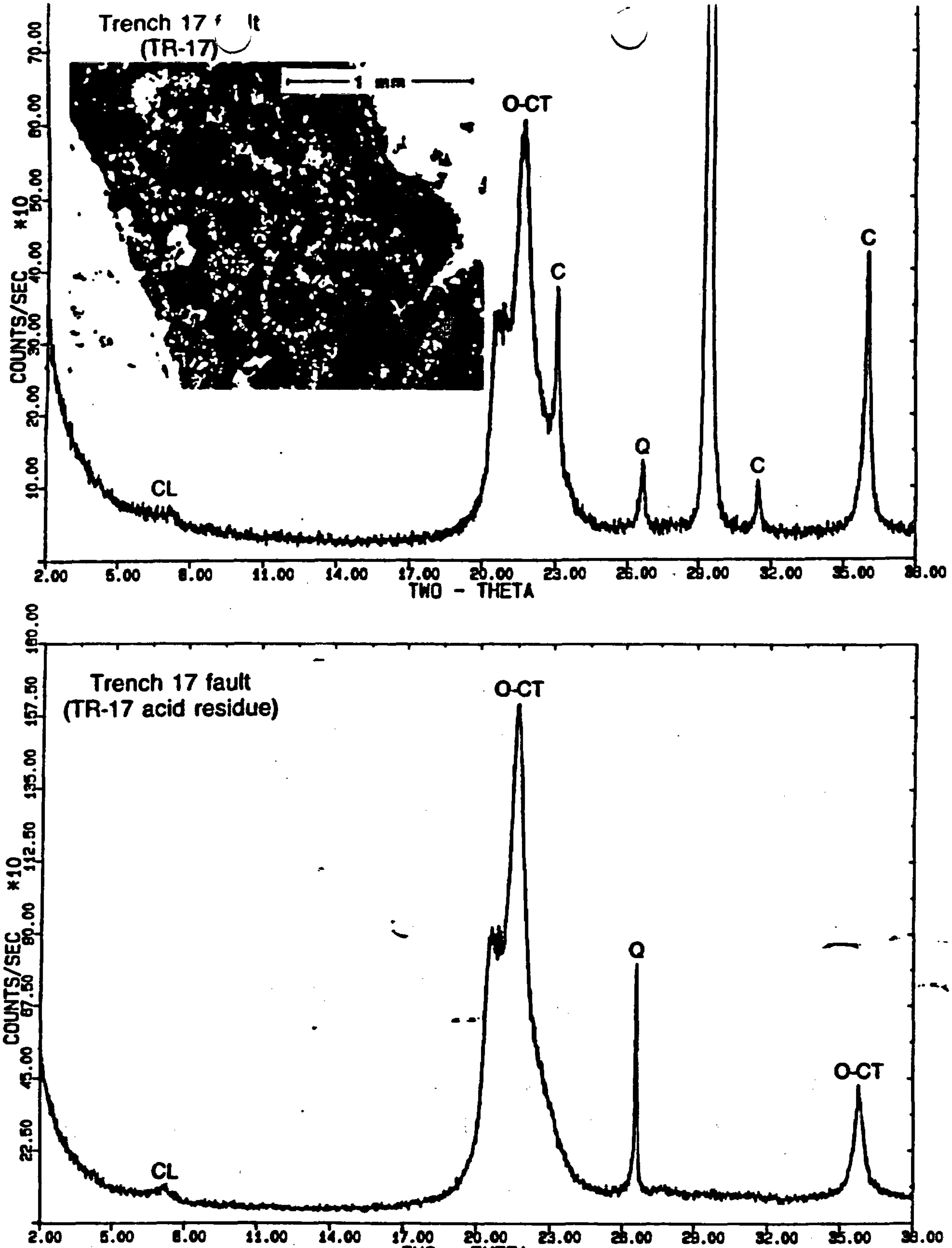


Fig. 10.

XRD patterns of both a bulk sample (TR-17) and an acid-treated sample (TR17-1 acid residue) from Trench 17. Inset photomicrograph shows possible relic ooids within dark calcite and opal of the bulk sample. The diffraction peaks of calcite (C), opal-CT (O-CT), quartz (Q), and clay (CL) are labeled.

deposits of economic minerals, primarily gold and silver (Sawkins 1984; Berger and Eimon 1983). The Tonopah district is one such locale, where quartz and quartz-calcite veins occur, which might be compared with the deposits in trenches near Yucca Mountain. Opalized zones can also be found near the surface in such systems (Berger and Eimon 1983); more will be said on this point in the discussion of warm spring sinter deposits below. A major distinction between the Yucca Mountain fault deposits and the Tonopah-type deposits, however, is the association with sulfur and sulfide/sulfate minerals (alunite, pyrite, and base-metal sulfides) in the hydrothermal veins. One might argue that it would be more appropriate to examine barren hydrothermal deposits because there is so little economic potential at Yucca Mountain, but for the same reason that valuable hydrothermal deposits are so well known there is very little known about the barren ones. Fortunately, there recently have been several studies of hydrothermal alteration at Yucca Mountain itself, because Yucca Mountain is being considered as a potential site for high-level waste disposal.

What kind of hydrothermal alteration occurs at Yucca Mountain? Caporuscio et al. (1982) describe hydrothermal alteration assemblages at depths of 1000 m and more below the surface at the northern end of Yucca Mountain, in a region west and northwest of Trenches 14 and 17. This alteration is marked by the development of calcite pseudomorphs after volcanic feldspar phenocrysts, by illite, by calcite-quartz-barite veins, by pyrite, by fluorite, and by manganese minerals (e.g. todorokite). In a more recent study (Bish 1986), the data obtained from illite and smectite interstratifications have been used to estimate the temperatures of this hydrothermal alteration (temperatures from 100°C to greater than 275°C have been calculated, depending on depth and location within the hydrothermally altered zone). Moreover, the report by Bish (1986) presents some preliminary K/Ar age data from three illite samples of the hydrothermally altered zone which give consistent ages of 11 Ma for the end of the hydrothermal alteration. Thus the hydrothermal features beneath the trenched faults near Yucca Mountain are deeper (1000 m), older (11 Ma), and mineralogically very different (common sulfide, sulfate and manganese minerals) than deposits in the trenched faults.

There are also near-surface hydrothermal veins just ten kilometers to the north of Trenches 14 and 17. Most of these veins are quartz with minor accessory mineralization, but some of the veins contain opal. Figure 11 shows the

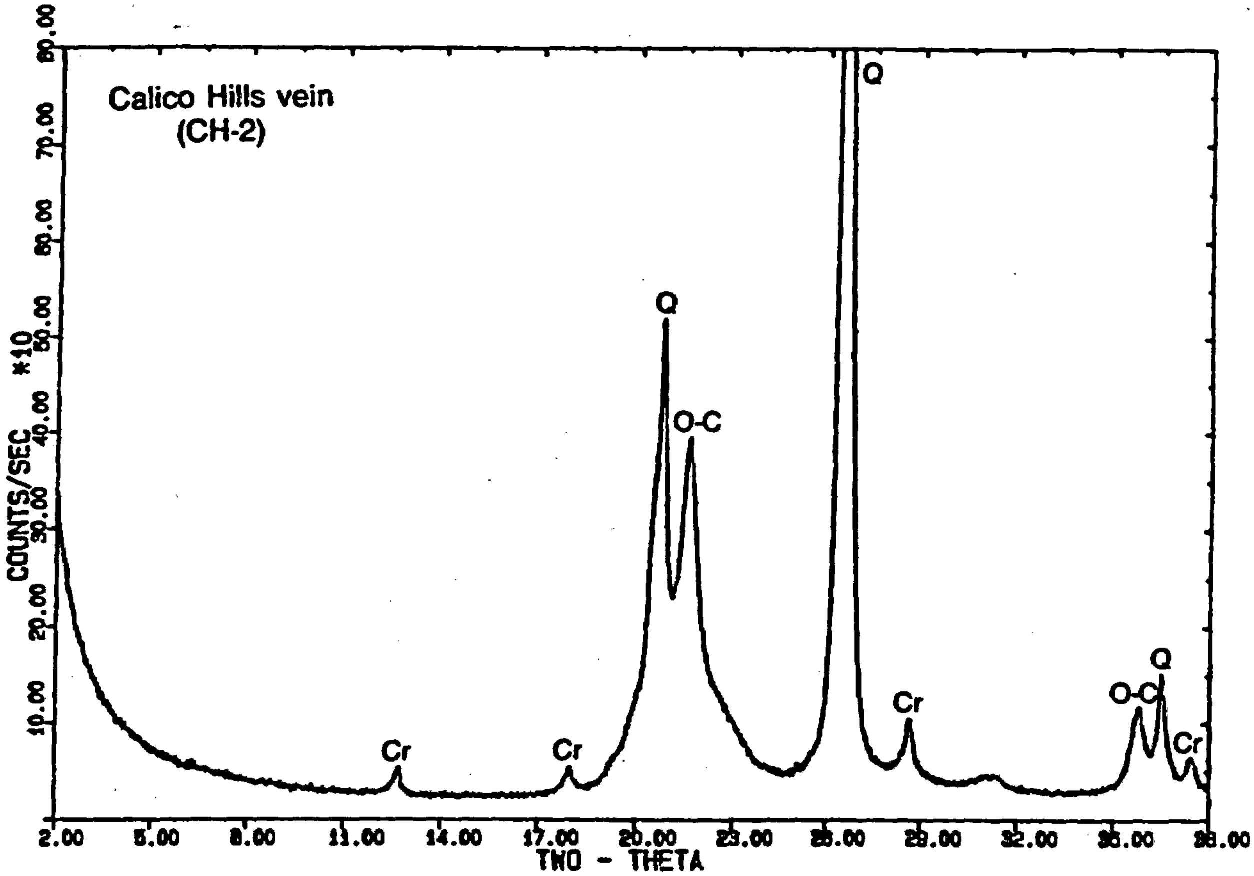


Fig. 11.
XRD pattern of a hydrothermal vein from the Calico Hills. The minerals labeled are quartz (Q), opal-C (O-C), and cryptomelane (Cr).

XRD pattern of a quartz-opal-cryptomelane vein from the Calico Hills. In this sample, unlike the fault deposits, the opal is highly crystalline (opal-C; compare with Fig. 5). As in the hydrothermal alteration at depth beneath Yucca Mountain, manganese minerals are associated with the silica. The absence of sulfides and calcite in this near-surface vein suggests different fluids or different timing of emplacement as the fluids evolved, but both the deep and the shallow hydrothermal deposits near Yucca Mountain are unlike the calcite - opal-CT deposits with opal-A and smectite or sepiolite that occur near-surface in faults.

(C) WARM-SPRING DEPOSITS

Figure 1A shows the distribution of some active warm springs and some warm-spring sinter deposits in Nevada. One (Bailey Spring) is in Oasis Valley within 30 Km of Yucca Mountain (Fig. 1B); the closest active springs with notable sinter deposits are far to the north, about 300 Km from Yucca Mountain Fig. 1A). In this section the efflorescence deposits in the valley floor at Oasis Valley, the sinter deposits around Steamboat and Brady springs, and a paleo-spring mound near Wahmonie (Fig. 1B) are described for comparison with the near-surface deposits in faults at Yucca Mountain.

