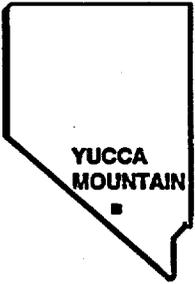


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U.S. DEPARTMENT OF ENERGY

**WM**



**YUCCA MOUNTAIN  
SITE CHARACTERIZATION  
PROJECT**

**REPORT ON THE ORIGIN OF  
CALCITE-SILICA DEPOSITS AT TRENCH 14 AND  
BUSTED BUTTE AND METHODOLOGIES USED  
TO DETERMINE THEIR ORIGIN**



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**UNITED STATES DEPARTMENT OF ENERGY  
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## ABSTRACT

The origin of calcite-silica deposits found at Trench 14 and Busted Butte during site characterization was questioned by Yucca Mountain Site Characterization Project geologists, the Nuclear Regulatory Commission and the State of Nevada. Several types of calcareous or siliceous deposits are exposed in Trench 14: laminated calcite and opaline silica veins formed in open fractures caused by recent Pleistocene-age activity on the Bow Ridge fault, older silica- and calcite-cemented breccias of Tiva Canyon tuff and drusy quartz which was soon recognized as being much older. Busted Butte exposures include breccias in the Topopah Spring tuff formed shortly after the tuff was deposited (12.8 million years), colluvial breccias cemented by opal and calcite, and extensive soil-zone calcretes and calcite-filled fractures. The ages and origins of the deposits have been subjects of concern. This report focuses on the younger veins, provides data and conclusions as to their origin and validates the scientific methods applied to determine their origin.

The U.S. Department of Energy (DOE) implemented a comprehensive, focused approach using experts from many disciplines and state-of-the-art techniques to determine the genesis of the deposits. These efforts were readily included in the Site Characterization Program. The data were obtained and analyzed and the conclusions made by the application of proven techniques for investigation and analysis widely accepted in the scientific community. Based upon the data presented in this report, DOE concludes that these two specific deposits are not due to upwelling water. Most likely they are the result of pedogenic processes. The DOE finds no basis to continue to study the origin of these specific deposits, but will continue related characterization activities designed to evaluate calcite-silica deposits from cores retrieved in the drilling program and from samples taken during underground excavations. These activities will augment data related to the conclusions of this report and in determining the suitability of the site.

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**ACRONYMS AND ABBREVIATIONS**

|                 |  |
|-----------------|--|
| <b>AMC</b>      | <b>authigenic-mineral-cemented</b>   |
| <b>CFR</b>      | <b>Code of Federal Regulations</b>   |
| <b>CTM</b>      | <b>crushed-tuff-matrix</b>   |
| <b>DOE</b>      | <b>U.S. Department of Energy</b>   |
| <b>DOE/YMPO</b> | <b>U.S. Department of Energy/Yucca Mountain Site Characterization Project Office</b> |
| <b>ESR</b>      | <b>electron spin resonance</b>   |
| <b>INAA</b>     | <b>instrumental neutron activation analysis</b>                                      |
| <b>NAS/NRC</b>  | <b>National Academy of Sciences/National Research Council</b>                        |
| <b>NRC</b>      | <b>Nuclear Regulatory Commission</b>   |
| <b>NTS</b>      | <b>Nevada Test Site</b>  |
| <b>OCRWM</b>    | <b>Office of Civilian Radioactive Waste Management</b>                               |
| <b>PDB</b>      | <b>Pee Dee (formation of South Carolina) Belemnite</b>                               |
| <b>QA</b>       | <b>quality assurance</b>   |
| <b>QARD</b>     | <b>Quality Assurance Requirements Document</b>                                       |
| <b>SCA</b>      | <b>Site Characterization Analysis</b>  |
| <b>SCP</b>      | <b>Site Characterization Plan</b>  |
| <b>SEM</b>      | <b>scanning electron microscope</b>  |
| <b>SMOW</b>     | <b>Standard Mean Ocean Water</b>   |
| <b>USGS</b>     | <b>U.S. Geological Survey</b>  |
| <b>XRD</b>      | <b>X-ray diffraction</b>   |
| <b>YMP</b>      | <b>Yucca Mountain Site Characterization Project</b>                                  |

## EXECUTIVE SUMMARY

The extensive study of the Trench 14 and Busted Butte calcite-silica and breccia deposits was prompted by questions of Yucca Mountain Site Characterization Project geologists, the Nuclear Regulatory Commission and the State of Nevada. The discovery of calcite-silica deposits that filled fault fractures raised concerns about the presence of potentially adverse hydrologic conditions for Yucca Mountain as a possible repository site.

This report examines the origin of the calcite-silica deposits at Trench 14 and Busted Butte and validates the scientific methods applied to determine their origin. It does not examine all the lines of evidence relevant to the potential for rise in the ground water table. Based upon the data presented in this report, DOE concludes that these two specific deposits are not due to upwelling water. Most likely they are the result of pedogenic processes. This conclusion was reached after a comprehensive, focused approach using experts from many disciplines, proven scientific investigative and analytical measures, and the recommendations and findings of numerous project scientists and external review panels. Although the principal focus of the investigations was on the deposits exposed in Trench 14, the conclusions presented here apply equally well to the deposits at Busted Butte.

The DOE received recommendations to consider four possible conceptual models of origin (Hanson et al., 1987; Justus and Stablein, 1989): (1) pedogenic, which would include any origin by which meteoric waters interact with surficial materials and deposit minerals within soil profiles and along fractures; (2) cold springs, which would include movement of regional or perched ground water along normal hydrologic gradients with deposition of minerals; (3) hydrothermal springs, which would involve movement of warm or hot water ( $T > 30\text{ }^{\circ}\text{C}$ ) up along faults with deposition of minerals; and (4) seismic pumping, which would involve movement of hot or cold water up along faults as a direct result of faulting or tectonism. Data and analysis supporting conceptual models 2, 3 or 4 would imply that the ground water may have risen to the surface in the past. The DOE also considered pyroclastic-hydrothermal processes, which would involve the infiltration of water into hot volcanic rock.

Analysis of data obtained in geochemical, isotopic, mineralogic, geologic, paleontologic, field and morphological studies supports only the pedogenic model for the calcite-silica deposits. Data obtained from geochemical, mineralogic, geological and geochronological studies support a combination of ancient (more than 10 million years) pyroclastic-hydrothermal processes and modification by more recent surficial processes to account for older silica deposits and breccias. Therefore, based on the data and analyses, the DOE concludes that the calcite-silica deposits in Trench 14 and Busted Butte at the Yucca Mountain site are the result of processes consistent with a pedogenic origin.

Field data are consistent with a pedogenic origin for the calcrete deposits at Trench 14 and at Busted Butte. Trench 14 exposes slope-parallel calcium carbonate-enriched zones that are laterally extensive, unlike springs which form discrete mounds. The slope-parallel deposits are physically, chemically, isotopically and biologically typical of carbonate-enriched pedogenic deposits that occur throughout the southwestern United States. The carbonate-enriched horizons exposed in Trench 14 can be traced upslope and over near-vertical calcite-silica veins in a fault zone that some interpreted as feeder veins for spring deposits. Feeders for spring mounds typically maintain sub-parallel walls over depths of tens to hundreds of meters. The portion of Trench 14, deepened in July, 1991, in the area of the near-vertical veins, exposes the veins diminishing from a thickness of nearly 1 meter near the top of the trench to 2-3 cm over a depth of only 7 meters.

Mineralogic and chemical data indicate that the calcretes consist predominately of calcite with lesser amounts of opal-A and opal-CT, along with small proportions of sepiolite. This report demonstrates that the mineralogic assemblage is the same as that noted in the calcic horizon of arid region soils. Chemical data further indicate that the detritus in the deposits underwent surface pedogenic modification before it was incorporated into the calcretes. Such intermediate processing rules out direct incorporation of wall rock into the veins, which would be expected if these were spring deposits.

The absence of calcareous microfossils indicates that no shallow-seated or perched spring that would create a saturated environment was involved in vein formation. This conclusion is supported by comparison of mineral assemblages of Trench 14 to those of known spring deposits and by study of microscale textures. Furthermore, geohydrologic conditions are not favorable for sustaining a perched-spring system.

Data for natural tracer-isotope systems of  $^{87}\text{Sr}/^{86}\text{Sr}$  and  $^{234}\text{U}/^{238}\text{U}$  show that the calcite vein fillings exposed in Trench 14 were not formed by ascending waters like those currently found in the regional aquifers beneath Yucca Mountain. The large differences observed between isotopic compositions of ground water (or old ground water deposits) and isotopic compositions of vein carbonate at Trench 14 preclude a genetic relationship between the two at any time during the last million years. This conclusion is further supported by the isotopic compositions of carbon and oxygen in the vein carbonates and ground water samples.

Field and laboratory studies of silica deposits and breccias that occur in the wall of Trench 14 indicate that most were formed soon after pyroclastic deposition of host tuffs more than 10 million years ago (Tiva Canyon tuff has been dated at 12.7 million years ago). The hydrothermal processes responsible for the silica deposits were associated with rootless hydrothermal systems generated by infiltration of meteoric water into hot pyroclastic deposits. These hydrothermal systems died with the cooling of the tuffs and have never been reactivated. Most breccias at Busted Butte and Trench 14 formed by settling of the host pyroclastic units shortly after deposition. Localized brecciation has accompanied movement on the Bow Ridge fault. Some breccias were entirely formed by surficial processes such as accumulation and cementation of slope-wash alluvium.

The studies focused strictly on determining the origin of Trench 14 and Busted Butte calcite-silica vein deposits are complete. The methods, analysis and approach used for this effort are effective in determining the origin of calcite-silica deposits and will be used by the DOE, where appropriate, in evaluating similar mineral deposits. The data and analyses in this report lead to the DOE conclusion that the deposits in Trench 14 and at Busted Butte at the Yucca Mountain site are the result of processes consistent with a pedogenic origin.

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## 1.0 INTRODUCTION

### 1.1 PURPOSE OF REPORT

The purpose of this report is to provide data and state conclusions concerning the origin of calcite-silica (siliceous calcrete) deposits found at Trench 14 and the western side of Busted Butte, near Yucca Mountain. This report describes and serves to validate the application of the scientific methods used to determine the origin of the deposits.

The extensive study of the Trench 14 and Busted Butte deposits was prompted by concerns of U.S. Department of Energy (DOE) geologists, the Nuclear Regulatory Commission (NRC) and the State of Nevada. The discovery of the deposits and debate over their genesis raised concerns about the presence of potentially adverse conditions for Yucca Mountain as a possible repository site.

This report documents the origin of the calcite-silica vein deposits at Trench 14 and within the sand ramps on the west side of Busted Butte and considers the origins and ages of silica deposits and breccias, a related concern. It shows the relationship of the completed studies to the Site Characterization Plan (SCP) (DOE, 1988) developed by the DOE and the effectiveness of the scientific methods used by investigators on the site characterization program.

### 1.2 HISTORY OF ISSUE

The concerns began in 1982 with shallow excavation on the west side of Exile Hill for examination of the Bow Ridge fault as part of the investigation of Quaternary faulting in the vicinity of Yucca Mountain. The two meter deep excavation, designated as Trench 14 (Figure 1), exposed a vein-like deposit of calcium carbonate and subordinate opaline silica as well as extensive silica- and calcite-cemented bedrock breccias and minor drusy quartz deposits in the Tiva Canyon Member of the Paintbrush Tuff Formation. The vein also cuts the overlying Q2 alluvial deposits of middle to late Pleistocene age (Swadley et al., 1984). Yucca Mountain Site Characterization Project geologists and the NRC questioned the origins of the deposits. A DOE physical scientist, Jerry S. Szymanski, questioned whether the discovery indicated a spring deposit. Four other trenches, Trenches 14A, 14B, 14C and 14D, were subsequently excavated nearby to obtain a perspective of the areal extent of the deposits. Trench 14 was deepened in 1984 to four meters and again in 1991 to seven meters to expose these deposits further (Figure 2).

Two workshops on the Trench 14 deposits were held in Las Vegas, Nevada, on February 28 and April 28, 1986. The first addressed the present state of knowledge and the second proposed methods of investigation. Participants included the U.S. Geological Survey (USGS), DOE Yucca Mountain Site Characterization Project Office (DOE/YMPO), Los Alamos National Laboratory, and representatives of and consultants to the State of Nevada.

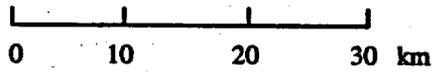
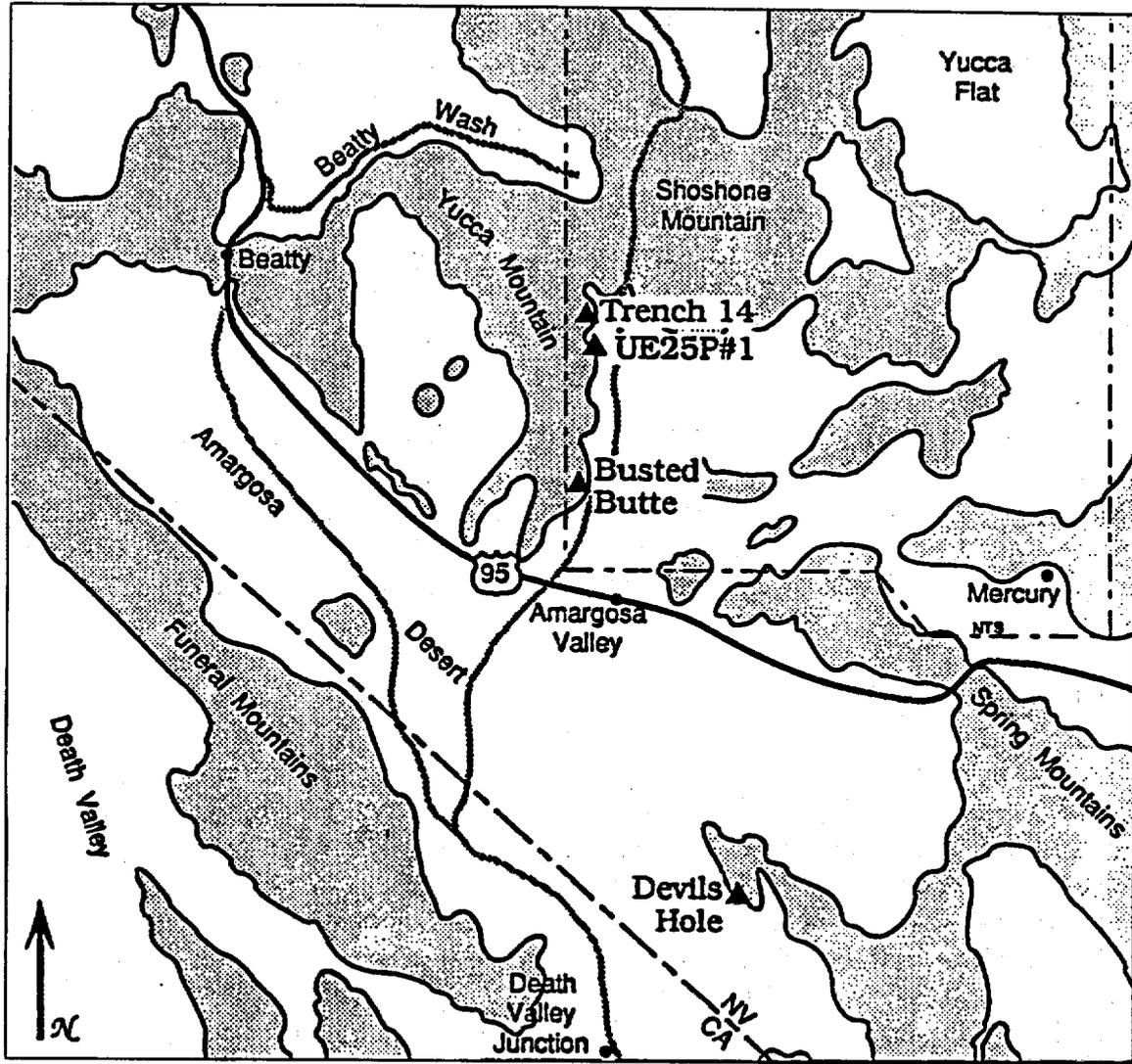
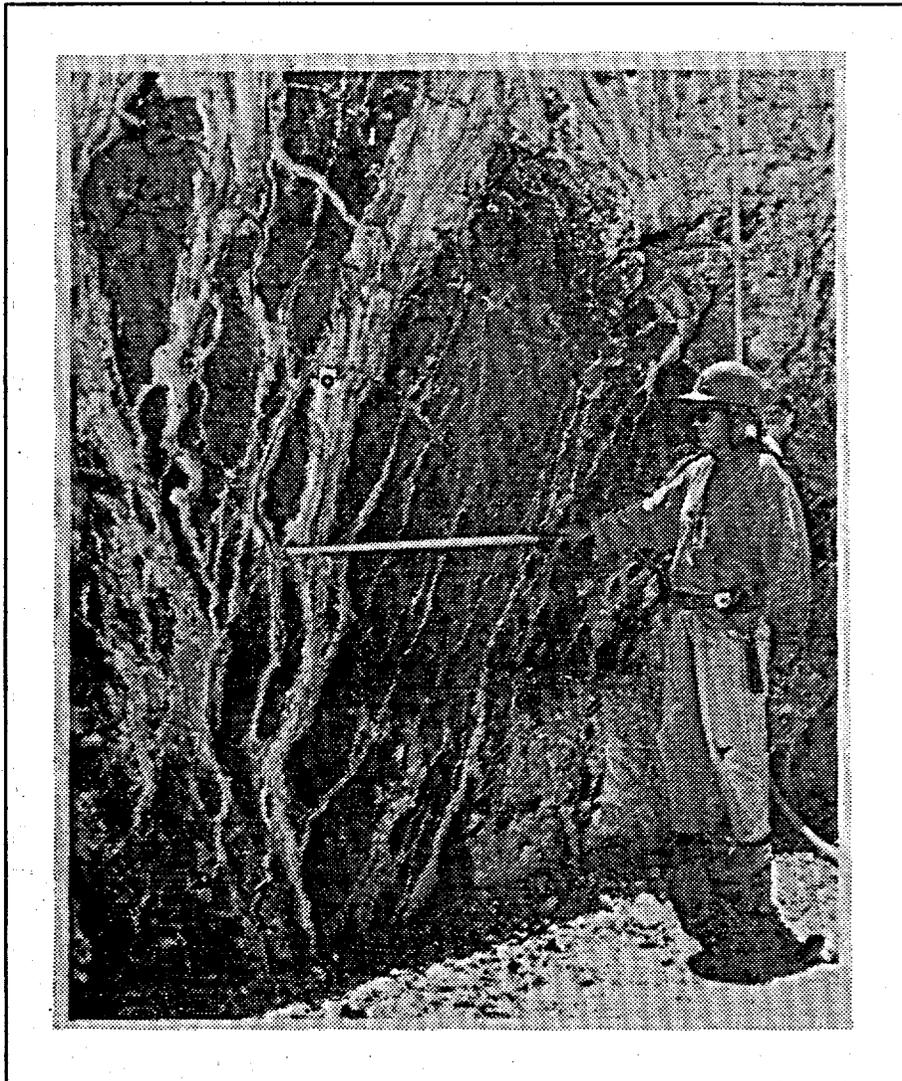


Figure 1. Location of Trench 14 and the Busted Butte sampling site.



**Figure 2.** *The south wall of Trench 14 showing the large vein deposits of calcite and opaline silica and the rapid pinch out of the vein with depth.*

The DOE established a five-member peer review committee in 1986 to examine the issue. This committee summarized four main categories of depositional models proposed earlier (Vaniman et al., 1985) and suggested ways to investigate and evaluate the deposits (Hanson et al., 1987). The four possible conceptual models of origin proposed were: (1) pedogenic, which would include any origin by which meteoric waters interact with surficial materials and deposit minerals within soil profiles and in fractures; (2) cold springs, which would include movement of regional or perched ground water along normal hydrologic gradients with deposition of minerals; (3) hydrothermal springs, which would involve movement of warm or hot water ( $T > 30\text{ }^{\circ}\text{C}$ ) up along faults with deposition of minerals; and (4) seismic pumping, which would involve movement of hot or cold water up along faults as a direct result of faulting or tectonism. Data and analysis supporting conceptual models 2, 3 or 4 would imply that ground water may have risen to the surface through the repository horizon in the past. The DOE also considered pyroclastic-hydrothermal processes, which would involve the infiltration of water into hot volcanic rock. These models and recommendations of others (Justus and Stablein, 1989) were factored into the development of the study plan for Quaternary Regional Hydrology. This study plan was reviewed by more than twenty Project scientists and consultants, prior to receiving DOE approval. Revision 0 of the study plan was approved in 1989 (DOE, 1989a). Subsequently, comments on the approved study plan were received from the NRC and the State of Nevada. DOE has responded to all of these comments.

Subsequent to these Project activities, Mr. Szymanski proposed an hypothesis of catastrophic upwelling ground water for the origin of the deposits at Trench 14. DOE requested that he draft a report to Project Office management. A preliminary draft report (Szymanski, 1987) was released prior to DOE review and attracted wide public interest. The Project Office initiated a comprehensive internal review of his report using twenty-four principal reviewers representing several disciplines. The review included numerous discussions with Mr. Szymanski designed to understand his models. The review effort resulted in numerous general and specific comments documented in a formal report (DOE, 1989b). The general conclusion of all reviewers was that the draft would require extensive revision by Mr. Szymanski and further review before it should be published by the DOE. The committee also concluded that planned characterization activities expressed in the SCP (DOE, 1988) and study plans would adequately address most of Mr. Szymanski's recommendations for investigation, study and analysis. Several additional tests were recommended to enhance confidence in the conceptual models chosen to represent hydrology at Yucca Mountain.

The DOE held a technical exchange with the NRC staff on February 5-6, 1990 that included visits to locales cited in support of the proponent's upwelling hypothesis. Newly acquired data were discussed with NRC staff at the technical exchange and in the field. The DOE concluded that this technical exchange was highly productive based on discussions with the NRC staff.

Several external reviews have been performed to address the Trench 14 deposits. The State of Nevada sponsored independent isotopic studies of calcite-silica deposits, including Trench 14, as part of its oversight activities (Quade and Cerling, 1990). Mr. Szymanski issued a final report

and requested a formal review as offered by the Yucca Mountain Project Manager (Szymanski, 1989). In 1990, DOE initiated this review of the final report with a five-member review panel, external to the DOE or its project contractors. At the same time, a panel of the National Academy of Sciences/National Research Council (NAS/NRC) was asked by the DOE to review Mr. Szymanski's final report as part of its evaluation of coupled hydrologic/tectonic/hydrothermal processes.

The five-member external review panel formed in 1990 had the specific purpose of reviewing the 1989 final report by Mr. Szymanski. Three members of this panel were chosen by DOE/YMPO and two were chosen by Mr. Szymanski. The panel charter was to make an evaluation concerning the validity of Mr. Szymanski's hypothesis and make recommendations for further studies. The panel completed its review and provided its findings in two reports due to an inability to reach a consensus (Powers et al., 1991; Archambeau and Price, 1991).

The NAS/NRC panel, consisting of seventeen members, was established in 1990 to evaluate (1) if the water table had risen in the geologically recent past to the level of the proposed repository horizon, and (2) if it is likely that it would happen in the manner described in Mr. Szymanski's final report within the 10,000-year period covered by the regulations. The panel completed its review and provided its conclusions in a final report (National Research Council, 1992). The DOE reviewed the recommendations of the National Research Council and responded in a letter to the council (Gertz, 1992).

Over several years, project scientists have considered the findings and the comments from various internal and external reviews to determine whether any changes are warranted to planned investigations. With the publication of this report, the DOE has finished its focused activities to determine the origin of the Trench 14 and Busted Butte deposits.

### 1.3 INCLUSION OF INVESTIGATIONS IN THE SITE CHARACTERIZATION PROGRAM

The Trench 14 deposits caused much controversy largely because they were visually striking and the divergent hypotheses for their origin had significant potential impact on site suitability. Determination of the origin of the deposits was necessary because compliance with provisions from NRC regulations covering the geologic setting, the engineered barrier system, and the repository system could be adversely affected if evidence showed that the water table had risen to the level of the proposed repository horizon.

The current data and analyses, presented in Chapter 2, indicate that ground water did not rise to the surface during the Quaternary and produce the deposits found at Trench 14 and Busted Butte. Therefore, based on this analysis of the information gathered thus far, the DOE finds no basis to continue specific studies to determine the origin of these deposits. Those efforts are complete, but the DOE will continue related characterization activities designed to evaluate calcite-silica

deposits from core retrieved in the drilling program for site characterization and from samples taken during underground excavations. These activities will augment data related to the conclusions of this report and in determining the suitability of the site.

### 1.3.1 Site Characterization Program

The DOE conducts its site characterization program in accordance with the SCP (DOE, 1988) and its approved changes. That document was prepared in accordance with the requirements of Section 113(b)(1)(A) of the Nuclear Waste Policy Act (NWPA, 1983), as amended (NWPAA, 1987). The purpose of the SCP was to summarize the information the DOE had collected about the geologic conditions at the site, to describe the conceptual designs for the repository and the waste package, and to present the plans for obtaining the geologic information necessary to demonstrate the suitability of the site for a repository. The SCP, Chapter 8, presents these plans.

The SCP (DOE, 1988) is divided into programs, investigations, studies and activities in Section 8.3.1 of that document. This framework provides the necessary organization of tasks for a multidisciplinary effort and the ability to assign responsibility and funding to required tasks.

DOE chose to manage the Trench 14 and Busted Butte efforts primarily under SCP Study Plan 8.3.1.5.2.1, "Quaternary Regional Hydrology". The studies done thus far have been performed primarily under Activity 8.3.1.5.2.1.5 "Studies of Calcite and Opaline-Silica Vein Deposits," and supported by Studies 8.3.1.3.2.1 "Mineralogy, Petrology and Chemistry of Transport Pathways" and 8.3.1.3.2.2 "History of Mineralogic and Geochemical Alteration."

### 1.3.2 Study Plan for Quaternary Regional Hydrology (8.3.1.5.2.1)

This study plan is primarily designed to identify those hydrologic conditions in the Yucca Mountain area which, during the Quaternary and more especially over the past 20,000 years (which includes the last pluvial cycle), have been significantly different from present conditions, owing to paleoclimate changes. The study will characterize the Quaternary regional hydrology of Yucca Mountain and environs and the data will be used to test various models of ancient hydrologic conditions. This characterization, in conjunction with others, will contribute to an evaluation of the effects of future climate episodes over the next 10,000 and 100,000 years on the regional ground-water regime and on the unsaturated- and saturated-zone systems in and near Yucca Mountain.

The activities of the study plan will provide information required to describe past water-table fluctuations and to develop reasonable hypotheses for their causes. One aspect of the study is to identify areas of paleodischarge without regard to possible causes of discharge; thus data can be used in any alternative conceptual model for paleohydrology or future hydrology. Another aspect is the identification of past tectonic events that have modified the hydrologic system. Also, some of the efforts of the calcite-silica vein deposits study will contribute to studies evaluating the probability of future volcanic and tectonic activity.

### 1.3.3 Activity: Studies of Calcite and Opaline-Silica Vein Deposits (8.3.1.5.2.1.5)

The examination of the Trench 14 and Busted Butte deposits is included in the Quaternary Regional Hydrology Study because of the possible implications in paleohydrology, but the activity emphasizes determining the origin of the deposits. Activity 8.3.1.5.2.1.5 is designed to acquire a thorough understanding of the origin of calcite and opaline-silica deposits, such as those in the fault zone intersected by Trench 14, and to understand what these deposits imply about hydrologic conditions at repository depth. Data collection includes a complete physical description so that different explanations for the origin of mineralization can be tested against the evidence. Another objective is to examine the origin of siliceous deposits in which calcite is absent or only a minor constituent and compare the age and mode of origin of these siliceous deposits with the calcite and opaline-silica vein fillings. A general description of the DOE's approach and a summary of the tests and analyses are discussed in Section 2 of this report.

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## 2.0 ANALYTICAL METHODS AND TECHNICAL BASIS

### 2.1 ANALYTICAL METHODS

Investigations of the hydrogenic deposits have involved numerous techniques, some of which would ordinarily be familiar in principle to a well educated lay person, but others of which are highly specialized. This section provides an explanation of the principles involved in these techniques. Those techniques which are already generally familiar will, of course, require less extensive coverage than others.

The various analytical techniques serve different purposes. Some simply provide data on the chemical composition of a sample by element. Others determine the mineralogical makeup of a sample, usually in conjunction with textural evidence that sheds light on the sequence of deposition or alteration of the minerals. Yet others provide indications of the age of formation of the mineral or rock. Isotopic data may be used in this way, but may also assist in serving as tracers which fingerprint the source of a particular component in the sample. The following sections describe these various purposes, which are not always separate.

The fundamental purpose of the studies and analyses described in this section is to determine the origin or origins of the calcite-silica deposits in Trench 14 and in the sand ramps on Busted Butte, or at least to narrow the possibilities. Numerous kinds of evidence can contribute to such a determination. Ordinary petrologic study can provide evidence of the sequence of geochemical processes that occurred; often this is no more complicated than deducing the sequence of deposition of minerals based on textural relationships or their relation to offsets caused by minor faulting. Scanning electron microscopy, electron microprobe study, and X-ray diffraction all contribute to this kind of analysis and strengthen and quantify the conclusions. A second type of investigation involves determinations of the ages of individual minerals, when feasible. Age determination is not possible in all cases. Dating carries the potential of ascertaining whether the deposits are of Quaternary or earlier origin, as well as for determining the sources of detritus, such as volcanic ash (by matching with ages of potential source rocks) included in the deposits. Three dating techniques were used: fission-track, electron spin resonance, and uranium series. A final type of analysis consisted of those useful for identifying the sources of the minerals or their component chemicals. If, for example, it could be shown that major components of the veins could not have been derived from below the sampled horizon, or if, conversely, the components could only have been derived from the surface, then all hypotheses of origin by rising waters would be eliminated. For this purpose three kinds of analyses were performed: chemical (instrumental neutron activation analysis), stable isotope, radiogenic isotope.

The initial Peer Review committee concurred at the April 8, 1986, workshop (see Section 1.2) that a multidisciplinary approach to the origin of the hydrogenic deposits should be used. A group of experts was assembled to represent various disciplines and methods of study including field study, mineralogy, petrologic study, geochemistry, geochronology, radiogenic tracer isotope

studies, stable isotope studies, paleontology and hydrology. Following are descriptions of the analytical methods chosen.

### 2.1.1 Petrologic Study

Petrologic study involves the use of petrographic and stereoscopic microscopes. The petrographic microscope is used to examine thin sections (slices of rock cut so thin that most minerals in the rock transmit light), and the stereoscopic microscope is used to examine rock samples and slabs cut from rocks. The main purposes of study are to make preliminary identification of rock types and mineral phases and detailed examination of textural features related to the origin of the rock. Textural examination makes it possible to identify sequences of mineral deposition and the relative timing of brecciation, secondary-mineral cementation, plant root invasion and other processes of interest. For example, the presence of windblown volcanic ash and other exotic materials in a mineral deposit can be detected with the petrographic microscope.

The binocular microscope is used to examine samples for the existence and identification of microfossils.

### 2.1.2 Scanning Electron Microscopy (SEM)

SEM permits the examination of alteration textures on a finer scale than is possible with the petrographic microscope because of the greater magnification. Extremely small quantities of alteration products can be tentatively identified on the basis of crystal habit and semiquantitative energy-dispersive X-ray chemical analysis. Both thin sections and small rock chips can be examined. SEM study, like petrologic study, makes it possible to examine textural features that identify sequences of alteration or mineral deposition. SEM is an important technique for studying the fine-grained matrix of breccias. The distribution of key elements in a thin section of laminated fault-filling or other material can be mapped to help interpret the geochemical processes responsible for mineral deposition.

### 2.1.3 Electron Microprobe Study

The electron microprobe is used to perform nondestructive quantitative chemical analyses of individual mineral grains or other small areas in thin sections. The chemical data are used to characterize primary and secondary minerals and to investigate variations in secondary mineral composition that may have genetic significance. The microprobe is not used primarily for mineral identification, but it is helpful for identifying minerals present in quantities too small to be detected in X-ray patterns of bulk samples.

#### 2.1.4 X-Ray Diffraction (XRD)

XRD analysis provides a definitive identification of mineral phases in unaltered and altered rocks and secondary mineral deposits like the laminated fracture fillings in Trench 14. Quantitative XRD of suites of rock samples makes it possible to discern trends and significant differences in the distribution of secondary minerals. XRD is also used to assess the purity and mineral content of mineral separates. For rocks containing opal, XRD is used to determine the degree of crystallinity. Quantitative mineral abundance data for these samples were obtained at Los Alamos National Laboratory using the methods described in Bish and Chipera (1988, 1989).

#### 2.1.5 Fission-Track Dating

Fission-track dating is used in favorable cases to date certain minerals that contain minor to trace concentrations of uranium. The underlying principle is that  $^{238}\text{U}$  atoms undergo a slow, but known, rate of spontaneous fission into two heavy atoms of approximately equal atomic weight (Wagner et al., 1975). To use this principle to determine an age, one must know the concentration of the parent (radioactive) isotope, the number of decays per unit volume, and the rate of decay.

The amount of fission that has occurred can be measured by revealing the structural (crystallographic) damage that was produced in the mineral by the fission, known as a fission-track. When an atom undergoes fission the two fragments are hurled apart by enormous energy and these energetic atoms break chemical bonds and displace other atoms in the mineral from their normal positions. Because of this damage, the mineral is more soluble along the path taken by the energetic atoms, which means that fission tracks can be revealed by chemical etching (Gleadow et al., 1976). The older the mineral, such as zircon, and/or the higher its concentration of U, the more tracks will have been produced per unit volume. This track "density" is measured by counting the number of fission tracks per unit area under a microscope after the mineral has been chemically etched.

The  $^{238}\text{U}$  concentration of the mineral grain must be measured. This can be accomplished in two ways. First, the mineral may be heated to anneal the spontaneous tracks, i.e. by providing enough thermal motion within the crystal that atoms can migrate back to their normal positions and bonds be reformed. The sample can then be analyzed by inducing a new set of fission tracks, through the fission induced into  $^{235}\text{U}$  by neutrons of appropriate energy (i.e. thermal neutrons) and known flux. These new tracks can be etched and counted. Alternatively, the mineral can be covered with a detector capable of recording fission events of  $^{235}\text{U}$ , and irradiated with thermal neutrons. In both methods reliance is placed on the known ratio of  $^{235}\text{U}$  to  $^{238}\text{U}$ , which is constant in nature, except in very rare and recognizable instances.

The fission-track method determines ages for single grains. Thus in samples containing mineral grains of mixed origin, multiple ages will be obtained (Hurford et al., 1984), whereas other

methods would yield an average age. Sufficient heating of such a mixed sample would destroy evidence of a mixed origin.

Possibly during geologic time the minerals will have been heated sufficiently to anneal all pre-existing fission tracks. This means that data needed to determine the age of the mineral are lost. In such a case the age determined represents only that time span since the temperature has dropped enough to stop the annealing. Annealing is a rate dependent process. The "annealing", "critical", or "closure" temperature depends on the duration of heating and on how hot the mineral becomes, and is, consequently, not precise. It is, moreover, mineral specific. It is important to bear in mind in interpreting the "ages" determined for mineral grains that they may have been annealed.

### 2.1.6 Chemical Analysis

Chemical data, especially concentrations of trace elements or relative proportions of elements, can be used to test proposed origins for mineral deposits. Chemistry may also help to constrain the environments of deposition, and to determine the existence of detrital materials incorporated within the calcite-silica deposits. Chemical data for a suite of calcrete, soil, and tuff samples were obtained at the trace-element geochemistry laboratory of Washington University in Missouri, using the instrumental neutron activation analysis (INAA) procedures described by Korotev (1991). This technique is capable of providing concentrations of a large suite of elements down to very low (trace) values.

Many of the data obtained in this way are for the lanthanide, or rare earth elements (REE)—15 elements from lanthanum (La, atomic number 57) through lutetium (Lu, atomic number 71). Analyses for La, cerium (Ce), neodymium (Nd), samarium (Sm), europium (Eu), terbium (Tb), ytterbium (Yb), and lutetium (Lu) are shown on Figure 3. (Sometimes yttrium (Y) is included, also, because of its similar chemical properties, and for the same reason comparisons with scandium (Sc) may be made.) The REE elements are geochemically very coherent; in other words they have a strong tendency to remain associated with each other during various geochemical processes, such as dissolution, precipitation, weathering, igneous rock formation, metamorphism and even formation of meteorites. However, their total or absolute concentrations vary widely from one rock type to another. In addition the abundances change greatly from one element to the next in the REE series, the elements with even atomic number, such as Ce, having much greater abundances than the adjacent elements with odd atomic numbers, such as La and Tb; this sawtooth pattern of abundance against atomic number arises from relative stabilities of the nuclei and processes of origin of the elements. It has been found convenient to smooth out this sawtooth pattern by dividing the concentrations present in rocks and minerals by the average concentrations present in a group of meteorites known as chondrites, as for example shown in Figure 3. This procedure especially facilitates the recognition of small differences among distribution patterns, or "fingerprints".

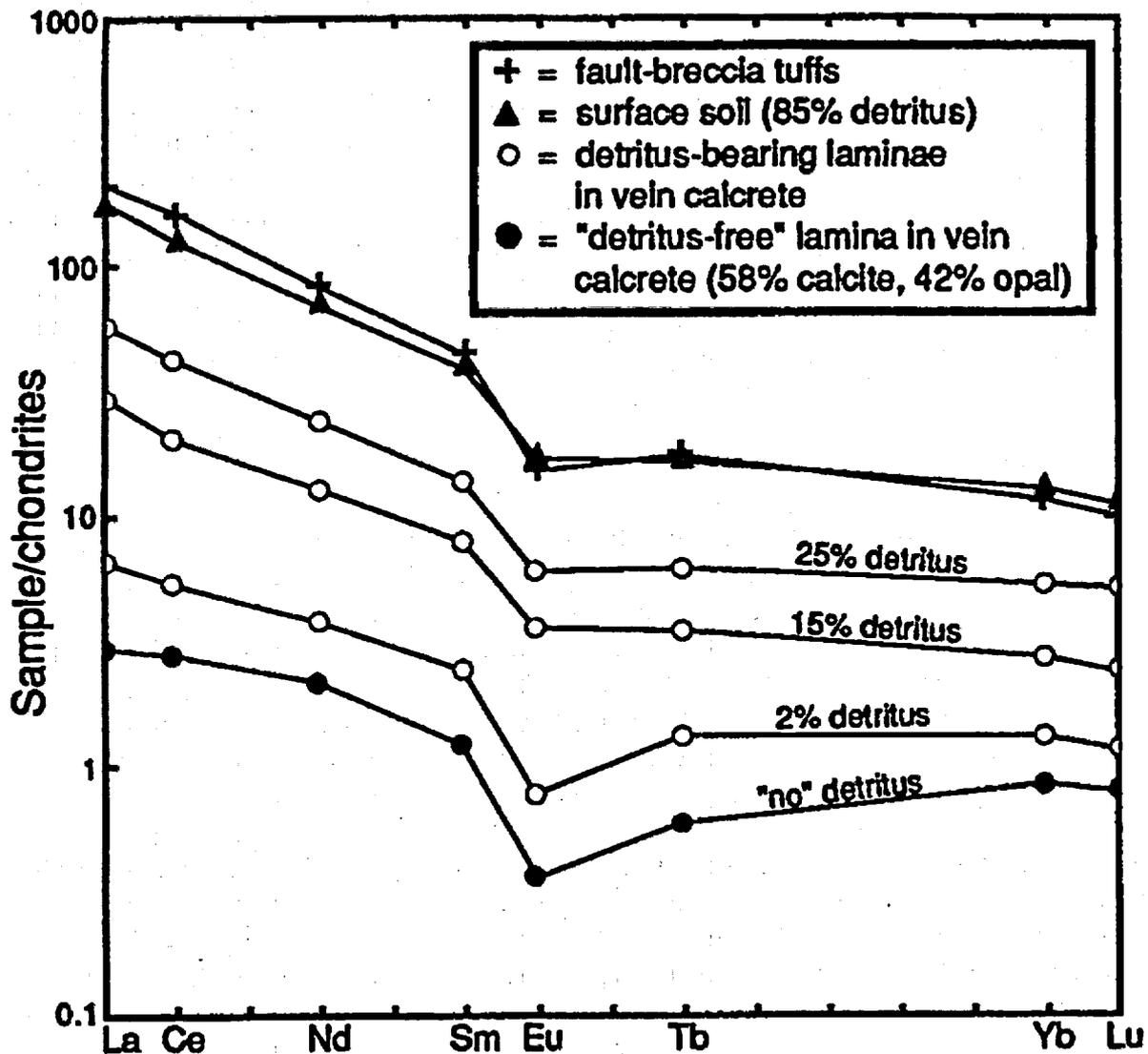


Figure 3. Lanthanide-element patterns, normalized to abundances in chondrites.

In spite of their general geochemical coherence the behavior of REEs does change from one element to another in keeping with well established geochemical principles. The lanthanide elements typically occur in rocks and minerals as the trivalent ions; however, their ionic radii decrease in a regular fashion from La to Lu. Consequently, the light REEs tend to be concentrated as trace elements in minerals with somewhat larger crystallographic sites than do the heavier REEs. The heavier lanthanides tend to concentrate in minerals with high contents of magnesium and iron, such as amphiboles and pyroxenes. These geochemical characteristics have given rise to a number of patterns of the ratio of REEs in a sample to that in chondrites as plotted against atomic number of the element (see Figure 3). Commonly, there is a downward trend with increasing atomic number, but in some cases there is a rise. The pattern tends to be characteristic of a specific mineral or rock type, and is therefore useful as a tracer. Europium is unique in that it often occurs as a divalent ion, rather than trivalent, and thus does not fit well into the same mineral structures as do the other REEs. During an igneous crystallization process, for example, it may concentrate into early formed feldspar crystals, providing both an enrichment, or positive anomaly, in early formed rocks, and a depletion, or negative anomaly, in later rocks. Figure 3 shows a negative Eu anomaly. These Eu anomalies are also useful as tracers.

#### 2.1.7 Stable Isotope

Stable isotope data apply to the present investigations because of two important reactive effects. In one sense both relate to the origin of the carbonate in the calcites. A fundamental principle here is that the strength of a bond between two atoms depends to a very slight extent on the masses of the atoms. Thus, the strength of the bond in, e.g. CO<sub>2</sub>, between <sup>12</sup>C and <sup>16</sup>O is not precisely the same as between <sup>12</sup>C and <sup>18</sup>O. The effect on chemical and physical properties depends on the percentage difference between the two masses. This difference leads to a slight separation of isotopes of a given element during many chemical and physical reactions. For example, <sup>12</sup>C<sup>16</sup>O<sub>2</sub> will tend to exsolve (i.e. a process analogous to evaporation) from water into the atmosphere slightly faster than does <sup>12</sup>C<sup>18</sup>O<sub>2</sub>. As just described, this would be known as a kinetic isotope effect. If the reverse process is taken into account and the rates of transfer in both directions become equal, it is an equilibrium isotope effect. In this case the heavier molecule will tend to dissolve (condense) more rapidly. In other words in both directions the heavier isotope tends to concentrate in the liquid phase, but to a different extent depending on the direction of the reaction. The amount of this fractionation varies with temperature, being greater (if only gases are involved, and generally for other phases as well) at lower temperatures. Note that for this example all carbon atoms are presumed to have the same mass; accordingly there will be no isotopic separation or fractionation of carbon, only of oxygen. To a good approximation the equilibrium fractionations can be calculated from a knowledge of bond strengths, crystal structure, etc., but not well enough for geochemical purposes, which require comparison standards.

A second important principle is embodied in the following isotopic reaction:



From the isotopic equilibrium constant,  $K_{iso}$ , equal to

$$\frac{(H_2^{18}O) (C^{16}O^{18}O)}{(H_2^{16}O) (C^{18}O_2)}$$

we see that the distribution of isotopes between phases or compounds is related to the isotopic ratios in each, in this case related to the ratio of  $^{18}O$  to  $^{16}O$  in  $H_2O$  to that in  $CO_2$ . Thus, if the ratio in one phase or compound is known and the system is known to be in equilibrium, the ratio in the other can be calculated. Similarly, if both ratios are known or can be inferred, the constant can be determined and the temperature corresponding to that value identified. Thus, from a measured oxygen isotope ratio in a calcite and an inferred isotopic ratio in the water from which it formed, presumably at equilibrium, the temperature of formation of the calcite may be estimated.

By contrast the isotopic ratio for carbon differs little between dissolved  $HCO_3^-$  and calcite and varies little with normal atmospheric temperatures (Friedman and O'Neil, 1977). Accordingly, this ratio cannot be used to estimate temperature. On the other hand, because  $HCO_3^-$  is the dominant carbonate anion in most ground waters it does mean that the ratio in the water and in the calcite which forms from it will be essentially the same. Thus, it provides a parameter against which various known waters can be compared and the potential to identify (fingerprint) a source.

Because of the small variations of the isotopic ratios, it is convenient to express them in the alternative form of parts per thousand (i.e. per mil) deviation from a standard, commonly denoted by the symbol  $\delta$ .

All stable isotope data for calcite reported here are from splits of whole rock from which only the calcite was leached by selective chemical dissolution. Whole rock samples of several grams to tens of grams were collected by direct drilling from the trench wall with a masonry bit or by crushing and sizing of a chunk of vein. Samples of a few milligrams to tens of milligrams were collected by dental drill in the laboratory.

The carbon ( $\delta^{13}C$ ) and oxygen ( $\delta^{18}O$ ) isotopic compositions are reported as per mil deviation of the sample isotopic ratio from that of the international standards PDB (Pee Dee Belemnite) and SMOW (Standard Mean Ocean Water), respectively.

### 2.1.8 Radiogenic Isotopes

For heavy elements the kinetic and equilibrium fractionations noted for stable isotopes cannot be used because the amount of fractionation would be too small to be measured (Patchett, 1980). However, in a number of instances the isotopic ratios of heavy elements do vary as a

consequence of radioactive decay. One useful example is for the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio. Both isotopes are stable, but the amount of  $^{87}\text{Sr}$  is continually increasing in the earth, although very slowly, due to the decay of  $^{87}\text{Rb}$ . Broadly speaking, Rb is closely associated geochemically with K, and Sr with Ca. Therefore, the elements commonly are nearly separated into different minerals. Over the course of geological time potassium minerals weather and release their Rb and  $^{87}\text{Sr}$ . Much of the Sr eventually arrives in the sea. During weathering, transport, and deposition in the ocean the newly created  $^{87}\text{Sr}$  becomes mixed with older Sr, gradually changing the water's isotopic ratio. More generally, the entire scope of the geochemical and hydrologic cycles is involved, of which the description above is only a part. During precipitation of carbonate minerals from natural waters, some portion of the Sr will accompany Ca into crystal structures, but without any isotopic fractionation (see reasons above). This leads to two potential applications: One is the ability on a broad time scale to draw some conclusions about the general age of the deposit, if the ratio in the source water is approximately known, e.g. sea water. The other is to use the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio as an indicator, or tracer, of the source of the Ca; this is the application used here.

#### 2.1.9 Electron Spin Resonance (ESR)

ESR dating is based on the accumulation of paramagnetic defects in certain minerals as a result of bombardment by natural radioactive decay products (Calas, 1988). The defects are produced at a rate proportional to the rate of decay product bombardment. By determining the natural defect concentration, the relationship between radiation dose and defect production, and the radionuclide content of the sample environment, one can calculate the rate of defect production and the age of the sample. This technique was used by a researcher independent of the Yucca Mountain Project, Professor David Cowan of the University of Missouri, to date quartz collected in Trench 14 by a Los Alamos National Laboratory scientist.

#### 2.1.10 Uranium Series Isotopes

Uranium series isotopes resemble the tracer isotopes discussed above in that they are too heavy to fractionate during chemical reactions and in that isotopic ratios can be used to fingerprint solutions that formed various minerals. Like the Rb-Sr, the U-Pb decay scheme has a very long half-life and is therefore not useful for geochronology of young deposits such as those under investigation here. However, uranium decays to lead via a long decay chain (Figure 4), and the ratio of parent ( $^{238}\text{U}$ ) to intermediate daughter ( $^{234}\text{U}$  or  $^{230}\text{Th}$ ) can be used to date deposits younger than 350,000 years. The half lives of  $^{238}\text{U}$  and  $^{234}\text{U}$  are long (about  $4.5 \times 10^9$  and  $2.5 \times 10^5$  years, respectively), but those of  $^{234}\text{Th}$  and  $^{234}\text{Pa}$  very short (days to hours), such that effectively from a geological viewpoint the latter two isotopes have only a fleeting existence and need not be considered further.

Like all parent-daughter dating systems, the  $^{238}\text{U} - ^{234}\text{U} - ^{230}\text{Th}$  system within a rock or mineral must satisfy two critical conditions: (1) the amount of daughter present when the system formed must be zero or determinable, and (2) neither parent nor daughter can be gained or lost from the time the system formed through to the present; that is the system is isotopically closed.

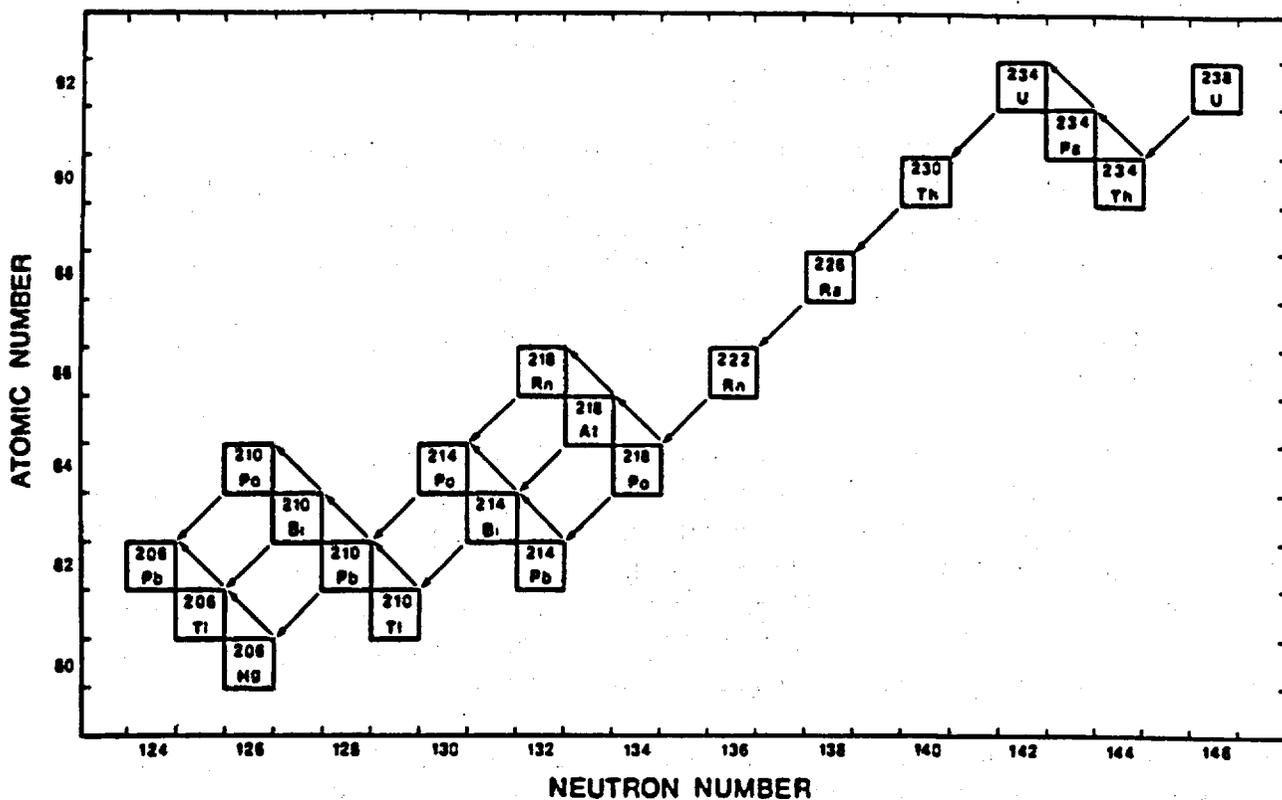


Figure 4. The decay of  $^{238}\text{U}$  to stable  $^{206}\text{Pb}$  from Faure (1986a).

For any closed-system parent-daughter decay scheme, the age of formation of a mineral or rock can be obtained from the relationship:

$$D_p = D_o + P(e^{-\lambda t} - 1)$$

where

- D and P stand for the symbol of an isotope
- $D_p$  is the amount of daughter isotope currently present
- $D_o$  is the amount of daughter isotope originally present
- P is the amount of parent isotope currently present
- $\lambda$  is the decay constant for the parent isotope
- t is the age of the system.

For the  $^{238}\text{U} - ^{234}\text{U} - ^{230}\text{Th}$  system, this relationship results in 2 equations (the 2 parent-daughter equations) and 3 unknowns (age,  $^{234}\text{U}_o$ , and  $^{230}\text{Th}_o$ ). Thorium is exceedingly insoluble in all waters from which calcite may have precipitated, and thus, for pure calcites, one unknown ( $^{230}\text{Th}_o$ ) becomes zero and the original amount of  $^{234}\text{U}$  and age can be calculated. For impure samples, such as the pedogenic ones discussed here, the  $^{230}\text{Th}_o$  is assumed to reside in the detrital component and that amount is calculated from the results of a weak and a strong chemical attack (Szabo and Rosholt, 1982).

The condition of closed systems behavior is often difficult to demonstrate. Because of the exceptionally low solubility of thorium, open-system behavior is almost always due to uranium mobility. Loss of uranium from the systems (the most common type of open-system behavior) results in apparent ages that are too old. Preferential loss of  $^{234}\text{U}$  (see below) results in  $^{234}\text{U}/^{238}\text{U}$  ages that are too young and  $^{230}\text{Th}/^{234}\text{U}$  ages that are too old; a pattern which is easily recognized. In general, concordant  $^{234}\text{U}/^{238}\text{U}$  and  $^{230}\text{Th}/^{234}\text{U}$  ages, ages that agree with independent evidence or internally consistent ages can provide confidence in calculated ages.

The preferential loss of  $^{234}\text{U}$  can occur through either ejections of a  $^{234}\text{Th}$  atom from a solid to an adjacent liquid phase during decay of a  $^{238}\text{U}$  atom or by preferential leaching of  $^{234}\text{U}$  from a decay damaged uranium site. Both of these mechanisms yield anomalously large  $^{234}\text{U}/^{238}\text{U}$  values in water. Such anomalous ratios are exceptionally well developed in ground waters of southern Nevada (Osmond and Cowart, 1982) but Rosholt et al., (1985) do not report any for soils. Thus the initial  $^{234}\text{U}/^{238}\text{U}$  in calcites is diagnostic in differentiating soil and ground water deposits.

All of the foregoing discussion has been presented in terms of absolute abundances of isotopes, but for historic reasons results of U-series analyses are reported as activity ratios. For a closed system of sufficient age, the parent-daughter activity ratio is one; that is for every atom of parent that decays to a daughter, a daughter atom decays to its daughter. A daughter to parent activity ratio of 2 means that the sample has a 100% excess of daughter atoms. Ground waters near Yucca Mountain typically have  $^{234}\text{U}/^{238}\text{U}$  ratios much larger than 2 (Stuckless et al., 1991; Osmond and Cowart, 1982). This extreme anomaly transfers (during the precipitation process) to calcites deposited from ground water, and is therefore diagnostic.

## 2.2 APPLICATION OF METHODS

This section briefly presents results of the application of the methods described in section 2.1 to the study of the calcite-silica deposits in Trench 14 and the sand ramps on Busted Butte. Section 2.3 provides additional detail, primarily for the specialist, for most of these applications. In several of the subsections below references are given to tables. The locations of samples taken from Trench 14 and given in the tables are shown in Appendix D. Coordinate locations for samples taken from Trench 14 are included with sample descriptions in Tables A-3, A-4, A-15, and B-10.

### 2.2.1 Field Data

Characteristics of calcite-silica deposits that aid in distinguishing pedogenic from spring deposits include the following: 1) In pedogenic deposits  $\text{CaCO}_3$  enriched zones form parallel with slopes as contrasted with distinct mounds for springs (Bachman and Machette, 1977). Because the carbonate enriched horizons can be traced upslope past the vein fillings, the slope parallel deposits cannot be interpreted as a draped mound formed by springs. 2) The geometry of vein deposits underlying springs (best known from economic mineral deposits) tend to have sub-parallel walls that extend tens to hundreds of meters deep (e.g. Sawkins, 1984). See Figure 5. An example is the Santo Niño vein, Zacatecas, Mexico (Figure 6). This vein appears to be represented at the surface by a stockwork of small quartz-calcite veins, but at depth the vein ranges from 0.1 to >3 m wide (Gemmell et al., 1988). This splitting up of a major vein at depth over a vertical range of hundreds of meters into smaller ones closer to the surface contrasts with the relations found at Trench 14. Simmons et al., (1988) estimate the paleosurface when the veins formed as being 100 m above the present surface, and draw parallels between relations found for the Santo Niño vein to those at the active hydrothermal system at Broadlands, New Zealand. For both Santo Niño and Broadlands the evidence indicates that hydrothermal systems have been driven by the cooling of magma at depth following the eruption of welded tuffs. Additional examples of similar veins could be cited, but this would digress from the topic of this report. Extensive exposures along Furnace Creek, California (Figure 7) also exhibit sub-parallel walls in veins underlying a spring deposit (Winograd et al., 1988). In contrast veins formed pedogenically as fillings of fractures or faults should pinch out rapidly with depth (Gile et al., 1966) as a consequence of the narrowing of the apertures of the fractures and faults that were opened by various erosional and weathering phenomena, such as soil creep. 3) Detrital matter, as for example black volcanic ash, can easily become incorporated into pedogenic deposits, but is likely to be washed out from actively flowing springs. 4) In a spring deposit suspended mineral particles precipitated from solution would ordinarily be carried upward through the feeder vein or conduit, but often settle out within the pool of the spring. Consequently, textural relations will differ for spring deposits between the vein filling and horizontal deposits. The contrasts between the characteristics of pedogenic and spring deposits, rather than the characteristics themselves, constitute the criteria and are generic rather than site specific.

In respect to all these criteria the actual field evidence favors a pedogenic origin.

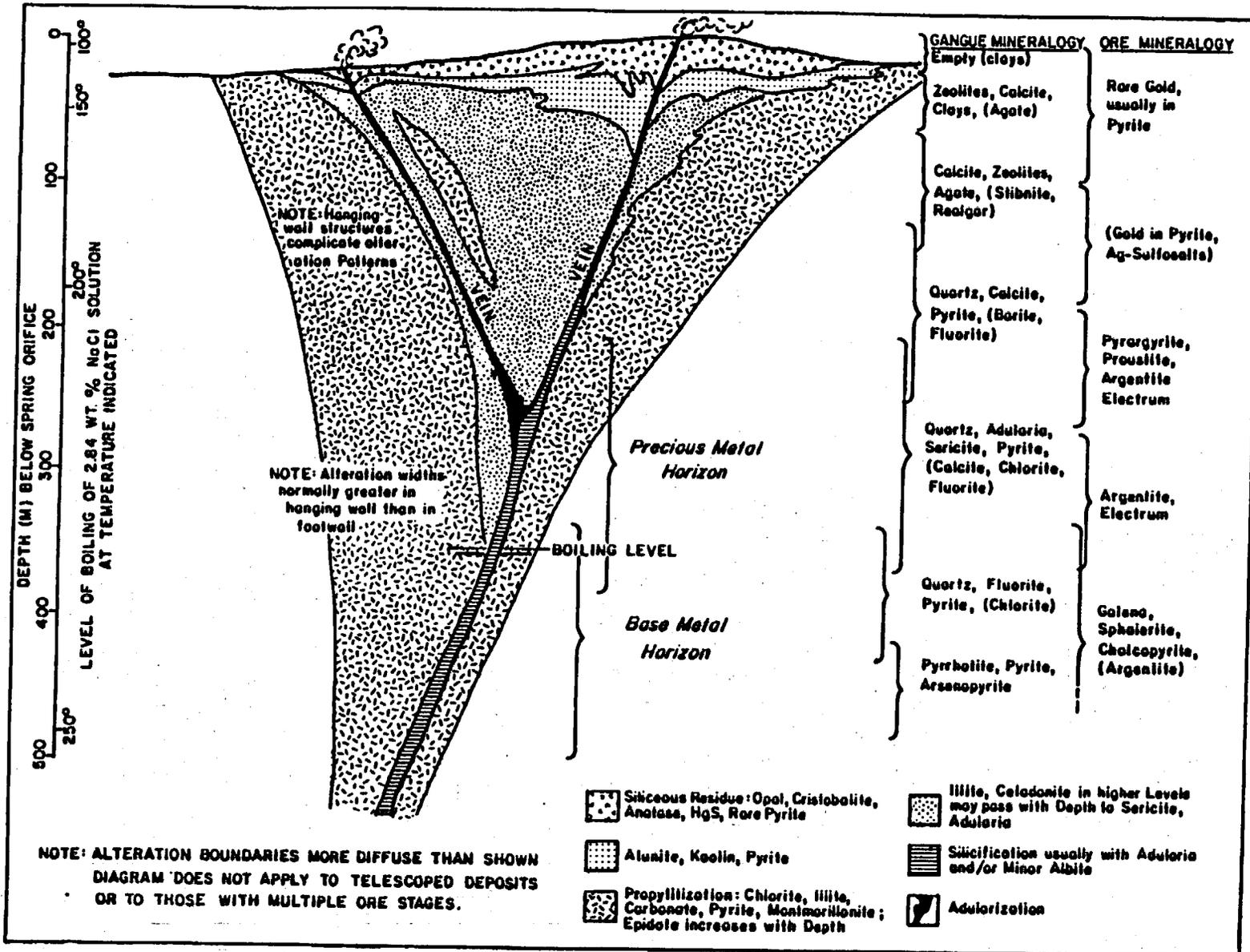
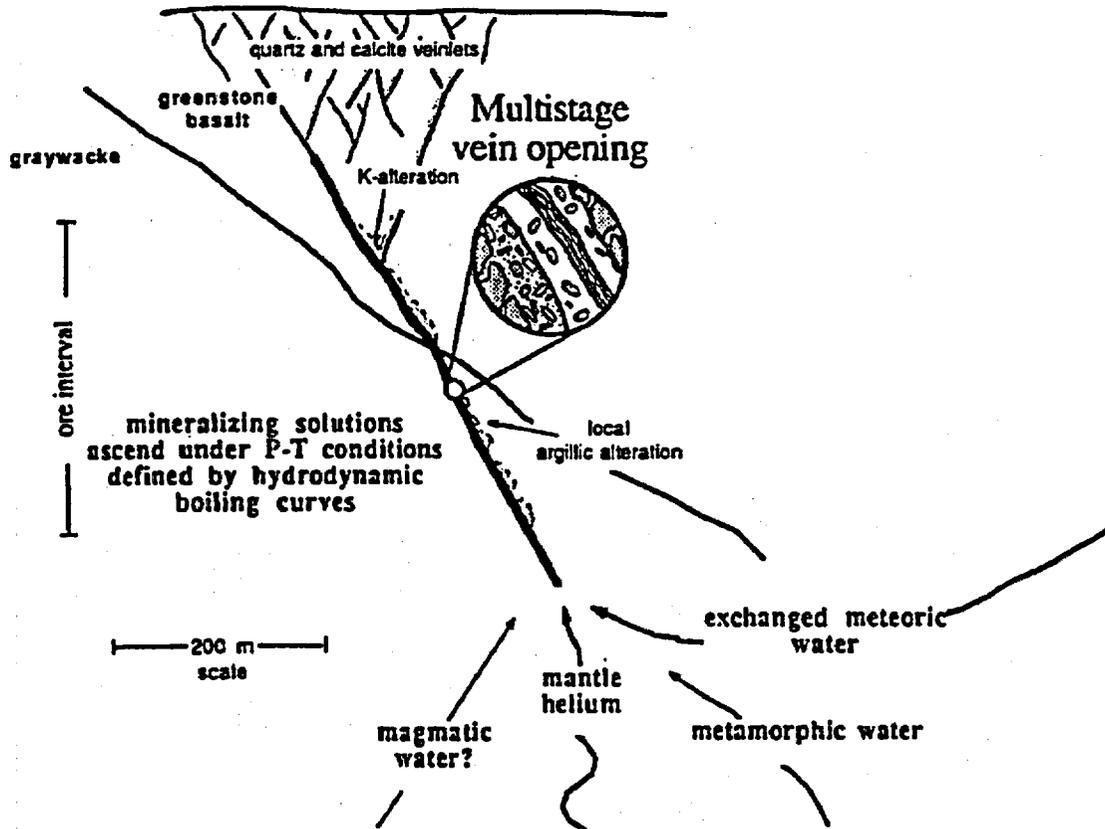
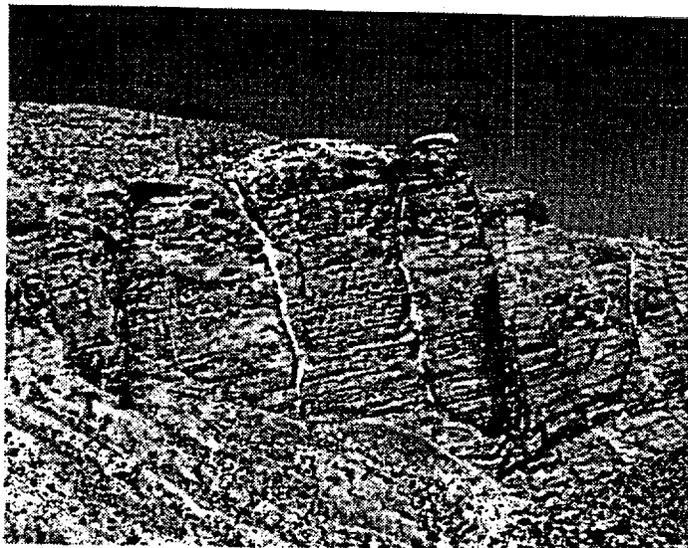


Figure 5. Idealized model for an epithermal precious metal vein system incorporating many of the features found in such systems. In any one system only some of features shown are manifest; for example, not all epithermal precious metal deposits pass downwards into base metal veins (from Sawkins, 1984).

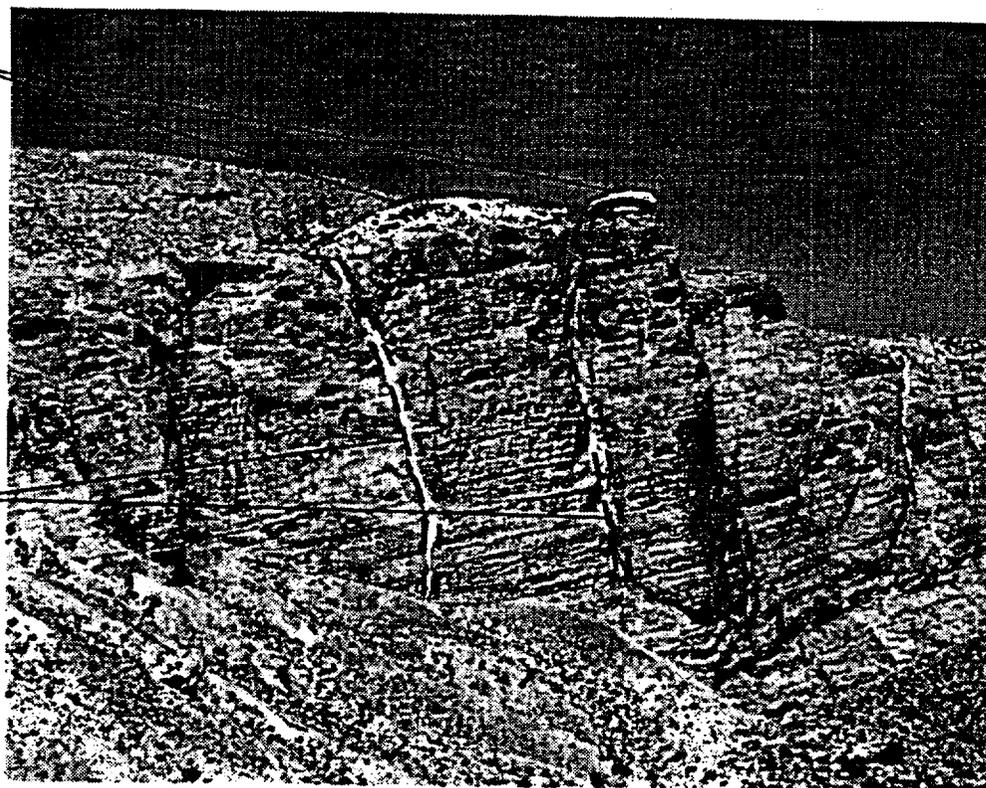


**Figure 6.** Schematic diagram of events and solution characteristics during the mineralization of the Santo Niño vein. Multistage vein opening diagram represents a 2-m diameter depicting three stages of mineralization. Surface is present-day. (After Simmons et al., 1988)



MOUNDS

VEINS



*Figure 7. A fossil spring mound with more than 60 m of feeder vein at Travertine Point along Furnace Creek in the Death Valley National Monument.*

### 2.2.2 Mineralogic and Textural Data

The laboratory examination of samples from the vein and slope deposits has provided additional details and insights. As an amplification of criterion 4, above, it would be reasonable to expect differences in mineralogy between vein and slope deposits in the case of spring action, but not from pedogenic processes. Microscopic examination also permitted the identification of 10% to 20% of detritus, partly as cores of ooids and pellets; as noted above under criterion 3 this is much more likely in pedogenic rather than spring deposits. (See Section 2.3.2 for definitions of ooid and pellet.) In fact ooids, pellets, and root casts are common in pedogenic deposits, but rare to absent in springs. The vein fillings at Trench 14 are fine grained and poorly indurated in contrast to typically coarse grained calcite in feeder veins and at discharge points of spring deposits. The characteristics of the laminae (banded, thin opaline, dense, small calcite crystals intergrown with opal and sepiolite) differ from those in spring deposits (megascopically visible banding but microscopically similar laminae, large single calcite crystals). Fragile forms and textures, such as root casts and needle fiber calcites, were preserved in the Trench 14 and Busted Butte deposits, but are rare to absent in spring and seep deposits. Deposits from evaporative seeps lack the concentric ooidal accumulation of calcite and opal around detrital grains, and show a single transition from calcite to silica rather than multiple alternating bands. Moreover, these seep deposits, as for spring deposits, contain ostracodes and casts of phreatophyte plants and algal or diatomaceous opal A; in other words a very different set of fossils from those found in pedogenic deposits.

In brief, whereas the characteristics noted here do not always provide unambiguous distinctions among spring, seep, and pedogenic deposits, the predominance of the evidence favors a pedogenic origin.

### 2.2.3 Quantitative Mineralogic and Chemical Analysis

The great similarity of shape in the distribution curves for the lanthanide elements (see Figure 3, based on data in Tables B-12 through B-14) in laminae in vein calcretes to that in tuff indicates a common component that determines the distribution. Clearly this must be the tuff itself, detritus from which is variably diluted by other components of the veins. It is also of interest that the pattern for the surface soil differs slightly, showing a small enrichment in the heavy lanthanides. As indicated in section 2.1.6 such enrichments are commonly caused by preferential incorporation of these elements into minerals rich in iron and magnesium. This relationship is confirmed by microscopic and X-ray diffraction results (relevant data appear in Tables B-12 and B-14). Similarly, iron (Fe) and scandium (Sc) concentrations are significantly higher in soils than in adjacent fault-breccia tuffs (see Figure 8, based on data in Tables B-11 through B-14). The data for Fe and Sc are particularly intriguing because they permit some insight into the pathway by which the tuff detritus became incorporated into the calcretes. If there had been a direct admixture of fresh unweathered tuff grains into the calcrete, compositions in the calcretes would lie on a straight line compositionally between Sc-free calcite + opal and tuff, i.e. along the lowest line in Figure 9, labeled "direct-mixing path". However, this figure shows instead that the

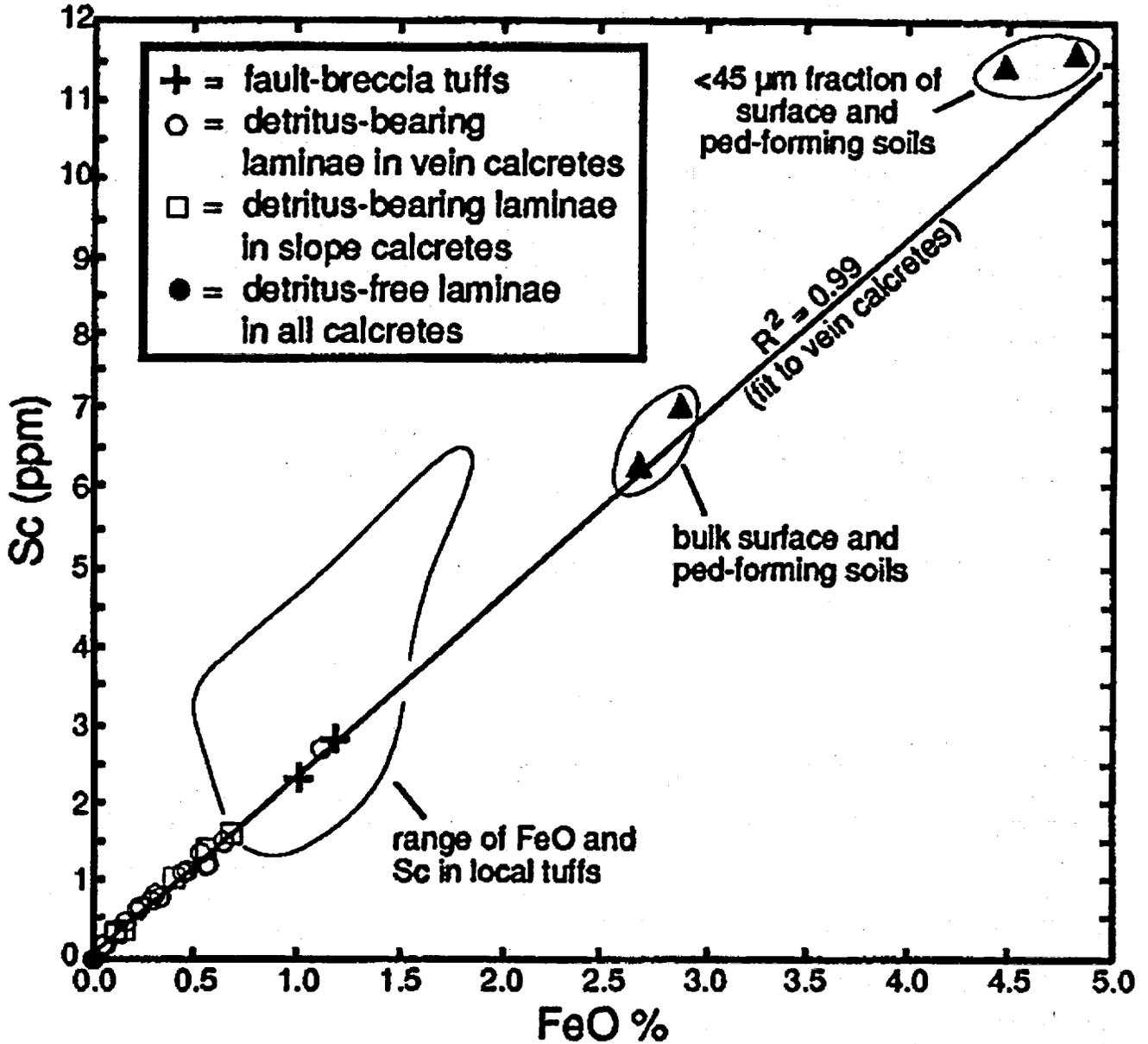


Figure 8. Sc as a function of FeO for the fault-breccia tuffs adjacent to the vein calcretes.

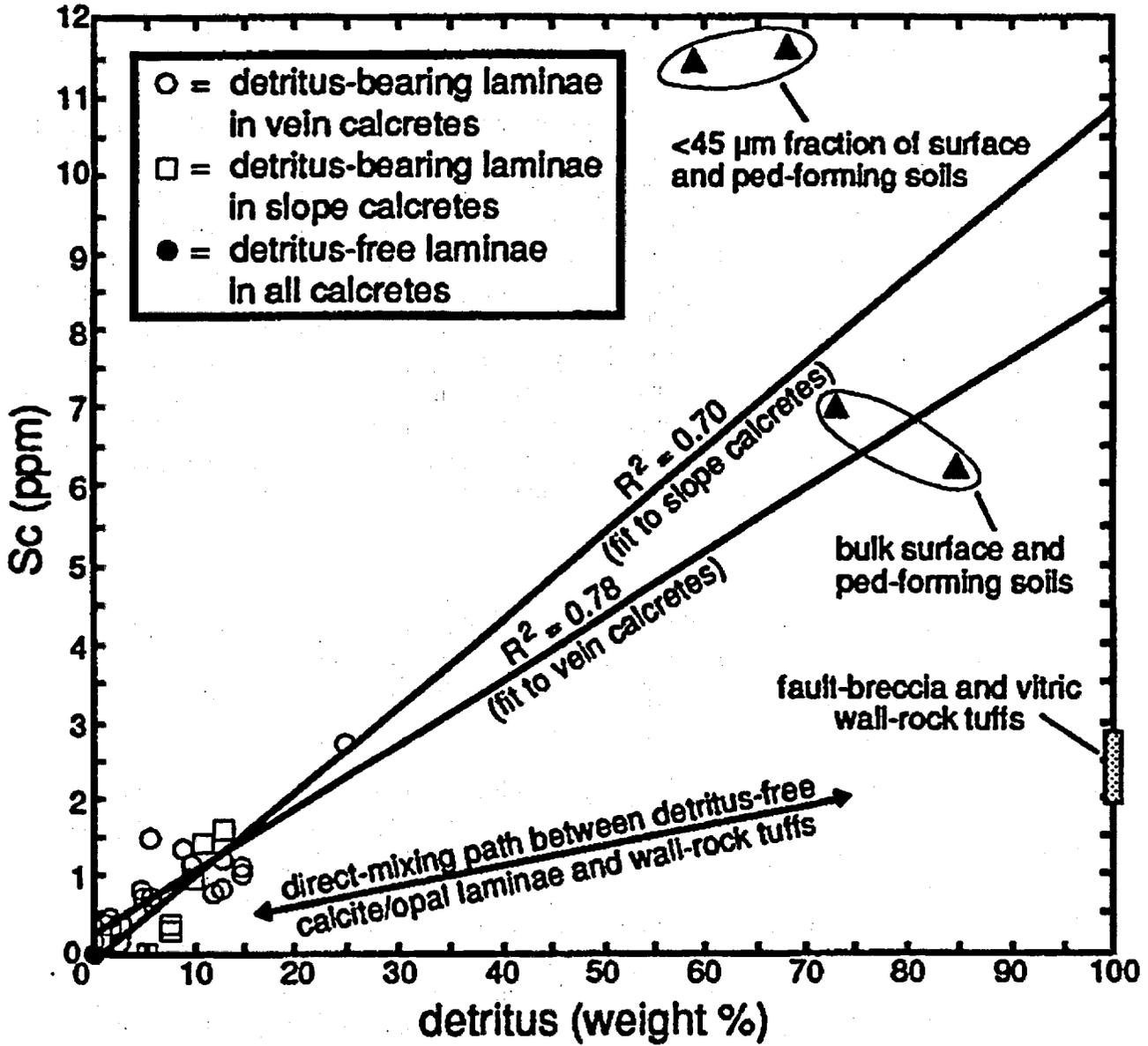


Figure 9. Sc concentration as a function of weight percent of detritus for laminae in the calcretes and for the bulk and <45  $\mu\text{m}$  fraction of surface and ped-forming soils above the calcretes.

best interpretation is that the mixture is between surface soils, which themselves contain tuff detritus, and the opal and calcite. In other words the evidence indicates that the tuff detritus did not enter the calcretes by direct removal from the walls of a feeder conduit, as would be expected for a spring origin and particularly in veins where hydrothermal brecciation has occurred, but rather by first entering the soil where weathering led to an enrichment in Sc and then incorporation into the veins. This evidence favors a pedogenic origin as a result of providing information about the source of a component of the veins.

Another type of question about source is the adequacy of available calcium and silica to form the deposits. For a pedogenic origin, in view of the relatively low content of Ca in rhyolitic welded tuff, a reasonable source would be from carbonate containing dust derived from Paleozoic carbonate rocks and playas in the vicinity and deposited on the soils. Many constituents of the tuffs, including volcanic glass, contain high percentages of SiO<sub>2</sub> (viewed as a chemical component, not as a mineral); this circumstance potentially provides an abundant supply of SiO<sub>2</sub>. Because the glass and some unstable volcanic silica minerals are more soluble than opal-CT or quartz, the rock silica will tend to dissolve slowly in soil and ground water and precipitate nearby as one of these minerals where conditions are favorable. Similarly, the deposited carbonate dust would dissolve and reprecipitate. These processes would occur very slowly. Still, as described in detail in Section 2.3.3, approximate calculations indicate that enough of these components would have been available over an appropriate span of time.

#### 2.2.4 Stable Isotope Data

Stable isotopic data can be used to gain insight into the sources of oxygen and carbon incorporated into calcite in the calcretes (See Tables A-1 and A-2). Two potential sources are considered here: soil water and gas (i.e. pedogenic sources), and local ground water from the saturated zone.

The pedogenic case was evaluated by comparing numerous measurements of pedogenic carbonates (Quade et al., 1989) widely distributed in southern Nevada with calcites at Trench 14 and Busted Butte (see Figure 10). In making this comparison it should be borne in mind that the calcretes may have formed at an earlier cooler time, which would correspond to a slightly higher altitude as compared to the data cited from Quade et al. (1989). Quade et al., selected pedogenic samples carefully to be geologically young, i.e. on the order of or younger than about 7000 years. [The reasons for the decrease of  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  with elevation involve a complex of kinetic factors, different for oxygen than for carbon. This empirical relation for  $^{13}\text{C}$  is discussed in Quade et al. (1989) and that for  $^{18}\text{O}$  in Faure (1986b).] Thus, Figure 10 shows a comparison of the Trench 14 and Busted Butte  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  with known pedogenic deposits in southern Nevada, as well as a match for  $\delta^{13}\text{C}$  the data.

The evaluation of the potential origin of the calcretes from local ground water that may have risen to surface requires estimation of the isotopic composition of calcite that would form from these waters. For this purpose the data of Benson and McKinley (1985) for several ground

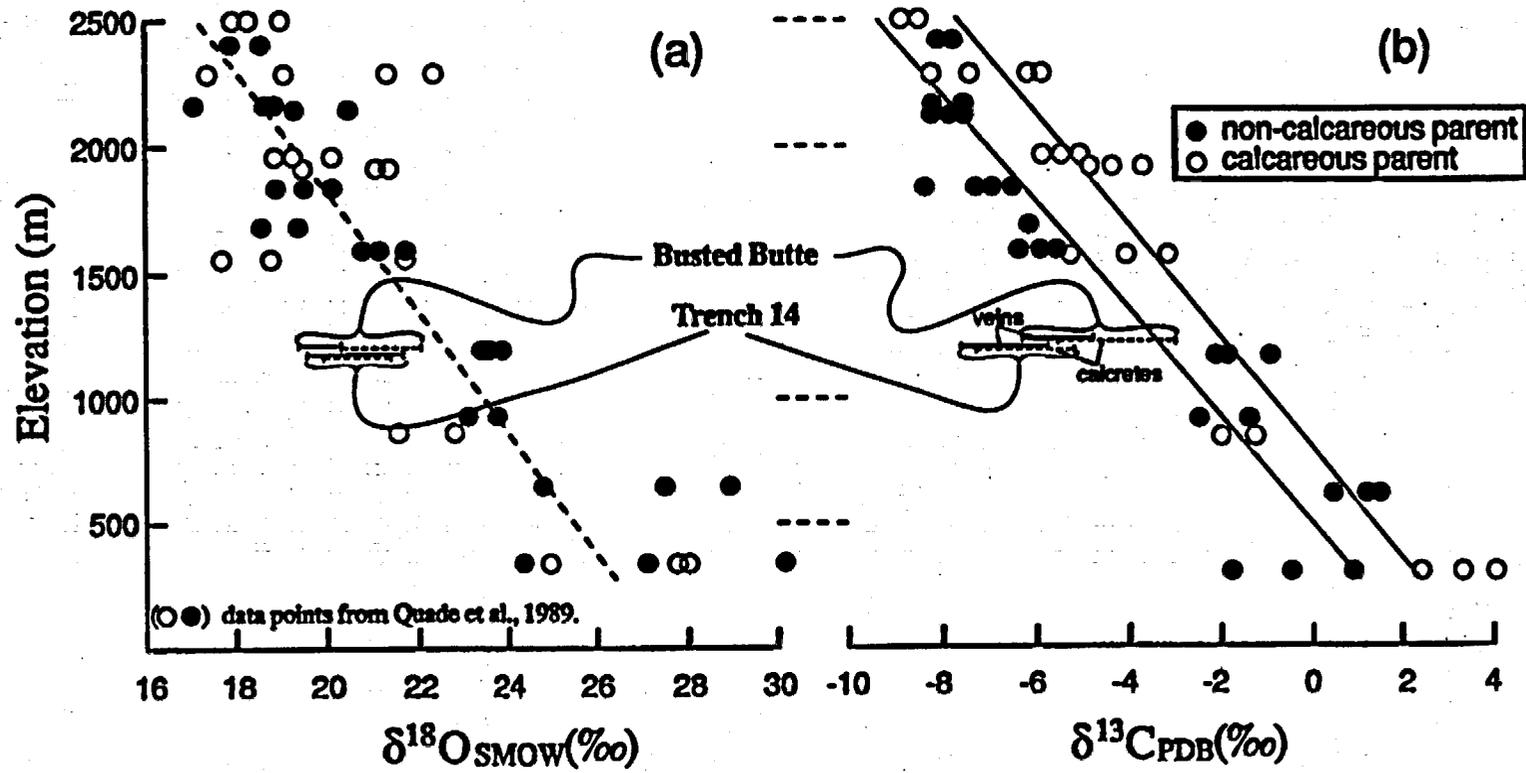


Figure 10. The relationship between  $\delta^{13}C$  and  $\delta^{18}O$  for pedogenic carbonates and samples from the Trench 14 veins.

waters and the equilibrium constant (Deines et al., 1974) for the measured temperature of the water were used to estimate the isotopic composition of calcite that would form at that temperature (for most of these ground waters the temperature was near 40 °C). Figure 11 shows these data and the method of calculation is provided in Section 2.3.4. Note that the calculated values of  $\delta^{18}\text{O}$  differ from those observed at Trench 14 and Busted Butte by about 10 per mil. Another way of looking at this result is to consider the relations shown in Figure 12. The data of Benson and McKinley (1985) for Yucca Mountain ground waters fall mostly between -13 and -14 per mil  $^{18}\text{O}$ . This yields, for calcite in equilibrium with the water,  $\delta^{18}\text{O}$  more or less between +11 and +14 per mil, i.e. to the left of the figure. For waters with that isotopic composition to precipitate calcite as observed in Trench 14 and Busted Butte it would first need to cool to about 0 °C, as shown by the rightmost dashed diagonal isotherm passing through the intersection of the observed ground water and calcite compositions. Because such a low temperature is geologically unrealistic, this argues strongly that no origin of the calcretes from water rising from the water table, by whatever means, is compatible with the isotopic evidence.

Note, however, that this analysis assumes that ground water several hundreds of thousands of years old, which would correspond to the ages of the calcite, resembled the present day ground water, which has apparent  $^{14}\text{C}$  ages of 2 to 30 thousand years old. In view of the data discussed in Section 2.3.4 of this report this assumption seems reasonable.

Note that by contrast the intersection of the composition ranges of present day meteoric water and the calcites is compatible with a reasonable formation temperature, such as 10 °C to 15 °C, in agreement with the conclusions reached for a possible pedogenic origin.

### 2.2.5 Radiogenic Tracer Isotope Data

Radiogenic isotopic data can also be used to gain insight into the sources of calcium and uranium incorporated into calcite in the calcretes. The same two potential sources are considered here as for stable isotopes, namely soil water and local ground water from the saturated zone. Both  $^{87}\text{Sr}/^{86}\text{Sr}$  (or  $\delta^{87}\text{Sr}$ ) and  $^{234}\text{U}/^{238}\text{U}$  ratios were used for this purpose. These isotopes do not undergo isotopic fractionation during geochemical processes, as noted in sections 2.1.8 and 2.1.10 of this document. Consequently, the ratios in calcites (see Tables A-9 through A-14) that precipitate from the ground or soil water will be the same as in the water at the time of formation. The  $^{234}\text{U}/^{238}\text{U}$  ratio in the calcite will evolve with time, owing primarily to the radioactive decay of  $^{234}\text{U}$ . Activity ratios cited in this paper were determined by alpha spectrometry and are generally precise to  $\pm 1.0\%$  (Rosholt et al., 1985). The  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio will remain constant on account of the absence of  $^{87}\text{Rb}$  in the calcite. The reader is also reminded of the strong geochemical coherence of Sr and Ca.

These evaluations for deep ground water involve the same assumption as required for the use of  $\delta^{18}\text{O}$  values, namely the assumption of constancy of the isotopic composition of the water for the last several hundred thousand years. An evaluation of this constancy is discussed below.

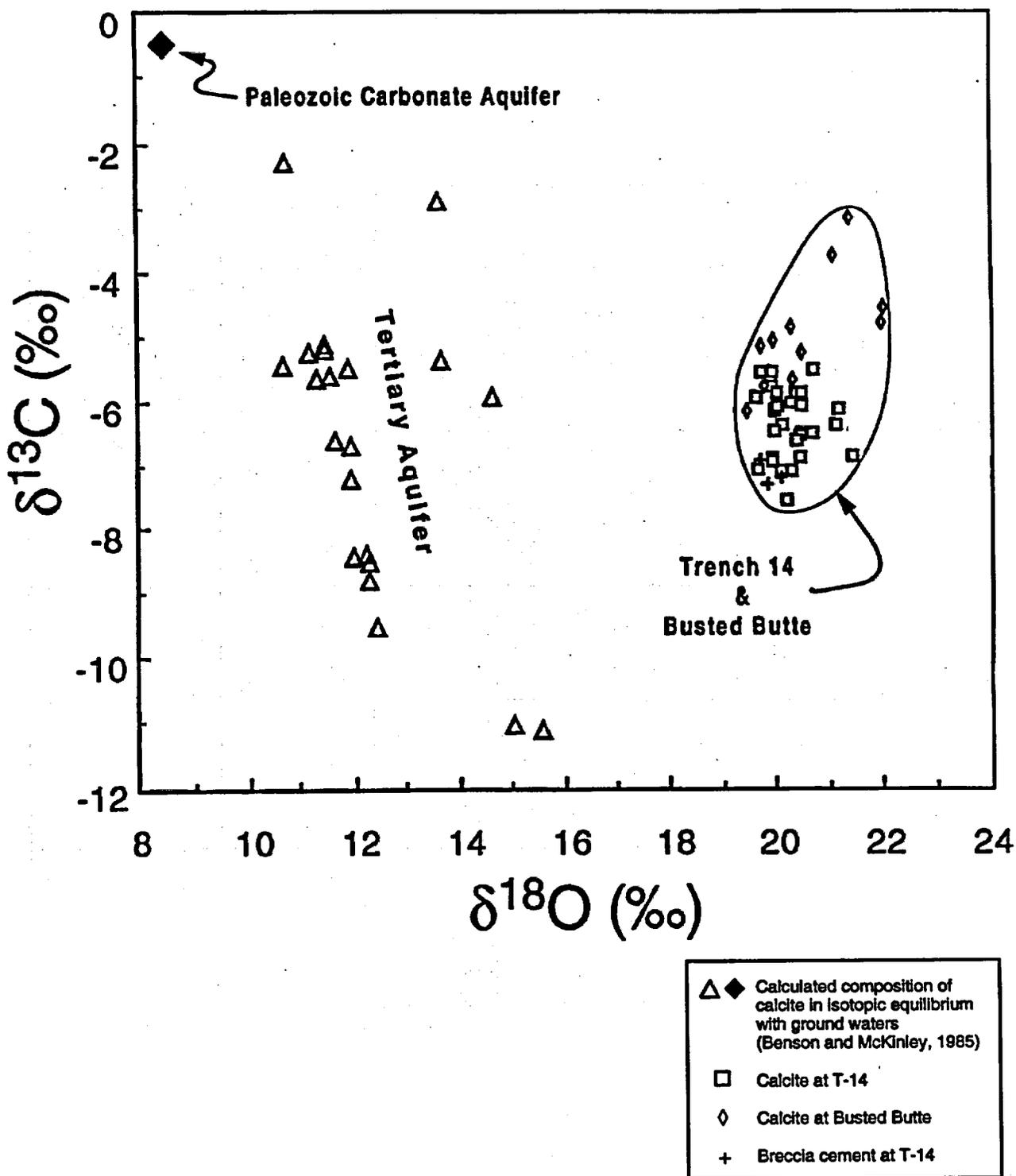


Figure 11. Relationship between  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  for carbonates compared with calculated compositions of calcites precipitated in equilibrium with waters beneath Yucca Mountain. (calculations were done for the measured temperature of the ground water.) (Deines et al., 1974)

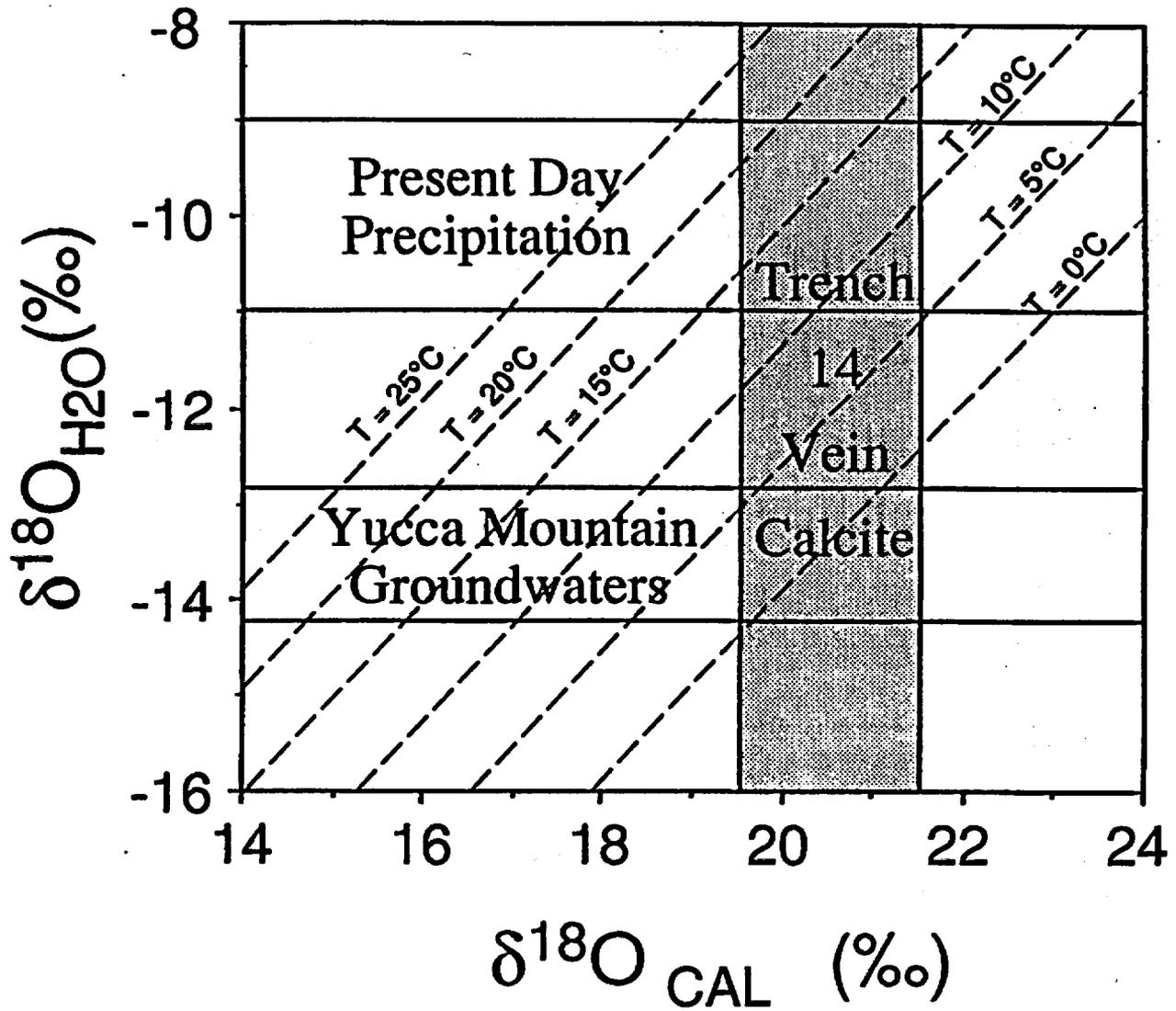


Figure 12. The equilibrium relationship between  $\delta^{18}\text{O}$  in calcite vein samples and  $\delta^{18}\text{O}$  for water as a function of temperature.