Spring Deposits in Oasis Valley

Oasis Valley contains more than 20 springs with discharge temperatures ranging from 19°C to 36°C (White 1979). Many of the tuffs surrounding the valley have been altered, with alteration assemblages composed of kaolinite, alunite ($KAl_3(SO_4)_2(OH)_6$), and opal-CT with lesser amounts of gypsum and calcite. It is not known whether this tuff alteration is related to present spring activity, but an analysis of the white to yellow-white efflorescence deposits in the valley includes one abundant sulfur-bearing phase: burkeite ($Na_6(CO_3)(SO_4)_2$) occurs along with trona ($Na_2(CO_3){:}Na(HCO_3){:}2H_2O$) and halite (Fig. 12). From the abundance of burkeite in the present-day efflorescence

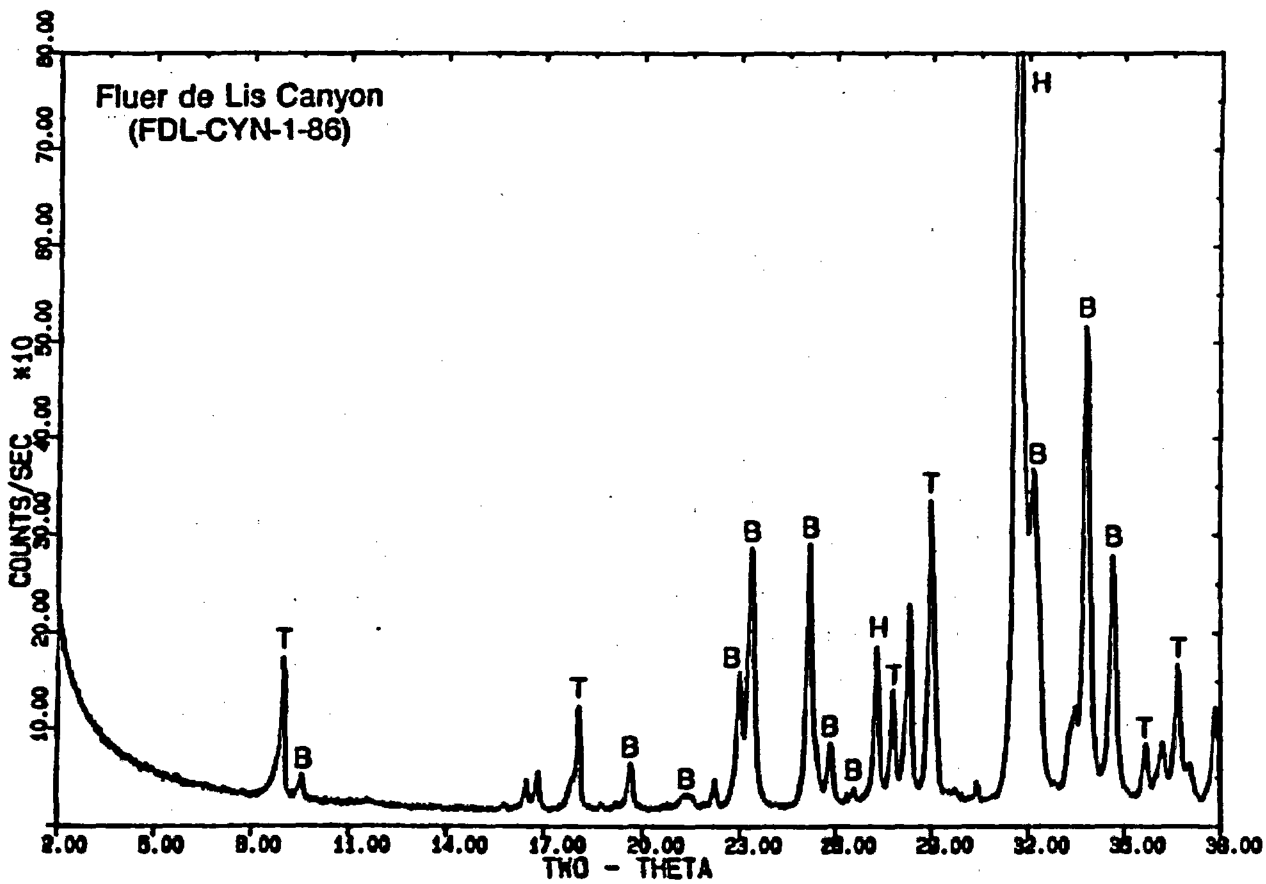


Fig. 12.
XRD pattern of spring efflorescence from Oasis Valley. The diffraction peaks labeled are halite (H), burkeite (B), and trona (T).

on the valley floor to the abundance of alunite in the past alteration of the tuffs, it is evident that the deposits produced in this system have always been strongly sulfur bearing. This type of alteration and deposition is unlike the sulfur-free deposits in faults exposed near Yucca Mountain.

Warm-Spring Sinter Deposits

Warm-spring sinter deposits have been studied from the nearest localities (Horton 1964) at Steamboat Springs and at Brady Hot Springs (also known as Springer's Spring). These sinter deposits are characterized by localized accumulations of almost pure opal-A (Fig. 13), along with sulfur or sulfur-containing minerals such as gypsum and alunite. The association with sulfur is evident even in the most purely opaline sinter materials, where trace-fossil tubules contain small residues of pyrite (inset photomicrograph, Fig. 13). At Sou Spring (Fig. 1) the altered tuff also contains gypsum. Further studies are planned of these and other sinter deposits of the region, but the data available so far are consistent in demonstrating the ubiquitous presence of sulfur which is unlike the calcite-silica deposits in the faults exposed around Yucca Mountain.

In the discussion of hydrothermal veins (section B), an important feature of the hydrothermal vein deposits around Tonopah was their association with sulfur-bearing minerals such as alunite. This association is evidence that the sulfur-silica systems found around the sinter deposits in west-central Nevada mirror the near-surface hydrothermal vein deposits of the same region. The relations between warm spring deposits and the formation of shallow mineralized veins has been known at Steamboat Spring for over a century (LeConte 1883). Thus both the hydrothermal veins and the surface sinter might be considered as essentially a single depositional system with depth gradations, such as Ross et al. (1982) describe at Roosevelt Hot Springs in Utah (in which sulfur minerals are also important associates with silica sinter).

This comparison of the fault deposits at Yucca Mountain with Nevada's sinter deposits begs the question of what a sinter deposit would look like in a sulfur-poor warm spring system. For an interim answer, petrographic and XRD data have been examined from an extensive siliceous sinter area at San Ignacio in Honduras. Although far from Nevada, this sinter also overlies an area of crustal extension. More importantly, this system is relatively sulfur-free. The sinter deposits here are petrographically different from the Nevada sinters; where the Nevada sinters contain laminated botryoidal opal with a

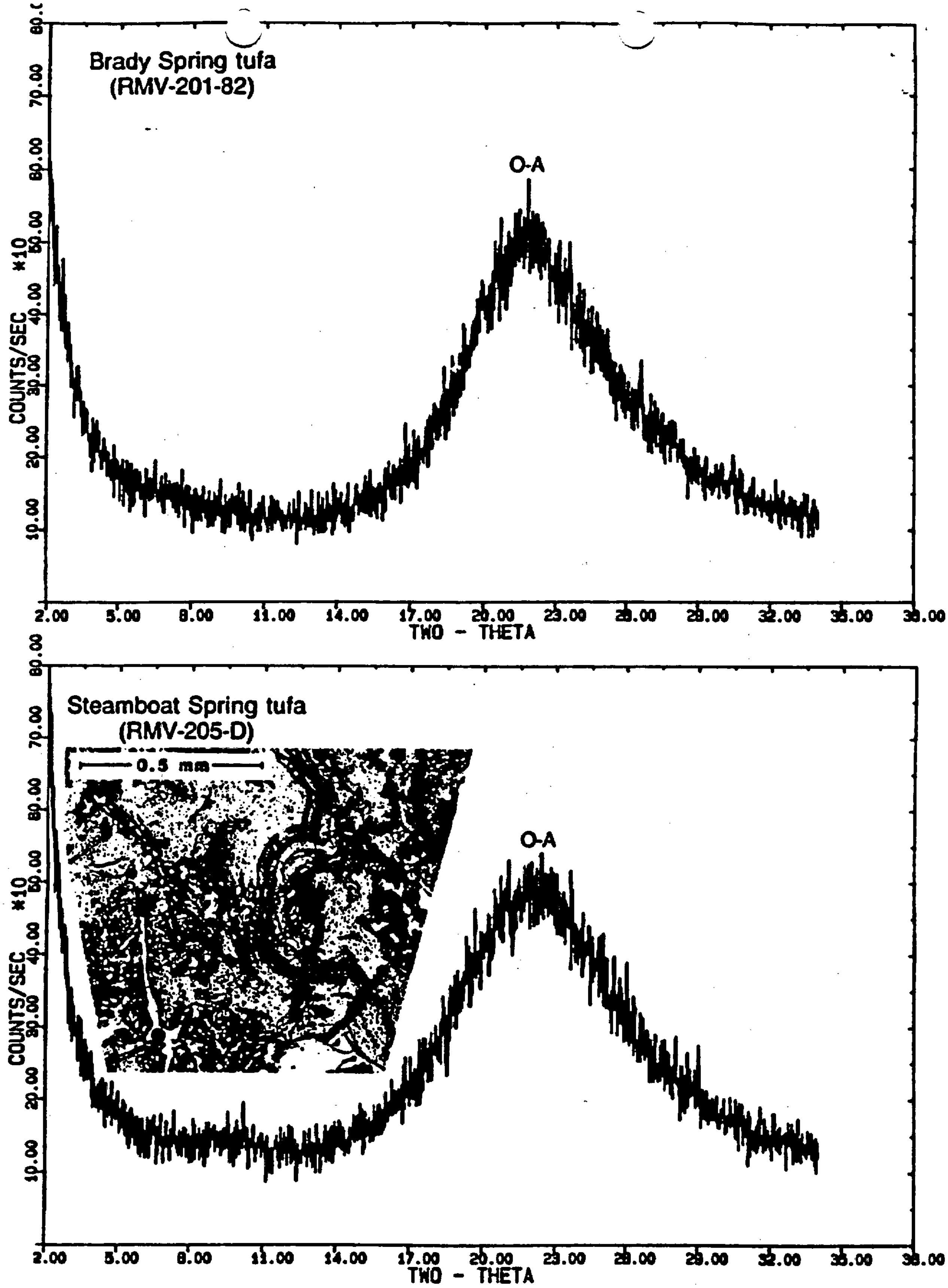


Fig. 13.

XRD patterns of opal-A sinter from the warm springs at Brady (RMV-201-82) and at Steamboat Springs (RMV-205-D). Inset photomicrograph shows tubules of organic origin containing small pyrite crystals in the opal-A of sample RMV-205-D.

few trace fossil remains (photomicrograph in Fig. 13) the San Ignacio sinters consist of cemented masses of opaline plant fossils. In both types of sinter deposits, however, the opal is opal-A. Further studies are planned, but our observation so far is that warm spring sinters are characterized by primary deposition or organic-debris cementation with amorphous opal (opal-A). With time it is certainly conceivable that the opal-A sinters might alter to opal-CT and then to quartz, in a manner analogous to the well-studied diagenetic sequence in deep-sea oozes and in siliceous sediments (Kano 1983; Kastner et al. 1977; Williams et al. 1985). However, the aging process in silica sinters has not been documented and it is quite possible that near-surface systems with hot circulating water may transform directly from opal-A to quartz (Oehler 1976). The complications of likely disequilibrium and impure systems (Williams et al. 1985) make theoretical treatment of such a transition largely impractical. More field data from sinter deposits are needed.

The Paleo-spring Mound at Wahmonie

Although the only active warm springs close to Yucca Mountain are in Oasis Valley, there is a paleo-spring mound on the Nevada Test Site above Wahmonie, 28 km east of Yucca Mountain (Fig. 1B). This spring mound consists of almost pure gypsum with minor calcite (Fig. 14), and appears to represent deposits from an old hot-water discharge centered in the Wahmonie ore district, which was once mined for gold, silver, and copper (Bell and Larson 1982). As at Tonopah, this hydrothermal system combines precious metals with sulfur-bearing mineralogy. Silica sinter, however, does not occur at Wahmonie. In its abundance of gypsum and lack of silica, the paleo-spring mound at Wahmonie is quite different from the fault-related calcite-silica deposits near Yucca Mountain.