The comparison of 39 samples from veins with 37 pedogenic calcites (see Tables A-12, A-13 and A-14) shows very little difference in  $\delta^{87}\text{Sr}$ , 4.48 vs. 4.41, respectively. Thus, the signatures or fingerprints match and identify pedogenic processes as a strong candidate for the formation of the calcretes.

To utilize the  $^{234}\text{U}/^{238}\text{U}$  data one must first extrapolate the measured ratios back to the initial values in order to remove differences between very old and much younger deposits because of the time evolution of the ratio. This can be done by using the solid lines in Figure 13 or equivalent computational methods. The solid curves show paths of isotopic evaluations as a function of time and in a closed system for  $^{234}\text{U}/^{238}\text{U}$  and  $^{230}\text{Th}/^{234}\text{U}$ . The data show a parallel trend and therefore demonstrate constancy of the initial  $^{234}\text{U}/^{238}\text{U}$  as a function of time. Rosholt et al. (1985) analyzed several soils in the Yucca Mountain area for  $^{234}\text{U}/^{238}\text{U}$  and  $^{230}\text{Th}/^{238}\text{U}$  (thus permitting the calculation of  $^{230}\text{Th}/^{234}\text{U}$  as required to obtain initial ratios — see Figure 13 and discussion in Section 2.3.5) along with numerous other Quaternary samples. These calculated initial values are, with the exception of one at 2.0, generally less than 1.40. This compares with two values for vein samples of less than 1.40. Thus, the result is compatible with a pedogenic origin for the veins.

Figure 14 shows a plot of  $\delta^{87}\text{Sr}$  for ground waters, calcite-silica veins, and pedogenic calcite. The only ground waters that possess appropriate values of  $\delta^{87}\text{Sr}$  lie to the south of the deposits in question (and in a different ground water flow system), but the present ground water flow is from the north. Under present circumstances upwelling of a ground water with the right Sr isotopic composition would require a reversal of the flow direction and a northward movement of 1 to 8 km. Thus, on the assumption that the present flow pattern and water composition are essentially the same as those prevailing while the calcretes were forming the Sr isotopic data are not compatible with formation from ground waters.

Figure 15 shows that the  $^{234}\text{U}/^{238}\text{U}$  ratio for most ground waters in southern Nevada (Osmond and Cowart, 1982; and Tables A-7 and A-8) differs significantly from the initial ratios calculated for carbonate samples from Trench 14 and Busted Butte. The discrepancy is particularly large for waters close to Yucca Mountain. In other words these data are generally not compatible with an origin of the deposits from upwelling ground water.

To address the question of the long term stability of the isotopic composition of ground waters recourse may be had to reasoning by analogy. This involves showing for some suitable site that the composition has been essentially constant over a sufficiently long time span at that locality and demonstrating that this site is sufficiently similar to Yucca Mountain and environs. Devils Hole appears to be sufficiently analogous. The argument presented below is, in principle, the same as for showing long term constancy for stable isotopes, referred to briefly in Section 2.2.4.

One modern water sample and six samples of calcite deposits from Devils Hole range in age from about 180,000 to 600,000 years and vary by only 0.71 per mil (Marshall et al., 1990. The value of 103,000 years should have been 180,000; this has been corrected here and in Table A-14.),

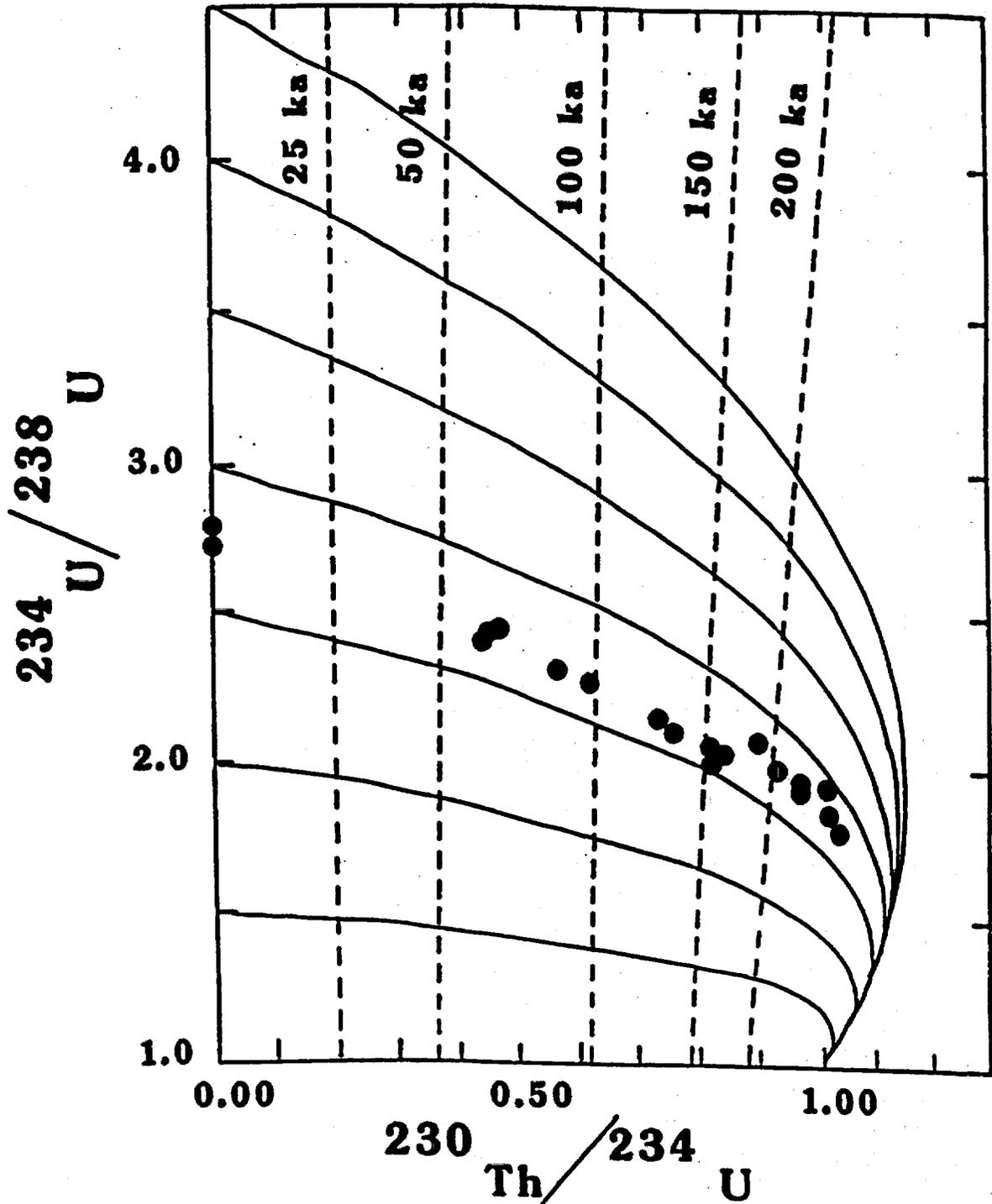


Figure 13. Uranium evolution diagram showing data points for water and calcite samples from Devils Hole, Nevada. The solid curves show paths of isotopic evolution as a function of time and in a closed system for  $^{234}\text{U}/^{238}\text{U}$  and  $^{230}\text{Th}/^{234}\text{U}$ . The data show a parallel trend and therefore demonstrate constancy of the initial  $^{234}\text{U}/^{238}\text{U}$  as a function of time.

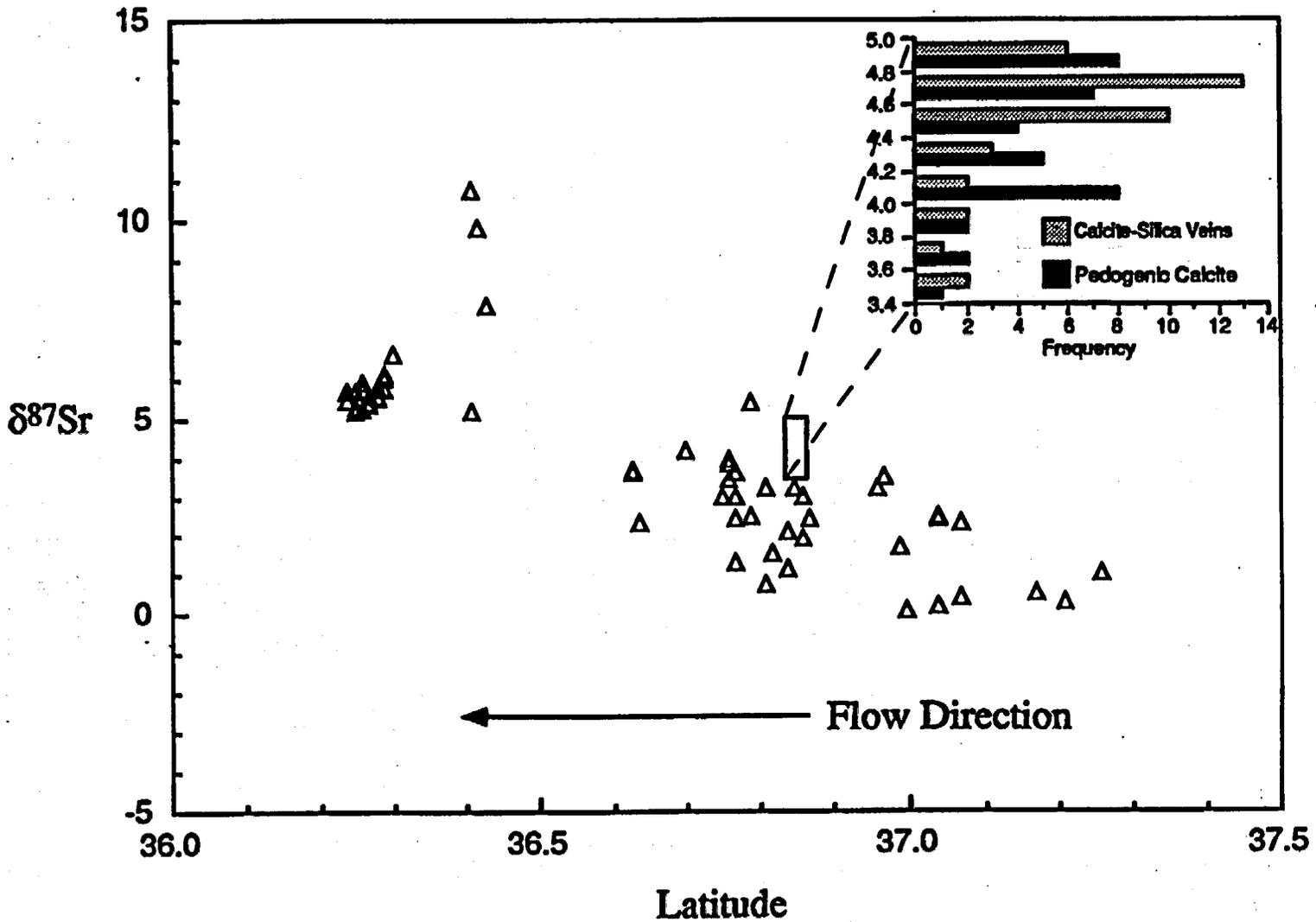


Figure 14.  $\delta^{87}\text{Sr}$  values for ground water samples in the Yucca Mountain region plotted against latitude of sample locality. The water table decreases in elevation from north to south, and flow is in a southerly direction. The cluster of points between latitudes 36.2° and 36.3° are samples from Franklin Lake Playa; they are located immediately south of the southern extent of Fig. 25. The histogram inset shows  $\delta^{87}\text{Sr}$  values of pedogenic calcite veins from Trench 14, Crater Flat, and Busted Butte. Some of the samples in the inset lay north, and others south, of Trench 14. The latitude position shown is that of Trench 14.

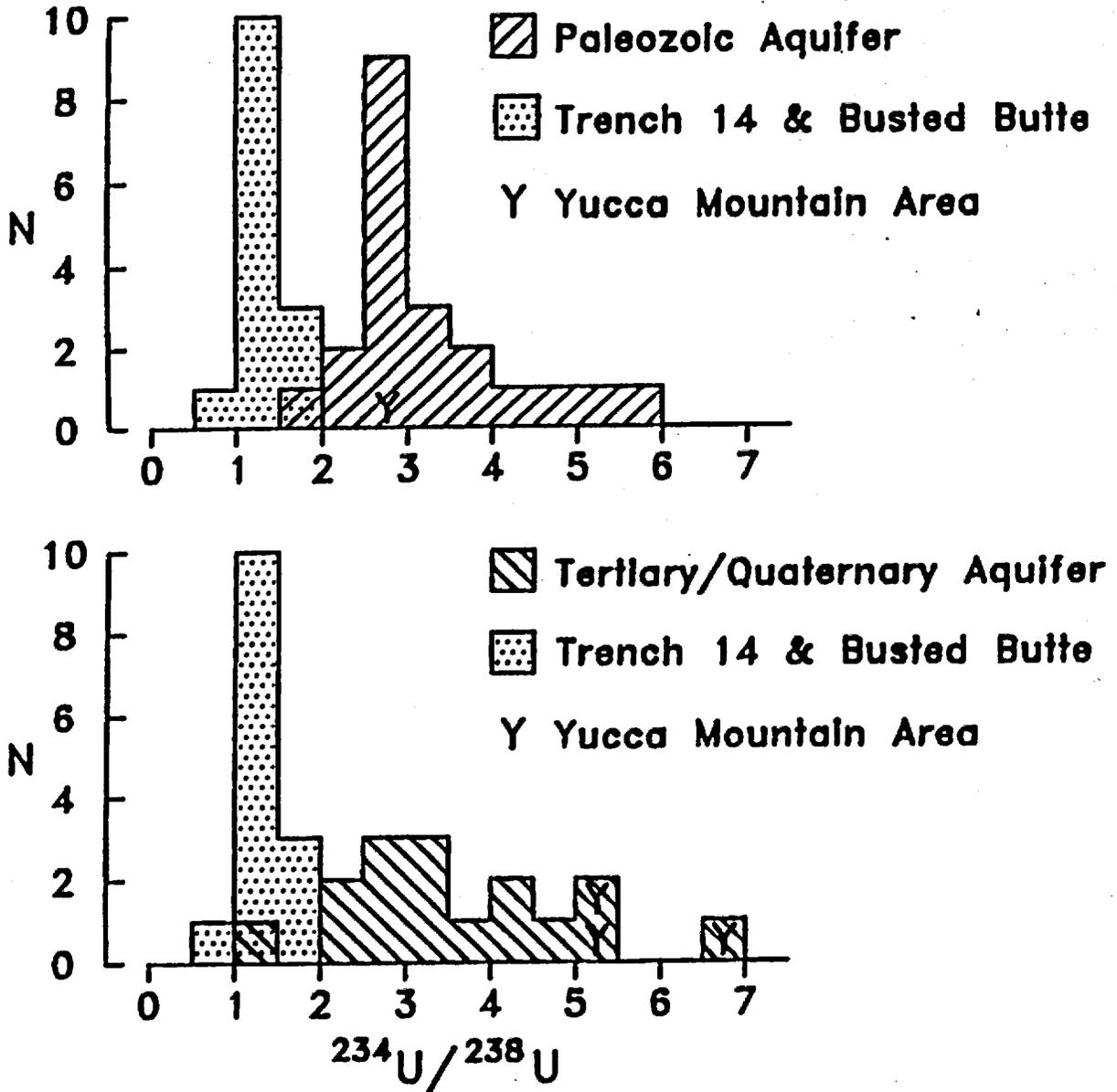


Figure 15. Histograms showing the isotopic composition of uranium in water from the Tertiary/Quaternary and Paleozoic aquifers and initial ratios for carbonates from Trench 14 and Busted Butte. N = number of samples.

demonstrating constancy over a long time frame. An additional 58 analyses of calcite from Devils Hole, spanning sample ages of 60,000 to 560,000 years, yield only a slightly larger variability in the  $\delta^{87}\text{Sr}$  value (Ludwig, 1993). Similarly, during the past 300,000 years the initial  $^{234}\text{U}/^{238}\text{U}$  ratio has ranged only from 2.53 to 2.85 (Winograd et al., 1988). Put into a more generic form these results indicate that so long as the aquifer system remains stable, i.e. the recharge area, host aquifer and flow path don't change, the tracer isotopic compositions will vary little. The available evidence for Yucca Mountain indicates that these hydrologic conditions have most probably not changed significantly during the Quaternary. Thus, the analogy seems acceptable. In turn this implies that the conclusions drawn earlier to the effect that the isotopic data are incompatible with an origin of the calcretes by precipitation from upwelling ground water are correct. Stable isotopic compositions have varied during the Quaternary in response to climate changes, but the record at Devils Hole only shows a variation of about 1‰ (Winograd et al., 1988), which is not enough to bring the ground water and calcretes of the Yucca Mountain region into agreement.

### 2.2.6 Paleontological Data

Eight samples of soil and vein carbonate were taken from the Trench 14 area to determine whether or not calcareous microfossils were present. No ostracodes or other aquatic animals such as mollusks were found (see Tables A-3 and A-4). Ostracodes are common in saturated environments of southern Nevada today including lacustrine settings, perched springs and discharge points for the regional aquifers, with a range of temperatures of 0 °C to 55 °C. The absence of such fossils implies that the carbonate veins were not deposited in an environment that was saturated with water for periods longer than about one month, which is roughly the time needed for the animals life cycle (Forester, 1991).

Eleven soil and vein samples were collected from the Trench 14 area to look for chrysophyte cysts (the resting stage of certain forms of freshwater algae). Rare cysts were found in two vein samples. In the modern environment, cysts are far more common in places where dilute surface waters are entering the hydrologic system (recharge areas) than in places where relatively concentrated ground water is emerging (discharge areas). In fact, modern chrysophyte cysts have been found in mud at the bottom of Trench 1 on Yucca Crest. Taken together, the two types of paleontological data argue against any type of spring environment for deposition of the Trench 14 calcite and opaline silica veins; the data are consistent with a pedogenic mode of deposition for the veins.

### 2.2.7 Possibility of Perched Water

The isotopic data are not particularly useful in evaluating a possible perched spring origin for the deposits exposed in Trench 14 because isotopic data are not available for perched waters. However, geologic and paleontologic data indicate that a perched origin is highly unlikely. Perched water occurs above aquitards such as air-fall tuffs (Winograd and Thordarson, 1975) or nonwelded and unfractured tuffs (Waddell et al., 1984). Strata that could form such aquitards are

more than 100 m deep in the vicinity of Exile Hill, and the veins pinch out along the fault contact with the welded tuff at Trench 14 which is highly fractured and very permeable. The textural, mineralogic, and morphologic data cited previously also argue against a perched spring origin because these data tend to differentiate between any type of spring and non-spring origin. These facts, combined with the relatively small catchment area upgradient from Trench 14, argue against a perched spring origin for the vein deposits at Trench 14.

### 2.2.8 Relationship of Silica Deposits and Breccias to Calcite-Silica Deposits

In addition to the issue of calcite-silica veins and their origin, questions about possible surface-discharging hydrothermal activity around Yucca Mountain engendered parallel studies of silica deposits and breccias. The intent of these studies was to identify surficial features most likely to be of hydrothermal origin and determine whether the ages and modes of origin indicate either recent or recurring surface discharge.

The term silica as used here (*nota bene*, this differs from common chemical usage) refers to a variety of anhydrous or hydrous crystalline to amorphous forms of silicon dioxide, SiO<sub>2</sub>. Important forms for this investigation include quartz, chalcedony, tridymite, cristobalite, and opal. Quartz is an anhydrous crystalline form. Chalcedony is a term for dense aggregates of fibrous microcrystalline quartz, commonly with small amounts of absorbed water. Tridymite is an anhydrous high temperature form of silica. Cristobalite is an anhydrous crystalline form with occurrence similar to tridymite. Both tridymite and cristobalite are considered to be high-temperature devitrification or vapor-phase crystallization products in the Yucca Mountain tuffs formed soon after the tuffs were deposited. Opal is hydrated silica with little or no crystallinity, described in detail in Section 2.3.2. Silica deposits are aggregates of one or more of the silica minerals described above, filling fractures or other void space in a rock or replacing part of the rock. Other secondary minerals may be present in subsidiary amounts.

Most of the sites selected for study (see Table B-1) contain silica deposits and bedrock breccias, locally in combination with each other. The Tiva Canyon Member of the Paintbrush Tuff, exposed east of the Bow Ridge fault in Trench 14, contains numerous fractures with deposits of 1- to 2-mm quartz crystals and chalcedony. Bedrock breccias are present in a zone about 4 m wide that includes the Bow Ridge fault and the main calcite-silica veins. At Busted Butte, several varieties of bedrock breccia are exposed within the Topopah Spring Member of the Paintbrush Tuff and along a fault scarp on the west side of the butte. Silica minerals locally present in the breccias include chalcedony, cristobalite, tridymite, and opal.

Characterizing the distribution of deposits involves determining their association with particular rock units, structural features, or syngenetic zones (zonation, such as devitrification zones, formed during the cooling of a pyroclastic deposit), and where they are in place, reworked, or truncated. Aspects of the deposits specifically relevant to the issue of surface discharge of fluid from depth include evidence of constructural features (e.g., secondary mineral mounds), fluid outlets or feeders, and relationships to past or present topography.

Laboratory studies have centered on textural analysis and identification of mineralogy. Textural analysis refers to the characterization of morphology and spatial relations among breccia and silica deposit constituents — clasts, matrix, fractures, mineral deposits, cements, and other components. Identification of the secondary minerals — minerals that formed after the volcanic tuffs were deposited — reveals something about the conditions under which the minerals formed and may provide links to other mineral-depositing processes of known origin.

#### 2.2.8.1 Silica deposits

The silica deposits are most likely linked to hydrothermal processes engendered by infiltration of meteoric water into newly deposited and still-hot pyroclastic flows more than 10 million years ago. This process is especially likely for deposits in brecciated tuff that contain tridymite and cristobalite as the principal secondary silica minerals, along with substantial amounts of alkali feldspar. Such a mineral assemblage is essentially identical to the vapor-phase minerals deposited in the upper parts of pyroclastic deposits while they cooled.

Abundant quartz and chalcedony have been observed within lithophysal cavities and moderately brecciated rock of the Tiva Canyon Member of the Paintbrush Tuff in the Trench 14 complex. Comparable mineral deposits are not present in the younger pyroclastic units exposed in the trenches nor are they present in calcite-silica deposits and authigenic-mineral cemented breccias (see below), except as recycled fragments. This indicates that the quartz and chalcedony predate the younger pyroclastic units, e.g., the 11.3 million year old Rainier Mesa Member of the Timber Mountain Tuff, and the calcite-silica deposits. Experimental ESR dating of one quartz sample from Trench 14 yielded an age of  $8.7 \pm 2.6$  million years (see Table B-7). There are several unevaluated sources of error, all of which would increase the calculated age. At the upper limit of the calculated error, the quartz age approaches the 12.7 million year age of the Tiva Canyon Member. Oxygen-isotope data for the quartz suggest it was deposited from fluids of slightly elevated temperature (Table B-8). The quartz might, therefore, have been deposited by warm silica-bearing water at a late stage in the cooling of the pyroclastic deposit. Alternatively, the quartz could be the product of an unidentified hydrothermal episode predating deposition of the younger pyroclastic units.

#### 2.2.8.2 Bedrock breccias

Bedrock breccias are classified into two general categories based on differences in the abundances of finely crushed tuff and authigenic minerals. The two categories are crushed-tuff-matrix (CTM) breccias and authigenic-mineral-cemented (AMC) breccias. CTM breccias contain clasts of local tuff in a matrix of finely crushed tuff, with little or no cement and no plant fossils. AMC breccias, more heterogeneous than CTM breccias, contain tuffaceous clasts, recycled CTM clasts, large amounts of authigenic mineral cements (opal and calcite), and very little fine-grained tuffaceous matrix material. Plant fossils are abundant. Small amounts of nontuffaceous clasts are also present. (See also Tables B-2, B-4, B-5 and B-6) Busted Butte contains extensive exposures of CTM breccias. The breccia zones lie within the Topopah Spring

Member of the Paintbrush Tuff. In the upper part of the tuff, breccias crystallized to alkali feldspar, cristobalite, and tridymite. As noted above, these are the same minerals that formed during devitrification (crystallization) of the original glassy tuff as it cooled. The extreme modification of the shapes of the breccia clasts during crystallization also indicates that the rock had been in a glassy condition when brecciation occurred. These observations tie the timing of brecciation to a period very soon after the tuff was deposited 12.8 million years ago (Sawyer et al., 1990). CTM breccias in the middle part of the tuff locally contain chalcedony or cristobalite cement that may have been deposited by infiltrating rainwater carrying dissolved silica from the altered breccias above. Additional evidence that the CTM breccias are very old includes the fact that the distribution of CTM breccia at Busted Butte and Trench 14 does not match the locations of recently active faults.

There is a prominent exposure of AMC breccia along a fault scarp at the bottom of a gully on the west side of Busted Butte. The site has been informally proposed by some observers as an example of a hydrothermal eruption breccia because it appears to consist of tuff fragments floating in a matrix of silica cement. Such a texture, if it existed, might indicate high-pressure and high-velocity transport of rock fragments by a solute-laden fluid.

Microscopic examination shows that the tuff fragments are not suspended in cement, but are generally grain-supported. Most of the tuffaceous clasts acquired coatings of calcite and opal, including plant root casts and fine-grained, broken calcite detritus, at some time perhaps prior to incorporation in the existing deposit. Post-depositional fracturing of the mostly rounded clasts has been very minor and the authigenic cements show few signs of breakage and recementation. These characteristics are not consistent with repeated episodes of breakage or explosive transport. The deposit may be a colluvial breccia or simple alluvium cemented by authigenic minerals.

Some AMC breccias in Trench 14 resemble the example from Busted Butte, whereas others do show evidence of repeated fracturing, both of tuffaceous clasts and authigenic cements. The breccias superficially appear to have a floating clast texture on a field scale, but microscopic study again shows grain-supported breccia fragments. Faulting and fracturing associated with the Bow Ridge fault have played an essential part in the formation of the vein breccias, but the contribution of hydraulic fracturing and mineral deposition by fluids from depth is not evident. The breccia cements are mineralogically the same as the cements in other AMC breccias and in laminated calcite-silica veins and calcretes. Some of the carbonate-rich fracture cements contain so many root casts that non-root mineral deposits from any source could only compose a small proportion of the total cement. The lack of alteration in the tuff clasts is uncharacteristic of hydrothermal breccias. Thus, the textural and mineralogic characteristics of the AMC breccias are not compatible with formation by recent surface-discharging hydrothermal activity.

### 2.2.8.3 Fission-track dating of zircons from AMC breccias

Zircon fission-track data for two AMC breccias from Trench 14 and Busted Butte indicate that both samples contain a heterogeneous population of zircons including a few crystals that are younger or older than the host tuff (Table B-3). Three possible interpretations can be made. The first is that the fluids that cemented the breccias brought zircons of different ages up from below the surface and they were incorporated in the cement. The zircons would have to have been heated sufficiently prior to or during emplacement to cause some track annealing because zircons are present that have fission-track ages younger than the host rock. The age of most recent cementation would have to have been equal to or younger than the age of the youngest zircon (4.8 $\pm$ 2.5 million years). The presence of a few zircons that are much older than the host rock does not preclude the possibility of heating, because the original ages could have been still older. The temperature would have to have been in excess of 180 °C (to lower the apparent age by annealing some fission tracks) and the fluid would have to be moving at a velocity at least sufficient to offset gravity settling of the zircon crystals. The second possible interpretation is that the breccias were open to the surface and wind or surface water washed the zircons present on the land surface into the breccia. Zircons of many different sources and ages could be redistributed on the land surface by either eolian or fluvial processes. These detrital zircons could then be cemented into the breccias. The third possible interpretation is that the mixed zircon population reflects both transport from depth (with or without heating episodes) and deposition of redistributed surficial material.

Zircon crystals from rocks around Yucca Mountain are sized less than 0.1 mm, smaller than most of the windblown basaltic ash particles within the fault at Trench 14. Most rock units in the Yucca Mountain area contain zircons, but no data are available at present to identify possible source areas or units.

Deposition of zircons by ascending waters that were hotter than 180 °C when they reached the surface is not compatible with the high abundance of plant root casts throughout the breccia cements. Upward transport of zircons by cold water from source regions that have not experienced recent heating cannot by itself account for the observed zircon age distributions in the AMC breccias because the zircons from such a source would all be older than the surface bedrock. Studies of illite/smectites from Yucca Mountain drill holes suggest that the most recent widespread heating event was about 11 million years ago (Bish, 1989), too old to have reset fission-track ages to less than 10 million years. Upward transport of zircons from depth may have been at most a subsidiary process and the addition of detrital zircons to AMC breccias by wind or surface waters a more widely active process. If this is correct, it may be difficult to distinguish a small number of zircons transported from depth within a heterogeneous population of mostly detrital zircons.

#### 2.2.8.4 Results of investigations on silica deposits and breccias

Quartz and chalcedony in Trench 14 are of hydrothermal origin, but the deposits are at least 8 million years old. Tridymite, cristobalite, and chalcedony associated with CTM breccias in the Topopah Spring tuff at Busted Butte are similar to the devitrification products in the bedrock formed during the cooling of the tuff 12.8 million years ago.

CTM breccias associated with the high temperature silica minerals in the Topopah Spring tuff at Busted Butte probably formed soon after the tuff was deposited 12.8 million years ago. AMC breccias in a gully at Busted Butte are cemented colluvium or slope-wash alluvium and are not related to either hydrothermal processes or faulting. AMC breccias at Trench 14 were formed by movement along the Bow Ridge fault and have been variably modified by the same pedogenic processes responsible for the calcite-silica vein deposits. Fission-track data for zircons in the AMC breccias are most compatible with input of surficial detrital material in the breccias.

#### 2.2.9 Summary

##### 2.2.9.1 Scientific investigations

The DOE has completed sufficient work under Activity 8.3.1.5.2.1.5, among others, to conclude that the deposits at Trench 14 and Busted Butte are not due to upwelling water. Most likely they are the result of pedogenic processes.

Four conceptual models have been proposed for the origin of the calcite-silica veins, as described in section 1.2: 1) pedogenic, 2) cold springs, 3) hydrothermal springs and 4) seismic pumping. That section also took note of potential pyroclastic-hydrothermal processes.

Based on the four criteria discussed in section 2.2.1, which relate to textural relationships among the minerals, structure of the deposits and the nature of detrital matter, the field data all favor a pedogenic origin over any other proposed mode of formation.

On a microscopic scale the mineralogic and textural investigations, discussed in section 2.2.2, revealed details of textures, e.g. root casts, ooids, pellets and features of laminae, that are characteristic of pedogenic deposits, but rare to absent in spring deposits and evaporative seeps. These observations all favor a pedogenic origin. Cold or hydrothermal springs and seismic pumping, which would result in some type of spring deposit or seep, would all produce deposits that, with perhaps rare exceptions, differ markedly from those actually present.

Quantitative chemical and mineralogic data are also consistent with a pedogenic origin. The lanthanide data show that tuff detritus controls the element distribution pattern in the calcretes. However, this does not rule out the possibility that rising waters could have picked up detritus from the vein walls and incorporated it into the veins. The iron/scandium ratio provides stronger support for the detritus found in the veins having first been weathered, and therefore supports a

pedogenic but none of the other proposed origins. The quantitative mineralogical data are consistent with all the chemical analyses.

Stable isotopic data for calcites in Trench 14 and on Busted Butte when compared to calcites that would form from any ground waters present now or in the recent past in the vicinity of Yucca Mountain indicate that the calcites could not have formed from ground water, but could have formed from water of meteoric origin at a time when the climate was about 5 °C cooler than at present.

The comparison of isotopic data for strontium from known pedogenic calcite with the calcites at Trench 14 and Busted Butte argues strongly for a pedogenic origin. Similarly, a comparison of the strontium data for the calcites with data from present day ground waters shows that these waters could not have precipitated the calcites actually present. Strontium isotopic data for present day ground waters are incompatible with any mode of formation of the calcites from upwelling water unless the existing flow direction is reversed. Thus, the strontium isotopic data strongly favor a pedogenic origin for the calcites, and argue against all of the other proposed origins. The  $^{234}\text{U}/^{238}\text{U}$  data for ground waters as compared to the ratios observed in the calcites on Busted Butte and in Trench 14 also argue against an origin from upwelling water and for a pedogenic related process. Thus, they argue against an origin from the last three proposed processes noted above. Note that although the isotopic compositions of Sr at Devils Hole, Trench 14 and pedogenic carbonates match, the isotopic compositions of U and C do not; thus the match for Sr is fortuitous.

Geologic, paleontologic, textural, mineralogic and morphologic data all argue against a perched spring origin for the deposits.

Studies of the relationship of silica deposits and breccias to calcite-silica deposits are summarized above in section 2.2.8.4. Briefly, the quartz, chalcedony, and CTM breccias are all old,  $\geq 8$  million years. Fission-track data for zircons in the AMC breccias at Trench 14 are most compatible with input of surficial detrital material.

The summary presented in the preceding eight paragraphs shows: 1) that no single type of analysis or interpretation of the data is entirely definitive by itself, 2) that no scenario of upwelling water is compatible with the observations, 3) that all analyses are compatible with pedogenic origin, and 4) that the predominance of evidence favors a pedogenic origin for the calcite-silica deposits at Trench 14 and on Busted Butte.

#### 2.2.9.2 Reports and Reviews

As noted in section 1.2, the DOE conducted several reviews. With the exception of the Minority Report of the Special DOE Review Panel (Archambeau and Price, 1991), the internal and external reviews commissioned by DOE on both the Trench 14 deposits and the Szymanski proposals agree that the deposits were not formed by upwelling water.

The NAS/NRC issued the final report by the Panel on Coupled Hydrologic/Tectonic/Hydrothermal Systems at Yucca Mountain (National Research Council, 1992). The charter of this panel was to evaluate (1) whether the water table had been raised in the geologically recent past to the level of the proposed repository horizon, and (2) whether it is likely that it will happen in the manner described in the DOE staff scientist's (Mr. Szymanski's) final report within the 10,000-year period covered by the regulations.

The panel's conclusions on question (1) include:

A) "The panel concludes, therefore, that the calcites of Trench 14 and Busted Butte formed from the same waters and by the same surface processes as the soil carbonates, and therefore are pedogenic in origin."

B) "The panel concludes from the geologic features observed in the field and geochemical data that there is no evidence to support the assertion that the water table has risen periodically hundreds of meters from deep within the crust. In fact, the evidence strongly supports a surface-process origin from rainwater for the vein and surface parallel carbonate and carbonate-silica deposits throughout the Yucca Mountain area."

C) "In the panel's view, those breccias that appear to have formed in response to hydrothermal processes in the vicinity of Yucca Mountain and Busted Butte originated at the time of emplacement of the ash-flow tuff sequence from 13-10 Ma."

"Younger breccias formed by a variety of processes through time, many of which show evidence of surficial water and progressive carbonate accumulation."

D) "Analytical data on both stable isotopes and radiogenic isotopes agree that the calcite vein deposits of Yucca Mountain did not precipitate from analyzed ground waters. The stable isotope data strongly imply that the calcites were deposited from surface waters under soil conditions in the unsaturated zone.

"The hypothesis of rising ground water as the origin of the calcites in the Yucca Mountain area has failed the tests of isotope geochemistry and is, in fact, contradicted by the available data."

The panel's conclusions to question (2) recognized the need to gather additional data, and that DOE has only performed a fraction of the numerous activities planned to characterize Yucca Mountain. The panel recommended that the DOE continue with those activities and made several specific recommendations for the DOE to consider in its characterization program. The DOE reviewed the recommendations of the panel and responded to the NAS/NRC in a letter (Gertz, 1992). Most of the recommendations are already addressed in existing study plans. The remaining recommendations can be factored into future characterization activities.

## 2.3 TECHNICAL DETAILS

This section provides, for some of the applications included in Section 2.2, additional technical details and interpretations of the investigations.

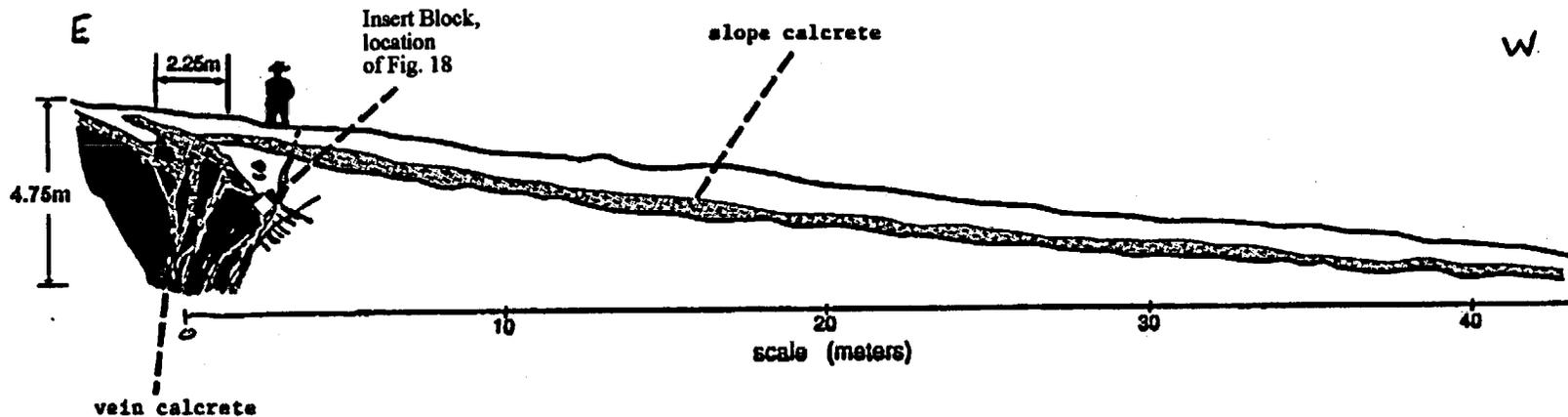
### 2.3.1 Field Data

Trench 14 exposes slope-parallel calcium carbonate enriched zones that are laterally extensive for thousands of square meters (Bachman and Machette, 1977), unlike springs which form discrete mounds (Figure 7). The slope-parallel deposits are physically typical of carbonate enriched pedogenic deposits that occur throughout the southwestern United States and other semi-arid regions of the world. The carbonate-enriched horizons exposed in Trench 14 can be traced upslope and over the fault vein fillings. Locally, the near-vertical veins and the carbonate horizons merge. In addition, the newly deepened portion of Trench 14, in the area of the near-vertical veins, exposes the veins pinching out and becoming discontinuous with depth (Figure 2). In contrast, feeders for spring mounds typically maintain sub-parallel walls over depths of tens to hundreds of meters (see discussion in Section 2.2.1). Furthermore, the calcite-silica veins contain a basaltic ash and other detrital materials that must have washed or fallen into open fractures. Such ashes would be difficult to explain within veins in an environment where water is issuing rapidly from an open fissure. These comparisons of the physical and chemical characteristics of the calcite-silica deposits exposed at Trench 14 with those of pedogenic and spring deposits favor a pedogenic origin for the deposits exposed in Trench 14 (Taylor and Huckins, 1986).

Field relations provide some evidence of age relations of the veins to other deposits. Deposits on the west side of Busted Butte, mapped as Q2, are cut by the veins; Q2e deposits on the south side of Busted Butte, which lie near the bottom of the Q2 units, contain lenses of the Bishop Ash (Swadley et al., 1984; Izett, 1982), which has been dated at 739,000 years (Izett, 1982). Relations at Trench 14 show veins cutting the Q2b and Q2s horizons (Swadley et al., 1984), who also indicate that both of these sub-units overlie Q2e. Plate D in Appendix D also shows relations at Trench 14, although alphanumeric designations differ from those used by Swadley et al. (1984). These relations indicate that the Trench 14 veins are younger than 739,000 years.

### 2.3.2 Mineralogic and Textural Data

In gross structure, the siliceous calcrete at Trench 14 consists of (a) subhorizontal slope calcretes and (b) nearly vertical vein calcretes (Figure 16 and Appendix D). Earlier studies of Trench 14 and of comparable localities around Yucca Mountain emphasized the similar calcite-opal-sepiolite mineralogy of both the widely distributed slope calcretes and the more restricted vein calcretes in faults (Vaniman et al., 1984, 1985). A single depositional mechanism would account for this similarity in both slope and vein calcretes. On a centimeter scale, slope and vein calcretes do not show distinctive characteristics relatable to the dips of laminae. Laminae within



**Figure 16.** Map of the south wall of Trench 14, excavated across the Bow Ridge fault east of Yucca Mountain, Nevada (no vertical exaggeration). Near-vertical vein calcrites fill the fault; slope calcrites parallel the land surface and are overlain by loose soils. Wall-rock tuffs and blocks of tuff within the fault zone are shown in black. A zone 2.25 m wide above the fault is used to calculate the total abundance of calcite and opal contained in the underlying wedge of slope and vein calcrite (see text). This figure is modified from a detailed map by E. Taylor, USGS. Insert block shows the location of a small-scale map of laminae within steeply-dipping slope calcrite (Figure 18). Location is also shown on Plate D.

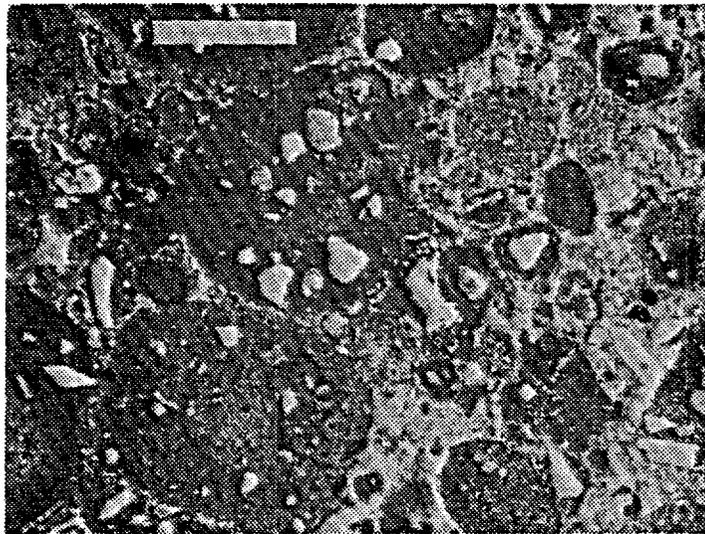
the calcretes reveal multiple episodes of fracturing and cross-cutting deposition. These structural complications are particularly prominent in the blocky rubble near faults.

The vein infilling at Trench 14 is fine grained and poorly indurated, in contrast to the typically coarse grained calcite found in feeder veins and at discharge points of spring deposits. The Trench 14 deposit consists of centimeter-scale bands including: (1) laminae with abundant ooids and pellets, (2) laminae with abundant root casts, (3) relatively dense laminae with some evidence of fault shearing, (4) thin (less than 5 mm) laminae of opal, and (5) rare laminae rich in sepiolite. The ooids are grains generally < 0.5 mm in diameter that have concentric coatings (mostly of calcite and opal) draped around detrital rock and mineral fragments. Pellets are larger round or ellipsoidal calcite-opal bodies that generally include several detrital fragments and may include earlier-formed ooids (Figure 17). Figure 18 is a detailed map of one 20-cm zone of generally west-dipping laminae above the blocky fault breccia of Trench 14. At least four generations of cross-cutting features can be seen at this scale, ending with a sepiolite-rich lamina that crosses many of the earlier structures.

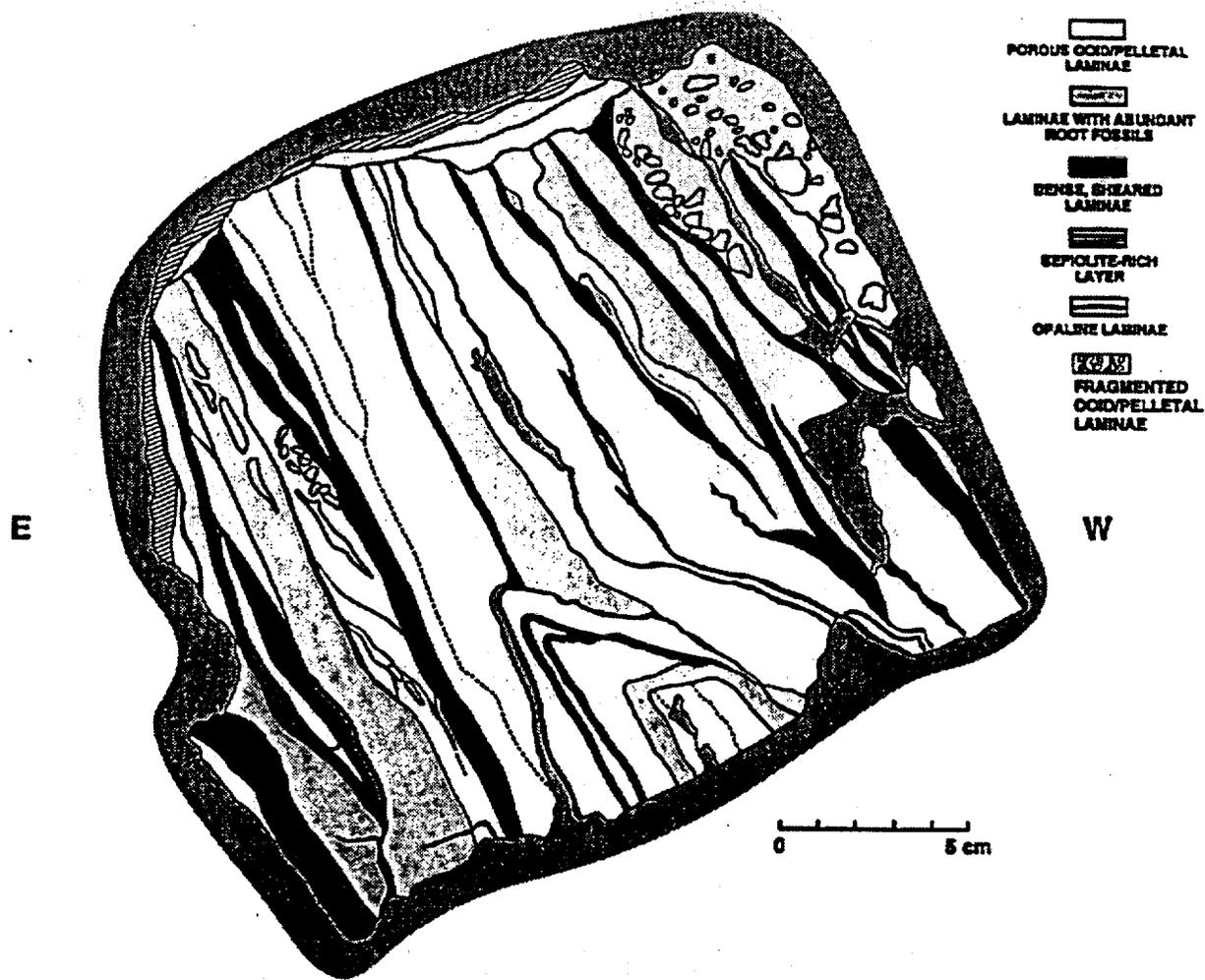
Banding is megascopically present in spring deposits, but laminae in spring deposits tend to be microscopically similar to one another with single crystals growing through several bands. Detrital minerals are rare or absent in veins that feed spring mounds; in contrast, about 10 - 20 percent of the vein material at Trench 14 is detrital. Figure 19 illustrates the considerable difference in texture between calcite at Devils Hole and the deposits in Trench 14. Devils Hole is typical of a spring deposit because it is a near surface ground water deposit.

Because ooids and pellets contain one or more detrital fragments, laminae with an abundance of ooids and pellets contain the most detritus. The detritus consists of tuffaceous volcanic rocks and minerals from the immediate vicinity of Trench 14, plus a small amount of exotic rock fragments. The dense, sheared laminae generally contain less tuff detritus than those laminae with abundant preserved root fossils or ooids. Some of the dense laminae consist of closely intergrown calcite and opal with essentially no detritus, but to date the only pure mineral separates from the calcretes have been of opal, either from the opaline laminae as mapped in Figure 18 or from large root fossils (Vaniman et al., 1988). Calcite crystals are small; most (>95%) are <5  $\mu\text{m}$  grains and the calcite is closely intergrown with opal or sepiolite. All attempts to obtain pure calcite separates by crushing and density separation have failed because of intimate intergrowth with other minerals.