(D) COLD-SPRINGS OR SEEPS, AND PLAYA DEPOSITS

Several active cold springs or seeps occur within a few tens of kilometers of Yucca Mountain in southern Nevada and in nearby Death Valley (Fig. 1). The springs of Oasis Valley include warm discharges and valley-floor efflorescences that are described in section C above. The springs of Death Valley, with their carbonate deposits and the associated carbonate deposits at Devil's Hole and along the eastern edge of the Amargosa Valley, are described by Winograd et al. (1985). A complete set of samples for these deposits is

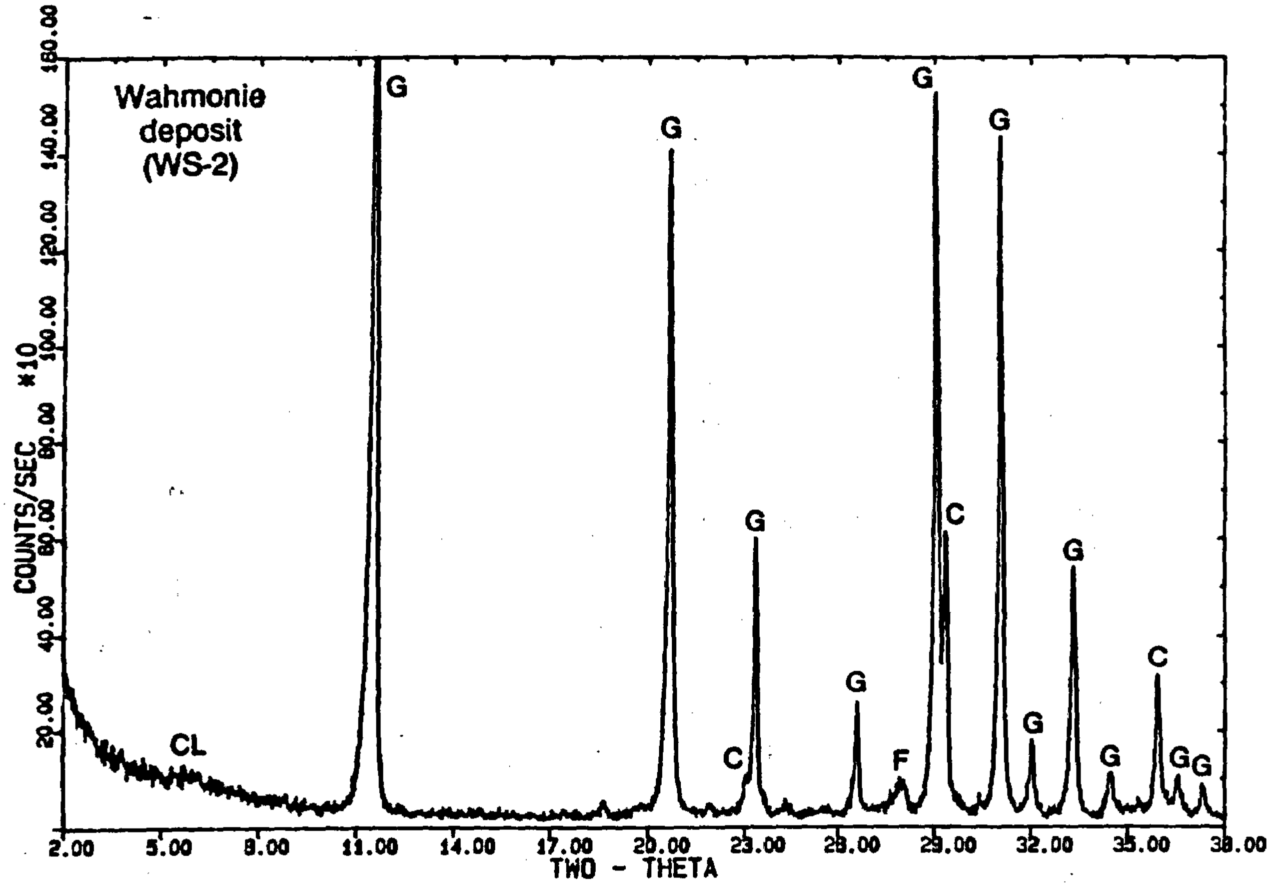


Fig. 14.

Gypsum (G) of the paleo-spring deposit near Wahmonie, with minor amounts of calcite (C) and smectite (CL).

not yet available, but one sample of the calcite deposit at Navares spring has been studied. The sample studied is dense and buff-colored, superficially similar to the dense lenticles that are found in the fault at Trench 14 (e.g., sample T14-F described in section III). However, petrographic and XRD analyses show that the Navares sample consists of almost pure calcite occurring as masses of euhedral microspar crystals with scalenohedral habit (Fig. 15). These crystals are of intermediate-Mg calcite (Milliman 1974) rather than low-Mg calcite as in Trench 14 and at the tufa deposit southwest of Moapa (described below). This distinction, however, is based on a small difference in magnesium content. The absence of any authigenic silica phase is more significant and makes this deposit very different from the calcite-silica deposits in faults around Yucca Mountain.

Several springs occur on the Nevada Test Site not far from Yucca Mountain. Topopah Spring contains no deposits except for some very thin rinds

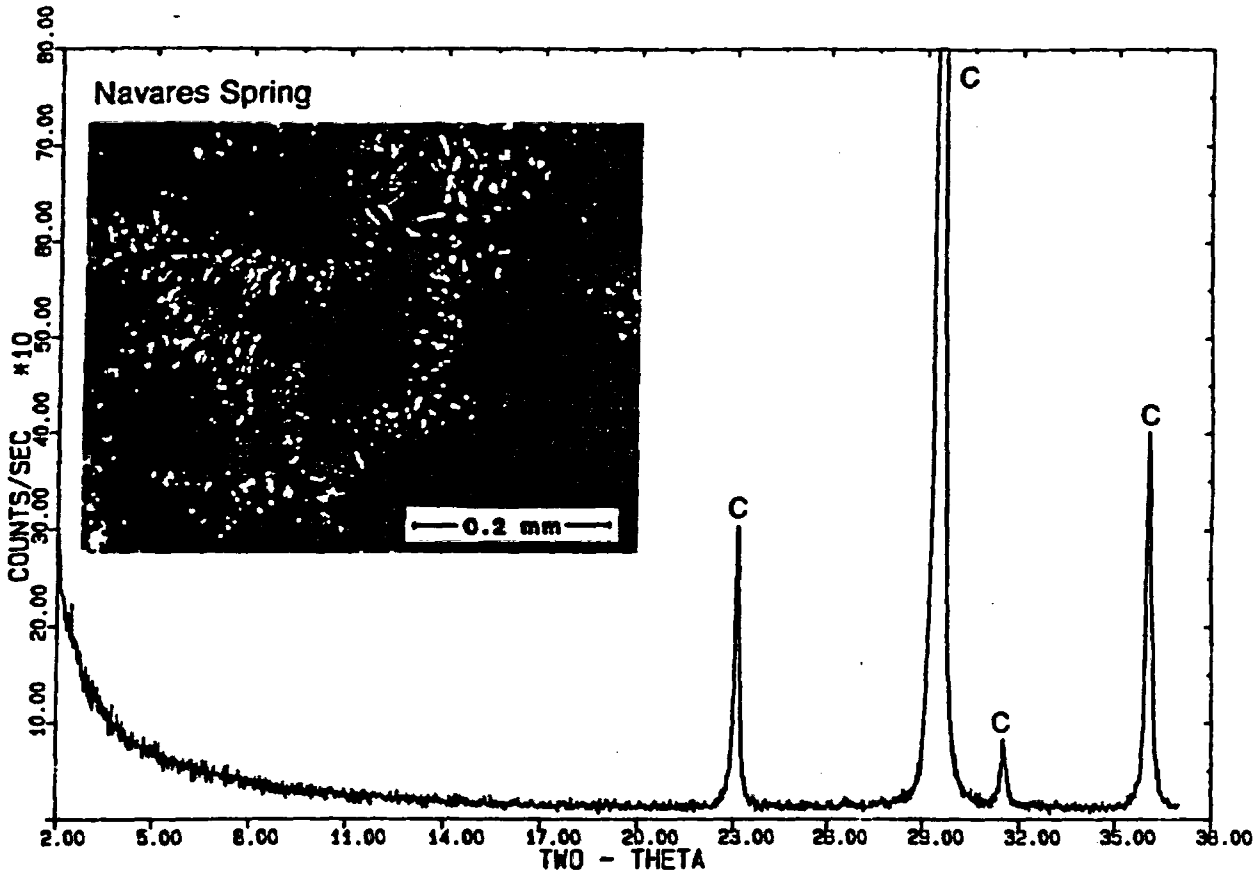


Fig. 15.
Calcite (C) of the dense microspar tufa from Navares. Inset photomicrograph shows scalenohedral habit of the calcite microspar.

of calcite on nearby boulders and cobbles; these deposits are of questionable origin because they are as likely to be caliche as deposits from the spring. Cane Spring has small calcite mounds and pedestals of less than 1 mm diameter underlying live algae near the point of spring discharge. These deposits at Cane Spring are of pure calcite. Both Topopah and Cane springs issue from tuff, but a small seep that issues from a thrust separating Mississippian Eleana argillite from overlying quartzite is described by Jones (1983) and has a deposit of calcite with abundant sepiolite. This seep, at the eastern flank of the Eleana range, is shown in Fig. 7. The sepiolite-calcite assemblage at the Eleana locality is closer in resemblance to the deposits in faults around Yucca Mountain, but even the Eleana seep deposit lacks the abundant opal of the faults at Yucca Mountain. Sepiolite from this locality is characterized by a highest-intensity peak at 12.6 Å and distinguished from palygorskite by a peak at 2.68 Å (Jones 1983, his Fig. 2). Sepiolite from Trench 14 (Fig. 6) differs by having comparable diffraction maxima at 7.2° 2θ (12.3 Å) and 34.86° 2θ (2.57 Å). There are not yet enough data to indicate whether the smaller lattice spacings at Trench 14 are significant.

Paleo-spring Deposits South of Yucca Mountain?

Szabo et al. (1981) describe two localities, with their identifying numbers 106 and 199 (Fig. 1B), as being a possible seep deposit of about 78,000 year age (locality 106) and a possible spring deposit of about 30,000 year age (locality 199). Locality 106 appears be fault-related and has field relations (deposit draped over a slope gradient from a subhorizontal surface into a fault) similar to those exposed in Trench 14. Locality 199 is poorly exposed. Both of these localities will require excavation and mapping before samples are collected for mineralogic comparison with other localities. There are not yet sufficient data to determine whether these deposits might be associated with warm-spring, cold- spring, seep, or soil-process origins.

Paleo-spring Deposit near Moapa

A paleo-spring travertine deposit occurs in Dry Lake Valley southwest of Moapa (Fig. 1B). Estimates of paloetemperature have not been made in this study, but the preservation of triangular casts of bull rushes near the paleo-spring source indicate that temperatures were not so high as to leave the mound barren of such plants. Present spring discharge in the Moapa area is about 32°C (Garside and Schilling 1979), but no direct connection between this active discharge and the deposits in Dry Lake Valley is known. The description of this spring travertine deposit is provisionally included with cold-spring deposits.

The remains of the spring orifice contain numerous tubular structures with walls constructed of concentric rings of small (0.02-0.06 mm) radially arranged calcite crystals (Fig. 16). The tubes themselves are a few centimeters in diameter. Central openings in the tubes were originally up to 1 cm in diameter but are now almost plugged with detrital mineral grains (quartz, with lesser amounts of microcline, plagioclase, pyroxene, biotite, amphibole, and altered lithic fragments) and with calcite ooids of 0.05-0.25 mm diameter. XRD analysis shows the tube walls to be composed of almost pure calcite (Fig. 17); electron microprobe analysis (Table II) shows that the calcite is low-Mg, comparable to the calcite in Trench 14. The greatest difference between this deposit and that at Trench 14 (section A, above) is the absence of authigenic silica. At this paleo-spring travertine deposit,

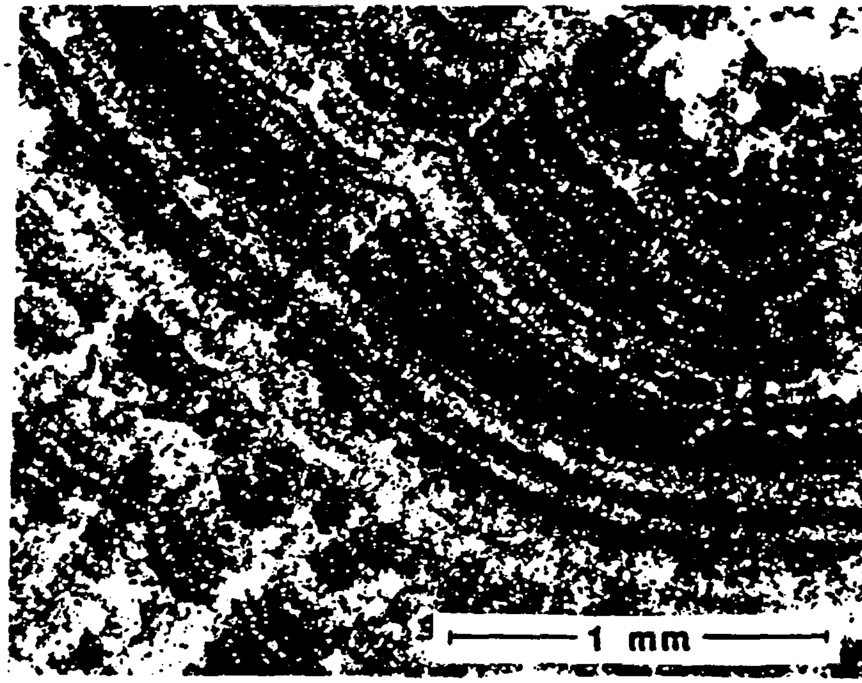


Fig. 16.
Photomicrograph of laminated calcite growth forming the wall of a discharge tube in mound southwest of Moapa (sample MO-1).

however, there is an outflow facies that extends for several tens of meters from the central source. It is appropriate to examine how the mineralogy and petrography of the travertine change away from the source, particularly where surface weathering and soil formation have occurred.

Figure 17 compares the XRD pattern for the pure calcite of the travertine source tubules (MO-1) with banded travertine 0.5 m deep within the outflow facies (MO-2), and travertine at the surface of the outflow facies (MO-3). Sample MO-2 contains a smectite not found in the spring source; sample MO-3 contains more of this smectite, suggesting that clay formation is part of the transition from travertine to soil in the flat outflow sheet. It is important to note that authigenic silica does not form as part of the alteration process. The quartz in samples MO-1, MO-2, and MO-3 (Fig. 17) is detrital and with other detrital minerals forms the nuclei of ooids. Both samples MO-2 and MO-3 contain the same detrital minerals as found in MO-1. These samples are characterized by abundant ooids. Small simple ooids of 0.05 mm occur, usually without cores of detrital minerals. Ooids of 0.3-0.4 mm diameter are abundant; many have detrital mineral cores. Sample MO-2 also contains complex ooids up to 1 mm across, some of which are formed by coalescence of several

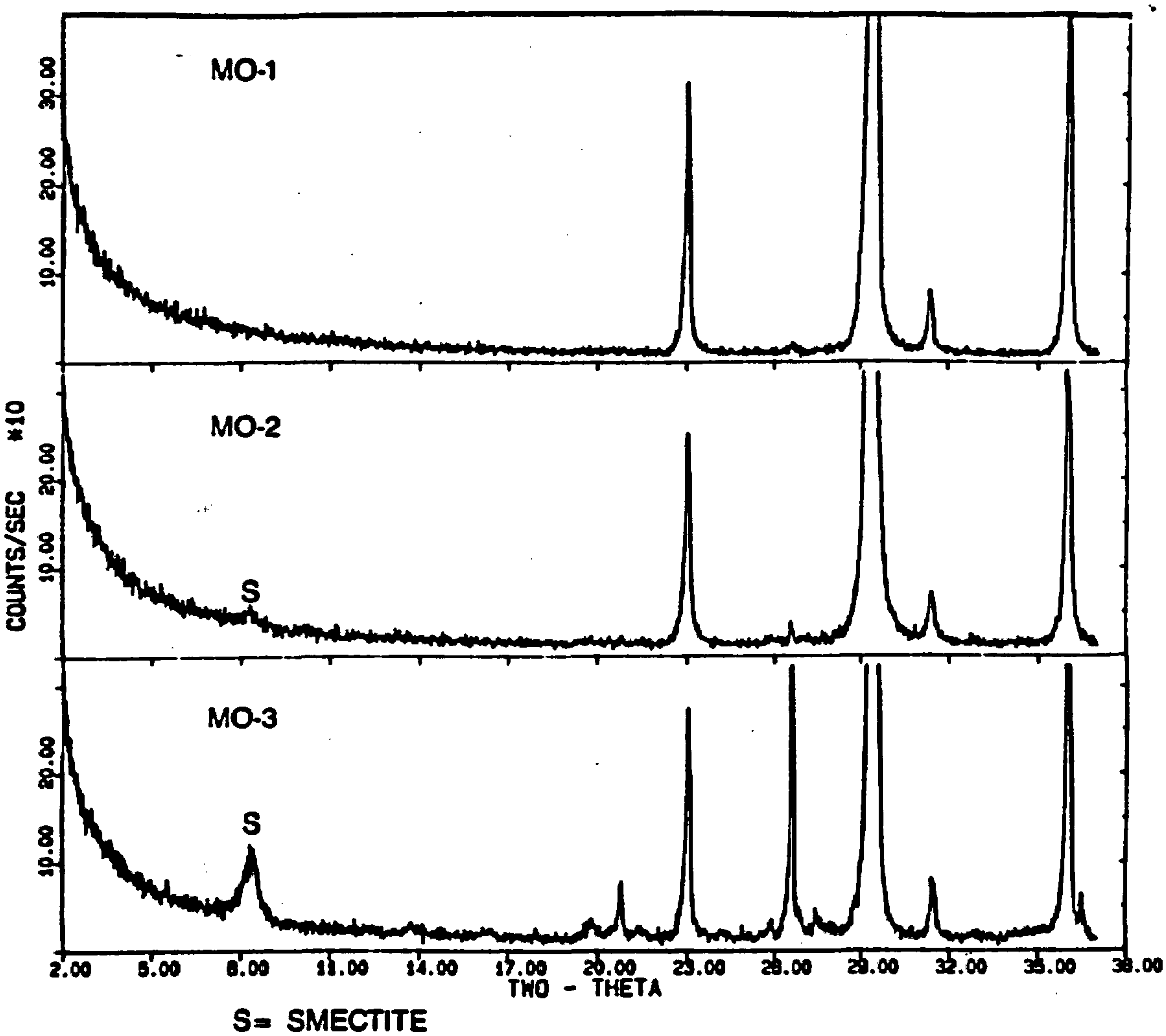


Fig. 17.

XRD patterns compared for a discharge tufa mound southwest of Moapa (MO-1), for a sample at 0.5 m deep in the outflow deposit from the tufa mound (MO-2), and for the surface of the outflow deposit immediately above sample MO-2 (MO-3). The progression from spring tufa to weathered deposit results in increased smectite (S) content. Quartz (Q) is detrital and forms one of the common nuclei for calcite ooids.

smaller ooids. Several bands of ooids in MO-2 appear to be matrix-supported by micrite in the upper few millimeters but grain-supported (ooids compacted together) in the bottom of the band. Recrystallization of ooids is common, particularly in MO-3 where voids are lined by small calcite spar crystals of up to 0.5 mm. The abundance of ooids is greater than in the deposits of Trench 14, but the presence or absence of ooid forms is not distinctive between the two environments. The greatest difference between the deposits within faults and the Moapa spring locality is the absence of opal in all facies of the spring deposit.

Playa and Playa/Seep Deposits of the Amargosa Valley

Deposits of the Amargosa Playa (Fig. 7) have been described in detail by Papke (1972), Post (1978), Khoury et al. (1982), and Jones (1983). These descriptions have concentrated on the sepiolite found in this playa, and all have concluded that sepiolite can precipitate directly from solution in such an environment. Khoury et al. (1982) conclude that sepiolite saturation can occur in the local groundwater after about 10% evaporation. Within this playa deposit there are beds of essentially pure (80%) sepiolite with no other authigenic minerals, bounded by beds of an authigenic smectite-sepiolite-dolomite-calcite assemblage (Khoury et al. 1982). Paleo-spring mounds occur southwest of the Amargosa Playa in the Hectorite Whiting pit along the Amargosa River (Fig. 1B); these deposits contain the assemblage calcite-smectite-chalcedony-quartz. These Amargosa River spring mounds described by Khoury et al. are more similar to the deposits in faults around Yucca Mountain than are the playa deposits, although the silica in the spring mounds is relatively minor and consists of a late fracture filling by quartz rather than by opal.

The complex groundwater alteration of playa deposits described by Hay et al. (1986) along Carson Slough (Fig. 13) is the closest playa/seep approximation of the mineralogy precipitated in faults around Yucca Mountain. At Carson Slough the original playa deposits of limestone, dolomite and clays (with local phillipsite and K-feldspar) have been replaced by opal-CT, chalcedony and quartz from siliceous groundwaters. Distinct from the Yucca Mountain fault deposits is the transformation of opal to quartz and the two-stage separation of early carbonate and later silica deposition, without co-precipitation. Nevertheless, the partial similarity between this playa/seep deposit and the deposits in faults at Yucca Mountain is of interest and will be reviewed in the summary and conclusions (section V).

(E) SOIL DEPOSITS

Post (1978) describes caliche in an alluvial terrace north of Las Vegas as being somewhat similar to the Amargosa Playa deposit: calcite at the top, with sepiolite-dolomite at greater depth. In general, however, dolomite does not form in soils of the region and sepiolite occurs with calcite instead (Hay and Wiggins 1980; Jones 1983). A further characteristic of soils is the occurrence of opal, often occurring as a coating on ooid or pellet structures that are common among the calcretes (Hay and Wiggins 1980). Hay and Wiggins report that opal in the calcrete of Kyle Canyon, in the Spring Mountains west of Las Vegas (Fig. 1B), occurs as cement, veinlets and ooid coatings of opal-A and in chertlike layers and nodules of opal-CT. Thus, as in the fault-related deposits described in section III, both opal-A and opal-CT are present, although the relative abundance and the textural distributions are different: the fault-related deposits consist predominantly of ooid-coating and relatively pure laminae of opal-CT, with opal-A restricted to occurrences in which organic structures are preserved.

Hay and Wiggins (1980) cite evidence for the replacement of sepiolite and calcite by silica. They attribute this to a change in water chemistry, either due to short-term increased rainfall or to the long-term increase in Pleistocene vegetation leading to higher pCO_2 and lower pH in the vadose zone. These conditions would be sufficient to account for the cessation of carbonate deposition, although the conditions leading to opal deposition are not known and may include a combination of the principal factors of organic fixation, evaporation, temperature and local pH variations (Summerfield 1983) as well as being dependent on the relative purity of local fluids (Williams et al. 1985). The problems of trying to unravel which of these parameters were operative are multiplied by the consideration that "microsite" deposition was probable (Chadwick and Hendricks 1985), with a multitude of small isolated environments that were not necessarily all evolving in the same way.

The assemblage calcite-opal-sepiolite is found in soils of the region, but the most relevant comparison to the deposits in Trench 14 will be of soils from the immediate environment. It is important to emphasize that soil mineralogy can be quite variable on a local scale; Jones (1983), for instance, describes the regional transition from palygorskite at Mormon Mesa (Fig. 1) to sepiolite in samples around Yucca Mountain. Jones also found variation in soil deposits over a much smaller range around Yucca Mountain. For example, he found that calcic soils immediately west of Trench 14 (Fig. 7) contain no sepiolite or only traces of material that might be tentatively identified as chain-silicate clay whereas there is well-formed sepiolite in some (but not all) of the calcic soils in Jackass Flat and in Crater Flat. A more detailed study of soils in the area around Yucca Mountain is being pursued by E. Taylor

(USGS); Figure 18 shows the XRD patterns from one of the carbonate-plugged horizons in one of the oldest soils based on the soil geochronology developed by Taylor (oral commun., Jan. 1986), following the work of Hoover et al. (1981). The XRD pattern of the bulk sample (Figure 18) is complicated somewhat by detrital minerals, but the pattern of the clay-mineral separate is clearly of illite rather than that of a chain-silicate clay such as sepiolite. This illite is probably detrital rather than neoformed. In thin section, calcareous ooids (0.3-1.0 mm diameter) are common as in the fault-filling samples of Trench 14, but opal is relatively rare and occurs in the topsides of open voids between ooids (inset photo in Fig. 18) and coating the bottoms of some pebbles. Opal was not abundant enough in YW-2 for XRD determination of which structure type is present, and the development of discrete opaline layers or bands as in Trench 14 is not seen in this or in other terrace-forming soils of the area (E. Taylor, oral commun., Jan. 1986). A separate split of this sample (YW-2,R) was analyzed by XRD to determine the opal types, and the probable presence of both opal-A and opal-CT was found. Even in this old soil with extensive silica deposition, there is not as much silica as in the nearby fault deposits.