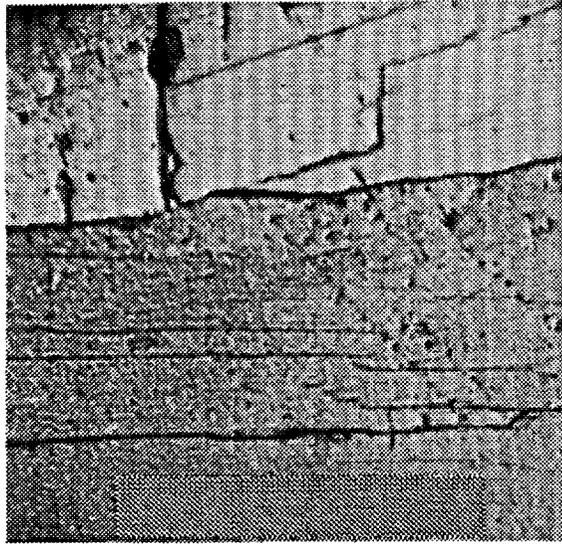
Quantitative X-ray powder diffraction (XRD) provides a direct measurement of calcite, clay, and detrital mineral abundances in the calcretes (Tables B-11 and B-12). Although both opal-A and opal-CT are recognized in the XRD data, opal-A abundance must be determined by difference from 100%, using internal standard methods. The errors introduced in this manner are primarily those of ignoring volcanic glass and organic material that have amorphous diffraction properties similar to opal. Nevertheless, petrographic analysis indicates a low abundance of volcanic glass (<2%) and low-temperature ashing indicates <3% organic material in the samples described here. Petrographic, electron microprobe, and scanning electron microscope studies confirm the



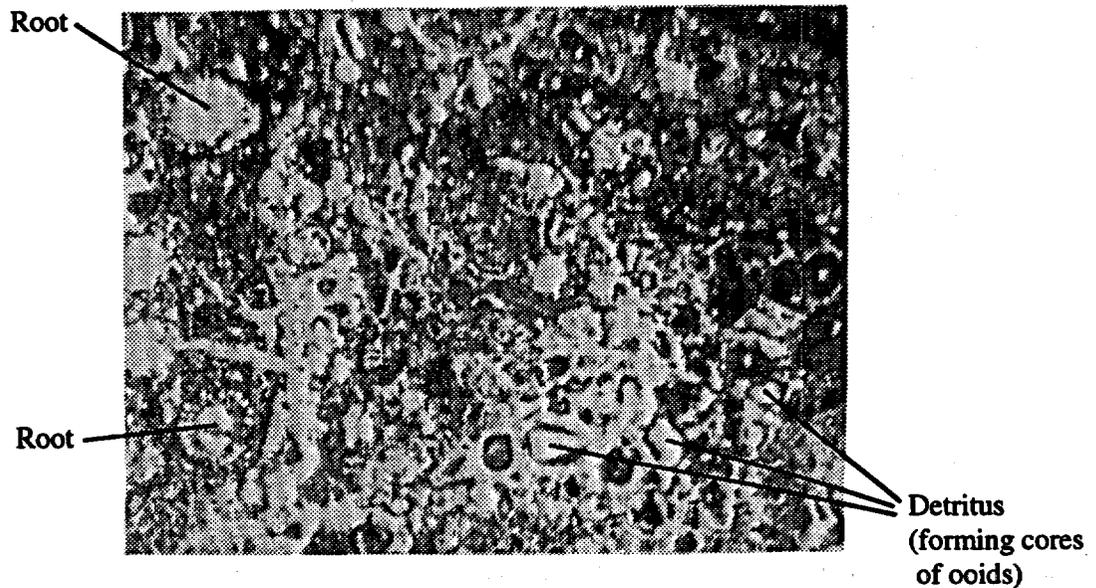
**Figure 17.** *Detail photomicrograph in plane-polarized light of a detritus-rich ooidal/pelletal lamina. Ooids (left side), formed around single rock or mineral fragments, have concentric rims that include both calcite and opal. Pellets (right side) contain multiple detrital fragments. Scale bar is 0.5 mm.*



**Figure 18.** Large scale map of laminae within block of steeply dipping slope calcrete from Trench 14 (Fig. 16 and Plate D). The map legend ranks lamina types from ooidal/pelletal to opaline in order of decreasing abundance of tuff detritus. Some thin opaline stringers are essentially pure opal-A or opal-CT; all other laminae have fine-grained intergrowths of calcite and opal. Unconformities between laminae indicate multiple generations of deposition, with oldest laminae at the bottom center of the block and youngest laminae (including the sepiolite-rich layer) draping the upper part of the block.



(a)



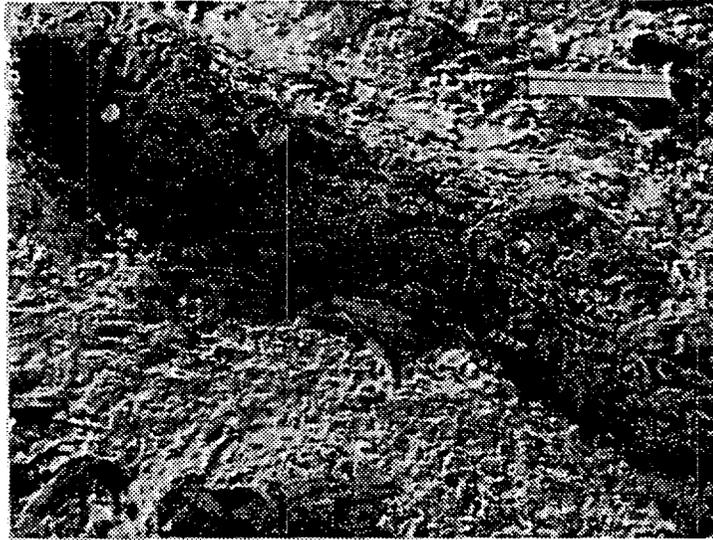
(b)

**Figure 19.** Photomicrographs of (a) a sample of a typical spring-deposited vein at Devils Hole showing contact between two large calcite crystals and (b) a vein sample from Trench 14. Fields of view are approximately 2.5 mm across. Note the coarse crystal size in the former and the abundant detrital material and roots in the latter. Dark matrix (b) consists of a very fine grained intergrown opal and calcite.

widespread distribution of opal in the calcretes. Sepiolite is locally abundant (ca. 50%) in only a few laminae (Figure 18). The overall abundance of sepiolite and amorphous Fe, Mn, Ti-oxides is less than 1 percent. Section 2.3.3 discusses the XRD determinations of calcite, opal, and tuff detritus proportions in the slope and vein calcretes (see Tables B-11 and B-12), as well as in the loose overlying soils (Table B-14). These overlying soils differ from the calcretes in their very low abundance of calcite. This is the expected relationship where calcrete forms pedogenically by accumulation of calcite leached from overlying soils (Machette, 1985).

The intimate intergrowth of calcite and opal in these calcretes is atypical of spring deposits (Vaniman et al., 1988). Cool and warm springs, from deep or perched sources, have higher water flow that leads to distinct pH regimes in which either calcite or silica is precipitated (White et al., 1956; Viles and Goudie, 1990; Chafetz and Folk, 1984). In contrast, evaporative processes within arid soils of siliceous igneous terrains can cause a rise in pH from only slightly alkaline to  $>9$  (Vaniman et al., 1992; Chadwick et al., 1989; Boettinger and Southard, 1990), passing from regimes of calcite dissolution and silica precipitation into those of calcite precipitation and silica dissolution (Watts, 1980). Numerous pedogenic wetting and drying cycles can lead to the complex calcite and opal intergrowths seen in the calcretes of Trench 14. The closest analogous spring deposits would be evaporative seeps (Vaniman et al., 1988); however, deposits in such environments have distinct differences attributable to more abundant water. Evaporative seeps lack concentric ooidal accumulations of calcite and opal around detrital nuclei (Figure 17) and have simpler and often single-stage calcite-to-silica transitions, in which opal-CT forms thin ( $\sim 10$ - $20 \mu\text{m}$ ) isopach opal (i.e., rinds of constant thickness) over calcite along fractures, and authigenic quartz may occur as late veins. These features reflect the longer timescales for evaporation of seep deposits, tied to deep-seated flow rates, in contrast with the constant seasonal cycling of pedogenic environments. Also present in evaporated seeps is biogenic evidence of their past higher water content: ostracode fossils, casts of phreatophyte plants and algal or diatomaceous deposits of opal-A. A very different set of fossil remains is found in pedogenic calcretes.

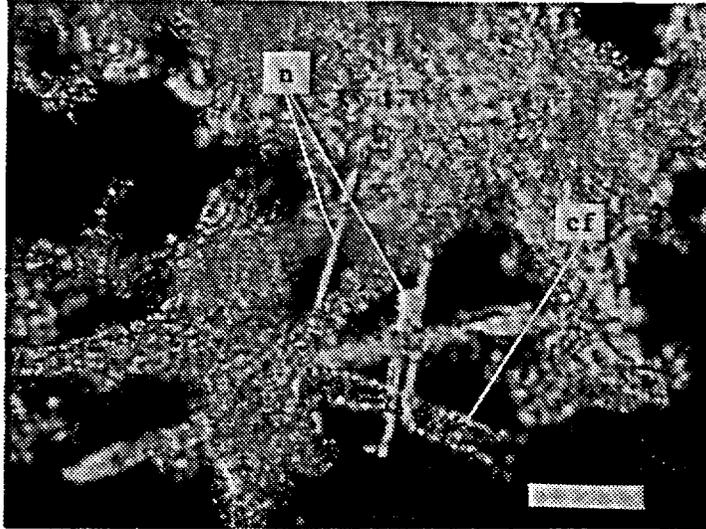
Figures 20-23 show several microfossil forms associated with root casts from the Trench 14 vein calcrete. The outer walls of most roots are replaced by opal-A; the interior of this opalized shell is generally draped with calcified filaments that appear as tubules  $\sim 5 \mu\text{m}$  in diameter (Figures 20 and 21). The walls of the calcified filaments are formed of small calcite crystals. Pedogenic calcified filaments or tubules may be formed by a number of microorganisms or by calcite precipitation around root hairs (Klappa, 1979). Superficially similar calcareous filaments occur as algal products in active spring deposits (Viles and Goudie, 1990; Chafetz and Folk, 1984), but these delicate features are not preserved in the inactive deposits where the high water/rock ratio of the spring environment leads to their dissolution. This contrasts with the roughly similar calcified filaments in the Trench 14 calcretes, which are found in the oldest as well as the youngest laminae. Moreover, algal filaments in springs are not restricted to associations with fossil roots of vascular plants, as are the calcified filaments in the Trench 14 calcretes.



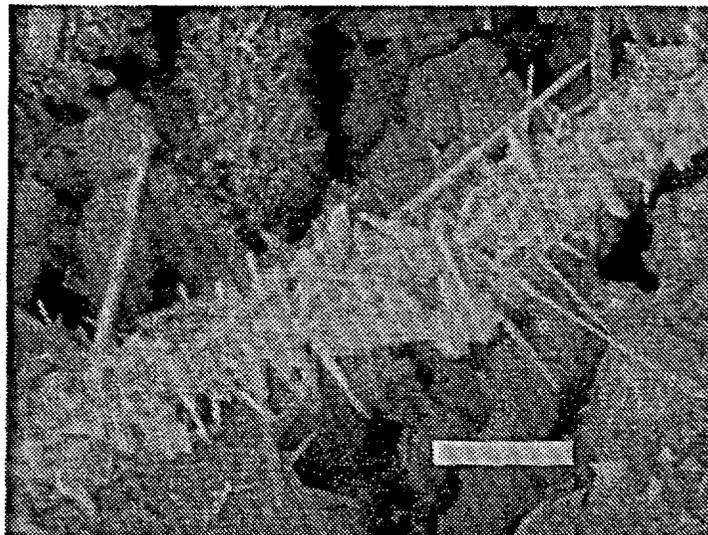
**Figure 20.** Backscattered-electron (BSE) image of calcified filaments draping the inside of a fossil root cavity. Scale bar is 200  $\mu\text{m}$  long. The dark cavity is the root cast. Finer structures within it are calcified filaments.



**Figure 21.** Closeup BSE image of calcified filaments. The tubule walls are defined by calcite crystals of diameter less than 1  $\mu\text{m}$ . Scale bar is 5  $\mu\text{m}$  long. Each filament has a hollow core which is seen as black in this image. Surrounding these cores are small angular crystals of calcite.



**Figure 22.** *Photomicrograph (crossed polarizers) of needle-fiber calcites (n), ~1-2  $\mu\text{m}$  in diameter and up to 150  $\mu\text{m}$  long calcified fillaments (CF) projecting into center of root cavity. Scale bar is 20  $\mu\text{m}$  long.*



**Figure 23.** *Image of acicular microcrystals, ~0.5  $\mu\text{m}$  wide at their bases and tapering outward. Scale bar is 5  $\mu\text{m}$  long.*

In the Trench 14 calcretes, the centers of the root casts are commonly void but may contain needle-fiber calcite (~1-2 x 10-150  $\mu\text{m}$ ; Figure 22). Needle-fiber calcite has been described from a number of pedogenic environments and attributed to calcification of fungal hyphae within decaying roots (Phillips and Self, 1987; Wright, 1986 and 1989). Also found within some of the root casts are extremely delicate acicular microcrystals, tapering from ~0.5  $\mu\text{m}$  at their bases to narrow points (Figure 23). This fossil form is characteristic of fungal hyphae (Simkiss and Wilbur, 1989), and may consist of Ca-oxalate crystals. XRD analyses of living roots from desert plants presently growing near Trench 14, as well as from pinyon and juniper of the region, show that calcium accumulates within the roots as the Ca-oxalate mineral whewellite ( $\text{CaC}_2\text{O}_4 \cdot \text{H}_2\text{O}$ ), rather than as calcite. Fungal and perhaps bacterial processes within decaying roots would account for the absence of calcite in living roots as well as the calcite fossil forms such as those shown in Figures 20-22 and possible intermediate Ca-oxalate forms (Figure 23).

These delicate calcite and possible Ca-oxalate fossils within fossilized roots provide two important constraints on the origins of the siliceous calcretes. First, the delicate fossil forms are preserved even within the earliest-formed calcrete laminae (Figure 18); such preservation would be unlikely if the laminae were emplaced by successive forceful fluid injections with catastrophic brecciation. Indeed, the pervasive distribution of fragile root fossils indicates that root penetration plays a distinctly noncatastrophic but nevertheless forceful role (Klappa, 1980) in the brecciation observed in these calcretes. Second, similar needle-fiber calcites and calcified filaments associated with fossil roots are typical of pedogenic calcretes (Klappa, 1979; Phillips and Self, 1987; Wright, 1986 and 1989). In evaporative seeps, and at the tops of calcareous tufa mounds around springs, the fossilization of vascular plants typically leaves casts of the plant form without preserving such fine features of root decay. The high water flux in seeps and springs flushes out the products of decay, leaving only the plant casts behind. Calcified filaments, needle-fiber calcites, and other delicate fungal fossils within root forms thus provide an important field guide to pedogenic calcretes.

### 2.3.3 Quantitative Mineralogic and Chemical Analysis

Chemical composition of the overlying soil can be an important factor in evaluating calcrete origin. If the calcrete is pedogenic, the detritus incorporated into it is likely to carry with it the effects of surface exposure and soil-zone processes. Nonpedogenic calcretes may also incorporate soil detritus, but if they originate from upwelling waters the veins should show more evidence of interaction with their wall rock than with the surface soil. This would be expected for vein deposits as seen in Trench 14, if proposals (Archambeau and Price, 1991) of deep origin assuming explosive injection and wall-rock brecciation by the vein-forming fluids were correct.

Quantitative mineralogic data (see Tables B-11, B-12 and B-14) for the calcretes and the overlying soils are summarized in Figure 24. Chemical data are compared with quantitative XRD data in Figures 3, 8 and 9. Chemical data for the calcretes, the overlying soils, and the local fault-breccia tuffs clarify the relationships of all three. Figure 3 shows that tuff detritus determines the lanthanide-element signature of the calcite and opal; even where XRD data detect

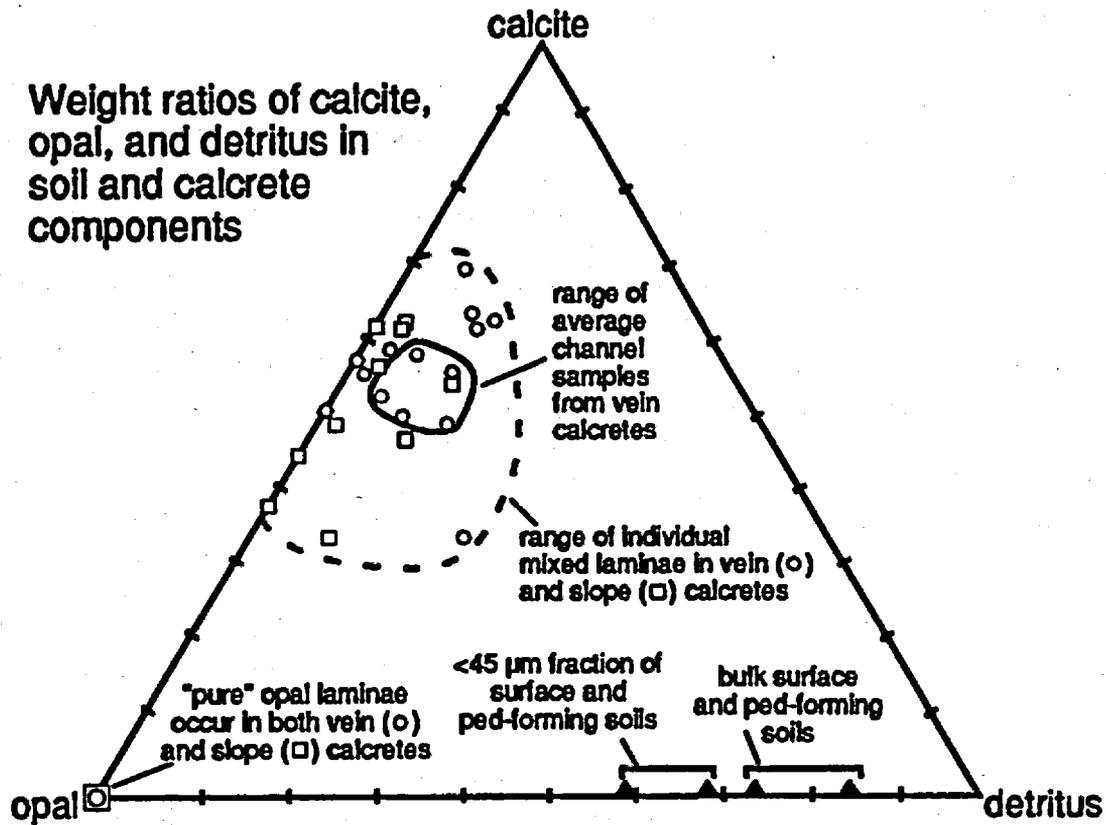


Figure 24. Weight ratios of calcite, opal, and detritus determined by XRD.

no detritus (<1%), the lanthanide-element signature bears the imprint of the tuff detritus. Figure 3 also shows a slight but significant enrichment of the heavy lanthanide elements (Yb, Lu) in the surface soils relative to the tuff detritus. Petrography and XRD data indicate that this difference is accounted for by an enrichment in the soils of heavy minerals (principally amphibole and clinopyroxene) that have relatively high heavy-lanthanide abundances. A similar effect is seen in the Fe and Sc data (Figure 8), where the Fe/Sc ratio of both the calcretes and the overlying soils carries the specific imprint of the tuff detritus.

Examination of abundances as well as ratios in Figure 8 indicates that some of the individual laminae in the calcretes have Fe and Sc contents as high as those of the tuff detritus, even though the laminae contain no more than 25% of such detritus (Figure 24). This indicates that the detritus in the calcretes must be derived from surface soils with the same Fe/Sc ratio but higher Fe and Sc content than the tuff. Figure 9 confirms this conclusion by illustrating the very high Sc content of soils compared with typical rhyolites of the region, such as the wall-rock tuffs that are adjacent to the vein calcretes (few of the volcanic rocks at Yucca Mountain have sufficiently high Sc (>5 ppm); those that do differ from the detritus in the calcretes by having very different La/Yb or other chemical ratios, and by lacking key minerals such as sphene that characterize the detritus in the calcretes). The direct-mixing path between calcite/opal and wall-rock tuff does not significantly affect any of the calcretes in Trench 14, including the vein calcretes interpreted by some (e.g. Mr. Jerry Szymanski) as products of explosive injection based on presumptions of extensive wall-rock interaction (e.g. reports and articles by Archambeau and Price, 1991).

Tables B-11 through B-14 contain trace element analyses for several other elements. Evaluations of these data as tracers of origin or as indicators of geochemical processes are planned, but have not been completed.

Archambeau and Price (1991) have suggested that there is too much calcite and opal in Trench 14 to be accounted for by pedogenic accumulation. This is not the case. The subsurface accumulation of calcite and opal is greatest within the fault; Figure 16 shows a 2.25-m span of greatest calcite vein width near the surface, wedging down to a few centimeters wide at 4.75 m depth. Approximately six-tenths of the material in this wedge is laminated calcite; the remainder consists of blocks of the wall-rock tuffs. Average bulk density of the calcretes is 1.6 g/cm<sup>3</sup>. The average calcite weight fraction of the calcretes is 53% (Figure 24), leading to an estimated calcite abundance of 5.1x10<sup>5</sup> g/m<sup>3</sup> or 1.2x10<sup>6</sup> g per m<sup>2</sup> of overlying ground surface above this wedge of vein calcite. Estimates of eolian carbonate accumulation rates for soils on non-calcareous parent materials in the southwestern United States range from 0.3 to 5 g/m<sup>2</sup>/yr (Machette, 1985; Reheis et al., 1992); at these rates, the amount of calcite within the excavated veins at Trench 14 could accumulate over a time span between 4,000,000 and 240,000 years (one-third to one-fiftieth of the age of the wall-rock tuffs). The requisite time spans become even shorter if the carbonate component landing on bedrock upslope washes down to the fault zone and contributes to the vein formation. Carbon and oxygen isotope data permit the interpretation

that most of the calcite in Trench 14 was deposited during colder and wetter climates (Quade and Cerling, 1990). The data indicate that the carbonate portion of the calcretes in Trench 14 are consistent with pedogenic deposition during the Pleistocene.

Because the calcretes of Trench 14 are siliceous, a comparison of likely silica precipitation rates with the rates of carbonate accumulation is in order. Within the same volume of vein calcrete described above, the average opal weight fraction is 36%, leading to an estimated opal abundance of  $0.8 \times 10^6$  g/m<sup>2</sup>. The solubility of silica in arid soils containing abundant siliceous glass may exceed 0.07 g/L (Chadwick et al., 1989); however, waters in local higher elevation soils at Rainier Mesa have SiO<sub>2</sub> contents of 0.02 - 0.04 g/L (Kerrisk, 1987). At 0.02 g/L concentration of SiO<sub>2</sub> in soil water, evaporation of  $4.0 \times 10^6$  cm/cm<sup>2</sup> of water is required to deposit the opal within the vein calcrete. The current range in annual precipitation at elevations comparable to Trench 14 is 14-17 cm (Spaulding, 1983; Spaulding et al., 1984). At this precipitation rate, sufficient rainwater could infiltrate, dissolve local silicates, and evaporate to form the opal in the vein calcrete in less than 270,000 years. Slope runoff would increase the estimate by decreasing the amount of infiltration. There is a wide range of calculated rainfall increases during past pluvial cycles (Spaulding, 1983; Spaulding et al., 1984), any of which would lower the estimate. Unknown quantities of silica in solution may be lost by runoff and by flow into deeper fractures. Within these uncertainties, the time required for opal precipitation is similar to the time required for eolian carbonate accumulation during pluvial cycles - a few hundred thousand years. Thus the independent estimates of eolian contributions (of Ca for calcite) and of in-situ dissolution (of SiO<sub>2</sub> for opal) fall within a consistent time span that is well within the frame of pedogenic processes.

#### 2.3.4 Stable Isotope Data

Carbon and oxygen isotopes (Tables A-1 and A-2) in the vein carbonates at Trench 14 match those in pedogenic carbonate collected over a wide area of southern Nevada (Figure 10) (Quade and Cerling, 1990). In detail, the isotopic compositions imply pedogenic deposition of the Trench 14 calcites under conditions of a cooler climate with a mean temperature of about 15° C (Quade and Cerling, 1990). Samples of soil carbonates and vein infilling from both Trench 14 and Busted Butte show that the isotopic compositions of oxygen and carbon of most samples are virtually identical for the two locations and for the two types of deposits, soils and veins (Whelan and Stuckless, 1990). Four of the Busted Butte soil carbonates are slightly enriched in <sup>13</sup>C and <sup>18</sup>O (Figure 11 and Tables A-1 and A-2), but the variability in the data is small enough that all of the soil and vein carbonate can be explained by pedogenesis.

Extraction of calcite CO<sub>2</sub> followed the procedure of McCrea (1950), and isotope ratios were determined on a Finnigan MAT251 mass spectrometer by standard techniques and are precise and accurate to +/- 0.1 per mil absolute. The carbon ( $\delta^{13}\text{C}$ ) and oxygen ( $\delta^{18}\text{O}$ ) isotopic compositions are reported as per mil deviation of the sample isotopic ratio from that of the international standards PDB (Pee Dee belemnite) and SMOW (Standard Mean Ocean Water), respectively, according to the transformations.

$$\delta^{18}\text{O} = \left[ \frac{(^{18}\text{O}/^{16}\text{O})_{\text{sample}} - (^{18}\text{O}/^{16}\text{O})_{\text{std}}}{(^{18}\text{O}/^{16}\text{O})_{\text{std}}} \right] * 1000$$

$$\delta^{13}\text{C} = \left[ \frac{(^{13}\text{C}/^{12}\text{C})_{\text{sample}} - (^{13}\text{C}/^{12}\text{C})_{\text{std}}}{(^{13}\text{C}/^{12}\text{C})_{\text{std}}} \right] * 1000$$

The calculated carbon and oxygen isotopic compositions of hypothetical calcites formed in equilibrium with ground waters of the Yucca Mountain area (assuming temperatures currently observed at the ground water table and equations of Deines et al., 1974) are very different from those measured for the vein calcites (Figure 11). This difference shows that the veins could not have formed directly from ground waters like those present in the region today. Most of the available ground water data are for the Cenozoic aquifer for which the water table is at a depth of 460 to 700 m in the vicinity of Yucca Mountain (Waddell et al., 1984). Calculations based on lower temperatures for calcite precipitation would produce better agreement with the observed oxygen compositions of the vein calcites, but some of the waters would have to be cooled to impossibly low temperatures (0 °C and lower) to precipitate Trench 14 calcite with the appropriate isotopic composition (Figure 12). The isotopic compositions of Trench 14 calcites could derive through deposition from water like modern precipitation at reasonable temperatures (5 °C to 22 °C).

As noted earlier, carbon isotopes do not fractionate significantly between dissolved carbonate and calcite at the temperatures in question. About half of the ground water samples, including the one sample analyzed from the Paleozoic aquifer, are either too enriched or too depleted in <sup>13</sup>C to be possible sources for the vein carbonates. Based on the similarity of carbon isotopic data in soils and the Trench 14 deposits, the most likely source for carbon in the Trench 14 calcites is biogenic. (See Quade and Cerling, 1990.)

The preceding discussion assumes that the isotopic composition of ground water beneath Yucca Mountain is representative of ground water that might have formed the Trench 14 veins. However, ground waters beneath Yucca Mountain have apparent <sup>14</sup>C ages of less than 20,000 years in the Tertiary aquifer and about 30,000 years in the Paleozoic aquifer (Benson and McKinley, 1985), whereas the deposits in Trench 14 are much older with reported ages greater than 400,000 years (Szabo and O'Malley, 1985). The youngest age found thus far at Trench 14 is 92,000 ± 5,000 years (see Table A-9).

The isotopic composition of ancient ground waters in the Yucca Mountain region cannot be determined. However, the Ash Meadows flow system, which is located just to the east of the Yucca Mountain area, has left a long-term record at its discharge site (Winograd and Thordarson, 1975). Uranium series ages have been obtained for individual laminae within a vein of continuously deposited calcite at Devils Hole, and oxygen isotope analyses of these laminae show a variation of only +/- 1 per mil (parts per 1,000) during the last 320,000 years (Winograd et al., 1988). A similar variation for waters beneath Yucca Mountain would be reasonable

because the isotopic composition of both flow systems should be governed by the same climatic conditions. Even if a similar per mil increase (at currently observed temperatures) did occur for ground water beneath Yucca Mountain, precipitated calcites would not have the isotopic compositions of those observed at Trench 14 (Figure 11).

### 2.3.5 Radiogenic Tracer Isotope Data

Studies of strontium isotopes in calcite from the Yucca Mountain area support a pedogenic origin for veins exposed in Trench 14 and elsewhere (Stuckless et al., 1991). The initial isotopic studies of samples from Trench 14 and Busted Butte (Marshall et al., 1990) demonstrated the close similarity of  $\delta^{87}\text{Sr}$  values in the vein and pedogenic calcites.  $\delta^{87}\text{Sr}$  is defined in a parallel manner as for oxygen and carbon, namely,

$$\delta^{87}\text{Sr} = \left[ \frac{(^{87}\text{Sr}/^{86}\text{Sr})_{\text{sample}} - (^{87}\text{Sr}/^{86}\text{Sr})_{\text{std}}}{(^{87}\text{Sr}/^{86}\text{Sr})_{\text{std}}} \right] * 1000$$

In this report the  $(^{87}\text{Sr}/^{86}\text{Sr})_{\text{sample}}$  values are measured  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios adjusted to a scale on which the  $^{87}\text{Sr}/^{86}\text{Sr}$  value for modern sea water is 0.70920. The  $\delta^{87}\text{Sr}$  values are then calculated relative to the  $(^{87}\text{Sr}/^{86}\text{Sr})_{\text{std}}$  which is modern sea water.

Twenty-seven samples of vein calcite yielded a mean  $\delta^{87}\text{Sr}$  value of  $4.54 \pm 0.32$  (1 sigma) and 16 samples of pedogenic calcite a mean of  $4.06 \pm 0.58$  (1 sigma). The study was broadened to include vein and pedogenic calcite from Crater Flat collected in various trenches cutting fault zones (Marshall et al., 1991). This expanded data base clearly demonstrated the isotopic similarity between the vein and pedogenic calcites with 39 (see Tables A-13 and A-14) samples of veins with an average  $\delta^{87}\text{Sr}$  of  $4.48 \pm 0.37$  (1 sigma) and 37 samples of pedogenic calcite averaging  $4.41 \pm 0.39$  (1 sigma) (see Tables A-12, A-13 and A-14). The Sr isotopic data for the vein and pedogenic calcites are presented together with  $\delta^{87}\text{Sr}$  for samples of ground water from Tertiary aquifer in the Yucca Mountain region in Figure 14 where  $\delta^{87}\text{Sr}$  is plotted against the latitude of the sample. Data for all of the pedogenic and vein samples are summarized in this histogram. Some of the solid samples included in the inset lay either north or south of Trench 14.  $\delta^{87}\text{Sr}$  values of ground water (Figures 14 and 25) increase progressively from north to south. Tables A-12, A-13 and A-14 include data for numerous soil and water samples. The water table decreases in elevation from north to south and flow is in a southerly direction. At the latitude of Trench 14 and to the north, all of the ground water samples have  $\delta^{87}\text{Sr}$  values less than those of both pedogenic and vein calcite samples at Trench 14. Thus, none of the saturated zone waters sampled to date in the Yucca Mountain area in the vicinity of Trench 14 and northward upgradient along the flow path can be related genetically through seismic pumping or any other method to the calcite deposits in Trench 14 and elsewhere. The ground water sample at latitude 36.80 immediately south of the latitude for Trench 14 is from well VH-2 in Crater Flat. Unlike water from the nearby well VH-1 with  $\delta^{87}\text{Sr}$  value of 2.49 and a composition typical of water from the Tertiary aquifer, VH-2 water, with a large  $\delta^{87}\text{Sr}$  of 5.36, is high in Ca, Mg, and  $\text{HCO}_3^-$ .

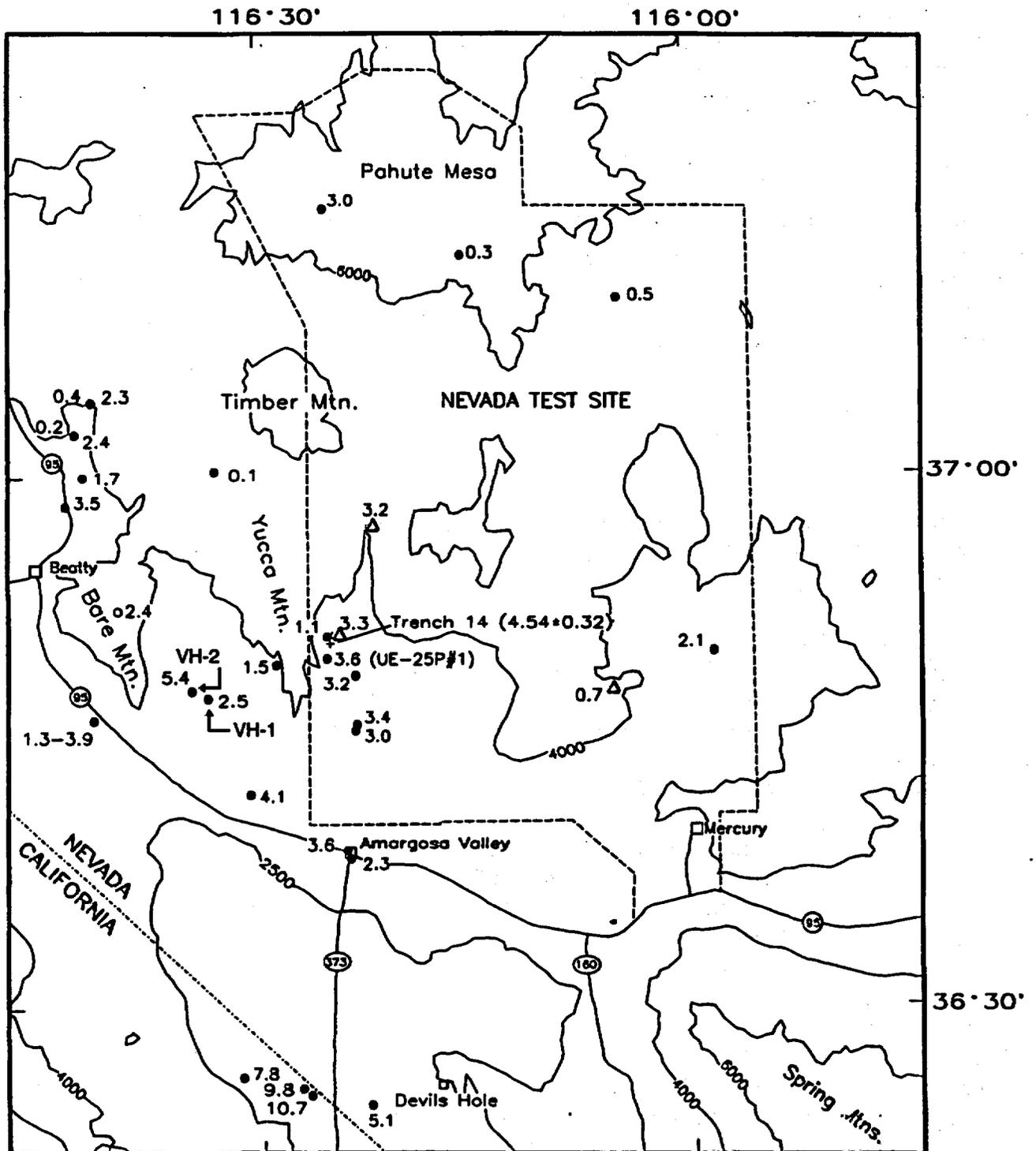


Figure 25.  $\delta^{87}\text{Sr}$  values in ground water samples from the Tertiary/Quaternary aquifer. Solid circles are wells. Triangles represent perched water from springs and water collected from a neutron hole (triangle near Trench 14). The mean  $\delta^{87}\text{Sr}$  value for calcite veins at Trench 14 is shown in parentheses.

attributes more common to ground water in the Paleozoic aquifer away from the Spring Mountains (Peterman et al., 1992). Apparently VH-2 is tapping a local entity of ground water which is strongly influenced by limestones from the adjacent Bare Mountain. Limestones in some areas along the eastern side of Bare Mountain contain strontium with elevated  $\delta^{87}\text{Sr}$  values (see Tables A-12 and A-13). Bailed water from the Paleozoic aquifer tapped in UE-25 P#1 has a  $\delta^{87}\text{Sr}$  of 3.61, which is also well below most of the values for pedogenic and vein calcites (Figure 14 and Tables A-12 and A-14).

Data from Devils Hole can again be used to evaluate the likely compositional changes in ancient ground water beneath Yucca Mountain (Figure 26).  $\delta^{87}\text{Sr}$  values for water presently issuing from Devils Hole, and for six samples of calcite deposits ranging in age from approximately 180,000 to 600,000 years, differ by only 0.71 per mil (Marshall et al., 1990. The value of 103,000 years should have been 180,000; this has been corrected here and in Table A-14.). An additional 58 analyses of calcite from Devils Hole, spanning sample ages of 60,000 to 560,000 years, yield only a slightly larger variability in the  $\delta^{87}\text{Sr}$  value (Ludwig, 1993).  $\delta^{87}\text{Sr}$  values of water within the Tertiary/Quaternary aquifer in the Yucca Mountain area probably behaved in a similar fashion because the recharge area and host aquifer have most probably not changed during the Quaternary. The similarity between the Devils Hole and Trench 14 isotopic compositions is fortuitous. Thus, it is highly unlikely that water beneath Yucca Mountain ever had high enough  $\delta^{87}\text{Sr}$  values to have been a source for the strontium in the Trench 14 deposits.

The isotopic composition of the vein carbonate at Trench 14 and Busted Butte may have been influenced in part by reaction of depositing fluids with entrained solid material, and the isotopic composition may also be affected by reaction with the host wall rock as well (Marshall et al., 1990). However, most of the strontium in the subhorizontal deposits (and, by geochemical analogy, calcium as well) is much more homogeneous than the surficial materials and therefore seems to come from a well homogenized source such as wind-blown dust. Lead isotopic data for acid leached portions of soil and vein samples yield the same general conclusions about a well homogenized source as strontium. (See also Tables A-5 and A-6)

The remarkable homogeneity of strontium isotopic composition in hydrogenic deposits over broad geographic regions argues against deposition from ground water because the isotopic composition of ground water is very inhomogeneous in the vicinity of the Nevada Test Site (Figure 25). Water emerging at the surface would impart this inhomogeneous characteristic to deposited calcite, which is not the case at Yucca Mountain.

Uranium and thorium isotopes are also useful natural tracers for constraining the origin of calcite at Yucca Mountain. When a calcite forms, it will acquire the  $^{234}\text{U}/^{238}\text{U}$  of the water from which it precipitated because the two uranium isotopes do not fractionate. The  $^{230}\text{Th}/^{234}\text{U}$  in the calcite will initially be zero because of the exceedingly low concentrations of Th in natural waters. Over time, both the  $^{230}\text{Th}/^{234}\text{U}$  and  $^{234}\text{U}/^{238}\text{U}$  ratios will grow to unity under closed system conditions. For a given initial  $^{234}\text{U}/^{238}\text{U}$  value, the  $^{234}\text{U}/^{238}\text{U}$  and  $^{230}\text{Th}/^{234}\text{U}$  ratios in a calcite will define a distinctive evolution path (Figure 13). The determined values for any sample plotted on such a

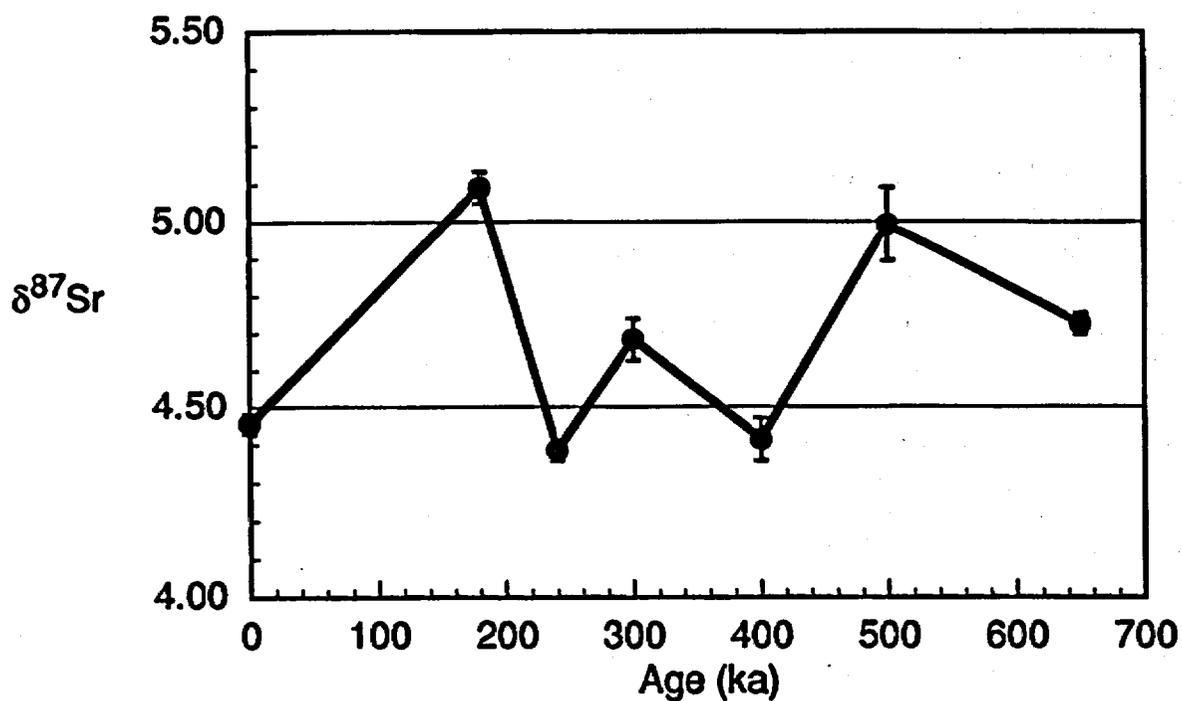


Figure 26. Variations in the isotopic composition of strontium at Devils Hole as a function of age. Analytical error for strontium (95% confidence level) is shown by vertical error bars.

diagram can be projected back to an initial  $^{234}\text{U}/^{238}\text{U}$  assuming closed system evolution. These calculated initial  $^{234}\text{U}/^{238}\text{U}$  values can be compared with  $^{234}\text{U}/^{238}\text{U}$  values for natural waters for constraining possible sources of the calcite.

Ground water in southern Nevada is typically anomalous with  $^{234}\text{U}/^{238}\text{U}$  greater than 2.0 for most samples from both the Paleozoic and the Tertiary/Quaternary aquifers, but vein and soil calcites at Trench 14 and Busted Butte were largely deposited by waters with a  $^{234}\text{U}/^{238}\text{U}$  less than 1.5 (Figure 15). (See Tables A-7 and A-8.) The difference between water and initial vein compositions is even more pronounced in the vicinity of Yucca Mountain where three samples from the Tertiary/Quaternary aquifer have values greater than 5.0, and one sample from the Paleozoic aquifer is  $2.71 \pm 0.09$  (Figure 27). The two analyzed vein samples have initial  $^{234}\text{U}/^{238}\text{U}$  less than 1.4. Thus the veins and ground waters cannot be genetically related. In contrast, the initial  $^{234}\text{U}/^{238}\text{U}$  for soils of the Yucca Mountain area is generally less than 1.40 with only one value as high as 2.0 (initial ratios calculated from measured values given by Rosholt et al., 1985). These values agree well with those observed for the Trench 14 carbonate veins (Figure 15) and, therefore, support a pedogenic origin for the fault infillings.

The record from Devils Hole can again be used to evaluate the variability of the  $^{234}\text{U}/^{238}\text{U}$  during the past 300,000 years. The initial uranium isotopic ratio in Devils Hole calcites has ranged from 2.53 to 2.85 (Figure 13). If a similar variability has occurred in waters beneath Yucca Mountain, the veins at Busted Butte and Trench 14 cannot have been precipitated from either of the regional aquifers.

### 2.3.6 Fission-track dating of zircons from AMC breccias

Section 2.2.8.3 reports the results of zircon age dating. This section provides indications of appropriate closure temperatures and details of the methods used.

The fission-track annealing properties of zircon, used for this study, are not well known. Numerous studies (e.g., Harrison et al., 1979; Naeser, 1981; Hurford, 1986) have established that fission tracks in zircon are more resistant to annealing than those in apatite. Harrison et al. (1979) estimated the closure temperature for zircon to be about 175 °C, and Hurford (1986) estimated to it to be  $240 \pm 50$  °C. Because Hurford's estimate is based on data from an area of relatively rapid cooling in the Lepontine Alps, Switzerland, the value should be considered a maximum temperature. In areas of less rapid uplift, zircon ages can probably be considered to indicate the cooling of the rock below about 200 °C. Temperatures as high as 182 °C do not have any effect on the fission-track age of zircon from a granite recovered from core hole CGEH-1 at Coso Hot Springs, California (Naeser, 1981), where the duration of heating is estimated to be on the order of  $10^5$  years.

Zircons were separated from two bedrock breccia samples representing one type of breccia described in this report. The external detector method was used to date individual zircon grains

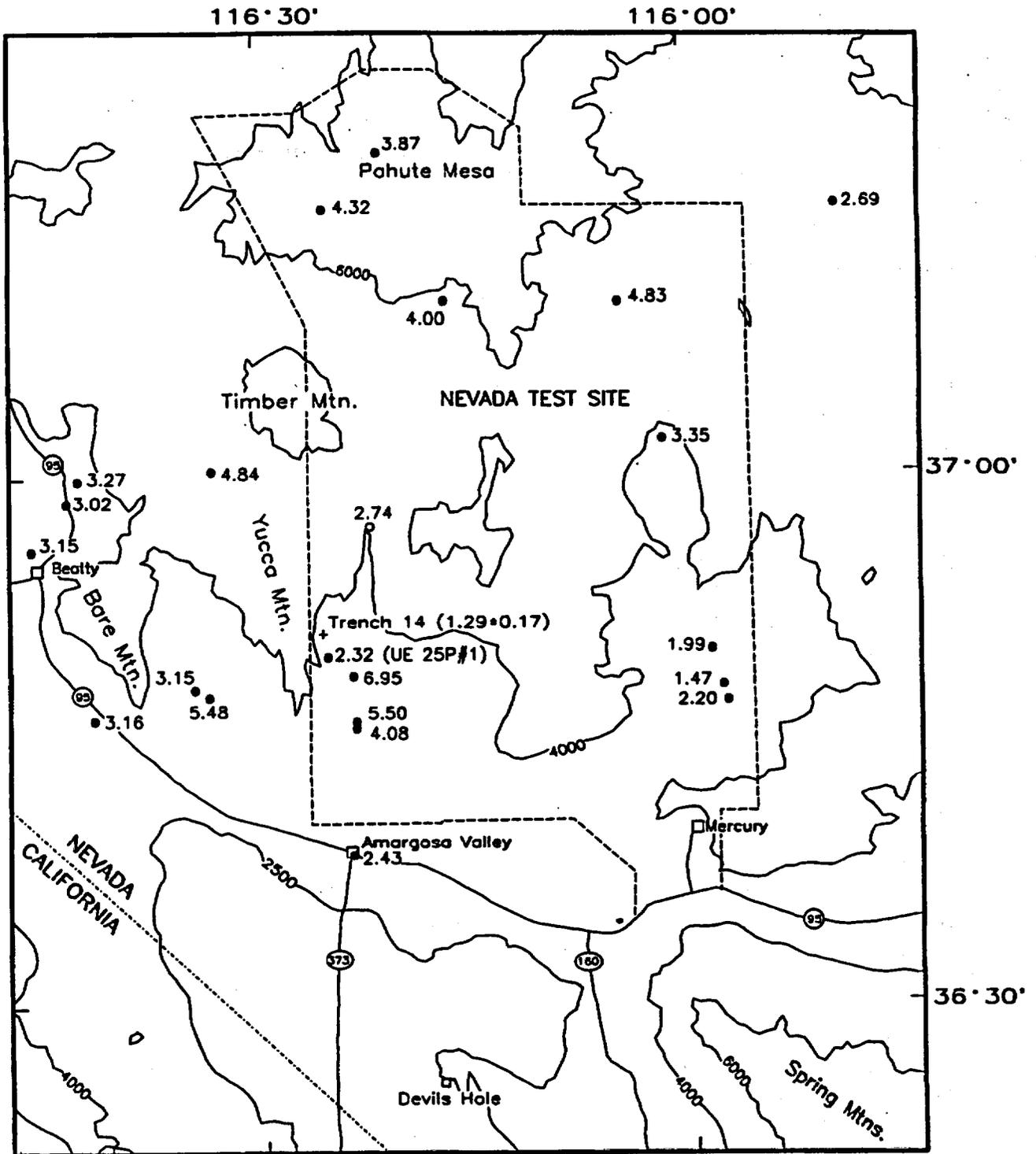


Figure 27.  $^{234}\text{U}/^{238}\text{U}$  ratios in ground water samples from the Tertiary/Quaternary aquifer. Solid circles are wells and the open circle is a spring at Waterpipe Butte. Sources of data are cited in Stuckless et al. (1992). A few of the analyses are from Ludwig et al., 1993 and are presented in Appendix A.