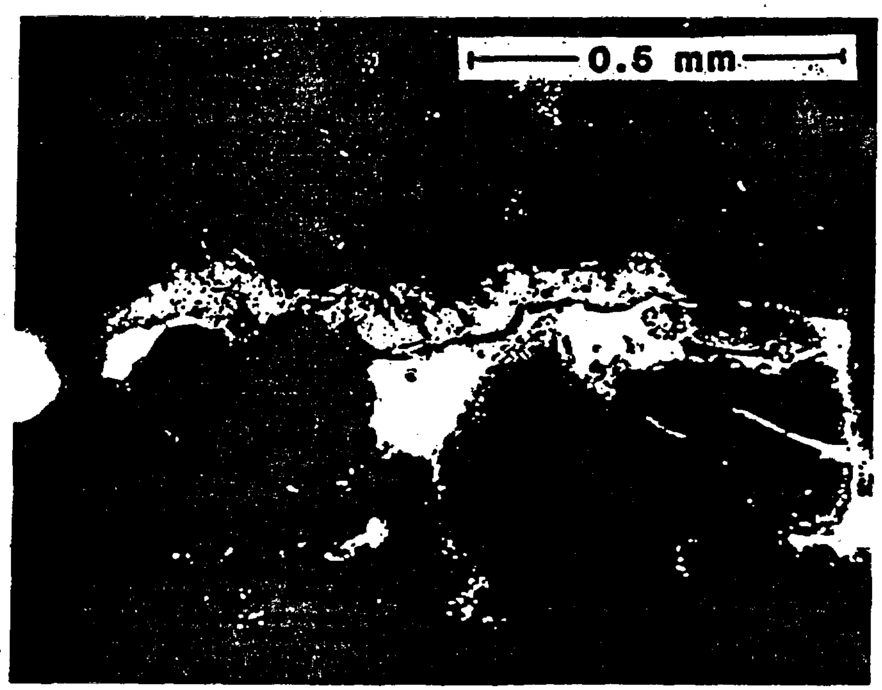


Fig. 18.
Photomicrograph of opal (opal-CT?) concentrated in the tops of a void above ooids and below a pebble in soil sample YW-2.

(F) CALCITE-SILICA DEPOSITS IN AEOLIAN SEQUENCES

Aeolian sands occur in several areas around Yucca Mountain. One of the most prominent areas of aeolian deposition is around Busted Butte and along the western flank of Fran Ridge (Fig. 1Q; in this area the sand deposits are several meters to several tens of meters thick and record a complex series of deflation and deposition events that can cumulatively form "sand ramps" around the tuff buttes and ridges (J. Whitney, USGS, oral commun., Feb. 1986). The upper portions of the sand ramps in this area commonly contain a slope-parallel calcite-silica deposit or a series of calcite-silica deposits that are approximately slope-parallel. Faults that cross upward through the sand ramps contain similar deposits (Fig. 19).

Figure 20 compares samples from a slope-parallel deposit on the flank of Fran Ridge (FR-6), a slope-parallel deposit from the northern flank of Busted Butte (BB-1), a near-surface fault filling from the western flank of Busted Butte (BB-2) and the slope-parallel deposit immediately above it (BB-3), and a clay-mineral separate (BB-5) from the surface sand immediately above the BB-3 deposit. All of the deposits, either along the sand ramp slopes or in the faults, consist predominantly of opal-CT and calcite, plus a clay mineral or clay minerals. The crystallinity of the opal may vary greatly between closely related samples; note that the slope-parallel deposit BB-3 has a much sharper opal-CT diffraction maximum at about 22° 2θ than the immediately underlying fault-filling sample BB-2.

Samples BB-3 and BB-2 were collected to examine the differences between slope-parallel deposits and the underlying fault fillings. In addition to the difference in opal crystallinity, the calcite-opal intergrowth textures differs in these samples. The slope-parallel deposit, BB-3, contains elongate cellular structures that appear to be fossilized plant remains oriented parallel to the deposit foliation (Fig. 21). Vegetation of the area is dominated by the genus Larrea (creosote bush) but includes mixed Lycium (boxthorn) and other plants (US DOE 1986). The fossilized remnants have not been correlated with a specific species but represent a vascular plant in which the cell walls have been replaced by very fine-grained calcite-silica and the cell interiors are filled by relatively clear opal. No such structures are found in the underlying fault filling (BB-2), and we infer that the the in-situ deposition of discrete opal during plant fossilization in the slope-parallel deposits

Fig. 19.
Photograph of slope-parallel calcite-silica deposit in a sand ramp on the western flank of Busted Butte. The geologist at the bottom of the ravine is examining a fault-filling extension of the deposit; the fault runs directly upward from his position to cut the slope-parallel deposit.

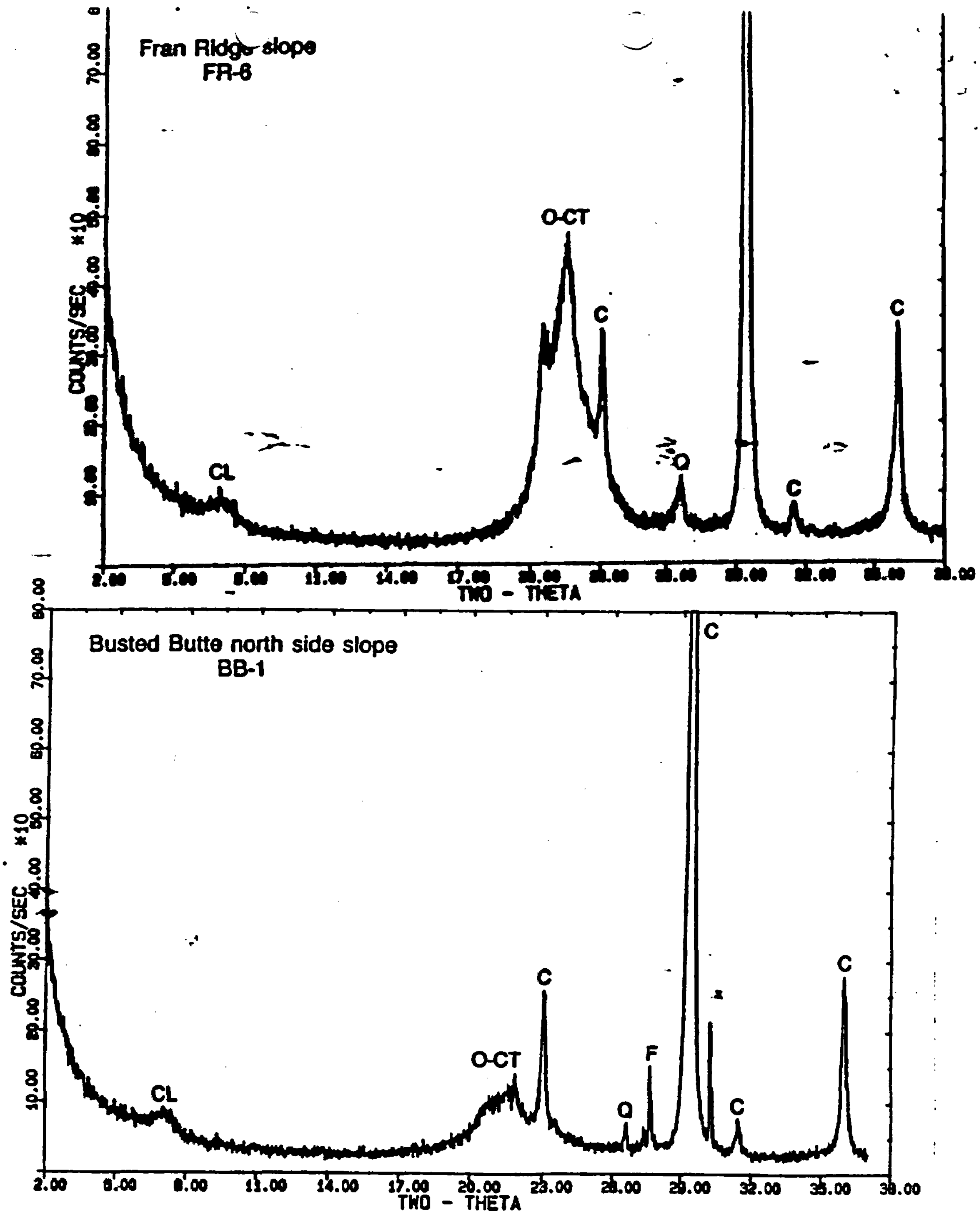
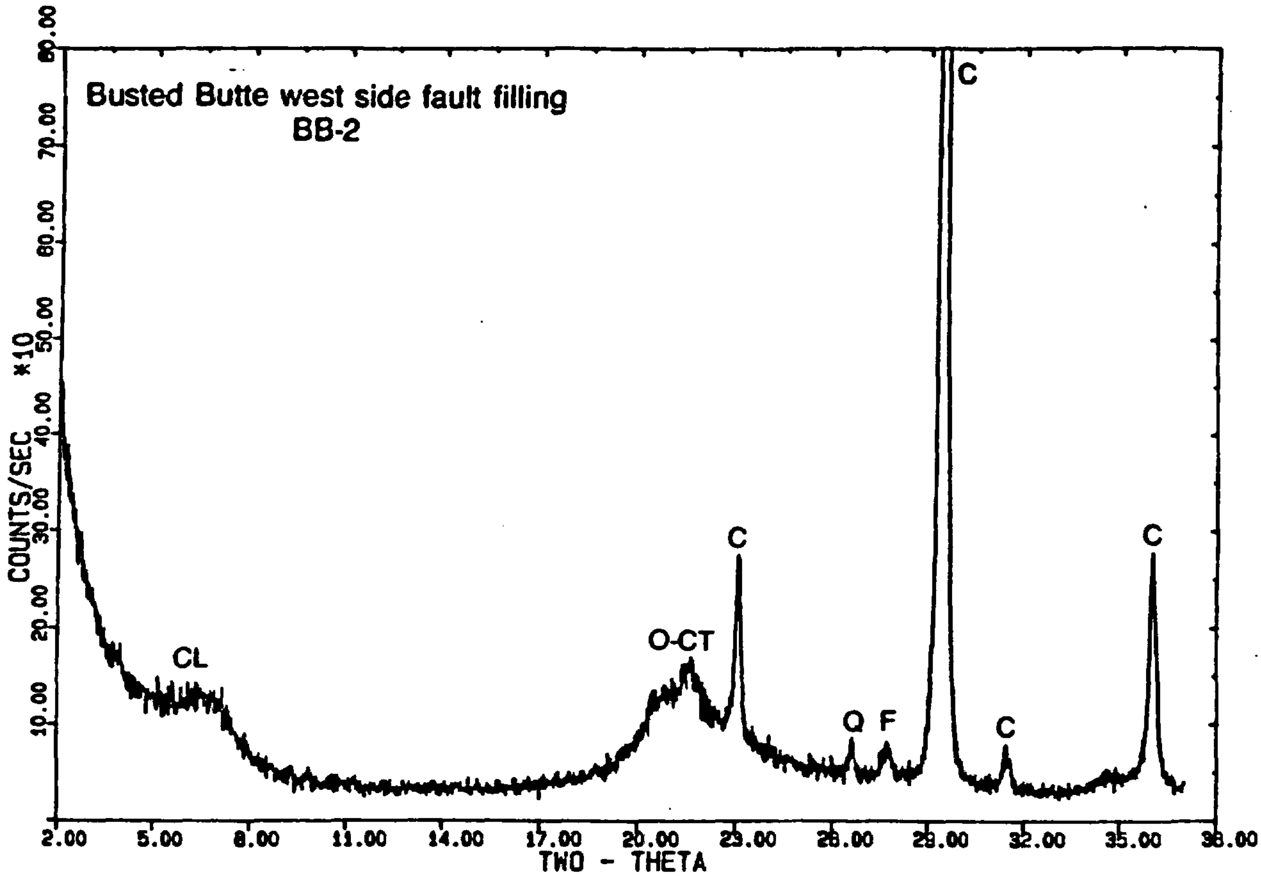
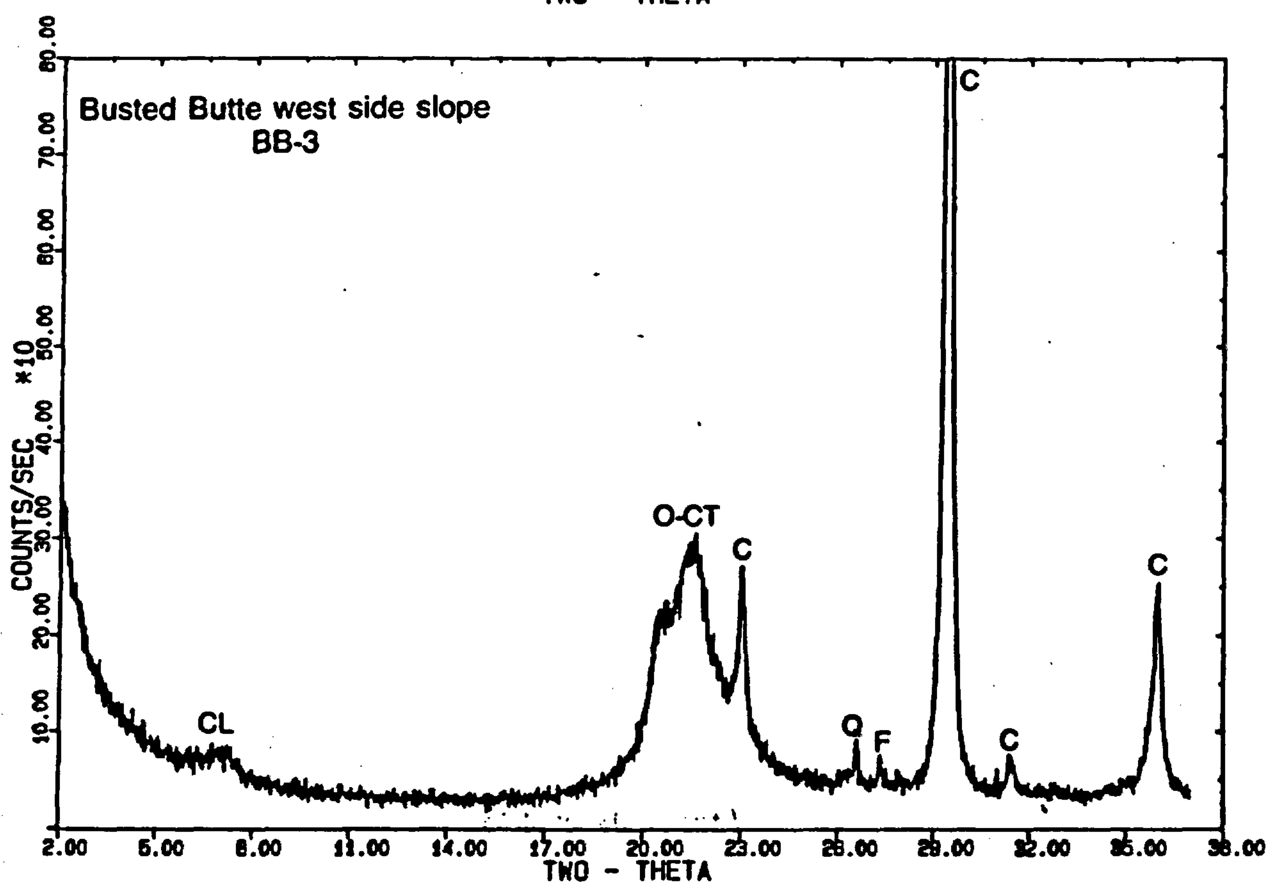
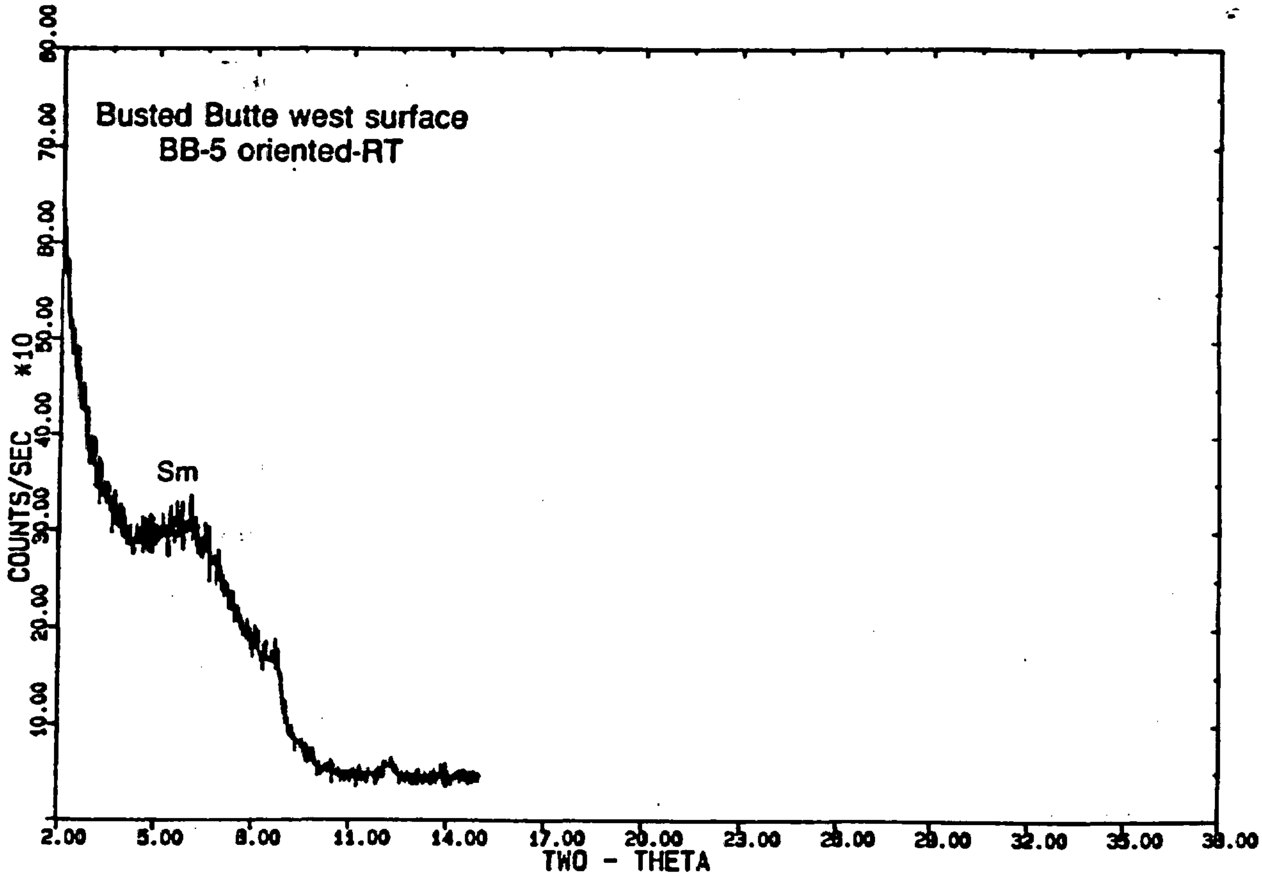