(Naeser, 1976, 1979). The zircons were mounted in teflon and etched in a eutectic melt of KOH-NaOH at 215 °C for 30-50 hours. The teflon mounts were then covered with a muscovite detector and irradiated along with neutron dose monitors (U-doped glass SRM 962, also covered with muscovite detectors) in the U.S. Geological Survey reactor at Denver, Colorado. Ages were calculated by the Zeta method (Hurford and Green, 1983). The neutron dose was determined by measuring track densities in the muscovite detectors used to cover the dose monitors (Carpenter and Reimer, 1974) during neutron irradiation.

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### 3.0 CONCLUSIONS

Based upon the data presented in this report, the DOE concludes that the calcite-silica deposits in Trench 14 originated from pedogenic processes and do not indicate the presence of upwelling waters. This conclusion has resulted after a comprehensive, focused approach using experts from many disciplines and proven scientific investigative and analytical measures.

Field data are consistent with a pedogenic origin for the calcrete deposits at Trench 14 and at Busted Butte. Trench 14 exposes slope-parallel calcium carbonate-enriched zones that are laterally extensive, unlike springs which form discrete mounds. The slope-parallel deposits are physically, chemically, isotopically and biologically typical of carbonate-enriched pedogenic deposits that occur throughout the southwestern United States. The carbonate-enriched horizons exposed in Trench 14 can be traced upslope and over the fault vein fillings that some interpreted as feeder veins for spring deposits. Feeders for spring mounds typically maintain sub-parallel walls over depths of tens to hundreds of meters. In contrast, the portion of Trench 14, deepened in July, 1991, in the area of the near-vertical veins, exposes the veins wedging out from a thickness of nearly 1 meter near the top of the trench to 2-3 cm over a depth of only 7 meters.

Mineralogic and chemical data indicate that the calcretes consist predominantly of calcite with lesser amounts of opal-A and opal-CT, along with small proportions of sepiolite. The detrital component is very large relative to that found in spring deposits. Chemical data further indicate that the detritus in the deposits underwent surface pedogenic modification before it was incorporated into the calcretes. Such intermediate processing rules out direct incorporation of wall rock into the veins, which would be expected if these were spring deposits.

Data for natural tracer-isotope systems of  $^{87}\text{Sr}/^{86}\text{Sr}$  and  $^{234}\text{U}/^{238}\text{U}$  show that the calcite vein fillings exposed in Trench 14 did not form by ascending waters like those currently found in the regional aquifers beneath Yucca Mountain, because the large differences observed between isotopic compositions of ground water (or old ground water deposits) and isotopic compositions of vein carbonate at Trench 14 preclude a genetic relationship between the two at any time over the last million years. This conclusion is further supported by the isotopic compositions of carbon and oxygen in the vein carbonates and ground water samples.

The lack of calcareous microfossils suggests that no shallow-seated or perched spring that would create a saturated environment was involved in vein formation. This conclusion is supported by mineralogic and petrographic data in terms of both comparison of mineral assemblages of Trench 14 to those of known spring deposits and by microscale textures. Furthermore, geohydrologic conditions are not favorable for sustaining a perched-spring system, as previously noted (Section 2.2.7).

Field and laboratory studies of the silica deposits and breccias indicate that most were formed soon after pyroclastic deposition of host tuffs more than 10 million years ago (Tiva Canyon tuff has been dated at 12.7 million years ago). The hydrothermal processes responsible for some of the deposits were associated with rootless hydrothermal systems generated by infiltration of meteoric water into hot pyroclastic rocks. These hydrothermal systems died with the cooling of the tuffs and have never been reactivated. Some breccias have no hydrothermal origin at all and were entirely formed by surface processes such as accumulation and cementation of slope-wash alluvium. Other breccias are associated with discrete fault zones and contain the same mineral cements and root fossils as the calcite-silica deposits.

The studies focused strictly on determining the origin of Trench 14 calcite-silica vein deposits are complete. The vein deposits will no longer be the focus of site characterization activities related to potential disqualifying conditions, but they may provide information on past climates. The methods, analysis and approach used for this effort are effective and will be used by the DOE, where appropriate, in evaluating other mineral deposits. Planned characterization activities provide the means to obtain further data that are relevant to the conclusions in this report.

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**GLOSSARY**

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|            |  |
|------------|--|
| alluvium   | A general term for detrital deposits made by streams on river beds, flood plains, and alluvial fans; esp. a deposit of silt or silty clay laid down during time of flood. The term applies to stream deposits of recent time. It does not include subaqueous sediments of seas and lakes.  |
| amphibole  | A group of dark ferromagnesian minerals, common constituents of igneous and metamorphic rocks and their sediments. It is a minor constituent of igneous rocks in southwestern Nevada.  |
| ash        | Fine pyroclastic material (<4 mm), also called volcanic ash. The term also applies more specifically to thin layers or deposits of airborne ash distinguishable from material of local origin on the basis of color, composition, or other criteria.   |
| authigenic | Rock constituents and minerals that have not been transported or that were derived locally on the spot where they are now found. The term includes mineral cements deposited directly from solution. The term is most commonly applied to minerals formed in place at relatively low temperatures. The major authigenic minerals of Trench 14 and Busted Butte are calcite, opal, and sepiolite. |
| bedrock    | A general term for the rock that underlies soil or other unconsolidated material.  |
| breccia    | A rock or deposit composed of fragmental rock material. Breccias can form under a wide variety of geologic conditions. Some breccias form in place, e.g., fault breccias, whereas other breccias consist of fragmental material transported and deposited away from its source, e.g., colluvial breccias and hydrothermal eruption breccias.   |
| calcic     | rich in calcium  |
| calcite    | A common mineral, calcium carbonate, $\text{CaCO}_3$ . Calcite is a common constituent of rocks and soils.   |
| calcrete   | (a) A conglomerate consisting of surficial sand and gravel cemented into a hard mass by calcium carbonate precipitated from solution and redeposited through the agency of infiltrating waters, or deposited by the escape of carbon dioxide from vadose water. (b) A calcareous duricrust; caliche.   |

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|---------------------------|--|
| <b>cementation</b>        | The deposition or precipitation of minerals in the void spaces of a particulate rock deposit or soil. Cementation can also occur by in-situ dissolution and precipitation of mineral matter. The minerals deposited or precipitated are referred to as cement. |
| <b>Cenozoic</b>           | The latest of the four geologic time eras, extending from the close of the Mesozoic Era to and including the present.  |
| <b>clast</b>              | An individual constituent, grain, or fragment in a deposit of such material.   |
| <b>clinopyroxene</b>      | A monoclinic mineral of the pyroxene group and a common minor constituent of igneous rocks in southwestern Nevada.   |
| <b>colluvium</b>          | A general term applied to any loose mass of soil material or rock fragments deposited chiefly by mass-wasting, usually at the base of a slope or cliff. The associated adjective is "colluvial."   |
| <b>detritus</b>           | A collective term for loose rock and mineral material that is worn off or removed by mechanical means, as by disintegration or abrasion; esp. fragmental material such as sand, silt, and clay, derived from older rocks and moved from its place of origin.   |
| <b>devitrification</b>    | The process by which glassy igneous rocks change to an assemblage of one or more crystalline phases (minerals) after emplacement.  |
| <b>drusy quartz</b>       | Aggregates of well-formed quartz (SiO <sub>2</sub> ) crystals that encrust the surfaces of rock cavities or fractures.   |
| <b>eolian</b>             | Material transported and deposited by the wind.  |
| <b>exotic</b>             | Applies to clastic material that is not derived from local rocks, but has been transported to its present location.  |
| <b>hydrogenic deposit</b> | Materials, deposits precipitated from water. No specific manner of origin is implied.  |
| <b>Holocene</b>           | An Epoch of the Quaternary Period, from the end of the Pleistocene to the present time, approximately 10,000 years ago, to the present.  |

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|-----------------------|---|
| hydrothermal          | An adjective referring to heated water, to the action of heated water, or to the products of the action of heated water. Sources of hot water can be either deep or shallow in the earth. Deep sources include ground waters heated by molten or partially molten rocks below the Earth's surface. Shallow sources might include newly erupted and still-hot volcanic rocks interacting with surface or recharge water. |
| isopach               | In regard to the microscopic textures of rock cements, this term refers to a cement of approximately equal thickness on all affected surfaces.  |
| opal                  | A general term for amorphous or partially crystalline silica, SiO <sub>2</sub> , containing a varying proportion of water. A synonymous term is "opaline silica."   |
| opal-A                | Amorphous opal.   |
| opal-CT               | Opal with short-range cristobalite- and tridymite-type crystal lattice stacking.  |
| Paleozoic             | Era of geologic time - that between the Precambrian and Mesozoic  |
| pedogenic             | Pertaining to soil formation.   |
| per mil               | Per 1,000   |
| phreatophyte          | A plant that obtains its water supply from zones of saturation and is characterized by a deep root system.  |
| plane-polarized light | The standard illumination employed in microscopic studies of rock thin sections. The polarization of the light is essential in identifying certain optical properties of minerals.  |
| Pleistocene           | The initial Epoch of the Quaternary Period, ending about 10,000 years ago.  |
| pluvial               | Referring to an episode of time, especially one corresponding to a glacial age, characterized by abundant rainfall.   |
| pyroclastic           | Refers to a deposit or rock consisting of solid particulate material explosively or aerially ejected from a volcanic vent.  |
| Quaternary            | The second Period of the Cenozoic Era, following the Tertiary. It began approximately 1.65 million years ago and extends to the present. It consists of two epochs: the Pleistocene, up to about 10,000 years ago and the Holocene since that time.   |

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| radiogenic tracer isotope | A naturally occurring nuclide that formed by the radioactive decay of another natural occurring isotope.   |
| rhyolite                  | A group of extrusive igneous rocks, either lavas or pyroclastic flows.   |
| saturated zone            | The zone below the water table or static water level.  |
| sepiolite                 | A chain-lattice clay mineral, $Mg_4(Si_2O_5)_3(OH)_2 \cdot 6H_2O$ .  |
| silica                    | A general term denoting a variety of anhydrous or hydrous, crystalline to amorphous forms of silicon dioxide, $SiO_2$ . Also $SiO_2$ combined in silicate minerals of siliceous materials as an essential constituent.   |
| silica deposits           | Aggregates of one or more silica minerals, filling fractures or other void space in a rock or replacing part of the rock. Other secondary minerals may be present in subsidiary amounts.   |
| siliceous                 | A material that contains abundant $SiO_2$ , but does not necessarily contain a discrete silica mineral.  |
| spring mound              | A mound, up to several meters high, formed by a spring emerging at the surface and depositing its load. Constituents of the mound may include minerals precipitated from the discharging water and particulate material carried by the water. Many spring mounds have a laminated texture (e.g., travertine).  |
| stable isotope            | A nuclide that does not undergo radioactive decay.   |
| tectonism                 | Regional movement or deformation of the earth's crust, associated with high- or changing- stress conditions.   |
| Tertiary                  | The first Period of the Cenozoic Era (after the Cretaceous of the Mesozoic Era and before the Quaternary), thought to have covered the span of time between 65 and approximately 1.65 millions years ago.  |
| travertine                | (a) A dense, finely crystalline massive or concretionary limestone, of white, tan, or cream color, often having a fibrous or concentric structure and splintery fracture, formed by rapid chemical precipitation of calcium carbonate from solution in surface and ground waters, as by agitation of stream water or by evaporation around the mouth or in the conduit of a spring, esp. a hot spring. It also occurs in limestone caves, where it forms stalactites, stalagmites, and |

other deposits; and (b) as a vein filling, along faults, and in soil crusts. The spongy or less compact variety is tufa.

- tufa** A chemical sedimentary rock composed of calcium carbonate, formed by evaporation as a thin, surficial, soft, spongy, cellular or porous, semifriable incrustation around the mouth of a hot or cold calcareous spring or seep, or along a stream carrying calcium carbonate in solution, and exceptionally as a thick, bulbous, concretionary or compact deposit in a lake or along its shore. It may also be precipitated by algae or bacteria. The hard, dense variety is travertine. The term is rarely applied to a similar deposit consisting of silica.
- tuff** A general term for all consolidated pyroclastic rocks.
- unsaturated zone** The subsurface above the water table or static water level. Conditions of local or transient saturation may exist within the unsaturated zone.
- vapor-phase crystallization** Deposition of minerals by high-temperature water vapor within lavas or pyroclastic rocks. This is a process that may accompany devitrification.
- zircon** A mineral,  $ZrSiO_4$ , a common minor constituent of igneous and metamorphic rocks and their derivative sediments. Zircon crystals are usually minute (<0.1 mm).

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**APPENDIX A**  
**U.S. GEOLOGICAL SURVEY**  
**DATA TABLES**

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Table A-2.  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  Values (‰) of Carbonates from Trench 14 and Busted Butte,  
Using Current USGS QA Program Prior to Approval

| <b>TRENCH 14</b>    |                                    |                                     |         |
|---------------------|------------------------------------|-------------------------------------|---------|
| <b>Calcretes</b>    |                                    |                                     |         |
| Sample              | $\delta^{13}\text{C}_{\text{PDB}}$ | $\delta^{18}\text{O}_{\text{SMOW}}$ | Date    |
| HD-1                | -6.2                               | 21.1                                | 9/27/89 |
| HD-1 Do.            | -6.1                               | 21.2                                | 9/29/89 |
| HD-2 Do.            | -6.9                               | 20.3                                | 9/27/89 |
| HD-3                | -6.1                               | 20.6                                | 9/27/89 |
| HD-4                | -6.1                               | 19.9                                | 10/4/89 |
| HD-7                | -5.8                               | 19.8                                | 9/29/89 |
| HD-8                | -5.6                               | 19.8                                | 9/29/89 |
| HD-9 Do.            | -5.9                               | 20.3                                | 9/29/89 |
| HD-10 Do.           | -5.6                               | 19.6                                | 9/29/89 |
| HD-11               | -5.9                               | 20.4                                | 9/29/89 |
| HD-12               | -6.0                               | 20.2                                | 9/29/89 |
| <b>Veins</b>        |                                    |                                     |         |
| HD-20-1 Do.         | -7.5                               | 20.2                                | 10/5/89 |
| HD-22-4 Do.         | -7.1                               | 19.6                                | 10/4/89 |
| HD-54-1 Do.         | -6.9                               | 21.5                                | 9/29/89 |
| <b>BUSTED BUTTE</b> |                                    |                                     |         |
| <b>Calcretes</b>    |                                    |                                     |         |
| HD-57               | -5.2                               | 20.4                                | 10/6/89 |
| HD-58               | -4.8                               | 22.1                                | 10/6/89 |
| HD-75               | -4.8                               | 20.2                                | 10/6/89 |
| HD-76               | -4.6                               | 22.1                                | 10/6/89 |
| <b>Veins</b>        |                                    |                                     |         |
| HD-56-6             | -5.7                               | 20.2                                | 9/29/89 |
| HD-56-7 Do.         | -5.0                               | 19.9                                | 9/29/89 |

*Do. denotes replicate analyses*

All data were collected under the same YMP-USGS QA Program that was approved 9/12/90.

Table A-3. Results of Calcareous and Siliceous Microfossil Studies of  
Trench 14 and Busted Butte, Nye County, Nevada,  
Prior to USGS QA Program Implemented on May 3, 1990  
(Page 1 of 6)

### PART I CALCAREOUS MICROFOSSILS

#### LOCALITIES, PROCESSING STATUS, RESULTS SUMMARY

| LOCALITY<br>NUMBER | SAMPLE<br>NUMBER | LOCALITY  | STATUS<br>CODE <sup>1</sup> | RESULTS<br>CODE <sup>2</sup> | BIOTA <sup>3</sup><br>(+/-) | COMMENTS                       |
|--------------------|------------------|-----------|-----------------------------|------------------------------|-----------------------------|--------------------------------|
| HD-14-2            | RMF88NV4         | Trench 14 | A                           | F                            | (-)                         | sparse ?modern<br>contaminants |

#### EXPLANATIONS OF CODES

- <sup>1</sup> Status Codes: Current processing status for submitted samples is given by the following codes:
- D: Sample remains in condition as collected.
  - C: Sample (or significant portion of total sample) has been prepared for microscopic examination.
  - B: Sample examination & records have been completed. Final release of examination results and identifications are pending until supervisory review is completed.
  - A: Final supervisory review has been completed. Samples & pertinent records are released for inclusion with permanent records, publication, etc.
- <sup>2</sup> Results Codes:
- T: tentative (processing status codes "D", "C", "B")
  - F: final (processing status code "A")
- <sup>3</sup> Biota, Presence/Absence:
- (+): charophytes and/or ostracodes present, consult notes and/or attachments
  - (-): sample yields no calcareous microbiota, calcareous microfossils

#### SAMPLE DESCRIPTIONS<sup>4</sup>

HD-14-2 (=RMF sample # 88NV4)

All data were collected prior to the approval of the YMP-USGS QA Program.

**Table A-3. Results of Calcareous and Siliceous Microfossil Studies of  
Trench 14 and Busted Butte, Nye County, Nevada,  
Prior to USGS QA Program Implemented on May 3, 1990  
(Page 2 of 6)**

**Locality:** Trench 14, south wall, trench coordinate 27-28C, soil sample from Unit 1 (top unit).  
**Description:** Unconsolidated silt. Brown, friable, structureless, very fine to fine-grained, mixed mineral/rock fragment/volcanic glass clast-supported matrix, contains modern-appearing insect, seed, and other plant material. 1615.6g processed for microbiota & microfossils following HP-78, R1.  
**Results:** Sample yields no calcareous microfossils, faunal/floral elements listed above are probably modern contaminants.  
**Date Sample Acquired Status Code B:** 24 JUNE 88

<sup>4</sup> The lithologic descriptions given above are based on hand specimens and disaggregated residues.

All data were collected prior to the approval of the YMP-USGS QA Program.

Table A-3. Results of Calcareous and Siliceous Microfossil Studies of  
Trench 14 and Busted Butte, Nye County, Nevada,  
Prior to USGS QA Program Implemented on May 3, 1990  
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## PART II: CHRYSOPHYTE CYSTS

## SUMMARY OF RESULTS

| SAMPLE LOCALITY | SAMPLE NUMBER | RESULTS <sup>1</sup> |
|-----------------|---------------|----------------------|
| HD-1-2          | DPA 1020      | A                    |
| HD-2-2          | DPA 1019      | A                    |
| HD-13-1         | DPA 1021      | A                    |
| HD-14-1         | DPA 1022      | A                    |
| HD-35-1         | DPA 1023      | A                    |
| HD-36-1         | DPA 1024      | A                    |
| HD-36-3         | DPA 1025      | A                    |
| HD-37-1         | DPA 1026      | R                    |
| HD-38-1         | DPA 1030      | A                    |
| HD-38-2         | DPA 779       | A                    |
| HD-42-17        | DPA 1029      | A                    |
| HD-47-1         | DPA 1028      | R                    |
| HD-48-1         | DPA 1027      | I                    |
| HD-55-1         | DPA 1036      | I                    |
| HD-57-2         | DPA 1034      | I                    |
| HD-58-2         | DPA 1035      | I                    |
| HD-59-2         | DPA 1037      | I                    |
| HD-60-1         | DPA 1039      | I                    |
| HD-63-1         | DPA 1033      | I                    |
| HD-75-2         | DPA 1040      | I                    |
| HD-76-2         | DPA 1042      | I                    |
| HD-77-2         | DPA 1038      | I                    |

<sup>1</sup> Results codes:

A = Chrysophytes absent  
I = Incomplete analysis  
R = Chrysophytes rare

## DESCRIPTIONS

HD-1-2 (=DPA-NTS-5; =DPA site # 302; DPA sample # 1020)

Locality: Trench 14: South wall of trench at top of platy K horizon. Trench coordinate C18.

Results: chrysophyte cysts absent

All data were collected prior to the approval of the YMP-USGS QA Program.

Table A-3. Results of Calcareous and Siliceous Microfossil Studies of  
Trench 14 and Busted Butte, Nye County, Nevada  
Prior to USGS QA Program Implemented on May 3, 1990  
(Page 4 of 6)

- HD-2-2 (=DPA-NTS-4; =DPA site # 302; DPA sample # 1019)  
Locality: Trench 14: South wall of trench at base of platy K horizon, immediately behind sample HD-2-1. Trench coordinate C18.  
Results: chrysophyte cysts absent
- HD-13-1 (=DPA-NTS-6; =DPA site # 302; DPA sample # 1021)  
Locality: Trench 14: South wall of trench, 25cm above the top of the platy K horizon in Unit 2. Trench coordinates 27-28C.  
Results: chrysophyte cysts absent
- HD-14-1 (=DPA-NTS-7; =DPA site # 302; DPA sample # 1022)  
Locality: Trench 14: South wall of trench, top 5cm of Unit 1, in vesicular A horizon. Trench coordinates 27-28C.  
Results: chrysophyte cysts absent
- HD-35-1 (=DPA-NTS-8; =DPA site # 302; DPA sample # 1023)  
Locality: Trench 14: South wall of trench, grab sample from vein filling. Trench coordinates 13-14E.  
Results: chrysophyte cysts absent
- HD-36-1 (=DPA-NTS-9; =DPA site # 302; DPA sample # 1024)  
Locality: Trench 14: North wall of trench 14A, from carbonate fracture filling in tuff.  
Results: chrysophyte cysts absent
- HD-36-3 (=DPA-NTS-10; =DPA site # 302; DPA sample # 1025)  
Locality: Trench 14: North wall of trench 14A, massive carbonate lump from vein, 80cm west of # 1024.  
Results: chrysophyte cysts absent
- HD-37-1 (=DPA-NTS-11; =DPA site # 302; DPA sample # 1026)  
Locality: Trench 14: South wall of trench, carbonate filling from near-vertical crack, about 80cm above #1023.  
Results: chrysophyte cysts rare
- HD-38-1 (=DPA-NTS-61; =DPA site # 302; DPA sample # 1030)  
Locality: Trench 14: South wall of trench, opaline silica lens or nodule about 3cm thick from vein dipping 20-30W, about 1m down dip from upper end of vein. 12C.  
Results: chrysophyte cysts absent
- HD-38-2 (=DPA-NTS-12; =DPA site # 302; DPA sample # 779)  
Locality: Trench 14: Granular, poorly consolidated, very pure-looking white carbonate(?) from immediately above the siliceous lens sampled for HD-38-1. Sample appears to include many fine root holes.  
Results: chrysophyte cysts absent

All data were collected prior to the approval of the YMP-USGS QA Program.

Table A-3. Results of Calcareous and Siliceous Microfossil Studies of  
Trench 14 and Busted Butte, Nye County, Nevada  
Prior to USGS QA Program Implemented on May 3, 1990  
(Page 5 of 6)

- HD-42-17 (=DPA-NTS-14; =DPA site # 302; DPA sample # 1029)  
Locality: Trench 14: South wall of trench, sandy crack filling — volcanic ash??.  
Trench coordinates 14D.  
Results: chrysophyte cysts absent
- HD-47-1 (=DPA-NTS-13; =DPA site # 302; DPA sample # 1028)  
Locality: Trench 14: South wall of trench, calcareous filling from vein dipping about 45 degrees west.  
Trench coordinates 16D.  
Results: chrysophyte cysts rare
- HD-48-1 (=DPA-NTS-15; =DPA site # 405; DPA sample # 1027)  
Locality: Busted Butte sand ramps, north ridge: Oolitic cemented carbonate sand layer,  
about 10m west of saddle on south slope, about 3-4m below crest.  
Results: none, sample not analyzed
- HD-55-1 (=DPA-NTS-24; =DPA site # 406; DPA sample # 1036)  
Locality: Busted Butte sand ramps, middle ridge: Roughly vertical granular-looking white calcite vein  
filling at north edge of ridge.  
Results: none, sample not analyzed
- HD-57-2 (=DPA-NTS-22; =DPA site # 406; DPA sample # 1034)  
Locality: Busted Butte sand ramps, middle ridge: Uppermost laminar K horizon, just west of vertical  
veins on middle ridge. See sample sheet for further notes.  
Results: none, sample not analyzed
- HD-58-2 (=DPA-NTS-23; =DPA site # 406; DPA sample # 1035)  
Locality: Busted Butte sand ramps, middle ridge: Lowermost laminar K horizon.  
Results: none, sample not analyzed
- HD-59-2 (=DPA-NTS-25; =DPA site # 406; DPA sample # 1037)  
Locality: Busted Butte sand ramps, middle ridge: Rhizoliths.  
Results: none, sample not analyzed
- HD-60-1 (=DPA-NTS-27; =DPA site # 406; DPA sample # 1039)  
Locality: Busted Butte sand ramps, middle ridge: Sand about 50cm below platy K horizon,  
avoiding rhizoliths.  
Results: none, sample not analyzed
- HD-63-1 (=DPA-NTS-21; =DPA site # 405; DPA sample # 1033)  
Locality: Busted Butte sand ramps, north ridge: Surface collection of rhizoliths weathering out of  
calcrete about 2m west of high point below saddle in ridge.  
Results: none, sample not analyzed

All data were collected prior to the approval of the YMP-USGS QA Program.

**Table A-3. Results of Calcareous and Siliceous Microfossil Studies of  
Trench 14 and Busted Butte, Nye County, Nevada  
Prior to USGS QA Program Implemented on May 3, 1990  
(Page 6 of 6)**

**HD-75-2 (=DPA-NTS-28; =DPA site # 406; DPA sample # 1040)**

**Locality:** Busted Butte sand ramps, middle ridge: Uppermost 7cm of platy K horizon. Ooidal in uppermost and lowermost parts, with dense opaline silica stringer (2cm) in center.

**Results:** none, sample not analyzed

**HD-76-2 (=DPA-NTS-30; =DPA site # 406; DPA sample # 1042)**

**Locality:** Busted Butte sand ramps, middle ridge: Lowermost 2cm of platy K horizon. No visible ooids or secondary silica.

**Results:** none, sample not analyzed

**HD-77-2 (=DPA-NTS-26; =DPA site # 406; DPA sample # 1038)**

**Locality:** Busted Butte sand ramps, middle ridge: Rhizoliths in a sandy matrix below a platy K horizon. Up to 1.5m is exposed.

**Results:** none, sample not analyzed

All data were collected prior to the approval of the YMP-USGS QA Program.

Table A-4. Results of Calcareous Microfossil Studies of Trench 14 and Busted Butte,  
Nye County, Nevada, After Approval of USGS QA Program  
(Page 1 of 4)

## LOCALITIES, PROCESSING STATUS, RESULTS SUMMARY

| LOCALITY NUMBER | SAMPLE NUMBER                           | LOCALITY      | STATUS CODE <sup>1</sup> | RESULTS CODE <sup>2</sup> | BIOTA <sup>3</sup> (+)/(-) | COMMENTS                    |
|-----------------|---|---------------|--------------------------|---------------------------|----------------------------|-----------------------------|
| HD-1-3          | RMF88NV2                                | Trench 14     | A                        | F                         | (-)                        |                             |
| HD-2-3          | RMF88NV1                                | Trench 14     | A                        | F                         | (-)                        |                             |
| HD-13-2         | RMF88NV3                                | Trench 14     | A                        | F                         | (-)                        | sparse ?modern contaminants |
| HD-35-2         | RMF88NV5                                | Trench 14     | A                        | F                         | (-)                        | ?root fragments             |
| HD-36-2         | RMF88NV6                                | Trench 14     | A                        | F                         | (-)                        |                             |
| HD-37-2         | RMF88NV7                                | Trench 14     | A                        | F                         | (-)                        |                             |
| HD-47-2         | RMF88NV8                                | Trench 14     | A                        | F                         | (-)                        |                             |
| HD-626          | T-14-91-2                               | Trench 14     | A                        | F                         | (-)                        |                             |
| HD-48-2         | RMF88NV9<br>Sand ramp,<br>N. Ridge      | Busted Butte, | A                        | F                         | (-)                        | ?modern lichen contaminants |
| HD-55-2         | RMF88NV10<br>Sand ramp,<br>Middle Ridge | Busted Butte, | A                        | F                         | (-)                        |                             |

## EXPLANATIONS OF CODES

- <sup>1</sup> Status Codes: Current processing status for submitted samples are given by the following codes:
- D: Sample remains in condition as collected.
  - C: Sample (or significant portion of total sample) has been prepared for microscopic examination.
  - B: Sample examination & records have been completed. Final release of examination results and identifications are pending until supervisory review is completed.
  - A: Final supervisory review has been completed. Samples & pertinent records are released for inclusion with permanent records, publication, etc.

All data were collected under the approved YMP-USGS QA Program.

Table A-4. Results of Calcareous Microfossil Studies of Trench 14 and Busted Butte,  
Nye County, Nevada, After Approval of USGS QA Program  
(Page 2 of 4)

**2 Results Codes:**

- T: tentative (processing status codes "D", "C", "B")  
F: final (processing status code "A")

**3 Biota, Presence/Absence:**

- (+): charophytes and/or ostracodes present, consult notes and/or attachments  
(-): sample yields no calcareous microbiota, calcareous microfossils

**SAMPLE DESCRIPTIONS<sup>4</sup>**

**HD-1-3 (=RMF sample # 88NV2)**

Locality: Trench 14, south wall, sample from block of carbonate from top of platy K horizon.

Description: Microcrystalline to earthy carbonate. Tan, structureless, silt- to pebble-sized, volcanic-clast-supported matrix, secondary silica infillings of fractures and some voids, root molds. 250.4g processed for microbiota & microfossils via HP-78, R1.

Results: Sample is abiotic.

Date Sample Acquired Status Code B: 25 SEP 90

**HD-2-3 (=RMF sample # 88NV1)**

Locality: Trench 14, grid 18C (bottom of colluvium), sample from block of carbonate from bottom of K horizon.

Description: Microcrystalline carbonate. Tan, microlaminated, silt-to pebble-sized quartz, volcanic, and reworked micro crystalline clast bearing, microcrystalline carbonate-supported matrix, root molds. 153.9g processed for microbiota & microfossils via HP-78, R1.

Results: Sample is abiotic.

Date Sample Acquired Status Code B: 27 SEP 90

**HD-13-2 (=RMF sample # 88NV3)**

Locality: Trench 14, south wall, trench grid coordinate 27-28C, sample from top of platy K horizon in Unit Two.

Description: Unconsolidated sandy to pebbly calcareous silt. Grayish-brown, structureless, silt- to coarse sand-sized quartz, volcanic, and ?reworked earthy textured carbonate clast-supported matrix, contains modern appearing root and rare insect fragment. 1480.6g processed for micro-biota & microfossils following HP-78, R1.

Results: Sample contains no calcareous microfossils, faunal elements are probably modern contaminants.

Date Sample Acquired Status Code B: 27 SEP 90

All data were collected under the approved YMP-USGS QA Program.

Table A-4. Results of Calcareous Microfossil Studies of Trench 14 and Busted Butte,  
Nye County, Nevada, After Approval of USGS QA Program  
(Page 3 of 4)

HD-35-2 (=RMF sample # 88NV5)

Locality: Trench 14, south wall, E 13-14, sample from 15-30 cm below marker in vein (nail).  
Description: Earthy to microcrystalline carbonate. White, structureless, minor silica clastics, root molds and root fragments (63 to 125 $\mu$  size). 276.2g processed for microbiota & microfossils following HP-78, R1.  
Results: Nothing beyond root fragments.  
Date Sample Acquired Status Code **B**: 25 SEP 90

HD-36-2 (=RMF sample # 88NV6)

Locality: Trench 14A, north wall, sample from carbonate fracture filling in tuff, sample is from horizontal fracture about 6cm thick, about 35 cm up trench from fracture that dips 70 W. Carbonate vein filling with no visible root casts—vein is ~170cm below ground surface, 28m below top of trench. Several chunks of material were taken from same vein 80cm to the west and mixed in with the rest of the sample.  
Description: Earthy to microcrystalline carbonate. White to off-white, structureless, rare silt to medium sand-sized quartz grains, common volcanic glass (ash) fragments, and sparse pebbles of indurate tuff supported by earthy to microcrystalline carbonate matrix, rare root molds. 835.2g processed for microbiota & microfossils following HP-78, R1.  
Results: Sample is abiotic.  
Date Sample Acquired Status Code **B**: 27 SEP 90

HD-37-2 (=RMF sample # 88NV7)

Locality: Trench 14, south wall, carbonate filling from near-vertical crack, 80cm above HD-35 (RMP88NV5).  
Description: Earthy to microcrystalline carbonate. White to off-white, structureless, sparse silt- to medium sand-sized quartz grains and volcanic glass (ash) fragments floating in microcrystalline carbonate matrix, secondary silica growths in fractures and voids, sparse root molds. 309.9g processed for microbiota & microfossils following HP-78, R1.  
Results: Sample is abiotic.  
Date Sample Acquired Status Code **B**: 26 SEP 90

HD-47-2 (=RMF sample # 88NV8)

Locality: Trench 14, south wall, calcareous vein filling from vein dipping 45 W.  
Description: Earthy to microcrystalline carbonate. White to off-white, structureless, sparse silt- to pebble-sized quartz clasts, reworked sparry calcite clasts, rock fragments, and brown volcanic glass (ash) fragments, earthy to microcrystalline carbonate matrix-supported, some secondary silica-lined fractures and voids, sparse multimineralic-appearing root molds. 308.6g processed for microbiota & microfossils following HP-78, R1.  
Results: Sample is abiotic.  
Date Sample Acquired Status Code **B**: 26 SEP 90

All data were collected under the approved YMP-USGS QA Program.

Table A-4. Results of Calcareous Microfossil Studies of Trench 14 and Busted Butte,  
Nye County, Nevada, After Approval of USGS QA Program  
(Page 4 of 4)

HD-626 (=sample # T-14-91-2)

Locality: Trench 14, grid F14, south wall, 34" (92cm) below sample T-14-91-1, in same vein, vein material.

Description: Sample consists of two distinct lithologies, A & B, of which A dominates. Contacts between A & B are sharp.

Lith. A: Calcrete. Tan, structureless, quartz clast-supported matrix, common microscopic root molds lined and/or filled by secondary fibrous calcite growths.

Lith. B: Calcrete. Grayish yellow-brown, indurate, sand- to pebble-sized ?rhyolite fragments supported by microcrystalline carbonate matrix, matrix is partially banded, bands vary in appearance from clear (larger crystals) to cloudy (small crystals).

Sample not disaggregated prior to microscopic examination for microbiota & microfossils.

Results: Sample is abiotic.

Date Sample Acquired Status Code B: 2 NOV 91

HD-48-2 (=RMF sample # 88NV9)

Locality: Busted Butte sand ramp, North Ridge, about 10m west of saddle on south slope, about 3-4m below crest, oolitic cemented carbonate sand layer.

Description: Calcrete. Brown to gray, structureless, carbonate-cemented silt- to coarse sand-sized quartz grains, earthy carbonate clasts ("oooid material"), volcanic rock fragments, and volcanic glass fragments, matrix is clast-supported, modern appearing lichen fragments noted during processing. 319.5g processed for microbiota & micro-fossils following HP-78, R1.

Results: Sample yielded no calcareous microfossils.

Date Sample Acquired Status Code B: 24 SEP 90

HD-55-2 (=RMF sample # 88NV10)

Locality: Busted Butte sand ramps, north edge of Middle Ridge, vertical (roughly) granular-looking white calcite vein filling at N edge of ridge, fine-grained carbonate on fault-line.

Description: Earthy microcrystalline carbonate. White to off-white, structureless, sparse silt- to fine sand-sized silica clastics, common fine sand-sized volcanic glass (ash) fragments, and rare volcanic pebbles supported by earthy to microcrystalline carbonate matrix, sparse root molds. 440.5g processed for microbiota & microfossils following HP-78, R1.

Results: Sample is abiotic.

Date Sample Acquired Status Code B: 24 SEP 90

<sup>4</sup> The lithologic descriptions given above are based on hand specimens and disaggregated residues.

All data were collected under the approved YMP-USGS QA Program.

Table A-5. U, Th, and Pb Concentrations and Lead Isotopic Compositions of  
Carbonate-Silicate Veins and Calcrete from Yucca Mountain, Nevada  
(Page 1 of 2)

| Sample          | U (ppm) | Th (ppm) | Pb (ppm) | $^{206}\text{Pb}/^{204}\text{Pb}$ | $^{207}\text{Pb}/^{204}\text{Pb}$ | $^{208}\text{Pb}/^{204}\text{Pb}$ |
|-----------------|---------|----------|----------|-----------------------------------|-----------------------------------|-----------------------------------|
| TRENCH 14       |         |          |          |                                   |                                   |                                   |
| HD-1 Calcrete   |         |          |          |                                   |                                   |                                   |
| Carbonate - 44% | 1.13    | 2.14     | 4.61     | 20.15                             | 15.78                             | 39.3                              |
| Silicate - 56%  | 6.47    | 10.4     | 24.9     | 18.34                             | 15.57                             | 38.94                             |
| HD-2 Calcrete   |         |          |          |                                   |                                   |                                   |
| Carbonate - 62% | 1.01    | 1.06     | 1.86     | 19.99                             | 15.79                             | 39.33                             |
| Silicate - 38%  | 7.57    | 0.98     | 12.3     | 18.47                             | 15.58                             | 38.87                             |
| HD-9 Calcrete   |         |          |          |                                   |                                   |                                   |
| Carbonate - 58% | (1.9)   | (3.7)    | (3.9)    | 18.73                             | 15.65                             | 39.17                             |
| Carbonate - 53% | 1.25    | 1.3      | 2.11     | 18.81                             | 15.66                             | 39.19                             |
| Silicate - 47%  | 7.56    | 5.41     | 7.5      | 18.52                             | 15.63                             | 39.08                             |
| HD-10 Calcrete  |         |          |          |                                   |                                   |                                   |
| Carbonate - 58% | (1.5)   | (0.9)    | (1.0)    | 18.8                              | 15.7                              | 39.25                             |
| Carbonate - 63% | 1.31    | 0.34     | 0.64     | 19.79                             | 15.77                             | 39.34                             |
| Silicate - 37%  | 8.59    | 1.19     | 1.21     | 18.54                             | 15.63                             | 39.16                             |
| HD-20-2 Vein    |         |          |          |                                   |                                   |                                   |
| Carbonate - 71% | 1.02    | 0.49     | 1.33     | 19.01                             | 15.61                             | 38.97                             |
| Silicate - 29%  | 9.9     | 3.18     | 2.49     | 18.38                             | 15.58                             | 39.05                             |
| HD-22-2 Vein    |         |          |          |                                   |                                   |                                   |
| Carbonate - 69% | (0.6)   | (3.0)    | (4.3)    | 18.35                             | 15.6                              | 39.1                              |
| Carbonate - 47% | 0.85    | 3.48     | 4.08     | 18.4                              | 15.56                             | 38.89                             |
| Silicate - 53%  | 3.17    | 2.8      | 3.49     | 18.27                             | 15.58                             | 39.05                             |
| HD-28-2 Vein    |         |          |          |                                   |                                   |                                   |
| Carbonate - 38% | 0.77    | 0.19     | 10.9     | 18.11                             | 15.56                             | 38.99                             |
| Silicate - 62%  | 4.31    | 17.9     | 63.2     | 18.09                             | 15.55                             | 38.96                             |

Carbonate and silicate fractions are the dissolved and residue portions of the sample after leaching in 0.8N CH<sub>3</sub>COOH for 2 hours. Percent silicate and, by difference, carbonate is calculated by weighing total and residue portions of samples. Concentrations shown in parentheses are accurate to only +/- 10%. For these samples percent carbonate is calculated from CO<sub>2</sub> loss assuming pure CaCO<sub>3</sub>. Samples were dissolved in 1.5N HCl after 2 hours.

All data were collected under the same YMP-USGS QA Program that was approved 9/12/90.

Table A-5. U, Th, and Pb Concentrations and Lead Isotopic Compositions of Carbonate-Silicate Veins and Calcrite from Yucca Mountain, Nevada  
(Page 2 of 2)

| Sample              | U (ppm) | Th (ppm) | Pb (ppm) | $^{206}\text{Pb}/^{204}\text{Pb}$ | $^{207}\text{Pb}/^{204}\text{Pb}$ | $^{208}\text{Pb}/^{204}\text{Pb}$ |
|---------------------|---------|----------|----------|-----------------------------------|-----------------------------------|-----------------------------------|
| <b>BUSTED BUTTE</b> |         |          |          |                                   |                                   |                                   |
| HD-31-2 Vein        |         |          |          |                                   |                                   |                                   |
| Carbonate - 57%     | (1.2)   | (0.6)    | (1.0)    | 18.89                             | 15.59                             | 39.05                             |
| Carbonate - 55%     | 0.91    | 0.24     | 0.49     | 19.89                             | 15.75                             | 39.33                             |
| Silicate - 45%      | 3.45    | 1.02     | 1.49     | 18.18                             | 15.53                             | 38.86                             |
| HD-42-10 Vein       |         |          |          |                                   |                                   |                                   |
| Carbonate - 44%     | (1.4)   | (5.8)    | (6.1)    | 18.66                             | 15.61                             | 39.04                             |
| Carbonate - 45%     | 0.93    | 2.01     | 2.63     | 18.62                             | 15.59                             | 38.94                             |
| Silicate - 55%      | 16.3    | 4.96     | 8.42     | 18.48                             | 15.61                             | 39.05                             |
| HD-42-12 Vein       |         |          |          |                                   |                                   |                                   |
| Carbonate - 54%     | (1.5)   | (3.7)    | (4.7)    | 18.69                             | 15.62                             | 38.97                             |
| Carbonate - 48%     | 1.13    | 0.88     | 1.67     | 18.73                             | 15.61                             | 38.99                             |
| Silicate - 52%      | 10.9    | 6.06     | 9.63     | 18.47                             | 15.59                             | 38.95                             |
| HD-54-5 Vein        |         |          |          |                                   |                                   |                                   |
| Carbonate - 75%     | 1.02    | 0.92     | 0.58     | 20.21                             | 15.79                             | 39.33                             |
| Silicate - 25%      | 15.8    | 0.99     | 1.11     | 18.84                             | 15.58                             | 38.51                             |
| HD-56-6 Vein        |         |          |          |                                   |                                   |                                   |
| Carbonate - 58%     | (1.3)   | (3.8)    | (3.7)    | 18.62                             | 15.63                             | 39.18                             |
| Carbonate - 40%     | 0.57    | 1.27     | 2.1      | 19.29                             | 15.69                             | 39.17                             |
| Silicate - 60%      | 12.2    | 7.94     | 11.7     | 18.36                             | 15.57                             | 38.97                             |
| HD-63-3 Rhizolith   |         |          |          |                                   |                                   |                                   |
| Carbonate - 18%     | 1.28    | 2.18     | 9.49     | 18.67                             | 15.63                             | 38.6                              |
| Silicate - 82%      | 5.75    | 8.81     | 15.2     | 18.49                             | 15.6                              | 38.95                             |

Carbonate and silicate fractions are the dissolved and residue portions of the sample after leaching in 0.8N CH<sub>3</sub>COOH for 2 hours. Percent silicate and, by difference, carbonate is calculated by weighing total and residue portions of samples. Concentrations shown in parentheses are accurate to only +/- 10%. For these samples percent carbonate is calculated from CO<sub>2</sub> loss assuming pure CaCO<sub>3</sub>. Samples were dissolved in 1.5N HCl after 2 hours.

All data were collected under the same YMP-USGS QA Program that was approved 9/12/90.

Table A-6. U and Th Concentrations and Lead Isotopic Compositions of Volcanic Rocks from Yucca Mountain, Nevada

| <u>Sample</u>                 | <u>U (ppm)</u> | <u>Th (ppm)</u> | <u>206Pb/204Pb</u> | <u>207Pb/204Pb</u> | <u>208Pb/204Pb</u> |
|-------------------------------|----------------|-----------------|--------------------|--------------------|--------------------|
| TIVA CANYON                   |                |                 |                    |                    |                    |
| HD-29                         | nd             | nd              | 18.12              | 15.563             | 39.033             |
| HD-32-1                       | nd             | nd              | 18.123             | 15.555             | 39.014             |
| 5-4-89D                       | nd             | nd              | 18.16              | 15.565             | 39.039             |
| 5-4-89F                       | nd             | nd              | 18.231             | 15.573             | 39.042             |
| Topopah Spring Composite (12) | 4.4            | 24.5            | 18.147             | 15.564             | 39.074             |
| Calico Hills Composite (4)    | 4.5            | 23              | 18.225             | 15.59              | 39.016             |
| Prow Pass Composite (2)       | 5.1            | 22.2            | 18.342             | 15.578             | 38.742             |
| Bullfrog Composite (16)       | 4              | 20.7            | 18.319             | 15.597             | 38.89              |
| Tram Composite (11)           | 4.2            | 20.3            | 18.354             | 15.579             | 38.907             |
| Flow Breccia Composite (4)    | 3.4            | 17.4            | 18.243             | 15.578             | 39.197             |
| Lithic Ridge Composite (6)    | 2.7            | 18.3            | 18.249             | 15.581             | 39.079             |
| Unit A Composite (6)          | 3.6            | 20              | 18.271             | 15.577             | 39.045             |
| Unit B Composite (1)          | 4.3            | 20              | 18.244             | 15.564             | 39.015             |
| Unit C Composite (7)          | 2.9            | 16.9            | 18.178             | 15.587             | 39.167             |

Pb concentration estimated from chemical yields to be 5-20 ppm.

All data were collected under the same YMP-USGS QA Program that was approved 9/12/90.

Table A-7. Uranium and Thorium Concentrations and Uranium Isotopic Activity Ratio in Yucca Mountain Area Ground Water, Using Current USGS QA Program Prior to Approval

| <u>Sample #</u> | <u>Date Spiked</u> | <u>U (ppb)</u> | <u>Th (ppb)</u> | <u>234U/238U (activity ratio)</u> |
|-----------------|--------------------|----------------|-----------------|-----------------------------------|
| UE-25 P1        | 06/16/90           | 06/16/90       | 2.3 +/-0.4      | 2.71 +/-0.09                      |

Table A-8. Uranium and Thorium Concentrations and Uranium Isotopic Activity Ratios in Yucca Mountain Area Ground Water, After Approval of USGS QA Program

| <u>Sample #</u> | <u>Date Spiked</u> | <u>U (ppb)</u> | <u>Th (ppb)</u> | <u>234U/238U (activity ratio)</u> |
|-----------------|--------------------|----------------|-----------------|-----------------------------------|
| J-12            | 03/25/91           | 0.584 +/-0.007 | <0.004          | 5.515 +/-0.037                    |
| J-13            | 03/25/91           | 0.593 +/-0.008 | <0.004          | 6.979 +/-0.059                    |

All data were collected under the same YMP-USGS QA Program that was approved 9/12/90.

Table A-9. Uranium Concentrations, Isotopic Activity Ratios, and Ages of Hydrogenic Carbonate Deposits,  
After Approval of USGS QA Program

| <u>Sample #</u>     | <u>Date Spiked</u> | <u>U (ppm)</u> | <u><math>^{234}\text{U}/^{238}\text{U}</math></u> | <u><math>^{230}\text{Th}/^{232}\text{Th}</math></u> | <u><math>^{230}\text{Th}/^{234}\text{U}</math></u> | <u>Uncorrected<br/>Age (ka)</u> | <u>Corrected<br/>Age (ka)</u> |
|---------------------|--------------------|----------------|---|---|--|---------------------------------|-------------------------------|
| HD-170-01-A RESIDUE | 04/10/92           | 5.04 +/-0.12   | 1.03 +/-0.03                                      | 0.91 +/-0.04  | 1.66 +/-0.07                                       | N/A                             | N/A                           |
| HD-170-01-A         | 12/11/91           | 1.88 +/-0.02   | 2.60 +/-0.02                                      | 2.68 +/-0.03  | 0.232 +/-0.002                                     | 28 +/-1                         | 19 +/-2                       |
| HD-15-3-3           | 02/12/91           | 1.02 +/-0.02   | 1.08 +/-0.02                                      | 2.80 +/-0.07  | 0.99 +/-0.02                                       | 349 +/-59/-39                   | nd                            |
| HD-15-3-4           | 12/18/90           | 2.80 +/-0.03   | 1.32 +/-0.01                                      | >600  | 0.59 +/-0.02                                       | 92 +/-5                         | 92 +/-5                       |

nd = no data; corrected age cannot be calculated until residues are analyzed.  
Uncorrected age is therefore a maximum possible "true" age.

All data were collected under the approved YMP-USGS QA Program.

Table A-10. Uranium Concentrations, Isotopic Activity Ratios, and Ages of Hydrogenic Carbonate Deposits, Using Current USGS QA Program Prior to Approval

| Sample #             | Date Spiked | U (ppm)      | $^{234}\text{U}/^{238}\text{U}$ | $^{230}\text{Th}/^{232}\text{Th}$ | $^{230}\text{Th}/^{234}\text{U}$ | Uncorrected Age (ka)     | Corrected Age (ka)       |
|----------------------|-------------|--------------|---------------------------------|-----------------------------------|----------------------------------|--------------------------|--------------------------|
| HD-12                | 03/08/90    | 2.39 +/-0.03 | 1.30 +/-0.01                    | 3.51 +/-0.07                      | 0.68 +/-0.01                     | 116 +/-3                 | 77 +/-5                  |
| HD-11                | 03/08/90    | 3.33 +/-0.04 | 1.36 +/-0.01                    | 11.6 +/-0.3                       | 1.07 +/-0.01                     | Excess $^{230}\text{Th}$ | Excess $^{230}\text{Th}$ |
| HD-42-5G-A RESIDUE   | 09/07/89    | 5.21 +/-0.07 | 0.89 +/-0.01                    | 1.15 +/-0.02                      | 1.03 +/-0.02                     | N/A                      | N/A                      |
| HD-42-50-A RESIDUE   | 09/07/89    | 8.0 +/- 0.1  | 0.948 +/-0.009                  | 2.51 +/-0.05                      | 1.00 +/-0.001                    | N/A                      | N/A                      |
| HD-1-A RESIDUE       | 09/07/89    | 8.56 +/-0.09 | 1.234 +/-0.008                  | 2.39 +/-0.03                      | 0.794 +/-0.010                   | N/A                      | N/A                      |
| HD-2                 | 06/22/89    | 2.35 +/-0.03 | 1.35 +/-0.01                    | 5.4 +/-0.1                        | 0.74 +/-0.01                     | 133 +/-4                 | 119 +/-8                 |
| HD-1-A CARBONATE     | 06/22/89    | 3.2 +/-0.04  | 1.20 +/-0.01                    | 3.05 +/-0.05                      | 0.73 +/-0.01                     | 133 +/-4                 | 87 +/-5                  |
| HD-42-5B-A           | 06/22/89    | 3.27 +/-0.04 | 1.31 +/-0.01                    | 19.1 +/-0.6                       | 0.93 +/-0.01                     | 223 +/-11                | 223 +/-11                |
| HD-42-5G-A CARBONATE | 06/22/89    | 3.64 +/-0.04 | 0.899 +/-0.009                  | 4.14 +/-0.07                      | 0.94 +/-0.01                     | >350                     | 327+infinity/-70         |
| HD-42-50-A CARBONATE | 06/22/89    | 2.31 +/-0.03 | 0.972 +/-0.009                  | 3.28 +/-0.07                      | 1.01 +/-0.02                     | Excess $^{230}\text{Th}$ | Excess $^{230}\text{Th}$ |

Note: Sample # HD-2, HD-11, and HD-12 were corrected with HD-1-A residue data.  
Sample # HD-42-5B-A and HD-15-3-3: Corrected age cannot be calculated until residues are analyzed. Uncorrected age is therefore a maximum possible 'true' age.

All data were collected under the same YMP-USGS QA Program that was approved 9/12/90.

Table A-11. Uranium Series Data Obtained From Busted Butte Carbonate Samples

| <u>Sample #</u> | <u>Date Spiked</u> | <u>U (ppm)</u> | <u><sup>234</sup>U/<sup>238</sup>U</u> | <u><sup>230</sup>Th/<sup>232</sup>Th</u> | <u><sup>230</sup>Th/<sup>234</sup>U</u> | <u>Uncorrected Age (ka)</u> | <u>Corrected Age (ka)</u> |
|-----------------|--------------------|----------------|--|--|---|-----------------------------|---------------------------|
| BB1-A           | 07/03/86           | 0.90 +/-0.03   | 1.11 +/-0.04                           | 22 +/-2                                  | 0.50 +/-0.03                            | 75 +/-6                     | 75 +/-6                   |
| BB1-B           | 07/03/86           | 2.71 +/-0.05   | 1.17 +/-0.02                           | 30 +/-1                                  | 0.60 +/-0.02                            | 97 +/-6                     | 97 +/-6                   |
| BB1-C           | 07/03/86           | 2.13 +/-0.05   | 1.16 +/-0.03                           | 15.6 +/-0.5                              | 0.68 +/-0.03                            | 119 +/-10                   | 113 +/-10                 |
| BB1-D Carbonate | 07/03/86           | 1.21 +/-0.03   | 1.22 +/-0.03                           | 5.1 +/-0.1                               | 0.74 +/-0.03                            | 137 +/-12                   | 114 +/-12                 |
| BB1-D Residue   | 07/03/86           | 4.11 +/-0.05   | 1.08 +/-0.01                           | 1.12 +/-0.01                             | 1.13 +/-0.02                            | N/A                         | N/A                       |
| BB2-A           | 07/15/86           | 3.00 +/-0.08   | 1.32 +/-0.03                           | 26 +/-2                                  | 0.24 +/-0.01                            | 29 +/-1                     | 29 +/-1                   |
| BB2-B           | 07/15/86           | 2.62 +/-0.08   | 1.27 +/-0.03                           | 21 +/-1                                  | 0.50 +/-0.02                            | 73 +/-5                     | 73 +/-5                   |
| BB2-C           | 07/15/86           | 3.61 +/-0.09   | 1.32 +/-0.03                           | 22 +/-1                                  | 0.38 +/-0.02                            | 52 +/-3                     | 52 +/-3                   |

Note: Corrected age for BB1-C derived from using BB1-D residue.

All data were collected under the approved YMP-USGS QA Program.

Table A-12. Strontium Isotope Ratios, After Approval of USGS QA Program  
(Page 1 of 2)

| Area           | Locality  | Sample ID          | Type                        | $^{87}\text{Sr}/^{86}\text{Sr}$ | $\delta 87$ | MS Date  |
|----------------|-----------|--------------------|-----------------------------|---------------------------------|-------------|----------|
| Fortymile Wash | JF3       | JF-3 1800          | water (well)                | 0.71129                         | 2.9 +/-0.1  | 04/30/92 |
| Fortymile Wash | JF3       | JF-3 1736          | water (well)                | 0.71136                         | 3.0 +/-0.1  | 04/16/92 |
| Fortymile Wash | JF3       | JF-3 0520          | water (well)                | 0.71128                         | 2.9 +/-0.1  | 04/02/92 |
| Fortymile Wash | JF3       | JF-3 1735          | water (well)                | 0.71137                         | 3.1 +/-0.1  | 03/30/92 |
| Yucca Mountain | UE-25p #1 | UE-25p #1          | water (well)                | 0.71175                         | 3.6 +/-0.1  | 02/27/92 |
| Fortymile Wash | J-12      | J-12 (3)           | water (well)                | 0.71158                         | 3.4 +/-0.1  | 02/21/92 |
| Fortymile Wash | J-12      | J-12 (5)           | water (well)                | 0.71155                         | 3.3 +/-0.1  | 02/16/92 |
| Fortymile Wash | J-12      | J-12 (4)           | water (well)                | 0.71152                         | 3.3 +/-0.1  | 02/15/92 |
| Fortymile Wash | J-13      | J-13 (5)           | water (well)                | 0.71154                         | 3.3 +/-0.1  | 01/10/92 |
| Fortymile Wash | J-13      | J-13 (6)           | water (well)                | 0.71146                         | 3.2 +/-0.1  | 01/10/92 |
| Fortymile Wash | J-13      | J-13 (4)           | water (well)                | 0.71145                         | 3.2 +/-0.1  | 01/07/92 |
| Yucca Mountain | Site 106  | HD-163 HCl-R       | calcite-silica vein         | 0.71269                         | 4.9 +/-0.0  | 09/10/91 |
| Yucca Mountain | Site 106  | HD-159 HCl-R       | calcrete                    | 0.71071                         | 2.1 +/-0.0  | 09/10/91 |
| Yucca Mountain | Trench 14 | HD-226 HCl-R       | calcite-silica vein         | 0.70892                         | -0.4 +/-0.0 | 09/10/91 |
| Bare Mountain  | Carrara   | HD-224-1 HCl-R     | soil, playa, eolian deposit | 0.70977                         | 0.8 +/-0.0  | 09/10/91 |
| Bare Mountain  | Carrara   | HD-223 HCl-R       | soil, playa, eolian deposit | 0.70969                         | 0.7 +/-0.0  | 09/10/91 |
| Crater Flat    |           | HD-204-1 HCl-R     | soil, playa, eolian deposit | 0.70950                         | 0.4 +/-0.0  | 09/10/91 |
| Yucca Mountain | Trench 14 | HD-3 HCl-R         | calcrete                    | 0.71049                         | 1.8 +/-0.0  | 09/09/91 |
| Yucca Mountain | Site 106  | HD-157-1 HCl-R     | calcrete                    | 0.70954                         | 0.5 +/-0.1  | 09/09/91 |
| Yucca Mountain | Trench 14 | HD-42-14 HCl-L (2) | calcite-silica vein         | 0.71247                         | 4.6 +/-0.0  | 07/30/91 |
| Yucca Mountain | Trench 14 | HD-54-2 HCl-L (2)  | calcite-silica vein         | 0.71269                         | 4.9 +/-0.0  | 07/30/91 |

1 Pedogenic samples used in average (N=37) discussed in Sections 3.2.5 and 3.3.5

2 Bare mountain samples

The strontium isotope ratios were determined on NIST 6-inch and VG Isomass 54E thermal ionization mass spectrometers.

In order to eliminate differences between instruments, all data were normalized to an  $^{87}\text{Sr}/^{86}\text{Sr}$  value of 0.70920 for EN-1,

a standard used routinely on both instruments for calibration. The Delta  $^{87}\text{Sr}$  notation is derived from the following transformation:

$$\delta 87\text{Sr} = ((^{87}\text{Sr}/^{86}\text{Sr}/0.70920 - 1)) * 1000$$

where the value of 0.70920 represents the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of modern seawater.

All data were collected under the approved YMP-USGS QA Program.

Table A-12. Strontium Isotope Ratios, After Approval of USGS QA Program  
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| Area            | Locality              | Sample ID                    | Type                                  | $^{87}\text{Sr}/^{86}\text{Sr}$ | $\delta^{87}$ | MS Date  |
|-----------------|-----------------------|------------------------------|---------------------------------------|---------------------------------|---------------|----------|
| Yucca Mountain  | Trench 14             | HD-12 HCl-L (2)              | calcrete                              | 0.71230                         | 4.4 +/-0.0    | 07/30/91 |
| Yucca Mountain  | Trench 14             | HD-42-13 HCl-L (2)           | calcite-silica vein                   | 0.71189                         | 3.8 +/-0.0    | 07/30/91 |
| Yucca Mountain  | Trench 14             | HD-7 HCl-L (2)               | calcrete                              | 0.71178                         | 3.6 +/-0.0    | 07/29/91 |
| Yucca Mountain  | Trench 14             | HD-3 HCl-L (2)               | calcite-silica vein                   | 0.71215                         | 4.2 +/-0.0    | 07/29/91 |
| Amargosa Desert | White-bed Locality    | JD-6 HCl-L                   | spring deposit                        | 0.71304                         | 5.4 +/-0.1    | 07/28/91 |
| Amargosa Desert | White-bed Locality    | HD-172-1 HOAc-R              | spring deposit                        | 0.70956                         | 0.5 +/-0.0    | 07/21/91 |
| Yucca Mountain  | UE-25 UZN #2          | UE-25 UZN #2 (3)             | water (well)                          | 0.71149                         | 3.2 +/-0.1    | 06/28/91 |
| Crater Flat     | Trench 8              | HD-181-3A HOAc-L             | calcite-silica vein                   | 0.71246                         | 4.6 +/-0.0    | 05/21/91 |
| Bare Mountain   | Black Marble Hill     | HD-212 HOAc-L <sup>2</sup>   | LS./ dolomite<br>(Paleozoic or older) | 0.71185                         | 3.7 +/-0.0    | 05/21/91 |
| Crater Flat     | Trench CF1            | HD-197-2 HOAc-L              | calcite-silica vein                   | 0.71264                         | 4.9 +/-0.0    | 05/21/91 |
| Bare Mountain   | Black Marble Hill     | HD-219 HOAc-L <sup>2</sup>   | LS./ dolomite<br>(Paleozoic or older) | 0.71172                         | 3.6 +/-0.0    | 05/21/91 |
| Crater Flat     | Trench 8              | HD-181-1A HOAc-L             | calcite-silica vein                   | 0.71227                         | 4.3 +/-0.0    | 05/21/91 |
| Amargosa Desert | White-bed Locality    | HD-172-1 HOAc-L              | spring deposit                        | 0.71257                         | 4.8 +/-0.0    | 05/20/91 |
| Fortymile Wash  | J-12                  | J-12 (2)                     | water (well)                          | 0.71197                         | 3.9 +/-0.0    | 05/07/91 |
| Fortymile Wash  | J-13                  | J-13 (3)                     | water (well)                          | 0.71147                         | 3.2 +/-0.0    | 05/06/91 |
| Beatty Wash     | Coffers Ranch         | 11S?10S/48-1dd               | water (well)                          | 0.70924                         | 0.1 +/-0.0    | 09/17/90 |
| Amargosa Desert | S. of White-bed Local | HD-173-1 HOAc-L              | soil, playa, eolian deposit           | 0.71254                         | 4.7 +/-0.1    | 09/15/90 |
| Yucca Mountain  | Site 106              | HD-153-1 HOAc-L <sup>1</sup> | calcrete                              | 0.71276                         | 5.0 +/-0.1    | 09/12/90 |
| Yucca Mountain  | Site 106              | HD-160 HOAc-L <sup>1</sup>   | calcrete                              | 0.71266                         | 4.9 +/-0.1    | 09/12/90 |

<sup>1</sup> Pedogenic samples used in average (N=37) discussed in Sections 3.2.5 and 3.3.5

<sup>2</sup> Bare mountain samples

The strontium isotope ratios were determined on NIST 6-inch and VG Isomass 54E thermal ionization mass spectrometers. In order to eliminate differences between instruments, all data were normalized to an  $^{87}\text{Sr}/^{86}\text{Sr}$  value of 0.70920 for EN-1, a standard used routinely on both instruments for calibration. The Delta  $^{87}\text{Sr}$  notation is derived from the following transformation:  
 $\delta^{87}\text{Sr} = ((^{87}\text{Sr}/^{86}\text{Sr}/0.70920 - 1)) * 1000$   
 where the value of 0.70920 represents the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of modern seawater.

All data were collected under the approved YMP-USGS QA Program.

Table A-13. Strontium Isotope Ratios, Using Current USGS QA Program Prior to Approval  
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REPORT - CALCITE-SILICA DEPOSITS

| Area             | Locality              | Sample ID                    | Type                                  | 87Sr/86Sr | δ87         | MS Date  |
|------------------|-----------------------|------------------------------|---------------------------------------|-----------|-------------|----------|
| Amargosa Desert  | S. of White-bed Local | HD-173-1 HCl-L               | soil, playa, eolian deposit           | 0.71091   | 2.4 +/-0.1  | 09/10/90 |
| Yucca Mountain   | Site 106              | HD-156-1 HOAc-L <sup>2</sup> | calcrete                              | 0.71257   | 4.7 +/-0.0  | 09/10/90 |
| Yucca Mountain   | Site 106              | HD-157-1 HCl-L <sup>2</sup>  | calcrete                              | 0.71248   | 4.6 +/-0.1  | 09/02/90 |
| Yucca Mountain   | Site 106              | HD-163 HCl-L <sup>2</sup>    | calcite-silica vein                   | 0.71271   | 4.9 +/-0.1  | 08/11/90 |
| Yucca Mountain   | Site 106              | HD-162 HCl-L <sup>2</sup>    | calcrete                              | 0.71269   | 4.9 +/-0.1  | 08/08/90 |
| Yucca Mountain   | Site 106              | HD-161 HCl-L <sup>2</sup>    | calcrete                              | 9.00000   | 4.8 +/-0.1  | 08/08/90 |
| Yucca Mountain   | Site 106              | HD-160 HCl-L <sup>2</sup>    | calcrete                              | 0.71273   | 5.0 +/-0.1  | 08/03/90 |
| Yucca Mountain   | Site 106              | HD-150-1 HCl-L <sup>2</sup>  | calcrete                              | 0.71265   | 4.9 +/-0.1  | 08/02/90 |
| Yucca Mountain   | Site 106              | HD-152-1 HCl-L <sup>2</sup>  | calcrete                              | 0.71221   | 4.2 +/-0.1  | 08/02/90 |
| Yucca Mountain   | Site 106              | HD-159 HCl-L <sup>2</sup>    | calcrete                              | 0.71277   | 5.0 +/-0.1  | 08/02/90 |
| Crater Flat      | Trench CF1            | HD-197-2 HCl-L <sup>1</sup>  | calcite-silica vein                   | 0.71271   | 4.9 +/-0.1  | 08/01/90 |
| Crater Flat      | Trench CF1            | HD-196-1 HCl-L <sup>2</sup>  | calcrete                              | 0.71266   | 4.9 +/-0.1  | 08/01/90 |
| Crater Flat      | Trench CF1            | HD-198-1 HCl-L <sup>1</sup>  | calcite-silica vein                   | 0.71233   | 4.4 +/-0.1  | 08/01/90 |
| Yucca Mountain   | Site 106              | HD-151-2 HCl-L <sup>2</sup>  | calcrete                              | 0.71258   | 4.8 +/-0.1  | 07/31/90 |
| Crater Flat      | Trench CF1            | HD-201-1 HCl-L <sup>2</sup>  | calcrete                              | 0.71233   | 4.4 +/-0.1  | 07/31/90 |
| Amargosa Desert  | White-bed Locality    | HD-172-1 HCl-L               | spring deposit                        | 0.71291   | 5.2 +/-0.1  | 07/30/90 |
| Yucca Mountain   | Site 106              | HD-155-1 HCl-L <sup>2</sup>  | calcrete                              | 0.71225   | 4.3 +/-0.1  | 07/27/90 |
| Crater Flat      | Trench 8              | HD-181-1A HCl-L <sup>1</sup> | calcite-silica vein                   | 0.71237   | 4.5 +/-0.2  | 07/26/90 |
| Yucca Mountain   | Site 106              | HD-156-1 HCl-L <sup>2</sup>  | calcrete                              | 0.71265   | 4.9 +/-0.1  | 07/26/90 |
| Bare Mountain    | Black Marble Hill     | HD-220 HCl-L <sup>3</sup>    | LS./ dolomite<br>(Paleozoic or older) | 0.71121   | 2.8 +/-0.0  | 07/25/90 |
| Crater Flat      | Site 199              | HD-168-1 HCl-L               | spring deposit                        | 0.71303   | 5.4 +/-0.1  | 07/25/90 |
| Crater Flat      | Trench 8              | HD-181-2A HCl-L <sup>1</sup> | calcite-silica vein                   | 0.71258   | 4.8 +/-0.1  | 07/25/90 |
| Crater Flat      | Site 199              | HD-169-1 HCl-L               | spring deposit                        | 0.71306   | 5.4 +/-0.1  | 07/24/90 |
| Spring Mountains | Hwy 156 loop          | HD-231 HCl-L                 | LS./ dolomite<br>(Paleozoic or older) | 0.70845   | -1.1 +/-0.1 | 07/24/90 |

1. Vein samples used in average (N=39) discussed in Sections 3.2.5 and 3.3.5
2. Pedogenic samples used in average (N=37) discussed in Sections 3.2.5 and 3.3.5
3. Bare Mountain samples

The strontium isotope ratios were determined on NIST 6-inch and VG Isomass 54E thermal ionization mass spectrometers. In order to eliminate differences between instruments, all data were normalized to an 87Sr/86Sr value of 0.70920 for EN-1, a standard used routinely on both instruments for calibration.

The Delta 87Sr notation is derived from the following transformation:  $\delta 87Sr = ((87Sr/86Sr/0.70920 - 1)) * 1000$  where the value of 0.70920 represents the 87Sr/86Sr ratio of modern seawater.

All data were collected under the same YMP-USGS QA Program that was approved 9/12/90.

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Table A-13. Strontium Isotope Ratios, Using Current USGS QA Program Prior to Approval  
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| Area             | Locality          | Sample ID                   | Type                                  | $^{87}\text{Sr}/^{86}\text{Sr}$ | $\delta^{87}$ | MS Date  |
|------------------|-------------------|-----------------------------|---------------------------------------|---------------------------------|---------------|----------|
| Spring Mountains | Hwy 156 loop      | HD-237 HCl-L                | Ls./ dolomite<br>(Paleozoic or older) | 0.70826                         | -1.3 +/-0.2   | 07/23/90 |
| Bare Mountain    | Black Marble Hill | HD-214 HCl-L <sup>3</sup>   | Ls./ dolomite<br>(Paleozoic or older) | 0.71280                         | 5.1 +/-0.1    | 07/23/90 |
| Spring Mountains | Hwy 156 loop      | HD-234 HCl-L                | Ls./ dolomite<br>(Paleozoic or older) | 0.70923                         | 0.0 +/-0.1    | 07/20/90 |
| Crater Flat      | Trench CF1        | HD-203-2 HCl-L <sup>1</sup> | calcite-silica vein                   | 0.71170                         | 3.5 +/-0.2    | 07/19/90 |
| Bare Mountain    | Black Marble Hill | HD-216 HCl-L <sup>3</sup>   | Ls./ dolomite<br>(Paleozoic or older) | 0.71126                         | 2.9 +/-0.0    | 07/19/90 |
| Crater Flat      | Site 199          | HD-166-1 HCl-L              | spring deposit                        | 0.71314                         | 5.5 .01       | 07/18/90 |
| Spring Mountains | Hwy 156 loop      | HD-236 HCl-L                | Ls./ dolomite<br>(Paleozoic or older) | 0.70860                         | -0.9 +/-0.1   | 07/18/90 |
| Spring Mountains | Hwy 156 loop      | HD-235 HCl-L                | Ls./ dolomite<br>(Paleozoic or older) | 0.70848                         | -1.0 +/-0.1   | 07/18/90 |
| Crater Flat      | Site 199          | HD-164-2 HCl-L              | spring deposit                        | 0.71331                         | 5.8 +/-0.1    | 07/16/90 |
| Bare Mountain    | Carrara           | HD-223 HCl-L                | soil, playa, eolian deposit           | 0.71168                         | 3.5 +/-0.1    | 07/13/90 |
| Bare Mountain    | Carrara           | HD-224-02 HCl-L             | soil, playa, eolian deposit           | 0.71168                         | 3.5 +/-0.1    | 07/13/90 |
| Crater Flat      | Trench CF2        | HD-209-1 HCl-L <sup>2</sup> | calcrete                              | 0.71203                         | 4.0 +/-0.1    | 07/12/90 |
| Crater Flat      | Trench CF1        | HD-202-1 HCl-L <sup>2</sup> | calcrete                              | 0.71236                         | 4.4 +/-0.1    | 07/12/90 |
| Crater Flat      |                   | HD-204-1 HCl-L              | soil, playa, eolian deposit           | 0.71177                         | 3.6 +/-0.1    | 07/12/90 |
| Crater Flat      | Trench CF2        | HD-206-2 HCl-L <sup>1</sup> | calcite-silica vein                   | 0.71256                         | 4.7 +/-0.0    | 07/11/90 |
| Spring Mountains | Hwy 156 loop      | HD-233 HCl-L                | Ls./ dolomite<br>(Paleozoic or older) | 0.70934                         | 0.2 +/-0.1    | 07/09/90 |
| Bare Mountain    | Black Marble Hill | HD-222 HCl-L <sup>3</sup>   | Ls./ dolomite<br>(Paleozoic or older) | 0.71191                         | 3.8 +/-0.0    | 07/09/90 |

1 . Vein samples used in average (N=39) discussed in Sections 3.2.5 and 3.3.5

2 Pedogenic samples used in average (N=37) discussed in Sections 3.2.5 and 3.3.5

3 Bare Mountain samples

The strontium isotope ratios were determined on NIST 6-inch and VG Isomass 54E thermal ionization mass spectrometers. In order to eliminate differences between instruments, all data were normalized to an  $^{87}\text{Sr}/^{86}\text{Sr}$  value of 0.70920 for EN-1, a standard used routinely on both instruments for calibration.

The Delta  $^{87}\text{Sr}$  notation is derived from the following transformation:  $\delta^{87}\text{Sr} = ((^{87}\text{Sr}/^{86}\text{Sr}/0.70920 - 1)) * 1000$  where the value of 0.70920 represents the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of modern seawater.

All data were collected under the same YMP-USGS QA Program that was approved 9/12/90.

Table A-13. Strontium Isotope Ratios, Using Current USGS QA Program Prior to Approval  
(Page 3 of 4)

| Area             | Locality          | Sample ID                    | Type                                  | $^{87}\text{Sr}/^{86}\text{Sr}$ | $\delta^{87}$ | MS Date  |
|------------------|-------------------|------------------------------|---------------------------------------|---------------------------------|---------------|----------|
| Crater Flat      | Trench CF2        | HD-208-1 HCl-L <sup>2</sup>  | calcrete                              | 0.71213                         | 4.1 +/-0.1    | 07/09/90 |
| Spring Mountains | Hwy 156 loop      | HD-232 HCl-L                 | Ls./ dolomite<br>(Paleozoic or older) | 0.70858                         | -0.9 +/-0.1   | 07/06/90 |
| Bare Mountain    | Black Marble Hill | HD-221 HCl-L <sup>3</sup>    | Ls./ dolomite<br>(Paleozoic or older) | 0.71071                         | 2.1 +/-0.1    | 07/06/90 |
| Spring Mountains | Hwy 156 loop      | HD-230 HCl-L                 | Ls./ dolomite<br>(Paleozoic or older) | 0.70828                         | -1.3 +/-0.1   | 07/06/90 |
| Spring Mountains | Hwy 156 loop      | HD-229 HCl-L                 | Ls./ dolomite<br>(Paleozoic or older) | 0.70832                         | -1.3 +/-0.1   | 07/05/90 |
| Bare Mountain    | Black Marble Hill | HD-219 HCl-L <sup>3</sup>    | Ls./ dolomite<br>(Paleozoic or older) | 0.71163                         | 3.4 +/-0.1    | 07/05/90 |
| Spring Mountains | Hwy 156 loop      | HD-238 HCl-L                 | Ls./ dolomite<br>(Paleozoic or older) | 0.70791                         | -1.8 +/-0.1   | 07/03/90 |
| Crater Flat      | Trench CF1        | HD-199-1 HCl-L <sup>2</sup>  | calcrete                              | 0.71248                         | 4.6 +/-0.1    | 07/03/90 |
| Bare Mountain    | Black Marble Hill | HD-212 HCl-L <sup>3</sup>    | Ls./ dolomite<br>(Paleozoic or older) | 0.71182                         | 3.7 +/-0.1    | 07/03/90 |
| Bare Mountain    | Black Marble Hill | HD-218 HCl-L <sup>3</sup>    | Ls./ dolomite<br>(Paleozoic or older) | 0.71202                         | 4.0 +/-0.1    | 07/03/90 |
| Yucca Mountain   | Site 106          | HD-153-1 HCl-L <sup>2</sup>  | calcrete                              | 0.71275                         | 5.0 +/-0.1    | 07/02/90 |
| Crater Flat      | Trench 8          | HD-181-6A HCl-L <sup>1</sup> | calcite-silica vein                   | 0.71199                         | 3.9 +/-0.1    | 06/29/90 |
| Crater Flat      | Trench 8          | HD-181-5A HCl-L <sup>1</sup> | calcite-silica vein                   | 0.71247                         | 4.6 +/-0.1    | 06/29/90 |
| Crater Flat      | Trench 8          | HD-181-3A HCl-L <sup>1</sup> | calcite-silica vein                   | 0.71255                         | 4.7 +/-0.1    | 06/28/90 |
| Crater Flat      | Trench 8          | HD-181-4A HCl-L <sup>1</sup> | calcite-silica vein                   | 0.71258                         | 4.8 +/-0.1    | 06/28/90 |
| Crater Flat      | Trench 8          | HD-185-1 HCl-L <sup>2</sup>  | calcrete                              | 0.71170                         | 3.5 +/-0.1    | 06/26/90 |
| Crater Flat      | Trench 8          | HD-184-1 HCl-L <sup>2</sup>  | calcrete                              | 0.71225                         | 4.3 +/-0.1    | 06/26/90 |

- 1 Vein samples used in average (N=39) discussed in Sections 3.2.5 and 3.3.5
- 2 Pedogenic samples used in average (N=37) discussed in Sections 3.2.5 and 3.3.5
- 3 Bare Mountain samples

The strontium isotope ratios were determined on NIST 6-inch and VG Isomass 54E thermal ionization mass spectrometers. In order to eliminate differences between instruments, all data were normalized to an  $^{87}\text{Sr}/^{86}\text{Sr}$  value of 0.70920 for EN-1, a standard used routinely on both instruments for calibration.

The Delta  $^{87}\text{Sr}$  notation is derived from the following transformation:  $\delta^{87}\text{Sr} = ((^{87}\text{Sr}/^{86}\text{Sr}/0.70920 - 1)) * 1000$  where the value of 0.70920 represents the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of modern seawater.

All data were collected under the same YMP-USGS QA Program that was approved 9/12/90.

Table A-13. Strontium Isotope Ratios, Using Current USGS QA Program Prior to Approval  
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| Area              | Locality              | Sample ID                   | Type                                  | $^{87}\text{Sr}/^{86}\text{Sr}$ | $\delta 87$    | MS Date  |
|-------------------|-----------------------|-----------------------------|---------------------------------------|---------------------------------|----------------|----------|
| Crater Flat       | Trench 8              | HD-186-1 HCl-L <sup>2</sup> | rhizolith                             | 0.71193                         | 3.8 $\pm$ 0.1  | 06/24/90 |
| Spring Mountains  | Point of Rocks        | HD-228 HCl-L                | ls./ dolomite<br>(Paleozoic or older) | 0.70843                         | -1.1 $\pm$ 0.1 | 06/19/90 |
| Yucca Mountain    | WT-7                  | USW WT-7                    | water (well)                          | 0.71027                         | 1.5 $\pm$ 0.1  | 06/19/90 |
| Amargosa Desert   | S. of White-bed Local | HD-173-1 HOAc-L (2)         | soil, playa, eolian deposit           | 0.71257                         | 4.8 $\pm$ 0.1  | 05/20/90 |
| Yucca Mountain    | Trench 14             | HD-226 HCl-L <sup>1</sup>   | calcite-silica vein                   | 0.71178                         | 3.6 $\pm$ 0.1  | 04/06/90 |
| Yucca Mountain    | Trench 14             | HD-226 HCl-R (2)            | calcite-silica vein                   | 0.70892                         | -0.4 $\pm$ 0.1 | 04/05/90 |
| Yucca Mountain    | Yucca Crest           | 5-4-89C                     | surface coating                       | 0.71220                         | 4.2 $\pm$ 0.1  | 03/23/90 |
| Yucca Mountain    | UE-25 UZN #2          | UE-25 UZN #2 (2)            | water (well)                          | 0.71150                         | 3.2 $\pm$ 0.1  | 01/24/90 |
| Yucca Mountain    | UE-25 UZN #2          | UE-25 UZN #2 (1)            | water (well)                          | 0.71144                         | 3.2 $\pm$ 0.1  | 01/23/90 |
| Amargosa Desert   | White-bed Locality    | 3B-1e HCl-L                 | spring deposit                        | 0.71285                         | 5.1 $\pm$ 0.1  | 11/20/89 |
| Spring Mountains  |                       | JD-13                       | ls./ dolomite<br>(Paleozoic or older) | 0.70837                         | -1.2 $\pm$ 0.1 | 10/11/89 |
| Yucca Mountain    | Yucca Crest           | 5-4-89E                     | surface coating                       | 0.71184                         | 3.7 $\pm$ 0.1  | 08/08/89 |
| Spring Mountains  |                       | JD-11                       | ls./ dolomite<br>(Paleozoic or older) | 0.70823                         | -1.4 $\pm$ 0.2 | 07/26/89 |
| Devils Hole Hills | Devils Hole           | 650 ka HCl-L                | spring deposit                        | 0.71255                         | 4.7 $\pm$ 0.1  | 07/13/89 |
| Devils Hole Hills | Devils Hole           | 400 ka HCl-L                | spring deposit                        | 0.71233                         | 4.4 $\pm$ 0.1  | 07/12/89 |
| Devils Hole Hills | Devils Hole           | 500 ka HCl-L                | spring deposit                        | 0.71274                         | 5.0 $\pm$ 0.1  | 07/11/89 |
| Bare Mountain     | Black Marble Hill     | 3C-1 HCl-L <sup>3</sup>     | ls./ dolomite<br>(Paleozoic or older) | 0.71105                         | 2.6 $\pm$ 0.1  | 07/05/89 |
| Yucca Mountain    | Castle Point          | 2AA-7 HCl-L                 | calcrete                              | 0.71166                         | 3.5 $\pm$ 0.1  | 06/28/89 |
| Fortymile Wash    | J-13                  | J-13 (2)                    | water (well)                          | 0.71128                         | 2.9 $\pm$ 0.1  | 06/22/89 |
| Amargosa Desert   | White-bed Locality    | 3B-1d HCl-L                 | spring deposit                        | 0.71278                         | 5.0 $\pm$ 0.1  | 05/03/89 |

- 1 Vein samples used in average (N=39) discussed in Sections 3.2.5 and 3.3.5
- 2 Pedogenic samples used in average (N=37) discussed in Sections 3.2.5 and 3.3.5
- 3 Bare Mountain samples

The strontium isotope ratios were determined on NIST 6-inch and VG Isomass 54E thermal ionization mass spectrometers. In order to eliminate differences between instruments, all data were normalized to an  $^{87}\text{Sr}/^{86}\text{Sr}$  value of 0.70920 for EN-1, a standard used routinely on both instruments for calibration.

The Delta  $^{87}\text{Sr}$  notation is derived from the following transformation:  $\delta 87\text{Sr} = ((^{87}\text{Sr}/^{86}\text{Sr}/0.70920 - 1)) * 1000$  where the value of 0.70920 represents the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of modern seawater.

All data were collected under the same YMP-USGS QA Program that was approved 9/12/90.

Table A-14. Strontium Isotope Ratios, Prior to USGS QA Program Implemented on May 3, 1990  
(Page 1 of 2)

| Area              | Locality       | Sample ID                   | Type                                  | 87Sr/86Sr | δ87        | MS Date  |
|-------------------|----------------|-----------------------------|---------------------------------------|-----------|------------|----------|
| Yucca Mountain    | Prow Pass      | 2A-2 HCl-L                  | surface coating                       | 0.71158   | 3.4 +/-0.1 | 04/26/89 |
| Fortymile Wash    | J-13           | J-13                        | water (well)                          | 0.71138   | 3.1 +/-0.0 | 12/17/88 |
| Yucca Mountain    | UE-25p #1      | UE-25p #1 (1983)            | water (well)                          | 0.71174   | 3.6 +/-0.1 | 08/22/88 |
| Yucca Mountain    | UE-25 WT #4    | UE-25 WT #4                 | water (well)                          | 0.71002   | 1.2 +/-0.1 | 08/17/88 |
| Yucca Mountain    | Busted Butte   | HD-56-9 HCl-L <sup>1</sup>  | calcite-silica vein                   | 0.71260   | 4.8 +/-0.1 | 08/16/88 |
| Yucca Mountain    | Busted Butte   | HD-56-7 HCl-L <sup>1</sup>  | calcite-silica vein                   | 0.71234   | 4.4 +/-0.0 | 08/11/88 |
| Yucca Mountain    | Trench 14a     | HD-28-1 HCl-L <sup>1</sup>  | calcite-silica vein                   | 0.71226   | 4.3 +/-0.0 | 08/11/88 |
| Yucca Mountain    | Trench 14      | HD-54-4 HCl-L <sup>1</sup>  | calcite-silica vein                   | 0.71251   | 4.7 +/-0.1 | 08/11/88 |
| Yucca Mountain    | Trench 14      | HD-54-2 HCl-L <sup>1</sup>  | calcite-silica vein                   | 0.71272   | 5.0 +/-0.0 | 08/10/88 |
| Yucca Mountain    | Busted Butte   | HD-56-5 HCl-L <sup>1</sup>  | calcite-silica vein                   | 0.71234   | 4.4 +/-0.0 | 08/09/88 |
| Devils Hole Hills | Devils Hole    | 240 ka HCl-L                | spring deposit                        | 0.71231   | 4.4 +/-0.0 | 07/15/88 |
| Devils Hole Hills | Devils Hole    | 300 ka HCl-L                | spring deposit                        | 0.71252   | 4.7 +/-0.1 | 07/14/88 |
| Devils Hole Hills | Devils Hole    | 180 ka HCl-L                | spring deposit                        | 0.71281   | 5.1 +/-0.0 | 07/14/88 |
| Devils Hole Hills | Devils Hole    | HD-112-1 HCl-L              | spring deposit (marsh)                | 0.71250   | 4.7 +/-0.0 | 07/07/88 |
| Devils Hole Hills | Devils Hole    | HD-110-1 HCl-L              | Ls./ dolomite<br>(Paleozoic or older) | 0.70990   | 1.0 +/-0.0 | 07/06/88 |
| Fortymile Wash    | Fortymile Wash | HD-78-1 (Q2B) HCl-L         | surface coating                       | 0.71133   | 3.0 +/-0.1 | 07/01/88 |
| Fortymile Wash    | Fortymile Wash | HD-79-1 (Q1C) HCl-L         | surface coating                       | 0.71133   | 3.0 +/-0.0 | 06/28/88 |
| Yucca Mountain    | Trench 14      | HD-8 HCl-L <sup>2</sup>     | calcrete                              | 0.71217   | 4.2 +/-0.1 | 06/27/88 |
| Yucca Mountain    | Trench 14      | HD-11 HCl-L <sup>2</sup>    | calcrete                              | 0.71211   | 4.1 +/-0.1 | 06/27/88 |
| Yucca Mountain    | Trench 14      | HD-3 HCl-L <sup>2</sup>     | calcrete                              | 0.71214   | 4.1 +/-0.0 | 06/24/88 |
| Yucca Mountain    | Trench 14      | HD-7 HCl-L <sup>2</sup>     | calcrete                              | 0.71179   | 3.6 +/-0.0 | 06/24/88 |
| Yucca Mountain    | Trench 14      | HD-12 HCl-L <sup>2</sup>    | calcrete                              | 0.71236   | 4.5 +/-0.0 | 06/23/88 |
| Yucca Mountain    | Trench 14      | HD-54-6 HCl-L <sup>1</sup>  | calcite-silica vein                   | 0.71258   | 4.8 +/-0.0 | 06/10/88 |
| Yucca Mountain    | Trench 14      | HD-54-1 HCl-L <sup>1</sup>  | calcite-silica vein                   | 0.71264   | 4.9 +/-0.1 | 06/06/88 |
| Yucca Mountain    | Trench 14      | HD-54-3 HCl-L <sup>1</sup>  | calcite-silica vein                   | 0.71233   | 4.4 +/-0.1 | 06/06/88 |
| Yucca Mountain    | Trench 14      | HD-42-16 HCl-L <sup>1</sup> | calcite-silica vein                   | 0.71261   | 4.8 +/-0.1 | 06/03/88 |

<sup>1</sup> Vein samples used in average (N=39) discussed in Sections 3.2.5 and 3.3.5

<sup>2</sup> Pedogenic samples used in average (N=37) discussed in Sections 3.2.5 and 3.3.5

The strontium isotope ratios were determined on NIST 6-inch and VG Isomass 54E thermal ionization mass spectrometers. In order to eliminate differences between instruments, all data were normalized to an 87Sr/86Sr value of 0.70920 for EN-1, a standard used routinely on both instruments for calibration.

The Delta 87Sr notation is derived from the following transformation:  $\delta 87Sr = ((87Sr/86Sr/0.70920 - 1)) * 1000$  where the value of 0.70920 represents the 87Sr/86Sr ratio of modern seawater.

All data were collected prior to the approval of the YMP-USGS QA Program.

Table A-14. Strontium Isotope Ratios, Prior to USGS QA Program Implemented on May 3, 1990  
(Page 2 of 2)

| Area              | Locality     | Sample ID                   | Type                | $^{87}\text{Sr}/^{86}\text{Sr}$ | $\delta 87$ | MS Date  |
|-------------------|--------------|-----------------------------|---------------------|---------------------------------|-------------|----------|
| Yucca Mountain    | Trench 14    | HD-42-15 HCl-L <sup>1</sup> | calcite-silica vein | 0.71260                         | 4.8 +/-0.0  | 06/02/88 |
| Yucca Mountain    | Trench 14    | HD-42-14 HCl-L <sup>1</sup> | calcite-silica vein | 0.71246                         | 4.6 +/-0.0  | 06/01/88 |
| Yucca Mountain    | Trench 14    | HD-42-13 HCl-L <sup>1</sup> | calcite-silica vein | 0.71187                         | 3.8 +/-0.1  | 05/27/88 |
| Yucca Mountain    | Trench 14    | HD-42-12 HCl-L <sup>1</sup> | calcite-silica vein | 0.71190                         | 3.8 +/-0.1  | 05/26/88 |
| Yucca Mountain    | Trench 14    | HD-42-11 HCl-L <sup>1</sup> | calcite-silica vein | 0.71263                         | 4.8 +/-0.1  | 05/26/88 |
| Yucca Mountain    | Trench 14    | HD-42-10 HCl-L <sup>1</sup> | calcite-silica vein | 0.71255                         | 4.7 +/-0.1  | 05/25/88 |
| Yucca Mountain    | Trench 14    | HD-22-4 HCl-L <sup>1</sup>  | calcite-silica vein | 0.71207                         | 4.0 +/-0.1  | 05/24/88 |
| Yucca Mountain    | Trench 14    | HD-22-3 HCl-L <sup>1</sup>  | calcite-silica vein | 0.71257                         | 4.8 +/-0.1  | 05/24/88 |
| Yucca Mountain    | Trench 14    | HD-1 HCl-L <sup>2</sup>     | calcrete            | 0.71208                         | 4.1 +/-0.0  | 05/23/88 |
| Yucca Mountain    | Trench 14    | HD-20-1 HCl-L <sup>1</sup>  | calcite-silica vein | 0.71252                         | 4.7 +/-0.0  | 05/23/88 |
| Yucca Mountain    | Trench 14    | HD-2 HCl-L <sup>2</sup>     | calcrete            | 0.71191                         | 3.8 +/-0.0  | 05/20/88 |
| Yucca Mountain    | Trench 14    | HD-5 HCl-L <sup>2</sup>     | calcrete            | 0.71229                         | 4.4 +/-0.1  | 05/19/88 |
| Yucca Mountain    | Busted Butte | HD-56-8 HCl-L <sup>1</sup>  | calcite-silica vein | 0.71235                         | 4.4 +/-0.1  | 05/18/88 |
| Yucca Mountain    | Trench 14    | HD-6 HCl-L <sup>2</sup>     | calcrete            | 0.71204                         | 4.0 +/-0.0  | 05/18/88 |
| Yucca Mountain    | Busted Butte | HD-56-6 HCl-L <sup>1</sup>  | calcite-silica vein | 0.71238                         | 4.5 +/-0.1  | 05/17/88 |
| Yucca Mountain    | Trench 14    | HD-54-5 HCl-L <sup>1</sup>  | calcite-silica vein | 0.71270                         | 4.9 +/-0.0  | 05/16/88 |
| Yucca Mountain    | Busted Butte | HD-63-4 HCl-L <sup>2</sup>  | rhizolith           | 0.71246                         | 4.6 +/-0.1  | 05/12/88 |
| Yucca Mountain    | Busted Butte | HD-63-3 HCl-L <sup>2</sup>  | rhizolith           | 0.71251                         | 4.7 +/-0.0  | 05/11/88 |
| Yucca Mountain    | Trench 14    | HD-28-2 HCl-L <sup>1</sup>  | calcite-silica vein | 0.71237                         | 4.5 +/-0.1  | 05/11/88 |
| Yucca Mountain    | Trench 14    | HD-9 HCl-L <sup>2</sup>     | calcrete            | 0.71233                         | 4.4 +/-0.1  | 05/10/88 |
| Yucca Mountain    | Trench 14    | HD-10 HCl-L <sup>2</sup>    | calcrete            | 0.71214                         | 4.1 +/-0.0  | 05/06/88 |
| Yucca Mountain    | Trench 14    | HD-20-2 HCl-L <sup>1</sup>  | calcite-silica vein | 0.71253                         | 4.7 +/-0.0  | 05/05/88 |
| Yucca Mountain    | Trench 14    | HD-22-2 HCl-L <sup>1</sup>  | calcite-silica vein | 0.71241                         | 4.5 +/-0.1  | 05/02/88 |
| Yucca Mountain    | Trench 14a   | HD-39-2 HCl-L <sup>1</sup>  | calcite-silica vein | 0.71206                         | 4.0 +/-0.1  | 04/26/88 |
| Yucca Mountain    | Trench 14a   | HD-31-2 HCl-L <sup>1</sup>  | calcite-silica vein | 0.71231                         | 4.4 +/-0.1  | 04/25/88 |
| Yucca Mountain    | Trench 14    | HD-22-1 HCl-L <sup>1</sup>  | calcite-silica vein | 0.71239                         | 4.5 +/-0.0  | 04/22/88 |
| Devils Hole Hills | Devils Hole  | Devil's Hole water          | water (spring)      | 0.71236                         | 4.5 +/-0.1  | 04/21/88 |

<sup>1</sup> Vein samples used in average (N=39) discussed in Sections 3.2.5 and 3.3.5

<sup>2</sup> Pedogenic samples used in average (N=37) discussed in Sections 3.2.5 and 3.3.5

The strontium isotope ratios were determined on NIST 6-inch and VG Isomass 54E thermal ionization mass spectrometers. In order to eliminate differences between instruments, all data were normalized to an  $^{87}\text{Sr}/^{86}\text{Sr}$  value of 0.70920 for EN-1, a standard used routinely on both instruments for calibration.

The Delta  $^{87}\text{Sr}$  notation is derived from the following transformation:  $\delta 87\text{Sr} = ((^{87}\text{Sr}/^{86}\text{Sr}/0.70920 - 1)) * 1000$  where the value of 0.70920 represents the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of modern seawater.

All data were collected prior to the approval of the YMP-USGS QA Program.