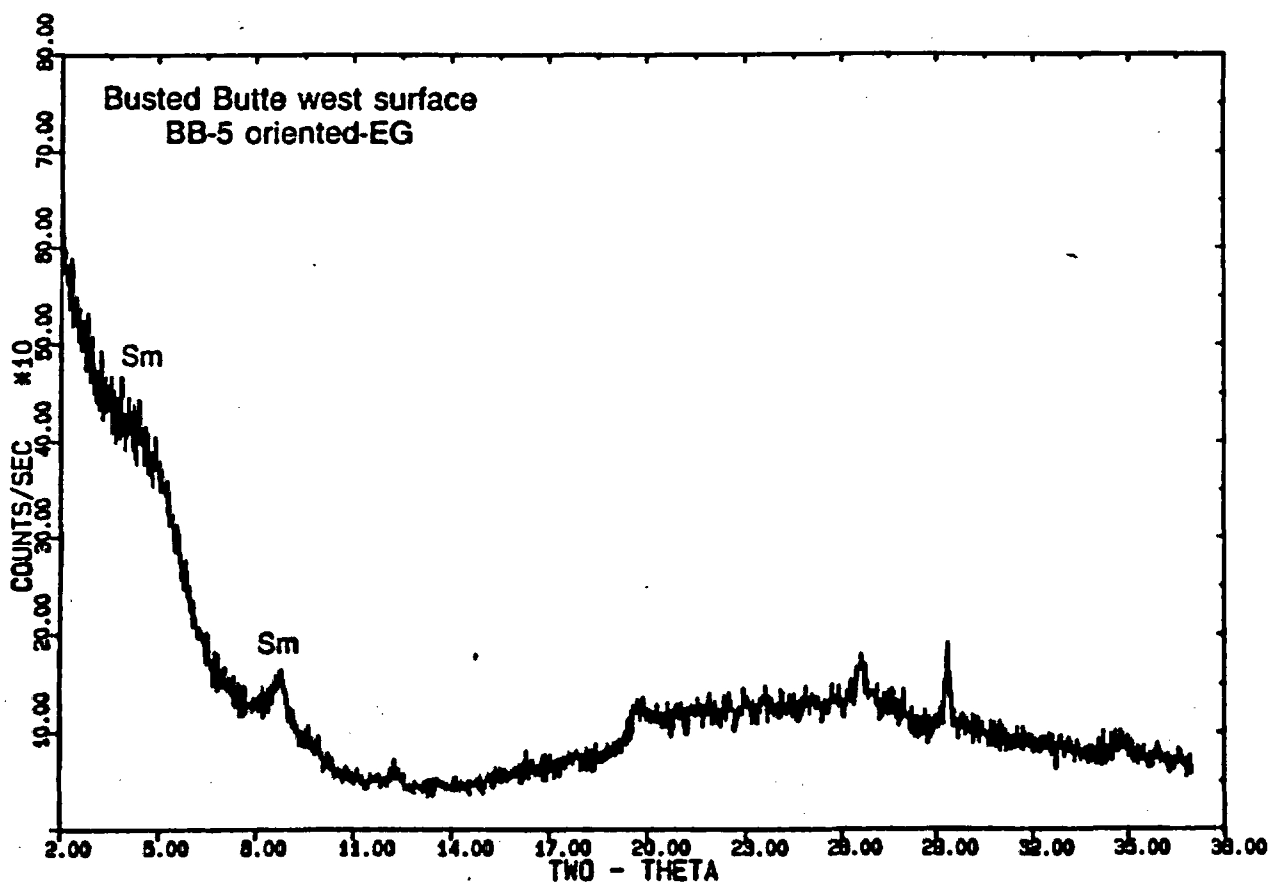
Fig. 20.

XRD patterns comparing slope-parallel calcite-silica deposits at Fran Ridge (FR-6) and at Busted Butte (BB-1 and BB-3), a fault-filling calcite-silica deposit in the sand ramp at Busted Butte (BB-2), and standard room-temperature and glycolated smectite samples (BB-5 RT and glyc.) from the sand overlying sample BB-3. Minerals indicated are calcite (C), opal-CT (O-CT), smectite (Sm), and detrital quartz (Q) and feldspar (F).


Busted Butte west side fault filling
BB-2
COUNTS/SEC *10
TWO - THETA
CL
O-CT
C
Q
F


Busted Butte west side slope
BB-3
COUNTS/SEC *10
TWO - THETA
CL
O-CT
C
Q
F


Busted Butte west surface
BB-5 oriented-RT
Sm
COUNTS/SEC *10
TWO - THETA


Busted Butte west surface
BB-5 oriented-EG
Sm
Sm
COUNTS/SEC *10
TWO - THETA

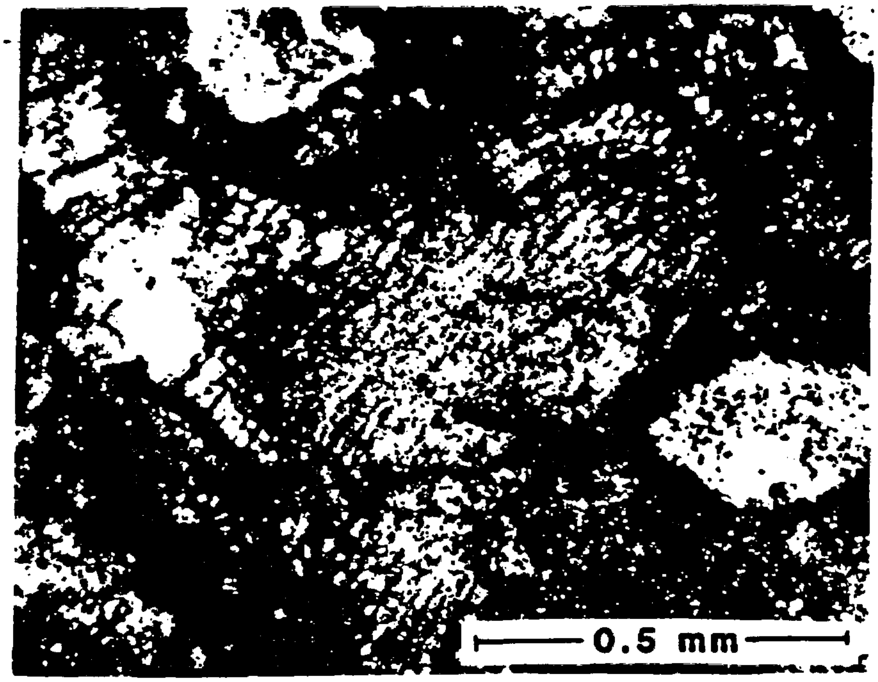


Fig. 21.
Photomicrograph of fossil plant materials in sample BB-3. The cell walls are replaced by calcite and opal-CT; the cell interiors are filled by opal-CT.

formed a more ordered opal polytype than did the mixed calcite-silica intergrowths within the underlying fault.

The clay minerals in these deposits will not be described in detail in this report. Studies of the clay separates are still in progress and indicate a complex series of poorly crystallized smectites and possible chain-silicate clays. Figure 20 shows the XRD pattern of the very poorly crystallized smectite fraction of sample BB-5, from the sand overlying the slope-parallel deposit BB-3. The major features of these deposits, however, have to do with the abundance and distribution of calcite and opal.

In the deposits at both Busted Butte and Fran Ridge, there are segregated laminae of opal-CT up to a millimeter wide and a centimeter long. Although smaller than the comparable laminae within the fault at Trench 14, the development of discrete opal-CT laminae is consistent in both the sand ramp deposits and the fault fillings. Calcite and opal-CT in the matrices of these deposits contain some ooids with diameters up to 1.0 mm; the concentric rings of these ooids are often separated by open intervals within which opal has been deposited. Clast-rich bands are cemented by a calcite-rich matrix that separates the clasts; many of the clasts have coatings of very fine-grained calcite-silica that may represent the initiation of ooid formation around foreign nuclei. Similar coatings are found around mineral and lithic fragments in the sandy fracture fillings within the fault at Trench 14. The clast populations in the sand ramps and in Trench 14 are extremely varied, including sand-size fragments of quartz, plagioclase, potassium feldspar, pyroxene, amphibole, olivine, magnetite, "quench"-texture remnants from basaltic ash, a variety of tuffs, reworked calcite-silica fragments, and both clear and colored pumice and dense glass fragments.

Organic control over opal structure type formation in the sand ramp environment can be seen in Fig. 22. This figure shows a cross section through a root cast; the wall of the cast contains numerous organic microstructures composed of dark brown opal-A, whereas the infilling formed after root death is of clear botryoidal opal-CT. This is evidence that organic materials can account for the formation of opal-A in sand ramps. The opal that formed by inorganic precipitation from solution or gel, however, is more ordered and forms opal-CT as in the infillings of dead plant cells in BB-3 (Fig. 21). As in the faults at Trench 14, opal-A is associated with organic structures and particularly with root sheaths.

V. SUMMARY AND CONCLUSIONS

Five types of analogs have been described for comparison to the calcite-silica deposits that occur within faults near Yucca Mountain. In making this comparison, it is important to bear in mind that the major depositional features in Trench 14 are abundant calcite and opal-CT, generally intergrown but with some relatively pure silica laminae. Clay minerals also occur, including smectites and chain-silicate clays such as sepiolite. Opal-A is present where organic structures are preserved.

Hydrothermal veins from well-studied mineralized areas of the region are typically associated with sulfur-bearing minerals; some near-surface hydrothermal veins in the Calico Hills, closer to Yucca Mountain, do not contain sulfur but also lack calcite and contain a more ordered opal structure (opal-C) plus quartz and abundant manganese mineralization. No hydrothermal veins with the mineralogy of the Yucca Mountain fault fillings have been found.

Warm spring deposits, whether in the active sinter-depositing systems of west-central Nevada, in the spring seeps of Oasis Valley, or in the fossil

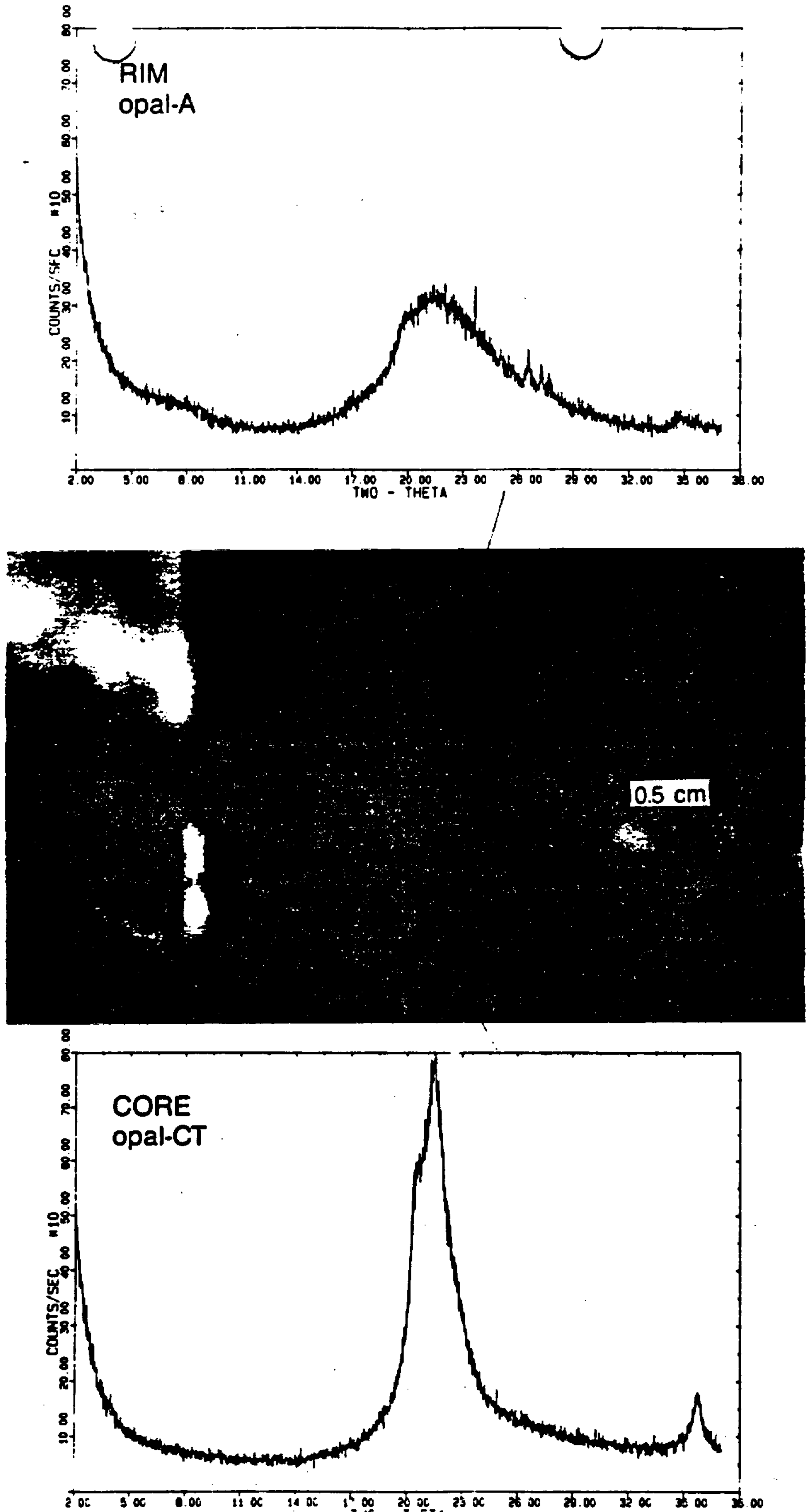


Figure 22
Photomicrograph of a fossil plant root (Larrea) from the sand ramp along Fran Ridge near Trench 16. The cast formed by the living root is made of opal-A; infilling of the cast after plant death is of opal-CT.

spring mound at Wahmonie, all contain abundant sulfur minerals. Opal can be found in some of the sinter deposits, but in all of the samples studied this is opal-A rather than opal-CT. Calcite is rare. No warm spring deposits with the mineralogy of the Yucca Mountain fault fillings have been found.

Cold spring deposits of the region around Yucca Mountain are composed mostly of calcite. The weathering surface in the Moapa deposit formed on the outflow sheet and tends toward smectite enrichment without opal formation. However, silica does occur as quartz in at least one spring mound along the Amargosa River and as opal-CT, chalcedony and quartz along Carson Slough. Abundant sepiolite is intergrown with calcite (but without silica) in a seep along the eastern foot of the Eleana Range. All components of the Yucca Mountain fault fillings can be found in either cold spring or seep deposits. However, the textures that result from flowing discharge (e.g., calcite tubules) and the remains of bull rushes are not found in the Yucca Mountain faults. Also, the restriction of silica deposition to late-stage replacement of carbonate in the playa/seep systems is different from the cyclic coprecipitation of calcite and opal in the faults around Yucca Mountain. Nevertheless, the partial similarity between fault and seep deposits suggests that further comparisons are needed.

Soils of the region contain calcrete deposits that include calcite, opal-CT, opal-A, smectite, and chain-lattice clays and are similar to the deposits in faults around Yucca Mountain. In all of the soils formed on alluvial deposits near the faults, however, opal is a relatively minor component.

Aeolian sands close to the fault deposits contain both slope-parallel and fault-filling deposits of calcite, opal-CT, and a complex series of clays. Most importantly, the textures and relative abundances of calcite and opal-CT within small faults cutting the aeolian sand ramps are very similar to those in the larger faults north of the sand ramps in Trench 14. The similarity in mineral abundances is illustrated in Fig. 23, where XRD patterns of bulk calcite-silica materials from the faults in Trenches 14 and 17 are compared with the slope-parallel deposits from the sand ramps flanking Fran Ridge and Busted Butte. Occurrences of opal-A in both environments can be related to organic materials, and in particular to root sheaths. The similarity in constituents and the almost identical geometry of slope-parallel deposits related to fault-filling deposits argue that, of all the analogs examined, the