Table A-15. Hydrogenic Deposits Descriptions  
(Page 1 of 2)

- HD-1-A: Trench 14, south wall, main section, C18S, carbonate from top of platy K horizon
- HD-2: Trench 14, south wall, main section, C18S, carbonate from bottom of platy K horizon
- HD-3: Trench 14, south wall, C23S, block of carbonate from top of platy K horizon
- HD-5: Trench 14, south wall, D28S, block of carbonate from top of platy K horizon
- HD-6: Trench 14, south wall, E28S, block of carbonate from bottom of platy K horizon
- HD-7: Trench 14, south wall, E33S, block of carbonate from top of platy K horizon
- HD-8: Trench 14, south wall, E33S, block of carbonate from top of platy K horizon
- HD-9: Trench 14, south wall, E37S, block of carbonate from top of platy K horizon
- HD-10: Trench 14, south wall, E37S, block of carbonate from bottom of platy K horizon
- HD-11: Trench 14, south wall, main section, F43S, carbonate from top of platy K horizon
- HD-12: Trench 14, south wall, main section, F43S, carbonate from bottom of platy K horizon
- HD-15-3-4: Trench 14, south wall, E16S, vein, stratigraphically younger than HD-15-3-3
- HD-15-3-3: Trench 14, south wall, E16S, vein, stratigraphically younger than HD-15-3-2
- HD-15-3-2: Trench 14, south wall, E16S, vein, stratigraphically oldest sample taken from this block
- HD-20: Trench 14, south wall, B4S, carbonate vein filling
- HD-22-1: Trench 14, north wall, D13N, Calcite-silica vein
- HD-22-2: Trench 14, north wall, D14N, Calcite-silica vein
- HD-22-3: Trench 14, north wall, D14N, Calcite-silica vein
- HD-22-4: Trench 14, north wall, D16N, Calcite-silica vein
- HD-42-5B-A: Trench 14, south wall, D14S, vertical vein, south slab, farthest from wall rock
- HD-42-50-A: Trench 14, south wall, D14S, vertical vein, south slab, about 2 cm from wall rock
- HD-42-5G-A: Trench 14, south wall, D14S, vertical vein, south slab, closest to wall rock
- HD-54: Trench 14, south wall, C14S, vein filling
- HD-57: Busted Butte, central ridge, uppermost part of laminar K horizon of uppermost (youngest) soil and sand ramp deposit
- HD-58: Busted Butte, central ridge, lowermost part of laminar K horizon of uppermost (youngest) soil and sand ramp deposit

Table A-15. Hydrogenic Deposits Descriptions  
(Page 2 of 2)

HD-59-1-A: Busted Butte, central ridge, rhizoliths below HD-58, in uppermost (youngest) sand ramp deposit

HD-59-1-B: Busted Butte, central ridge, rhizoliths below HD-58, in uppermost (youngest) sand ramp deposit, but different rhizoliths than HD-50-1-A.

HD-75: Busted Butte, central ridge, uppermost part of laminar K horizon of second-from-youngest soil and sand ramp deposit (i.e., stratigraphically, immediately below sand ramp deposit that HD-57 and HD-58R formed in)

HD-76: Busted Butte, central ridge, lowermost part of laminar K horizon of second-from-youngest soil and sand ramp deposit (i.e., stratigraphically, immediately below sand ramp deposit that HD-57 and HD-58R formed in)

HD-77-1-A: Busted Butte, central ridge, rhizoliths below HD-76

HD-77-1-B: Busted Butte, central ridge, rhizoliths below HD-76, but different from HD-77-1-A

HD-151-03: Stagecoach Road (near Lat. 36, 44, 01 - Long. 116, 27, 44), calcrete sample taken 0.70 m from top of calcrete

HD-166-03: Near Lat. 36, 43, 27 - Long. 116, 33, 12, vuggy carbonate that resembles tufa

HD-167-01: Approximately 10 m west of HD-166, carbonate deposit that looks spring-derived

HD-170-01-A: also near HD-166, carbonate root cast

HD-226: Trench 14, south wall, C14S, middle vein, black ash lens

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**APPENDIX B**

**LOS ALAMOS NATIONAL LABORATORY  
DATA TABLES**

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**ABBREVIATIONS AND GLOSSARY**

|      |  |
|------|--|
| s.d. | Standard deviation   |
| ppm  | parts per million  |
| op   | opal   |
| det  | detritus   |
| sep  | sepiolite  |
| cc   | calcite  |
| alt  | altered  |
| vit  | vitric   |
| v.p. | vapor phase  |
| ped  | A naturally formed unit of soil structure, e.g., granule, block, crumb, aggregate. |

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Table B-1. Bedrock Breccias: Sample Collection Summary

| Sample                             | Location  | Description <sup>3</sup>  |
|------------------------------------|---|---|
| BB-6-SSL <sup>1</sup><br>(HD-70-1) | west side of Busted Butte, above middle sand ramp.  | altered bedrock breccia in uppermost Tpt moderately welded tuff.  |
| BB-7-SSL <sup>1</sup><br>(HD-70-2) | west side of Busted Butte, above middle sand ramp.  | altered bedrock breccia in uppermost Tpt moderately welded tuff.  |
| BB-8-SSL <sup>1</sup><br>(HD-70-3) | west side of Busted Butte, above middle sand ramp.  | altered bedrock breccia in uppermost Tpt moderately welded tuff.  |
| DTV 2.1 <sup>1</sup><br>(HD-67)    | west side of Busted Butte, gully north of middle sand ramp.   | bedrock breccia in densely welded, devitrified Tpt tuff.  |
| HD-41-4 <sup>2</sup>               | Trench 14 (second stage of excavation), south wall.   | calcite- and silica-cemented breccia with Tpc fragments, from fault zone.   |
| HD-74-2 <sup>2</sup>               | west side of Busted Butte, gully north of middle sand ramp.   | silica- and calcite-cemented breccia exposed along fault scarp at base of densely welded, devitrified Tpt bedrock exposure.       |
| TR14-3A-SSL <sup>1</sup>           | Trench 14 (original excavation), ledge adjacent to south wall, east end, from ledge that projected north from C13S. | calcite- and silica-cemented bedrock breccia with fragments of drusy quartz, east of main fault zone.                             |
| TR14-3B-SSL <sup>1</sup>           | Trench 14 (original excavation), ledge adjacent to south wall, east end, from ledge that projected north from C13S. | calcite- and silica-cemented bedrock breccia, with fragments of Tpc densely welded, devitrified tuff, east of main fault zone.    |
| TR14-3C-SSL <sup>1</sup>           | Trench 14 (original excavation), ledge adjacent to south wall, east end, from ledge that projected north from C13S. | calcite- and silica-cemented brecciated bedrock in fracture within Tpc densely welded, devitrified tuff, east of main fault zone. |
| TR14-7-SSL <sup>1</sup>            | Trench 14 (second stage of excavation), north wall near east end, E12N to E13N.                                     | drusy quartz from lithophysal cavities and fractures in Tpc densely welded, devitrified tuff.                                     |

<sup>1</sup> Sample collected by Los Alamos National Laboratory before January 22, 1991.

<sup>2</sup> Sample collected by USGS before September 12, 1990.

<sup>3</sup> Tpt= Topopah Spring Member of the Paintbrush Tuff, Tpc = Tiva Canyon Member of the Paintbrush Tuff.

Table B-2. Microprobe Analysis of Sepiolite and Mg-Rich Authigenic Materials in Bedrock Breccias\*

| Weight<br>Percent              | DTV2.1 |       | TR14-3B-SSL |       | TR14-3A-SSL |      |
|--------------------------------|--------|-------|-------------|-------|-------------|------|
|                                | B1E-4  | B1F-2 | J-1         | K-1   | A-3         | X-2  |
| SiO <sub>2</sub>               | 49.5   | 49.7  | 75.6        | 68.4  | 62.4        | 63.9 |
| TiO <sub>2</sub>               | 0.00   | 0.00  | 0.03        | 0.06  | 0.00        | 0.00 |
| Al <sub>2</sub> O <sub>3</sub> | 0.61   | 2.44  | 0.13        | 0.23  | 0.26        | 0.54 |
| Fe <sub>2</sub> O <sub>3</sub> | 0.08   | <0.05 | <0.04       | <0.03 | 0.00        | 0.00 |
| MnO                            | 0.00   | 0.00  | 0.00        | <0.03 | 0.00        | 0.00 |
| MgO                            | 19.8   | 19.5  | 10.07       | 13.1  | 16.8        | 17.0 |
| CaO                            | 0.04   | 0.06  | 0.05        | 0.09  | 0.08        | 0.11 |
| Na <sub>2</sub> O              | <0.05  | 0.00  | 0.00        | 0.00  | <0.03       | 0.04 |
| K <sub>2</sub> O               | 0.05   | 0.08  | 0.00        | <0.03 | <0.02       | 0.04 |
| Total                          | 70.1   | 71.8  | 85.9        | 81.9  | 79.5        | 81.6 |
| Si/Mg<br>(molec.)              | 1.68   | 1.71  | 5.03        | 3.49  | 2.50        | 2.53 |

\*All data in this table collected by Los Alamos National Laboratory before January 22, 1991.

Table B-3. Fission Track Data for Samples from Trench 14 and Busted Butte\*  
(Page 1 of 2)

| Sample  | DF   | Mineral | Number Grains | $\rho_0$ ,<br>$\times 10^6$<br>t/cm <sup>2</sup> | Fossil Tracks Counted | $\rho_1$ ,<br>$\times 10^6$<br>t/cm <sup>2</sup> | Induced Tracks Counted | Dosimeter Density<br>$\times 10^5$<br>t/cm <sup>2</sup> | Tracks Counted | Ma    | $\pm 2\sigma$ |
|---------|------|---------|---------------|--|-----------------------|--|------------------------|---|----------------|-------|---------------|
| HD-41-4 | 6048 | Zircon  | 12            | 2.03   | 470                   | 10.1   | 1164                   | 2.20  | 3093           | 14.17 | 1.6           |
| 1       |      |         |               | .70  | 13                    | 5.94   | 55                     | do  | do.            | 8.3   | 5.1           |
| 2       |      |         |               | .65  | 3                     | 4.90   | 34                     | do.   | do.            | 9.3   | 7.0           |
| 3       |      |         |               | 1.15   | 16                    | 10.8   | 75                     | do.   | do.            | 7.5   | 4.1           |
| 4       |      |         |               | 2.13   | 79                    | 8.37   | 155                    | do.   | do.            | 17.9  | 4.9           |
| 5       |      |         |               | 3.89   | 36                    | 17.7   | 82                     | do.   | do.            | 15.4  | 6.2           |
| 6       |      |         |               | 1.30   | 24                    | 7.99   | 74                     | do.   | do.            | 11.4  | 5.3           |
| 7       |      |         |               | 1.24   | 23                    | 5.18   | 48                     | do.   | do.            | 16.8  | 8.5           |
| 8       |      |         |               | 1.51   | 21                    | 7.02   | 65                     | do.   | do.            | 11.3  | 5.7           |
| 9       |      |         |               | 5.45   | 101                   | 15.6   | 144                    | do.   | do.            | 24.6  | 6.4           |
| 10      |      |         |               | .76  | 6                     | 5.47   | 76                     | do.   | do.            | 9.7   | 4.8           |
| 11      |      |         |               | 2.95   | 41                    | 24.2   | 168                    | do.   | do.            | 8.6   | 3.0           |
| 12      |      |         |               | 3.72   | 86                    | 16.2   | 188                    | do.   | do.            | 16.1  | 4.2           |

\* Analyzed by C.W. Naeser, USGS, before September 12, 1990.  
ZETA (SRM 962)=319.3; DF=Laboratory Number.

Table B-3. Fission Track Data for Samples from Trench 14 and Busted Butte\*  
(Page 2 of 2)

| Sample  | DF   | Mineral | Number Grains | $\rho_a \times 10^6$<br>t/cm <sup>2</sup> | Fossil Tracks Counted | $\rho_i \times 10^6$<br>t/cm <sup>2</sup> | Induced Tracks Counted | Dosimeter Density<br>$\times 10^5$<br>t/cm <sup>2</sup> | Tracks Counted | Ma   | $\pm 2\sigma$ |
|---------|------|---------|---------------|---|-----------------------|---|------------------------|---|----------------|------|---------------|
| HD-74-2 | 6050 | Zircon  | 12            | 2.71                                      | 828                   | 11.8                                      | 1799                   | do.   | do.            | 16.2 | 1.5           |
| 1       |      |         |               | 1.47                                      | 34                    | 9.68                                      | 112                    | do.   | do.            | 10.7 | 4.2           |
| 2       |      |         |               | .32                                       | 9                     | 4.41                                      | 51                     | do.   | do.            | 6.2  | 4.5           |
| 3       |      |         |               | .35                                       | 13                    | 3.02                                      | 56                     | do.   | do.            | 8.2  | 5.0           |
| 4       |      |         |               | .89                                       | 37                    | 4.70                                      | 98                     | do.   | do.            | 13.3 | 5.1           |
| 5       |      |         |               | 14.5                                      | 268                   | 17.0                                      | 157                    | do.   | do.            | 59.7 | 12            |
| 6       |      |         |               | 9.07                                      | 168                   | 41.1                                      | 381                    | do.   | do.            | 15.5 | 2.9           |
| 7       |      |         |               | 4.17                                      | 116                   | 21.7                                      | 302                    | do.   | do.            | 13.5 | 2.9           |
| 8       |      |         |               | .82                                       | 19                    | 7.52                                      | 87                     | do.   | do.            | 7.7  | 3.9           |
| 9       |      |         |               | 1.86                                      | 43                    | 15.0                                      | 174                    | do.   | do.            | 8.7  | 3.0           |
| 10      |      |         |               | 2.16                                      | 40                    | 12.1                                      | 112                    | do.   | do.            | 12.5 | 4.6           |
| 11      |      |         |               | 2.76                                      | 64                    | 12.4                                      | 144                    | do.   | do.            | 15.6 | 4.7           |
| 12      |      |         |               | .73                                       | 17                    | 10.8                                      | 125                    | do.   | do.            | 4.8  | 2.5           |

\* Analyzed by C.W. Naeser, USGS, before September 12, 1990.

ZETA (SRM 962)=319.3; DF=Laboratory Number.

Table B-4. Bedrock Breccias: Sample Petrology\*

| Sample       | Location<br>(1) | Bedrock<br>(2) | Plant<br>Remains | Authigenic<br>Cement   | Exotic<br>Clasts | Breccia<br>Type<br>(3) |
|--------------|-----------------|----------------|------------------|--|------------------|------------------------|
| BB-6,7,8-SSL | BB              | Tpt            | no               | major<br>syngenetic;<br>feldspar,<br>cristobalite,<br>tridymite. | no               | CTM                    |
| DTV 2.1      | BB              | Tpt            | no               | minor<br>authigenic;<br>silica,<br>calcite,<br>sepiolite.        | no               | CTM                    |
| HD-41-4      | Trench 14       | Tpc            | yes              | major<br>authigenic.   | ---              | AMC                    |
| HD-74-2      | BB              | Tpt            | yes              | major<br>authigenic;<br>silica,<br>calcite.                      | yes              | AMC                    |
| TR14-3A-SSL  | Trench 14       | Tpc            | yes              | major<br>authigenic;<br>silica,<br>calcite,<br>sepiolite.        | no               | AMC                    |
| TR14-3B-SSL  | Trench 14       | Tpc            | yes              | major<br>authigenic;<br>silica,<br>sepiolite,<br>calcite.        | no               | AMC                    |
| TR14-3C-SSL  | Trench 14       | Tpc            | yes              | major<br>authigenic;<br>calcite,<br>silica,<br>sepiolite.        | yes              | AMC                    |

\* All data collected by Los Alamos National Laboratory before January 22, 1991.

(1) BB = Busted Butte.

(2) Tpt = Topopah Spring Member of the Paintbrush Tuff; Tpc = Tiva Canyon Member of the Paintbrush Tuff.

(3) CTM = crushed-tuff-matrix breccia; AMC = authigenic-mineral-cemented breccia.

Table B-5. Bedrock Breccias: Scanning-Electron Microscopy Data Summary

| Sample      | Secondary-electron images | Back-scattered electron images | Energy-dispersive x-ray analyses |
|-------------|---------------------------|--------------------------------|----------------------------------|
| BB-8 SSL.1  | yes*                      | no                             | yes*                             |
| DTV 2.1     | yes*                      | yes*                           | yes*                             |
| HD-74-2     | no                        | yes*                           | yes*                             |
| TR14-3A-SSL | yes*                      | yes*                           | yes*                             |
| TR14-3B-SSL | yes*                      | yes*                           | yes*                             |
| TR14-3C-SSL | yes*                      | yes*                           | yes*                             |

\* Data collected by Los Alamos National Laboratory before January 22, 1991.

Table B-6. Bedrock Breccias: Qualitative X-ray Diffraction Results

| Sample    | Smectite | Mica  | Tridymite | Cristobalite       | Quartz | Feldspar | Hematite |
|-----------|----------|-------|-----------|--------------------|--------|----------|----------|
| BB-8-SSL* | Trace    | Trace | Major     | Major <sup>1</sup> | Trace  | Major    | Minor    |

\* Data collected by Los Alamos National Laboratory before January 22, 1991.

<sup>1</sup> Opal-CT-like material is also present.

Table B-7. Electron-Spin Resonance Dating Results

| Sample      | Material     | Paramagnetic Defect | Age           |
|-------------|--------------|---------------------|---------------|
| TR14-7-SSL* | drusy quartz | superoxide radical  | 8.7 ± 2.6 Myr |

- \* Data collected by independent researcher Professor David Cowan (University of Missouri), not under LANL-YMP QA program.

Table B-8. Oxygen Isotopic Data for Silica Deposits\*

| Sample      | Description              | $\delta^{18}\text{O}$<br>(per mil) | Temperature       |
|-------------|--------------------------|------------------------------------|-------------------|
| TR14-3A-SSL | drusy quartz<br>separate | 22.1 ± 0.1                         | 50°C <sup>1</sup> |

- \* Data collected by J.R. O'Neil, USGS, Menlo Park, before September 12, 1990.

- <sup>1</sup> Based on quartz-water fractionation curve of Bottinga and Javoy (1973) and assumed equilibrium with meteoric water having  $\delta^{18}\text{O}$  of -13 per mil.

Table B-9. Correlation of USGS and Los Alamos National Laboratory Sample Numbers

| LANL# | USGS#      |   |
|-------|------------|---|
| 1     | HD-15-3:   | Trench 14, south wall, E16S, vein                       |
| 3     | HD-41-3:   | Trench 14, south wall, D13S, tuff                       |
| 4     | HD-42-1:   | Trench 14, south wall, D14S, tuff in vein               |
| 6     | HD-42-5:   | Trench 14, south wall, D14S, tuff in vein               |
| 7     | HD-42-6:   | Trench 14, south wall, D14S, vein                       |
| 47    | HD-225:    | Trench 14, north wall, D13N, vein                       |
| 48    | HD-225-01: | Trench 14, north wall, D13N, ash/detritus within vein   |
| 243   | HD-1-1:    | Trench 14, south wall, C18S, top of platy K horizon     |
| 245   | HD-5-1:    | Trench 14, south wall, D28S, top of platy K horizon     |
| 246   | HD-6-1:    | Trench 14, south wall, E28S, bottom of platy K horizon  |
| 248   | HD-10-1:   | Trench 14, south wall, E37S, bottom of platy K horizon  |
| 250   | HD-12-1:   | Trench 14, south wall, F43S, bottom of platy K horizon  |
| 349   | HD-465:    | Trench 14, north wall, D14N, vein draping fault breccia |
| 773   | HD-97:     | Trench 14, south wall, D14S, vein                       |

Table B-10. Samples With No Corresponding USGS HD Numbers

LANL#427 (SMF#SPC00005253)<sup>1</sup>, field I.D. 5/91-DTV-1:

Relatively unaltered glassy tuff from N wall of Trench 14, immediately west of marker 311-N.

LANL#428 (SMF#SPC00005254), field I.D. 5/91-DTV-2:

Relatively unaltered Tiva Canyon Member from N Wall of Trench 14, 30 cm below marker 361-N.

LANL#429 (SMF#SPC00005255), field I.D. 5/91-DTV-3:

Upper loamy soil from S wall of Trench 14, 15 cm west of marker 313-S.

LANL#430 (SMF#SPC00005256), field I.D. 5/91-DTV-5:

Lightly indurated soil peds 30 cm below sample 5/91-DTV-3.

LANL#431 (SMF#SPC00005257), field I.D. 5/91-DTV-5:

Unaltered Rainier Mesa Member from N wall of Trench 14A, 7 meters west of the main fault and 60 cm from the trench bottom.

<sup>1</sup> SMF#SPC denotes numbers assigned by the Sample Management Facility.

Table B-11. INAA and XRD Data for Slope Calcretes  
(Page 1 of 4)

| sample  | type    | Na2O % | Na2O s.d. | CaO % | CaO s.d. | Sc ppm | Sc s.d. | FeO %  | FeO s.d. | Co ppm | Co s.d. |
|---------|---------|--------|-----------|-------|----------|--------|---------|--------|----------|--------|---------|
| 243,P1A | bulk    | 0.612  | 0.009     | 27.9  | 0.5      | 1.42   | 0.02    | 0.569  | 0.008    | 2.23   | 0.03    |
| 245,P2A | opal-CT | 0.0138 | 0.0003    | 0.34  | 0.02     | 0.0312 | 0.0004  | 0.0196 | 0.0004   | 0.506  | 0.008   |
| 245,P3A | dense   | 0.0343 | 0.0006    | 24.3  | 0.5      | 0.0203 | 0.0003  | 0.0173 | 0.0003   | 0.472  | 0.007   |
| 245,P4A | clastic | 0.756  | 0.011     | 29.5  | 0.6      | 1.59   | 0.02    | 0.696  | 0.010    | 2.47   | 0.03    |
| 246,P1A | ooidal  | 0.293  | 0.004     | 30.8  | 0.6      | 0.358  | 0.005   | 0.1407 | 0.0020   | 0.702  | 0.010   |
| 246,P2A | porous  | 0.302  | 0.004     | 37.1  | 0.7      | 0.299  | 0.004   | 0.1256 | 0.0018   | 1.306  | 0.018   |
| 246,P3A | dense   | 0.1290 | 0.0019    | 22.8  | 0.5      | 0.0284 | 0.0004  | 0.0149 | 0.0003   | 0.428  | 0.006   |
| 248,P1A | dense   | 0.0683 | 0.0013    | 35.6  | 0.8      | 0.0942 | 0.0013  | 0.0414 | 0.0006   | 0.452  | 0.006   |
| 248,P2A | ooidal  | 0.218  | 0.003     | 37.5  | 0.7      | 0.317  | 0.004   | 0.1351 | 0.0019   | 1.001  | 0.014   |
| 250,P1A | ooidal  | 0.667  | 0.009     | 33.9  | 0.8      | 1.002  | 0.014   | 0.402  | 0.006    | 1.78   | 0.03    |
| 250,P2A | dense   | 0.192  | 0.003     | 27.7  | 0.5      | 0.339  | 0.005   | 0.168  | 0.002    | 0.540  | 0.008   |

| sample  | Ni ppm | Ni s.d. | Zn ppm | Zn s.d. | As ppm | As s.d. | Se ppm | Se s.d. | Br ppm | Br s.d. |
|---------|--------|---------|--------|---------|--------|---------|--------|---------|--------|---------|
| 243,P1A | <7     |         | 18.3   | 0.4     | 5.64   | 0.17    | 0.11   | 0.04    | 9.1    | 0.6     |
| 245,P2A | <2     |         | 1.43   | 0.12    | 0.062  | 0.017   | <0.1   |         | 0.46   | 0.03    |
| 245,P3A | 3.7    | 1.2     | 1.29   | 0.13    | 3.68   | 0.08    | 0.10   | 0.03    | 10.0   | 0.7     |
| 245,P4A | 9      | 4       | 23.8   | 0.7     | 5.61   | 0.15    | <0.2   |         | 9.4    | 0.7     |
| 246,P1A | <6     |         | 4.4    | 0.4     | 10.05  | 0.20    | 0.20   | 0.05    | 16.7   | 1.6     |
| 246,P2A | 10.0   | 1.6     | 3.9    | 0.3     | 12.21  | 0.19    | 0.21   | 0.03    | 12.9   | 0.8     |
| 246,P3A | 7.4    | 1.1     | 1.08   | 0.15    | 8.64   | 0.16    | 0.14   | 0.04    | 11.4   | 0.8     |
| 248,P1A | <5     |         | 1.91   | 0.17    | 10.4   | 0.2     | 0.17   | 0.03    | 13.4   | 1.0     |
| 248,P2A | 5.     | 2       | 4.3    | 0.2     | 8.62   | 0.14    | <0.19  |         | 11.7   | 1.0     |
| 250,P1A | <10    |         | 12.4   | 0.5     | 10.9   | 0.2     | 0.15   | 0.06    | 11.2   | 0.9     |
| 250,P2A | <8     |         | 5.7    | 0.2     | 7.94   | 0.19    | <0.14  |         | 11.3   | 1.0     |

\* All elemental data determined by instrumental neutron activation analysis.

\*\* Abundances of minerals and detritus determined by quantitative x-ray diffraction.

\*\*\* Chemical and mineralogic data listed in these tables represent work in progress. For this report discussions of data in the text focus on analysis of Fe, Sc, and lanthanide-element chemical data, and on mineralogic data. Mineralogic data are presented as *calcite*, *opal*, and *detritus*; the category of *detritus* includes all primary materials of the igneous rocks that are sources for detritus in the calcretes and overlying soils, as well as smectite clays that are products of weathering in the Bt soil horizons.

\*\*\*\* All data collected by Los Alamos National Laboratory after January 22, 1991.

Table B-11. INAA and XRD Data for Slope Calcretes  
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| sample  | Rb ppm | Rb s.d. | Sr ppm | Sr s.d. | Zr ppm | Zr s.d. | Ag ppm | Ag s.d. | Sb ppm | Sb s.d. |
|---------|--------|---------|--------|---------|--------|---------|--------|---------|--------|---------|
| 243,P1A | 29.4   | 0.6     | 392    | 7       | 63     | 4       | 0.74   | 0.04    | 1.010  | 0.018   |
| 245,P2A | 0.18   | 0.07    | 7.1    | 1.6     | <5     |         | 0.029  | 0.010   | 1.93   | 0.03    |
| 245,P3A | <0.4   |         | 517    | 9       | <8     |         | 0.159  | 0.013   | 1.052  | 0.017   |
| 245,P4A | 39.2   | 0.9     | 641    | 12      | 74     | 5       | 0.91   | 0.03    | 0.536  | 0.013   |
| 246,P1A | 6.1    | 0.4     | 879    | 16      | 17     | 4       | 0.46   | 0.03    | 0.725  | 0.015   |
| 246,P2A | 7.2    | 0.3     | 946    | 15      | 10.8   | 1.8     | 1.41   | 0.03    | 0.291  | 0.007   |
| 246,P3A | 0.63   | 0.13    | 543    | 10      | <5     |         | 0.87   | 0.02    | 1.025  | 0.017   |
| 248,P1A | 1.38   | 0.17    | 532    | 10      | <7     |         | 0.186  | 0.015   | 0.969  | 0.016   |
| 248,P2A | 7.2    | 0.3     | 593    | 11      | 19     | 3       | 0.26   | 0.02    | 0.475  | 0.010   |
| 250,P1A | 28.3   | 0.6     | 565    | 10      | 78     | 4       | 0.23   | 0.03    | 0.535  | 0.012   |
| 250,P2A | 7.1    | 0.3     | 423    | 9       | 15     | 3       | 0.166  | 0.020   | 0.732  | 0.014   |

| sample  | Cs ppm | Cs s.d. | Ba ppm | Ba s.d. | La ppm | La s.d. | Ce ppm | Ce s.d. | Nd ppm | Nd s.d. |
|---------|--------|---------|--------|---------|--------|---------|--------|---------|--------|---------|
| 243,P1A | 1.327  | 0.019   | 228    | 6       | 13.17  | 0.19    | 23.6   | 0.3     | 9.4    | 0.8     |
| 245,P2A | 0.017  | 0.002   | <6     |         | 0.44   | 0.10    | 0.52   | 0.09    | <1.5   |         |
| 245,P3A | 0.016  | 0.003   | 60     | 3       | 0.18   | 0.04    | 0.45   | 0.10    | <2     |         |
| 245,P4A | 1.68   | 0.03    | 260    | 7       | 19.4   | 0.3     | 28.9   | 0.4     | 13.4   | 1.1     |
| 246,P1A | 0.325  | 0.008   | 160    | 5       | 9.24   | 0.13    | 17.0   | 0.2     | 6.0    | 0.7     |
| 246,P2A | 0.337  | 0.006   | 140    | 4       | 2.57   | 0.04    | 5.09   | 0.08    | 2.0    | 0.4     |
| 246,P3A | 0.029  | 0.002   | 57     | 3       | 0.20   | 0.05    | 0.40   | 0.10    | <0.7   |         |
| 248,P1A | 0.093  | 0.004   | 116    | 3       | 0.74   | 0.02    | 1.34   | 0.04    | 1.1    | 0.3     |
| 248,P2A | 0.321  | 0.007   | 105    | 3       | 2.64   | 0.04    | 5.00   | 0.08    | 3.0    | 0.4     |
| 250,P1A | 1.107  | 0.017   | 241    | 6       | 11.46  | 0.16    | 22.8   | 0.3     | 8.1    | 0.8     |
| 250,P2A | 0.325  | 0.007   | 197    | 5       | 7.09   | 0.10    | 12.53  | 0.18    | 4.7    | 0.5     |

- \* All elemental data determined by instrumental neutron activation analysis.
- \*\* Abundances of minerals and detritus determined by quantitative x-ray diffraction.
- \*\*\* Chemical and mineralogic data listed in these tables represent work in progress. For this report discussions of data in the text focus on analysis of Fe, Sc, and lanthanide-element chemical data, and on mineralogic data. Mineralogic data are presented as *calcite*, *opal*, and *detritus*; the category of *detritus* includes all primary materials of the igneous rocks that are sources for detritus in the calcretes and overlying soils, as well as smectite clays that are products of weathering in the Bt soil horizons.
- \*\*\*\* All data collected by Los Alamos National Laboratory after January 22, 1991.

Table B-11. INAA and XRD Data for Slope Calcretes  
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| sample  | Sm ppm | Sm s.d. | Eu ppm | Eu s.d. | Tb ppm | Tb s.d. | Yb ppm | Yb s.d. | Lu ppm | Lu s.d. |
|---------|--------|---------|--------|---------|--------|---------|--------|---------|--------|---------|
| 243,P1A | 1.76   | 0.03    | 0.270  | 0.005   | 0.207  | 0.005   | 0.731  | 0.012   | 0.110  | 0.003   |
| 245,P2A | 0.09   | 0.03    | 0.0078 | 0.0011  | 0.0084 | 0.0011  | 0.028  | 0.003   |        |         |
| 245,P3A |        |         | 0.0044 | 0.0011  | 0.0067 | 0.0018  | 0.034  | 0.003   |        |         |
| 245,P4A | 2.45   | 0.04    | 0.327  | 0.007   | 0.260  | 0.008   | 0.887  | 0.016   | 0.135  | 0.005   |
| 246,P1A | 0.766  | 0.017   | 0.053  | 0.003   | 0.059  | 0.003   | 0.160  | 0.007   | 0.025  | 0.002   |
| 246,P2A | 0.389  | 0.009   | 0.0503 | 0.0017  | 0.047  | 0.002   | 0.153  | 0.005   | 0.0253 | 0.0016  |
| 246,P3A |        |         | 0.0052 | 0.0013  | 0.0035 | 0.0011  | 0.018  | 0.002   |        |         |
| 248,P1A | 0.110  | 0.019   | 0.0135 | 0.0013  | 0.0092 | 0.0016  | 0.047  | 0.004   |        |         |
| 248,P2A | 0.465  | 0.008   | 0.068  | 0.003   | 0.055  | 0.003   | 0.204  | 0.005   | 0.0297 | 0.0012  |
| 250,P1A | 1.43   | 0.02    | 0.203  | 0.004   | 0.151  | 0.005   | 0.548  | 0.011   | 0.090  | 0.003   |
| 250,P2A | 0.607  | 0.019   | 0.064  | 0.003   | 0.048  | 0.003   | 0.162  | 0.005   | 0.0237 | 0.0013  |

| sample  | Hf ppm | Hf s.d. | Ta ppm | Ta s.d. | W ppm | W s.d. | Au ppb | Au s.d. | Th ppm | Th s.d. |
|---------|--------|---------|--------|---------|-------|--------|--------|---------|--------|---------|
| 243,P1A | 1.72   | 0.03    | 0.298  | 0.008   | 1.05  | 0.17   | 5.2    | 1.0     | 4.06   | 0.06    |
| 245,P2A | 0.040  | 0.004   | <0.010 |         | 0.09  | 0.02   | 2.43   | 0.32    | 0.125  | 0.004   |
| 245,P3A | 0.027  | 0.004   | 0.0048 | 0.0020  | 0.97  | 0.07   | 2.4    | 0.4     | 0.062  | 0.004   |
| 245,P4A | 2.06   | 0.04    | 0.412  | 0.011   | 1.57  | 0.14   | 3.3    | 1.0     | 5.28   | 0.07    |
| 246,P1A | 0.515  | 0.013   | 0.077  | 0.005   | 1.98  | 0.13   | 6.3    | 0.8     | 1.336  | 0.019   |
| 246,P2A | 0.323  | 0.009   | 0.071  | 0.003   | 3.18  | 0.11   | 6.0    | 0.8     | 0.938  | 0.013   |
| 246,P3A | 0.032  | 0.004   | 0.006  | 0.003   | 1.40  | 0.12   | 6.6    | 0.6     | 0.071  | 0.003   |
| 248,P1A | 0.073  | 0.005   | 0.014  | 0.002   | 1.75  | 0.13   | 1.9    | 0.6     | 0.204  | 0.005   |
| 248,P2A | 0.578  | 0.012   | 0.079  | 0.004   | 2.01  | 0.09   | 5.3    | 0.6     | 0.978  | 0.014   |
| 250,P1A | 1.82   | 0.03    | 0.266  | 0.004   | 1.96  | 0.12   | 4.7    | 0.8     | 3.57   | 0.05    |
| 250,P2A | 0.547  | 0.012   | 0.070  | 0.004   | 1.19  | 0.16   | 4.0    | 0.6     | 1.241  | 0.018   |

- \* All elemental data determined by instrumental neutron activation analysis.
- \*\* Abundances of minerals and detritus determined by quantitative x-ray diffraction.
- \*\*\* Chemical and mineralogic data listed in these tables represent work in progress. For this report discussions of data in the text focus on analysis of Fe, Sc, and lanthanide-element chemical data, and on mineralogic data. Mineralogic data are presented as *calcite*, *opal*, and *detritus*; the category of *detritus* includes all primary materials of the igneous rocks that are sources for detritus in the calcretes and overlying soils, as well as smectite clays that are products of weathering in the Bt soil horizons.
- \*\*\*\* All data collected by Los Alamos National Laboratory after January 22, 1991.

Table B-11. INAA and XRD Data for Slope Calcretes  
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| sample  | U ppm | U s.d. | calcite | cc s.d. | opal | op s.d. | clay &<br>detritus | clay &<br>det s.d. |
|---------|-------|--------|---------|---------|------|---------|--------------------|--------------------|
| 243,P1A | 7.53  | 0.16   | 47      | 1       | 42   | 2       | 11                 | 2                  |
| 245,P2A | 18.3  | 0.4    | 1       | 1       | 99   | 5       | 0                  | <1                 |
| 245,P3A | 15.2  | 0.3    | 45      | 1       | 50   | 3       | 5                  | 1                  |
| 245,P4A | 3.64  | 0.09   | 56      | 2       | 31   | 2       | 13                 | 2                  |
| 246,P1A | 8.51  | 0.17   | 57      | 2       | 35   | 2       | 8                  | 2                  |
| 246,P2A | 4.21  | 0.10   | 63      | 2       | 29   | 2       | 8                  | 2                  |
| 246,P3A | 11.4  | 0.2    | 38      | 1       | 57   | 2       | 5                  | 2                  |
| 248,P1A | 8.58  | 0.17   | 62      | 2       | 37   | 2       | 1                  | 1                  |
| 248,P2A | 3.46  | 0.07   | 62      | 2       | 35   | 2       | 3                  | 1                  |
| 250,P1A | 3.36  | 0.08   | 57      | 2       | 33   | 2       | 10                 | 2                  |
| 250,P2A | 9.18  | 0.19   | 49      | 1       | 49   | 1       | 2                  | 1                  |

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- \*\*\*\* All data collected by Los Alamos National Laboratory after January 22, 1991.

Table B-12. INAA and XRD Data for Vein Calcrites  
(Page 1 of 7)

| sample  | type       | Na2O % | Na2O s.d. | CaO % | CaO s.d. | Sc ppm | Sc s.d. | FeO %  | FeO s.d. | Co ppm | Co s.d. |
|---------|------------|--------|-----------|-------|----------|--------|---------|--------|----------|--------|---------|
| 1,P15A  | ooidal     | 1.181  | 0.017     | 21.1  | 0.4      | 2.71   | 0.040   | 1.133  | 0.016    | 4.64   | 0.07    |
| 1,P16A  | dense      | 0.523  | 0.007     | 28.8  | 0.6      | 1.340  | 0.019   | 0.540  | 0.008    | 1.60   | 0.02    |
| 1,P18A  | root rich  | 0.313  | 0.004     | 39.1  | 0.7      | 0.734  | 0.010   | 0.298  | 0.004    | 2.53   | 0.04    |
| 1,P19A  | ooidal     | 0.628  | 0.009     | 32.4  | 0.6      | 1.098  | 0.016   | 0.455  | 0.006    | 2.71   | 0.04    |
| 1,P20A  | root rich  | 0.411  | 0.006     | 33.9  | 0.7      | 0.812  | 0.011   | 0.316  | 0.004    | 2.85   | 0.04    |
| 1,P23A  | dense      | 0.0984 | 0.0014    | 34.9  | 0.6      | 0.1224 | 0.0017  | 0.0658 | 0.0009   | 0.702  | 0.010   |
| 7,P2A   | root rich  | 0.0711 | 0.0011    | 28.2  | 0.5      | 0.1394 | 0.0020  | 0.0598 | 0.0008   | 0.760  | 0.011   |
| 7,P3A   | root rich  | 0.0667 | 0.0009    | 29.9  | 0.6      | 0.143  | 0.002   | 0.0611 | 0.0009   | 1.90   | 0.03    |
| 7,P4A   | dense      | 0.155  | 0.002     | 31.8  | 0.6      | 0.444  | 0.006   | 0.180  | 0.003    | 1.255  | 0.018   |
| 7,P5A   | ooidal     | 0.352  | 0.005     | 30.4  | 0.6      | 0.772  | 0.011   | 0.340  | 0.005    | 1.80   | 0.03    |
| 47,P1A  | channel    | 0.698  | 0.010     | 28.3  | 0.5      | 1.126  | 0.016   | 0.472  | 0.007    | 2.02   | 0.03    |
| 48,P2D  | bulk ash   | 2.14   | 0.03      | 16.2  | 0.5      | 2.97   | 0.04    | 1.316  | 0.019    | 3.10   | 0.04    |
| 48,P3A  | finer ash  | 0.305  | 0.004     | 41.8  | 0.8      | 1.50   | 0.02    | 0.652  | 0.009    | 2.75   | 0.04    |
| 773,P1A | channel    | 0.332  | 0.005     | 31.4  | 0.6      | 0.608  | 0.009   | 0.239  | 0.003    | 1.390  | 0.020   |
| 773,P1A | dup 773    | 0.337  | 0.005     | 31.8  | 0.6      | 0.641  | 0.009   | 0.241  | 0.003    | 1.52   | 0.02    |
| 47,P1A  | dup 47     | 0.607  | 0.009     | 28.4  | 0.6      | 1.018  | 0.014   | 0.408  | 0.006    | 1.70   | 0.02    |
| 349,P1  | opal-A     | 0.0237 | 0.0005    | 0.34  | 0.05     | 0.0181 | 0.0003  | 0.0237 | 0.0004   | 0.073  | 0.002   |
| 1,P13CD | sep+cc     | 0.150  | 0.002     | 33.6  | 0.5      | 0.319  | 0.005   | 0.136  | 0.002    | 1.29   | 0.02    |
| 1,P25B  | channel    | 0.587  | 0.008     | 27.8  | 0.6      | 1.21   | 0.02    | 0.580  | 0.008    | 3.69   | 0.05    |
| 7,P1B   | channel    | 0.390  | 0.006     | 27.7  | 0.5      | 0.809  | 0.011   | 0.322  | 0.005    | 1.85   | 0.03    |
| 1,P25B  | 1,P25B dup | 0.567  | 0.008     | 27.7  | 0.5      | 1.21   | 0.02    | 0.569  | 0.008    | 3.40   | 0.05    |
| 49,P1A  | opal-CT+cc | 0.0318 | 0.0005    | 22.5  | 0.4      | 0.0133 | 0.0004  | 0.0170 | 0.0004   | 0.249  | 0.006   |
| 7,P1B   | 7,P1B dup  | 0.368  | 0.005     | 28.0  | 0.5      | 0.732  | 0.010   | 0.299  | 0.004    | 1.85   | 0.03    |

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- \*\*\* Chemical and mineralogic data listed in these tables represent work in progress. For this report discussions of data in the text focus on analysis of Fe, Sc, and lanthanide-element chemical data, and on mineralogic data. Mineralogic data are presented as *calcite*, *opal*, and *detritus*; the category of *detritus* includes all primary materials of the igneous rocks that are sources for detritus in the calcrites and overlying soils, as well as smectite clays that are products of weathering in the Bt soil horizons.
- \*\*\*\* All data collected by Los Alamos National Laboratory after January 22, 1991.

Table B-12. INAA and XRD Data for Vein Calcretes  
(Page 2 of 7)

| sample  | Ni ppm | Ni s.d. | Zn ppm | Zn s.d. | As ppm | As s.d. | Se ppm | Se s.d. | Br ppm | Br s.d. |
|---------|--------|---------|--------|---------|--------|---------|--------|---------|--------|---------|
| 1,P15A  | 30     | 5       | 41     | 2       | 5.74   | 0.12    | <0.3   |         | 4.5    | 0.3     |
| 1,P16A  | 8      | 3       | 15.1   | 0.4     | 7.65   | 0.19    | <0.2   |         | 8.2    | 0.6     |
| 1,P18A  | <12    |         | 8.1    | 0.5     | 6.94   | 0.15    | <0.15  |         | 8.0    | 0.7     |
| 1,P19A  | 7      | 3       | 17.3   | 0.5     | 6.69   | 0.14    | <0.2   |         | 6.3    | 0.6     |
| 1,P20A  | 5      | 2       | 11.9   | 0.3     | 7.76   | 0.15    | 0.11   | 0.05    | 8.8    | 0.8     |
| 1,P23A  | 5.4    | 1.9     | 2.8    | 0.2     | 13.07  | 0.19    | 0.20   | 0.04    | 11.1   | 0.6     |
| 7,P2A   | <5     |         | 2.04   | 0.20    | 6.07   | 0.12    | <0.15  |         | 9.1    | 0.6     |
| 7,P3A   | <7     |         | 3.7    | 0.3     | 6.73   | 0.19    | <0.15  |         | 10.2   | 0.9     |
| 7,P4A   | <8     |         | 5.3    | 0.3     | 9.42   | 0.15    | 0.19   | 0.04    | 13.1   | 1.3     |
| 7,P5A   | <9     |         | 10     | 2       | 8.22   | 0.15    | 0.13   | 0.05    | 11.2   | 1.1     |
| 47,P1A  | 7      | 3       | 13.0   | 0.4     | 6.87   | 0.13    | <0.20  |         | 11.2   | 0.7     |
| 48,P2D  | >20    |         | 33.9   | 0.8     | 5.4    | 0.3     | <0.2   |         | 7.8    | 0.5     |
| 48,P3A  | >20    |         | 15.4   | 0.6     | 10.4   | 0.2     | 0.24   | 0.10    | 18.6   | 1.6     |
| 773,P1A | 7      | 2       | 8.6    | 0.4     | 7.54   | 0.15    | <0.2   |         | 9.6    | 0.6     |
| 773,P1A | <6     |         | 7.3    | 0.3     | 7.53   | 0.17    | <0.11  |         | 11.4   | 1.1     |
| 47,P1A  | 13     | 3       | 10.9   | 0.5     | 6.77   | 0.19    | <0.3   |         | 12.1   | 0.9     |
| 349,P1  | <5     |         | 210    | 40      | 0.34   | 0.07    |        |         | 1.02   | 0.07    |
| 1,P13CD |        |         | 12     | 3       | 10.8   | 0.2     | 0.14   | 0.06    | 26.1   | 1.2     |
| 1,P25B  |        |         | 22     | 4       | 6.9    | 0.2     | <0.2   |         | 6.4    | 0.5     |
| 7,P1B   |        |         | 9      | 2       | 7.16   | 0.14    | <0.2   |         | 9.9    | 0.4     |
| 1,P25B  |        |         | 20     | 4       | 6.91   | 0.14    | <0.3   |         | 6.5    | 0.3     |
| 49,P1A  | <4     |         | 130    | 30      | 5.05   | 0.11    |        |         | 8.0    | 0.4     |
| 7,P1    | <6     |         | 9      | 2       | 7.63   | 0.14    | 0.14   | 0.05    | 9.7    | 0.6     |

\* All elemental data determined by instrumental neutron activation analysis.

\*\* Abundances of minerals and detritus determined by quantitative x-ray diffraction.

\*\*\* Chemical and mineralogic data listed in these tables represent work in progress. For this report discussions of data in the text focus on analysis of Fe, Sc, and lanthanide-element chemical data, and on mineralogic data. Mineralogic data are presented as *calcite*, *opal*, and *detritus*; the category of *detritus* includes all primary materials of the igneous rocks that are sources for detritus in the calcretes and overlying soils, as well as smectite clays that are products of weathering in the Bt soil horizons.

\*\*\*\* All data collected by Los Alamos National Laboratory after January 22, 1991.

Table B-12. INAA and XRD Data for Vein Calcretes  
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| sample  | Rb ppm | Rb s.d. | Sr ppm | Sr s.d. | Zr ppm | Zr s.d. | Ag ppm | Ag s.d. | Sb ppm | Sb s.d. |
|---------|--------|---------|--------|---------|--------|---------|--------|---------|--------|---------|
| 1,P15A  | 57.5   | 1.0     | 556    | 12      | 125    | 7       | 3.34   | 0.05    | 0.889  | 0.016   |
| 1,P16A  | 25.4   | 0.6     | 698    | 13      | 61     | 5       | 0.61   | 0.04    | 0.772  | 0.016   |
| 1,P18A  | 13.4   | 0.4     | 895    | 16      | 30     | 4       | 0.26   | 0.03    | 0.516  | 0.011   |
| 1,P19A  | 25.4   | 0.6     | 946    | 16      | 84     | 4       | 2.34   | 0.03    | 0.440  | 0.011   |
| 1,P20A  | 15.0   | 0.4     | 927    | 15      | 59     | 3       | 1.74   | 0.05    | 0.485  | 0.011   |
| 1,P23A  | 2.3    | 0.2     | 1234   | 20      | 8      | 3       | 0.353  | 0.011   | 0.942  | 0.014   |
| 7,P2A   | 1.77   | 0.18    | 504    | 10      | <11    |         | 0.308  | 0.018   | 0.629  | 0.011   |
| 7,P3A   | 2.1    | 0.2     | 568    | 10      | <7     |         | 0.47   | 0.02    | 1.19   | 0.02    |
| 7,P4A   | 9.0    | 0.3     | 804    | 13      | 10     | 3       | 0.38   | 0.02    | 0.543  | 0.011   |
| 7,P5A   | 16.3   | 0.4     | 858    | 14      | 37     | 4       | 0.23   | 0.03    | 0.421  | 0.009   |
| 47,P1A  | 25.5   | 0.5     | 731    | 12      | 58     | 4       | 0.318  | 0.015   | 0.786  | 0.013   |
| 48,P2D  | 73.6   | 1.4     | 510    | 11      | 150    | 7       | <0.2   |         | 0.598  | 0.017   |
| 48,P3A  | 15.0   | 0.6     | 744    | 15      | 126    | 6       |        |         | 0.630  | 0.016   |
| 773,P1A | 14.0   | 0.4     | 712    | 13      | 29     | 4       | 0.74   | 0.03    | 0.954  | 0.016   |
| 773,P1A | 13.8   | 0.3     | 725    | 12      | 27     | 3       | 0.55   | 0.03    | 0.930  | 0.017   |
| 47,P1A  | 22.4   | 0.5     | 744    | 13      | 56     | 5       | 0.32   | 0.03    | 0.831  | 0.017   |
| 349,P1  |        |         | 39     | 5       | <15    |         |        |         | 1.27   | 0.02    |
| 1,P13CD | 6.3    | 0.4     | 1020   | 40      | 11     | 3       |        |         | 0.339  | 0.008   |
| 1,P25B  | 27.6   | 1.2     | 880    | 50      | 76     | 7       |        |         | 0.84   | 0.02    |
| 7,P1B   | 16.7   | 0.5     | 840    | 40      | 48     | 4       |        |         | 0.918  | 0.014   |
| 1,P25B  | 26.3   | 0.9     | 880    | 50      | 62     | 6       |        |         | 0.759  | 0.014   |
| 49,P1A  | <0.5   |         | 690    | 30      | <8     |         |        |         | 1.152  | 0.016   |
| 7,P1B   | 16.5   | 0.5     | 860    | 30      | 39     | 2       |        |         | 0.875  | 0.014   |

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- \* All elemental data determined by instrumental neutron activation analysis.
- \*\* Abundances of minerals and detritus determined by quantitative x-ray diffraction.
- \*\*\* Chemical and mineralogic data listed in these tables represent work in progress. For this report discussions of data in the text focus on analysis of Fe, Sc, and lanthanide-element chemical data, and on mineralogic data. Mineralogic data are presented as *calcite*, *opal*, and *detritus*; the category of *detritus* includes all primary materials of the igneous rocks that are sources for detritus in the calcretes and overlying soils, as well as smectite clays that are products of weathering in the Bt soil horizons.
- \*\*\*\* All data collected by Los Alamos National Laboratory after January 22, 1991.