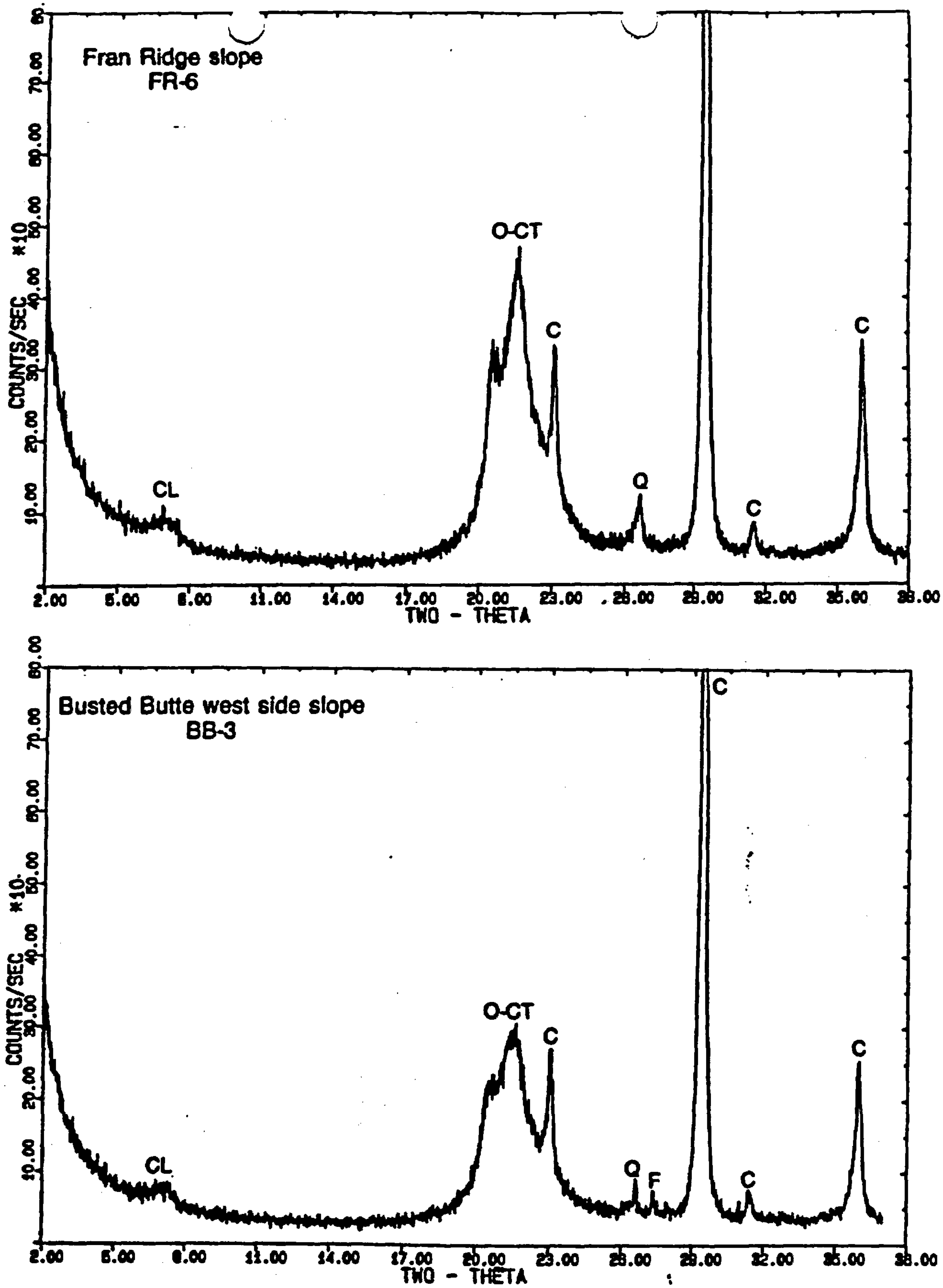
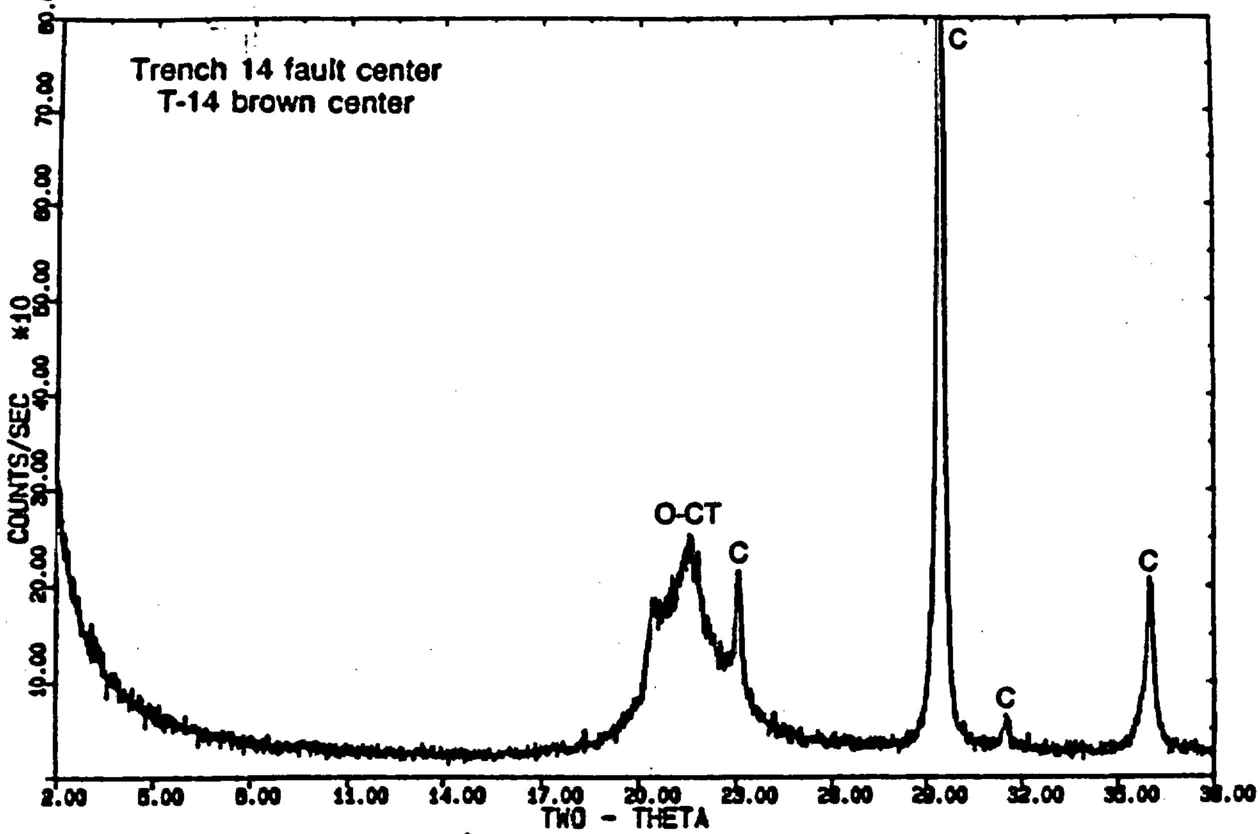
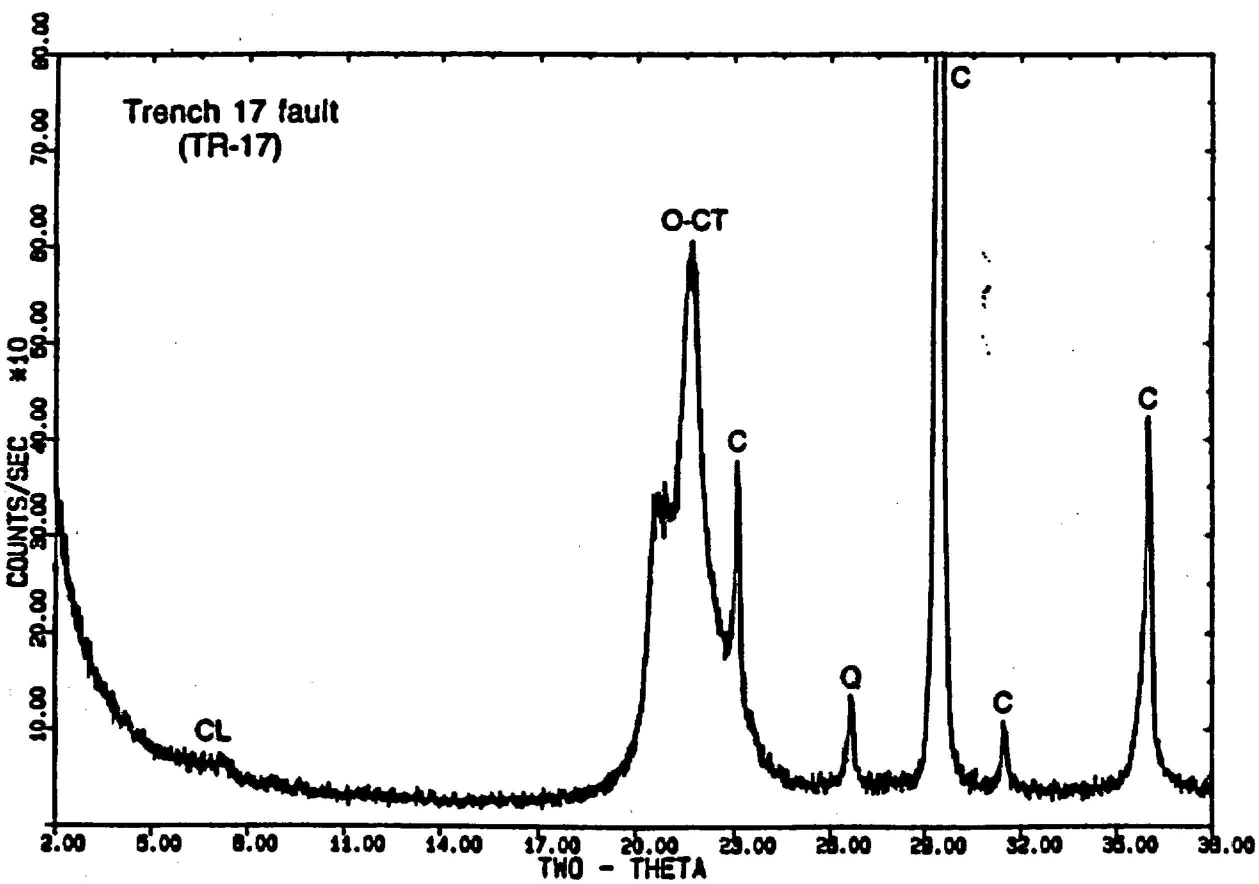


Figure 23

Comparative XRD patterns for slope-parallel sand ramp deposits (FR-6 and BB-3) and deposits from trenched faults (T-14 brown and T-17) along the eastern flank of Yucca Mountain. The subequal abundances of calcite and opal-CT are characteristic of both depositional environments.


Trench 14 fault center
T-14 brown center
O-CT
C
C
C
C
COUNTS/SEC *10
TWO - THETA


Trench 17 fault
(TR-17)
O-CT
C
C
C
C
Q
CL
COUNTS/SEC *10
TWO - THETA

deposits in the neighboring sand ramps are most similar. One of our preliminary conclusions is therefore that the slope-parallel and fault-filling deposits in the sand ramps are closely related to the deposits exposed in Trenches 14 and 17.

The relationship between the very small sand-ramp fault deposits and the much larger fault deposits in Trench 14 and in Trench 17 is not trivial. If the similarity means that both were formed by the same process, the ability to examine that process operating on various scales and in different situations (both with and without a large underlying aeolian deposit) should help in constraining the process. For example, Fig. 19 shows a geologist at the bottom of a small fault that cuts the weakly consolidated sands along the western flank of Busted Butte. This fault is visible because of the thin fault-filling deposit. Where the geologist is located, the deposit is a few millimeters wide and clogged with detrital grains. In this situation it would be unlikely that the materials deposited along the fault came from depth and rose upward under hydrologic pressure, confined within a very narrow fracture cutting poorly consolidated sand. In at least this occurrence transport downward seems much more likely. This exposure provides evidence that at least some fault deposits of this type did not originate by upward transport from depth. This conclusion is similar to that reached by Taylor and Huckins (1986) based on the mapping of Trench 14. However, the comparison of mineralogy presented in this paper is preliminary and is not a proof of one origin versus another for the fault deposits in Trench 14. Further studies of these deposits and of potentially analogous hydrothermal, warm spring, cold spring, and soil localities are planned in order to test these preliminary conclusions.

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Paleoclimatic, Paleohydrologic and Tectonic Implications of Uranium-Series Dating of Travertine and Calcite Vein Samples from Southern Great Basin and Grand Canyon.

PRELIMINARY DRAFT

by

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ABSTRACT

Significant climatic fluctuation and changes in hydrogeologic and tectonic conditions have occurred in the southern Great Basin area during the Quaternary period. Because similar changes may occur in the future, knowledge about the magnitude and frequency of these events are important for the evaluation of the suitability of the unsaturated zone for a nuclear waste repository at Yucca Mountain. Fossil travertines and calcite veins of groundwater origin in the southern Great Basin area provide proxy records of these Quaternary events and are suitable for uranium-series dating. We present here an overview of travertine and calcite vein dating results (both published and unpublished) bearing on paleoclimatic, paleohydrologic and tectonic events for southern Great Basin and Grand Canyon localities.

INTRODUCTION

Spring-related carbonate deposits occur in association with modern discharge localities at the southern Great Basin and Grand Canyon area and there is a variety of evidence for travertine deposition marking fossil groundwater flow. The highly variable morphologies of these travertines reflect local physical and chemical conditions influencing the style of deposition, such as, rate and mode (diffuse versus channel) of discharge, degree of $CaCO_3$ supersaturation, topography, type of local vegetation and the extent of weathering. One of the

ENCLOSURE 13

laminations (fig. 3), then dated by the uranium-series method. The measured $^{230}Th/^{234}U$ activity ratios are in or near secular equilibrium, thus yielding minimum age estimates only (table 2). For these older vein samples, ^{234}U ages are calculated from present day and initial $^{234}U/^{238}U$ values (table 2). The initial $^{234}U/^{238}U$ value of 2.70±0.02 used for the ^{234}U age calculation is obtained from results of dated Devils Hole veins DH2 (Winograd and others, 1988), DH11 (Winograd and Coplen, 1989 and Winograd and others, work in progress), and from analyzed groundwater samples of Devils Hole Spring (table 3). [redacted] and Thordarson, 1975), where local differences can be homogenized, and to the closed-system behavior of the pure calcite veins.

From the altitudes of fossil vein deposits AM7, DH1 and AM10 relative to modern water level in Devils Hole, and from preliminary age estimates of the youngest part of the veins (510, 660 and about 750 ka); Winograd and Szabo (1988) reported rates of water table decline between 0.02 and 0.08 m/kyr. Thus, the Ash Meadows area apparently underwent progressive lowering of the water table during the last 760 kyr.

Work in progress by Szabo and others addresses the concern about the magnitude of water table rise during past pluvial cycles superimposed on the slower regional decline of water table during the Quaternary. Dating results of calcite layers sampled above present water level in the cave in Devils Hole called Brown's Room indicate increased effective precipitation at Ash Meadows between about 10 and 100 ky ago that maintained groundwater table elevation between +4 and +9m above the modern level.

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