Table B-12. INAA and XRD Data for Vein Calcretes  
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| sample  | Cs ppm | Cs sd. | Ba ppm | Ba sd | La ppm | La s.d. | Ce ppm | Ce s.d. | Nd ppm | Nd s.d. |
|---------|--------|--------|--------|-------|--------|---------|--------|---------|--------|---------|
| 1,P15A  | 2.86   | 0.04   | 293    | 6     | 19.8   | 0.3     | 37.6   | 0.5     | 14.6   | 0.9     |
| 1,P16A  | 1.307  | 0.019  | 154    | 5     | 10.98  | 0.16    | 21.5   | 0.3     | 8.0    | 0.8     |
| 1,P18A  | 0.687  | 0.012  | 132    | 4     | 6.23   | 0.09    | 12.19  | 0.17    | 4.6    | 0.5     |
| 1,P19A  | 1.019  | 0.016  | 178    | 5     | 14.6   | 0.2     | 26.7   | 0.4     | 10.5   | 0.9     |
| 1,P20A  | 0.679  | 0.011  | 141    | 4     | 8.75   | 0.12    | 16.4   | 0.2     | 6.5    | 0.6     |
| 1,P23A  | 0.121  | 0.005  | 72     | 3     | 0.976  | 0.015   | 2.01   | 0.06    | <2     |         |
| 7,P2A   | 0.150  | 0.005  | 57     | 2     | 1.10   | 0.02    | 2.24   | 0.05    | 0.9    | 0.3     |
| 7,P3A   | 0.164  | 0.005  | 56     | 3     | 0.98   | 0.02    | 2.42   | 0.06    | 1.3    | 0.3     |
| 7,P4A   | 0.598  | 0.010  | 78     | 3     | 2.22   | 0.03    | 4.72   | 0.08    | 2.3    | 0.4     |
| 7,P5A   | 0.840  | 0.013  | 140    | 4     | 6.01   | 0.08    | 11.99  | 0.18    | 4.8    | 0.6     |
| 47,P1A  | 0.856  | 0.014  | 231    | 5     | 9.94   | 0.14    | 17.9   | 0.3     | 7.7    | 0.6     |
| 48,P2D  | 2.04   | 0.04   | 620    | 12    | 33.9   | 0.5     | 60.1   | 0.8     | 23.5   | 1.5     |
| 48,P3A  | 0.844  | 0.017  | 206    | 6     | 13.63  | 0.19    | 25.6   | 0.4     | 11.3   | 1.0     |
| 773,P1A | 0.610  | 0.010  | 119    | 4     | 6.39   | 0.09    | 12.03  | 0.18    | 5.1    | 0.6     |
| 773,P1A | 0.609  | 0.009  | 111    | 4     | 7.41   | 0.10    | 14.0   | 0.2     | 5.3    | 0.6     |
| 47,P1A  | 0.746  | 0.012  | 227    | 6     | 15.3   | 0.2     | 27.8   | 0.4     | 10.1   | 0.8     |
| 349,P1  | 0.033  | 0.005  | <40    |       | 11.29  | 0.16    | 0.27   | 0.08    | <2     |         |
| 1,P13CD | 0.472  | 0.009  | 126    | 4     | 2.70   | 0.04    | 4.89   | 0.09    | 2.3    | 0.5     |
| 1,P25B  | 1.24   | 0.02   | 178    | 7     | 10.43  | 0.15    | 20.5   | 0.3     | 7.7    | 1.0     |
| 7,P1B   | 0.815  | 0.013  | 140    | 4     | 8.98   | 0.13    | 17.1   | 0.2     | 6.7    | 0.5     |
| 1,P25B  | 1.24   | 0.02   | 165    | 5     | 9.43   | 0.13    | 18.5   | 0.3     | 6.8    | 0.7     |
| 49,P1A  | 0.028  | 0.005  | 38     | 7     | 8.65   | 0.12    | 0.18   | 0.06    | 1.2    | 0.5     |
| 7,P1B   | 0.790  | 0.011  | 141    | 4     | 5.40   | 0.08    | 10.90  | 0.15    | 4.5    | 0.6     |

\* All elemental data determined by instrumental neutron activation analysis.

\*\* Abundances of minerals and detritus determined by quantitative x-ray diffraction.

\*\*\* Chemical and mineralogic data listed in these tables represent work in progress. For this report discussions of data in the text focus on analysis of Fe, Sc, and lanthanide-element chemical data, and on mineralogic data. Mineralogic data are presented as *calcite*, *opal*, and *detritus*; the category of *detritus* includes all primary materials of the igneous rocks that are sources for detritus in the calcretes and overlying soils, as well as smectite clays that are products of weathering in the Bt soil horizons.

\*\*\*\* All data collected by Los Alamos National Laboratory after January 22, 1991.

Table B-12. INAA and XRD Data for Vein Calcretes  
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| sample  | Sm ppm | Sm s.d. | Eu ppm | Eu s.d. | Tb ppm | Tb s.d. | Yb ppm | Yb s.d. | Lu ppm | Lu s.d. |
|---------|--------|---------|--------|---------|--------|---------|--------|---------|--------|---------|
| 1,P15A  | 2.52   | 0.04    | 0.413  | 0.008   | 0.293  | 0.008   | 1.099  | 0.016   | 0.175  | 0.004   |
| 1,P16A  | 1.44   | 0.03    | 0.205  | 0.005   | 0.159  | 0.005   | 0.598  | 0.012   | 0.095  | 0.003   |
| 1,P18A  | 0.831  | 0.016   | 0.130  | 0.004   | 0.091  | 0.004   | 0.368  | 0.008   | 0.0585 | 0.0018  |
| 1,P19A  | 1.48   | 0.02    | 0.245  | 0.005   | 0.152  | 0.005   | 0.598  | 0.012   | 0.097  | 0.003   |
| 1,P20A  | 0.972  | 0.015   | 0.154  | 0.003   | 0.102  | 0.004   | 0.425  | 0.009   | 0.070  | 0.002   |
| 1,P23A  | 0.160  | 0.019   | 0.0211 | 0.0019  | 0.018  | 0.002   | 0.080  | 0.004   |        |         |
| 7,P2A   | 0.198  | 0.012   | 0.0252 | 0.0016  | 0.027  | 0.002   | 0.131  | 0.004   | 0.0202 | 0.0011  |
| 7,P3A   | 0.219  | 0.010   | 0.0247 | 0.0019  | 0.028  | 0.002   | 0.173  | 0.006   | 0.0279 | 0.0015  |
| 7,P4A   | 0.445  | 0.014   | 0.054  | 0.002   | 0.063  | 0.003   | 0.273  | 0.006   | 0.0420 | 0.0017  |
| 7,P5A   | 0.841  | 0.016   | 0.125  | 0.003   | 0.100  | 0.004   | 0.448  | 0.008   | 0.072  | 0.002   |
| 47,P1A  | 1.43   | 0.02    | 0.247  | 0.005   | 0.165  | 0.005   | 0.557  | 0.009   | 0.0850 | 0.0019  |
| 48,P2D  | 4.16   | 0.06    | 0.740  | 0.013   | 0.455  | 0.011   | 1.357  | 0.019   | 0.205  | 0.005   |
| 48,P3A  | 2.03   | 0.03    | 0.296  | 0.007   | 0.215  | 0.008   | 0.752  | 0.015   | 0.122  | 0.003   |
| 773,P1A | 0.752  | 0.019   | 0.104  | 0.003   | 0.085  | 0.004   | 0.346  | 0.008   | 0.057  | 0.002   |
| 773,P1A | 0.909  | 0.019   | 0.113  | 0.003   | 0.089  | 0.003   | 0.327  | 0.007   | 0.052  | 0.002   |
| 47,P1A  | 1.67   | 0.03    | 0.240  | 0.005   | 0.165  | 0.005   | 0.531  | 0.011   | 0.086  | 0.003   |
| 349,P1  | <0.16  |         | <0.004 |         | <0.007 |         | <0.020 |         | <0.019 |         |
| 1,P13CD | 0.414  | 0.008   | 0.063  | 0.002   | 0.052  | 0.002   | 0.182  | 0.008   | 0.026  | 0.002   |
| 1,P25B  | 1.37   | 0.02    | 0.209  | 0.006   | 0.162  | 0.005   | 0.602  | 0.015   | 0.093  | 0.003   |
| 7,P1B   | 1.07   | 0.02    | 0.145  | 0.004   | 0.108  | 0.004   | 0.471  | 0.009   | 0.0755 | 0.0014  |
| 1,P25B  | 1.33   | 0.02    | 0.212  | 0.005   | 0.155  | 0.005   | 0.569  | 0.011   | 0.086  | 0.002   |
| 49,P1A  | 0.035  | 0.016   | 0.0032 | 0.0015  | <0.01  |         | 0.021  | 0.005   |        |         |
| 7,P1    | 0.829  | 0.016   | 0.125  | 0.002   | 0.0982 | 0.0017  | 0.419  | 0.009   | 0.066  | 0.002   |

\* All elemental data determined by instrumental neutron activation analysis.

\*\* Abundances of minerals and detritus determined by quantitative x-ray diffraction.

\*\*\* Chemical and mineralogic data listed in these tables represent work in progress. For this report discussions of data in the text focus on analysis of Fe, Sc, and lanthanide-element chemical data, and on mineralogic data. Mineralogic data are presented as *calcite*, *opal*, and *detritus*; the category of *detritus* includes all primary materials of the igneous rocks that are sources for detritus in the calcretes and overlying soils, as well as smectite clays that are products of weathering in the Bt soil horizons.

\*\*\*\* All data collected by Los Alamos National Laboratory after January 22, 1991.

Table B-12. INAA and XRD Data for Vein Calcretes  
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| Sample  | Hf ppm | Hf s.d. | Ta ppm | Ta s.d. | W ppm | W s.d. | Au ppb | Au s.d. | Th ppm | Th s.d. |
|---------|--------|---------|--------|---------|-------|--------|--------|---------|--------|---------|
| 1,P15A  | 3.35   | 0.05    | 0.618  | 0.016   | 2.05  | 0.12   | 2.6    | 0.8     | 7.14   | 0.10    |
| 1,P16A  | 1.56   | 0.03    | 0.302  | 0.009   | 1.16  | 0.16   | 3.1    | 1.0     | 3.58   | 0.05    |
| 1,P18A  | 0.798  | 0.016   | 0.154  | 0.006   | 1.44  | 0.15   | 8.2    | 0.8     | 2.00   | 0.03    |
| 1,P19A  | 2.13   | 0.04    | 0.243  | 0.008   | 1.90  | 0.14   | 11.5   | 1.0     | 3.37   | 0.05    |
| 1,P20A  | 1.30   | 0.02    | 0.173  | 0.005   | 3.12  | 0.13   | 9.4    | 1.0     | 2.33   | 0.03    |
| 1,P23A  | 0.169  | 0.008   | 0.027  | 0.003   | 1.40  | 0.06   | 6.4    | 0.6     | 0.331  | 0.007   |
| 7,P2A   | 0.094  | 0.006   | 0.020  | 0.002   | 0.89  | 0.08   | 9.5    | 0.8     | 0.423  | 0.007   |
| 7,P3A   | 0.100  | 0.006   | 0.018  | 0.003   | 1.02  | 0.12   | 4.8    | 0.8     | 0.436  | 0.008   |
| 7,P4A   | 0.374  | 0.009   | 0.100  | 0.004   | 1.12  | 0.06   | 9.0    | 0.6     | 1.162  | 0.016   |
| 7,P5A   | 0.923  | 0.017   | 0.176  | 0.006   | 1.28  | 0.11   | 11.4   | 1.0     | 2.29   | 0.03    |
| 47,P1A  | 1.42   | 0.02    | 0.251  | 0.007   | 1.52  | 0.09   | 9.1    | 0.8     | 4.28   | 0.06    |
| 48,P2D  | 3.76   | 0.06    | 0.76   | 0.02    | 0.9   | 0.4    | 5.1    | 1.6     | 9.51   | 0.13    |
| 48,P3A  | 3.28   | 0.05    | 0.224  | 0.009   | 1.96  | 0.19   | 14.0   | 1.4     | 3.53   | 0.05    |
| 773,P1A | 0.879  | 0.017   | 0.155  | 0.005   |       |        | 9.3    | 0.8     | 1.93   | 0.03    |
| 773,P1A | 0.713  | 0.014   | 0.156  | 0.005   |       |        | 8.8    | 1.0     | 2.37   | 0.03    |
| 47,P1A  | 1.40   | 0.02    | 0.247  | 0.007   | 1.19  | 0.17   | 8.1    | 1.2     | 3.64   | 0.05    |
| 349,P1  | 0.023  | 0.011   | <0.01  |         | 0.63  | 0.13   | 9.8    | 2.0     | 0.080  | 0.007   |
| 1,P13CD | 0.305  | 0.011   | 0.067  | 0.004   | 20.2  | 0.3    | 15.0   | 2.8     | 0.888  | 0.015   |
| 1,P25B  | 1.72   | 0.03    | 0.302  | 0.011   | 1.22  | 0.15   | 8.1    | 2.6     | 3.43   | 0.05    |
| 7,P1B   | 1.04   | 0.02    | 0.173  | 0.005   | 1.12  | 0.12   | 9.1    | 1.8     | 2.28   | 0.03    |
| 1,P25B  | 1.57   | 0.03    | 0.285  | 0.010   | 1.32  | 0.08   | 6.0    | 1.6     | 3.20   | 0.05    |
| 49,P1A  | <0.02  |         | <0.01  |         | 0.67  | 0.05   | 5.5    | 1.2     | 0.053  | 0.006   |
| 7,P1    | 0.824  | 0.015   | 0.166  | 0.003   | 1.05  | 0.09   | 12.1   | 2.8     | 2.14   | 0.03    |

- \* All elemental data determined by instrumental neutron activation analysis.
- \*\* Abundances of minerals and detritus determined by quantitative x-ray diffraction.
- \*\*\* Chemical and mineralogic data listed in these tables represent work in progress. For this report discussions of data in the text focus on analysis of Fe, Sc, and lanthanide-element chemical data, and on mineralogic data. Mineralogic data are presented as *calcite*, *opal*, and *detritus*; the category of *detritus* includes all primary materials of the igneous rocks that are sources for detritus in the calcretes and overlying soils, as well as smectite clays that are products of weathering in the Bt soil horizons.
- \*\*\*\* All data collected by Los Alamos National Laboratory after January 22, 1991.

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Table B-12. INAA and XRD Data for Vein Calcretes  
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| sample  | U ppm | U s.d. | calcite | cc s.d. | opal | op s.d. | clay &<br>detritus | clay &<br>det s.d. |
|---------|-------|--------|---------|---------|------|---------|--------------------|--------------------|
| 1,P15A  | 7.27  | 0.12   | 34      | 2       | 41   | 2       | 25                 | 2                  |
| 1,P16A  | 9.34  | 0.19   | 50      | 3       | 41   | 2       | 9                  | 3                  |
| 1,P18A  | 5.26  | 0.11   | 70      | 4       | 24   | 2       | 6                  | 1                  |
| 1,P19A  | 4.44  | 0.10   | 64      | 3       | 26   | 2       | 10                 | 1                  |
| 1,P20A  | 4.54  | 0.10   | 63      | 3       | 24   | 2       | 13                 | 1                  |
| 1,P23A  | 12.6  | 0.2    | 59      | 3       | 38   | 2       | 3                  | 1                  |
| 7,P2A   | 4.88  | 0.10   | 51      | 3       | 49   | 2       | 0                  | <1                 |
| 7,P3A   | 6.24  | 0.13   | 58      | 3       | 42   | 2       | 0                  | <1                 |
| 7,P4A   | 7.44  | 0.15   | 56      | 3       | 42   | 2       | 2                  | 1                  |
| 7,P5A   | 6.01  | 0.12   | 62      | 4       | 26   | 2       | 12                 | 1                  |
| 47,P1A  | 5.63  | 0.10   | 49      | 2       | 36   | 2       | 15                 | 2                  |
| 48,P2D  | 3.96  | 0.10   | 17      | 2       | 29   | 3       | 54                 | 4                  |
| 48,P3A  | 3.73  | 0.09   | 75      | 4       | 19   | 2       | 6                  | 1                  |
| 773,P1A | 8.03  | 0.15   | 59      | 3       | 35   | 2       | 6                  | 1                  |
| 773,P1A | 8.04  | 0.17   | 59      | 3       | 35   | 2       | 6                  | 1                  |
| 47,P1A  | 6.21  | 0.13   | 49      | 2       | 36   | 2       | 15                 | 2                  |
| 349,P1  | 22.9  | 0.4    | 0       | <1      | 100  | 1       | 0                  | <1                 |
| 1,P13CD | 3.46  | 0.07   | 61      | 1       | 0    | 0       | 39+                | 2                  |
| 1,P25B  | 7.4   | 0.2    | 56      | 2       | 31   | 2       | 13                 | 3                  |
| 7,P1B   | 8.79  | 0.14   | 54      | 2       | 41   | 2       | 5                  | 1                  |
| 1,P25B  | 7.51  | 0.14   | 56      | 2       | 31   | 2       | 13                 | 3                  |
| 49,P1A  | 11.1  | 0.2    | 44      | 1       | 56   | 2       | 0                  | <1                 |
| 7,P1B   | 8.22  | 0.15   | 54      | 2       | 41   | 2       | 5                  | 1                  |

+ Sepiolite included with detritus

\* All elemental data determined by instrumental neutron activation analysis.

\*\* Abundances of minerals and detritus determined by quantitative x-ray diffraction.

\*\*\* Chemical and mineralogic data listed in these tables represent work in progress. For this report discussions of data in the text focus on analysis of Fe, Sc, and lanthanide-element chemical data, and on mineralogic data. Mineralogic data are presented as *calcite*, *opal*, and *detritus*; the category of *detritus* includes all primary materials of the igneous rocks that are sources for detritus in the calcretes and overlying soils, as well as smectite clays that are products of weathering in the Bt soil horizons.

\*\*\*\* All data collected by Los Alamos National Laboratory after January 22, 1991.

Table B-13. INAA and XRD Data for Tuff Samples  
(Page 1 of 2)

|         | type      | Na2O % | Na2O s.d. | CaO % | CaO s.d. | Sc ppm | Sc s.d. | FeO % | FeO s.d. | Co ppm | Co S.d. |
|---------|-----------|--------|-----------|-------|----------|--------|---------|-------|----------|--------|---------|
| 3,P1B   | alt Tiva  | 3.75   | 0.05      | <0.8  |          | 1.94   | 0.03    | 0.976 | 0.014    | 0.373  | 0.009   |
| 4,P1B   | alt Tiva  | 3.49   | 0.05      | 0.9   | 0.3      | 2.83   | 0.04    | 1.177 | 0.017    | 0.635  | 0.011   |
| 6,P1B   | alt Tiva  | 3.26   | 0.05      | 0.6   | 0.2      | 2.34   | 0.03    | 1.020 | 0.014    | 0.492  | 0.009   |
| 427,P1B | vit tuff  | 2.92   | 0.04      | <0.5  |          | 1.94   | 0.03    | 0.883 | 0.012    | 1.89   | 0.03    |
| 428,P1B | Tiva      | 3.87   | 0.05      |       |          | 1.45   | 0.02    | 0.871 | 0.012    | 0.173  | 0.009   |
| 428,P2B | Tiva v.p. | 3.61   | 0.05      | <0.5  |          | 1.65   | 0.02    | 0.812 | 0.011    | 0.178  | 0.004   |
| 431,P1B | Rainier   | 3.10   | 0.04      | 0.5   | 0.2      | 3.40   | 0.05    | 0.581 | 0.008    | 0.216  | 0.009   |

|         | Ni ppm | Zn ppm | Zn s.d. | As ppm | As s.d. | Se ppm | Br ppm | Br s.d. | Rb ppm | Rb s.d. |
|---------|--------|--------|---------|--------|---------|--------|--------|---------|--------|---------|
| 3,P1B   | <25    | 86     | 18      | 8.1    | 0.3     | <0.5   | 0.25   | 0.11    | 149    | 5       |
| 4,P1B   | <15    | 68     | 14      | 3.7    | 0.3     | <0.3   | 0.30   | 0.12    | 106    | 4       |
| 6,P1B   | <20    | 61     | 12      | 3.3    | 0.3     | <0.3   | <0.3   |         | 103    | 3       |
| 427,P1B | <20    | 74     | 15      | 4.9    | 0.3     | <0.2   | 0.92   | 0.12    | 183    | 5       |
| 428,P1B |        | 73     | 15      | 11.4   | 0.3     | <0.4   | 0.37   | 0.10    | 188    | 6       |
| 428,P2B | <20    | 74     | 15      | 7.7    | 0.3     | <0.3   | 0.24   | 0.10    | 189    | 4       |
| 431,P1B | <25    | 44     | 9       | 5.4    | 0.2     | <0.4   | 0.96   | 0.10    | 230    | 5       |

|         | Sr ppm | Sr s.d. | Zr ppm | Zr s.d. | Sb ppm | Sb s.d. | Cs ppm | Cs s.d. | Ba ppm | Ba s.d. |
|---------|--------|---------|--------|---------|--------|---------|--------|---------|--------|---------|
| 3,P1B   | 39     | 9       | 266    | 13      | 0.203  | 0.015   | 2.68   | 0.04    | 134    | 8       |
| 4,P1B   | 52     | 9       | 336    | 12      | 0.217  | 0.014   | 2.03   | 0.03    | 329    | 11      |
| 6,P1B   | 43     | 9       | 298    | 10      | 0.213  | 0.013   | 2.00   | 0.03    | 250    | 9       |
| 427,P1B | 134    | 12      | 208    | 8       | 0.491  | 0.016   | 4.87   | 0.07    | 166    | 8       |
| 428,P1B | 37     | 8       | 208    | 10      | 0.28   | 0.02    | 3.30   | 0.05    | 64     | 8       |
| 428,P2B | 31     | 5       | 256    | 7       | 0.291  | 0.012   | 3.33   | 0.05    | 38     | 6       |
| 431,P1B | 20     | 9       | 90     | 10      | 0.512  | 0.015   | 6.02   | 0.09    | 26     | 8       |

\* All elemental data determined by instrumental neutron activation analysis.

\*\* Abundances of minerals and detritus determined by quantitative x-ray diffraction.

\*\*\* Chemical and mineralogic data listed in these tables represent work in progress. For this report discussions of data in the text focus on analysis of Fe, Sc, and lanthanide-element chemical data, and on mineralogic data. Mineralogic data are presented as *calcite*, *opal*, and *detritus*; the category of *detritus* includes all primary materials of the igneous rocks that are sources for detritus in the calcretes and overlying soils, as well as smectite clays that are products of weathering in the Bt soil horizons.

\*\*\*\* All data collected by Los Alamos National Laboratory after January 22, 1991.

Table B-13. INAA and XRD Data for Tuff Samples  
(Page 2 of 2)

|         | La ppm | La s.d. | Ce ppm | Ce s.d. | Nd ppm  | Nd s.d. | Sm ppm | Sm s.d.         | Eu ppm | Eu s.d. |
|---------|--------|---------|--------|---------|---------|---------|--------|-----------------|--------|---------|
| 3,P1B   | 39.7   | 0.6     | 95.2   | 1.3     | 34      | 3       | 7.91   | 0.11            | 0.555  | 0.012   |
| 4,P1B   | 73.5   | 1.0     | 150    | 2       | 52      | 4       | 8.29   | 0.12            | 1.15   | 0.02    |
| 6,P1B   | 67.6   | 1.0     | 135    | 2       | 50      | 3       | 8.35   | 0.12            | 1.010  | 0.017   |
| 427,P1B | 38.2   | 0.5     | 88.1   | 1.2     | 34      | 2       | 8.28   | 0.12            | 0.480  | 0.009   |
| 428,P1B | 29.5   | 0.4     | 54.2   | 0.8     | 25      | 2       | 6.00   | 0.09            | 0.272  | 0.007   |
| 428,P2B | 23.3   | 0.3     | 71.2   | 1.0     | 24.7    | 1.6     | 7.26   | 0.10            | 0.323  | 0.006   |
| 431,P1B | 20.3   | 0.3     | 48.3   | 0.7     | 15.2    | 1.3     | 4.24   | 0.06            | 0.108  | 0.004   |
|         | Tb ppm | Tb s.d. | Yb ppm | Yb s.d. | Lu ppm  | Lu s.d. | Hf ppm | Hf s.d.         | Ta ppm | Ta s.d. |
| 3,P1B   | 1.11   | 0.02    | 3.11   | 0.05    | 0.444   | 0.010   | 7.93   | 0.13            | 1.34   | 0.03    |
| 4,P1B   | 0.829  | 0.014   | 2.37   | 0.04    | 0.361   | 0.009   | 8.07   | 0.13            | 0.948  | 0.016   |
| 6,P1B   | 0.889  | 0.015   | 2.41   | 0.04    | 0.350   | 0.008   | 7.46   | 0.12            | 0.923  | 0.016   |
| 427,P1B | 1.14   | 0.02    | 3.66   | 0.05    | 0.513   | 0.011   | 6.87   | 0.11            | 1.74   | 0.05    |
| 428,P1B | 0.95   | 0.02    | 3.27   | 0.05    | 0.471   | 0.010   | 7.56   | 0.13            | 1.64   | 0.05    |
| 428,P2B | 1.21   | 0.02    | 3.63   | 0.05    | 0.515   | 0.011   | 8.77   | 0.12            | 1.73   | 0.03    |
| 431,P1B | 0.724  | 0.017   | 3.05   | 0.04    | 0.438   | 0.007   | 3.40   | 0.05            | 2.20   | 0.05    |
|         | W ppm  | W s.d.  | Au ppb | Th ppm  | Th s.d. | U ppm   | U s.d. | clay & detritus |        |         |
| 3,P1B   | 1.7    | 0.8     | <2     | 20.2    | 0.3     | 5.00    | 0.14   | 100             |        |         |
| 4,P1B   | <2     |         | <2     | 15.4    | 0.2     | 5.97    | 0.17   | 100             |        |         |
| 6,P1B   | <2     |         | <5     | 15.0    | 0.2     | 5.36    | 0.15   | 100             |        |         |
| 427,P1B | 1.7    | 0.3     | <3     | 24.3    | 0.3     | 5.12    | 0.14   | 100             |        |         |
| 428,P1B | 2.1    | 0.3     | <2     | 24.3    | 0.3     | 4.57    | 0.14   | 100             |        |         |
| 428,P2B | <2     |         | <2     | 24.5    | 0.3     | 3.95    | 0.12   | 100             |        |         |
| 431,P1B | 1.9    | 0.2     | <1.5   | 20.7    | 0.3     | 6.86    | 0.15   | 100             |        |         |

\* All elemental data determined by instrumental neutron activation analysis.

\*\* Abundances of minerals and detritus determined by quantitative x-ray diffraction.

\*\*\* Chemical and mineralogic data listed in these tables represent work in progress. For this report discussions of data in the text focus on analysis of Fe, Sc, and lanthanide-element chemical data, and on mineralogic data. Mineralogic data are presented as *calcite*, *opal*, and *detritus*; the category of *detritus* includes all primary materials of the igneous rocks that are sources for detritus in the calcretes and overlying soils, as well as smectite clays that are products of weathering in the Bt soil horizons.

\*\*\*\* All data collected by Los Alamos National Laboratory after January 22, 1991.

Table B-14. INAA and XRD Data for Bt Soil Samples  
(Page 1 of 2)

| sample  | type       | Na2O % | Na2O s.d. | CaO % | CaO s.d. | Sc ppm | Sc s.d. | Cr ppm | Cr s.d. | FeO % | FeO s.d. |
|---------|------------|--------|-----------|-------|----------|--------|---------|--------|---------|-------|----------|
| 429,P1B | loose soil | 2.92   | 0.04      | 2.0   | 0.2      | 6.26   | 0.09    | 23.5   | 0.4     | 2.67  | 0.04     |
| 429,P2A | soil fines | 2.23   | 0.03      | 2.4   | 0.3      | 11.63  | 0.16    | 58.3   | 0.9     | 4.82  | 0.07     |
| 430,P1B | ped        | 2.36   | 0.03      | 1.75  | 0.19     | 7.02   | 0.10    | 26.1   | 0.4     | 2.87  | 0.04     |
| 430,P2A | ped fines  | 1.45   | 0.02      | 1.6   | 0.2      | 11.47  | 0.16    | 48.4   | 0.8     | 4.47  | 0.06     |

| sample  | Co ppm | Co s.d. | Ni ppm | Ni s.d. | Zn ppm | Zn s.d. | As ppm | As s.d. | Se ppm | Br ppm | Br s.d. |
|---------|--------|---------|--------|---------|--------|---------|--------|---------|--------|--------|---------|
| 429,P1B | 5.72   | 0.08    | 21     | 9       | 68.2   | 1.4     | 5.3    | 0.3     | <0.3   | 2.4    | 0.3     |
| 429,P2A | 10.04  | 0.14    | <50    |         | 100    | 10      | 9.1    | 0.6     | <0.9   | 3.6    | 0.4     |
| 430,P1B | 6.49   | 0.09    | 12     | 6       | 74     | 8       | 5.2    | 0.3     | <0.4   | 0.90   | 0.15    |
| 430,P2A | 9.28   | 0.13    | 40     | 13      | 105    | 10      | 8.0    | 0.3     | <0.5   | 2.3    | 0.3     |

| sample  | Rb ppm | Rb s.d. | Sr ppm | Sr s.d. | Zr ppm | Zr s.d. | Ag ppm | Sb ppm | Sb s.d. | Cs ppm | Cs s.d. |
|---------|--------|---------|--------|---------|--------|---------|--------|--------|---------|--------|---------|
| 429,P1B | 126    | 2       | 304    | 13      | 380    | 14      |        | 0.82   | 0.03    | 4.58   | 0.07    |
| 429,P2A | 136    | 3       | 342    | 20      | 820    | 20      | <0.5   | 1.48   | 0.04    | 6.89   | 0.11    |
| 430,P1B | 122.4  | 1.8     | 268    | 8       | 295    | 9       | <1.0   | 0.98   | 0.02    | 5.71   | 0.08    |
| 430,P2A | 148    | 3       | 252    | 17      | 347    | 18      |        | 1.45   | 0.04    | 9.31   | 0.14    |

| sample  | Ba ppm | Ba s.d. | La ppm | La s.d. | Ce ppm | Ce s.d. | Nd ppm | Nd s.d. | Sm ppm | Sm s.d. |
|---------|--------|---------|--------|---------|--------|---------|--------|---------|--------|---------|
| 429,P1B | 799    | 19      | 60.8   | 0.9     | 111.9  | 1.6     | 44     | 3       | 7.37   | 0.10    |
| 429,P2A | 650    | 20      | 70.3   | 1.0     | 144    | 2       | 53     | 5       | 9.38   | 0.14    |
| 430,P1B | 672    | 14      | 47.3   | 0.7     | 85.8   | 1.2     | 36     | 2       | 6.19   | 0.09    |
| 430,P2A | 531    | 17      | 46.5   | 0.7     | 88.8   | 1.3     | 35     | 3       | 6.61   | 0.09    |

\* All elemental data determined by instrumental neutron activation analysis.

\*\* Abundances of minerals and detritus determined by quantitative x-ray diffraction.

\*\*\* Chemical and mineralogic data listed in these tables represent work in progress. For this report discussions of data in the text focus on analysis of Fe, Sc, and lanthanide-element chemical data, and on mineralogic data. Mineralogic data are presented as *calcite*, *opal*, and *detritus*; the category of *detritus* includes all primary materials of the igneous rocks that are sources for detritus in the calcretes and overlying soils, as well as smectite clays that are products of weathering in the Bt soil horizons.

\*\*\*\* All data collected by Los Alamos National Laboratory after January 22, 1991.

Table B-14. INAA and XRD Data for Bt Soil Samples  
(Page 2 of 2)

| sample  | Eu ppm | Eu s.d. | Tb ppm | Tb s.d. | Yb ppm | Tb s.d. | Lu ppm | Lu s.d. | Hf ppm | Hf s.d. |
|---------|--------|---------|--------|---------|--------|---------|--------|---------|--------|---------|
| 429,P1B | 1.19   | 0.02    | 0.811  | 0.019   | 2.64   | 0.04    | 0.405  | 0.010   | 9.33   | 0.16    |
| 429,P2A | 1.43   | 0.03    | 1.08   | 0.03    | 4.18   | 0.07    | 0.673  | 0.016   | 21.4   | 0.4     |
| 430,P1B | 1.076  | 0.015   | 0.703  | 0.013   | 2.47   | 0.04    | 0.384  | 0.009   | 7.98   | 0.12    |
| 430,P2A | 1.04   | 0.02    | 0.83   | 0.02    | 3.34   | 0.05    | 0.525  | 0.012   | 9.79   | 0.20    |

| sample  | Ta ppm | Ta s.d. | W ppm | W s.d. | Au ppb | Au s.d. | Th ppm | Th s.d. | U ppm | U s.d. |
|---------|--------|---------|-------|--------|--------|---------|--------|---------|-------|--------|
| 429,P1B | 1.35   | 0.04    | 2.1   | 0.4    | <4     |         | 15.7   | 0.2     | 3.10  | 0.11   |
| 429,P2A | 1.81   | 0.05    | 2.8   | 0.8    | <5     |         | 25.0   | 0.4     | 5.42  | 0.20   |
| 430,P1B | 1.23   | 0.02    | 1.7   | 0.4    | <3     |         | 15.5   | 0.2     | 4.24  | 0.12   |
| 430,P2A | 1.55   | 0.05    | 2.5   | 0.3    | 4.8    | 2.4     | 19.8   | 0.3     | 5.19  | 0.15   |

| sample  | calcite | cc s.d. | opal | op s.d. | clay &<br>detritus | clay &<br>det s.d. |
|---------|---------|---------|------|---------|--------------------|--------------------|
| 429,P1B | 0       | <1      | 15   | 1       | 85                 | 4                  |
| 429,P2A | <1      | <1      | 32   | 3       | 68                 | 4                  |
| 430,P1B | 0       | <1      | 27   | 2       | 73                 | 4                  |
| 430,P2A | 0       | <1      | 41   | 4       | 59                 | 4                  |

- \* All elemental data determined by instrumental neutron activation analysis.
- \*\* Abundances of minerals and detritus determined by quantitative x-ray diffraction.
- \*\*\* Chemical and mineralogic data listed in these tables represent work in progress. For this report discussions of data in the text focus on analysis of Fe, Sc, and lanthanide-element chemical data, and on mineralogic data. Mineralogic data are presented as *calcite*, *opal*, and *detritus*; the category of *detritus* includes all primary materials of the igneous rocks that are sources for detritus in the calcretes and overlying soils, as well as smectite clays that are products of weathering in the Bt soil horizons.
- \*\*\*\* All data collected by Los Alamos National Laboratory after January 22, 1991.

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**APPENDIX C**  
**QUALIFICATION OF DATA**

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Much of the collection and analysis of samples which provide the basis for the DOE conclusions in this report occurred prior to NRC acceptance of DOE's Quality Assurance Requirements Document (QARD) (DOE, 1990). For the purpose of data qualification, OCRWM acceptance of the principal investigators' QA programs is noted to be September 12, 1990, for the U.S. Geological Survey (USGS) and January 22, 1991, for Los Alamos National Laboratory. DOE policy states that the determination of which existing data need qualification and the method of that qualification will be made on a case-by-case basis as components of the license application are prepared (Roberts to Holonich, 1992). It is premature to decide whether any of the existing data summarized in this report will be the primary data on which a licensing position is based. Appendices A and B identify the Los Alamos and USGS data and summarize information about the QA programs under which they were collected. Qualification of these data will be undertaken in the future, if the DOE chooses to use the data to support a licensing position.

### U.S. Geological Survey (USGS) Data

The USGS data used in support of this paper are provided in Appendix A. The tables are split into three categories, 1) data collected under the approved QA program (beginning September 12, 1990); 2) data collected under the same, but not yet approved, program (May 3, 1989 through September 11, 1990); and 3) data collected prior to that program (1986 through May 2, 1989).

All data were collected, both before and after acceptance of the QA program, with approved USGS Technical Procedures and to equivalent QA programs. The methods of data collection have not varied substantially throughout the years; therefore, the qualified data can substantiate the USGS's level of confidence in the quality and reliability of data collected prior to program approval.

The strontium isotope ratios were determined on three different solid-source, thermal ionization, mass spectrometers: (1) a NIST 6-inch, (2) a VG Isomass 54E, and (3) a Finigan MAT 262. In order to eliminate the effects of instrumental differences, all data were adjusted to a scale on which the  $^{87}\text{Sr}/^{86}\text{Sr}$  for USGS standard EN-1 is 0.70920. This standard is used routinely on all three instruments for calibration. The  $\delta^{87}\text{Sr}$  notation is derived from the following transformation:  $\delta^{87}\text{Sr} = \{[(^{87}\text{Sr}/^{86}\text{Sr})/0.70920] - 1\} * 1000$  where the value of 0.70920 represents the mean  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio for modern sea water.

Samples analyzed in 1988 were collected prior to approval of the YMP-USGS QA Program. Samples analyzed in 1990 and later were controlled by the YMP-USGS QA Program that was approved September 12, 1990.

Conclusions reached in the working paper rely in part on samples collected prior to, and outside of, the current USGS QA program:

The data from Quade and Cerling (1990), Benson and Klieforth (1989), and Winograd et al. (1988), were not developed under a qualified QA program; however, these data have been published in refereed scientific journals.

The data from Benson and McKinley (1985) and Winograd and Thordarson (1975) were collected prior to approval of the YMP-USGS QA program; however, these data were published by the USGS and received internal technical review.

The data from Osmond and Cowart (1982), Environmental Protection Agency (EPA, 1976), and Zielinski and Rosholt (1978) were collected outside of the USGS QA program, however, they agree with YMP-USGS approved  $^{234}\text{U}/^{238}\text{U}$  data collected under the current QA program at wells J-12 and J-13.

The data from Rosholt et al. (1985) were collected by the USGS prior to approval of the QA Program; however, since then the same laboratory has used the same equipment and procedures to produce data qualified under the approved program.

Additionally a question as to possible contamination of water samples by drilling fluids has been considered. Stuckless et al. (1991) have noted that there is a regional pattern in the isotopic data for hydrogen, oxygen, and carbon which would not be expected if there were variable contamination. The carbonate carbon data show mixing relations that can be accounted for by three known end members. The data are internally consistent showing no differential contamination. Additionally, oxygen and hydrogen are greatly concentrated in water, therefore contamination would have little if any measurable effect on the analyses. If carbon isotopes were contaminated by drilling fluid, the most likely contaminant would be detergent and the introduced carbon would be organic. Carbon analysis is done by precipitating inorganic carbon and analyzing the precipitates. Organic carbon stays in solution, thereby being separated from the inorganic carbon and is not analyzed. Confirmatory samples of water from wells J-12, J-13, VH-1, and VH-2 have been taken. Analyses for stable isotopes under the qualified QA program are in progress to confirm the early data.

#### Los Alamos National Laboratory Data

The Los Alamos National Laboratory data used in support of this paper are provided in Appendix B. The Los Alamos National Laboratory-YMP quality assurance program was approved by OCRWM on January 22, 1991. Los Alamos National Laboratory participation in the calcite-silica studies has been in progress from 1984 through 1992. During this period, prior to January 22, 1991, Los Alamos National Laboratory was developing a quality assurance program to required standards (10 CFR Part 60, 1993). All data collected during the study period followed detailed technical procedures and applicable quality procedures of the Los Alamos National Laboratory-YMP QA program in effect at the time, and the methods of data collection and analysis have not changed substantially during this period. Data collected before the approval of the Los Alamos National Laboratory-YMP QA program are identified in each table of Appendix B.

The OCRWM-approved Los Alamos National Laboratory-YMP QA program includes numerous detailed technical procedures and quality procedures governing the collection of data for calcite-silica studies. Early versions of these procedures, accepted by Los Alamos National Laboratory-YMP according to the requirements of the QA program in effect at the time, governed data collection prior to acceptance of the QA program by OCRWM.

All work predating OCRWM acceptance of the Los Alamos National Laboratory-YMP QA program was performed in accordance with good scientific practice and the QA program in existence at the time. Traceability of the samples from the field to Los Alamos National Laboratory is documented in notebooks and log books.

The same analytical systems — electron microprobe, x-ray diffraction, x-ray fluorescence, and scanning electron microscope — have been in use during the calcite-silica study, both before and after OCRWM approval of the QA program. The acceptability of quantitative analytical results has always been based on the use of standards.

The INAA data acquired by outside contract were collected after OCRWM approved the Los Alamos National Laboratory-YMP QA program. QA requirements for such work include vendor certification and specification of accept/reject criteria for the data.

Collaboration with an independent outside researcher, Professor David Cowan of the University of Missouri, on ESR dating predated acceptance of the Los Alamos National Laboratory QA program. The samples themselves are traceable and sample preparation done at Los Alamos National Laboratory was performed in accordance with existing QA requirements. Research performed by the outside collaborator followed good scientific practice and the results have been submitted to a refereed journal. The interpreted results are included in a data table in Appendix B.

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#### CODE

10 CFR Part 60 (Code of Federal Regulations), 1993. Title 10, "Energy," Part 60, Subpart G, "Quality Assurance," Washington, D.C.: U.S. Government Printing Office, p. 127.

**APPENDIX D**  
**PLATES**

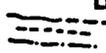
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**LEGEND**

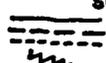
**Plates 1-6. Geologic Sections of North and South Wall of Trench 14 \***

**EXPLANATION FOR PLATES 1-6**

**TERTIARY VOLCANIC ROCKS**

 **LITHOLOGIC UNIT BOUNDARIES**—Solid line where contact is clear; dashed where inferred; dot-dashed where transitional

Unit 2 **LITHOLOGIC UNIT DESIGNATION**

 **SOIL-HORIZON BOUNDARIES**—Solid line at lithologic discontinuities; dashed at soil horizon within the same lithologic unit; zigzagged at transitional contacts

38kq1 **SOIL-HORIZON DESIGNATION**

 **SOIL SAMPLE LOCATION**

\* HD-22 **ISOTOPE SAMPLE LOCATION**

 **CALCIUM CARBONATE STRINGERS**—Schematic; location and spacing are generalized; orientation of stringers is accurate

 **CALCIUM CARBONATE PLATELETS**—Schematic; location and spacing are generalized; orientation of platelets is accurate

 **OPALINE SILICA STRINGERS**—Boundaries are commonly distinct

 **FRACTURES AND FAULTS**—Strike and dip are recorded in degrees, dashed and dotted were approximately located; queried where inferred

 **FRACTURE FACES**—Orientation recorded in degrees

I-V **MAIN VERTICAL VEIN NUMBERS**

 **BLACK ASH-FILLED FRACTURES**

fracture 1 **FRACTURE NUMBERS IN SLOPE-WASH ALLUVIUM**

 **RECESS IN WALL**—Due to collapse, excavation, or open fractures

 **LEDGE**—Due to excavation

 **COBBLES AND BOULDERS**—Composed of tuff

YM-14  
10-14  **SAMPLE INTERVAL FOR URANIUM-TREND DATING**—Dashed were approximately located; queried where inferred

 **PLANT**

 **ROOT**

 **NWT—HIGHLY FRACTURED NONWELDED TUFF**

 **IT—SLIGHTLY FRACTURED INTACT TIVA CANYON MEMBER, PAINTBRUSH TUFF**

 **HFT—HIGHLY FRACTURED TIVA CANYON MEMBER, PAINTBRUSH TUFF**

 **CCT—CARBONATE-CEMENTED AND FRACTURED TIVA CANYON MEMBER, PAINTBRUSH TUFF**

 **DCT—DENSELY CARBONATE-CEMENTED AND FRACTURED TIVA CANYON MEMBER, PAINTBRUSH TUFF**

**FAULT ZONE—BRECCIA AND VEINS**

 **NWB—NONWELDED TUFF FAULT BRECCIA**

 **UFB—UNCEMENTED TIVA CANYON MEMBER FAULT BRECCIA**

 **SFB—SILICA-CEMENTED TIVA CANYON MEMBER FAULT BRECCIA**

 **CB—CEMENTED CATACLASTIC FAULT BRECCIA**

 **VF—VEIN FILLING**

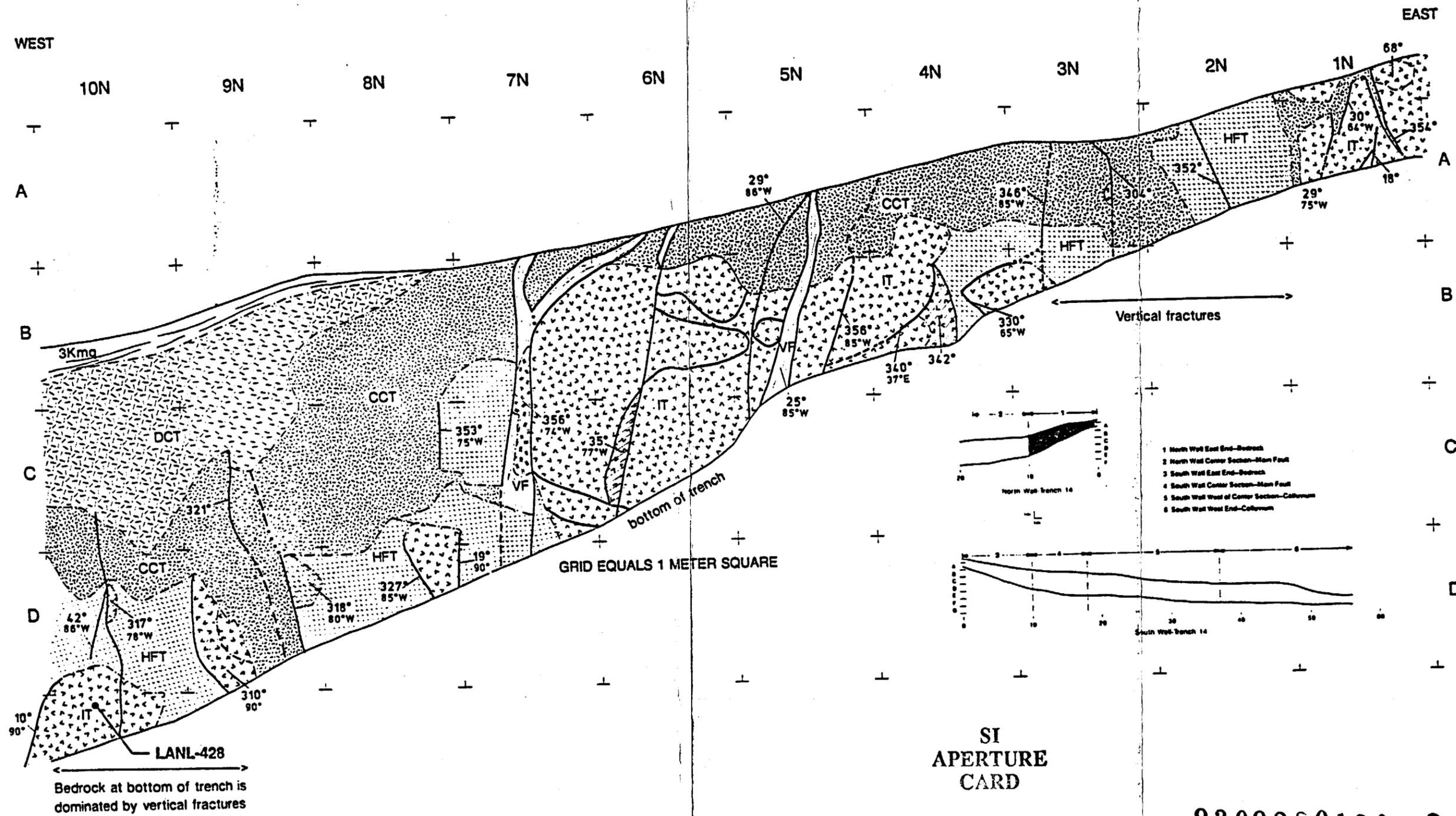
**SLOPE-WASH ALLUVIUM AND COLLUVIUM**

 **SLOPE-WASH ALLUVIUM**

 **COLLUVIUM**—Colluvial wedges adjacent to bedrock scarp

\*Note: Geologic sections mapped previous to deepening of Trench 14 in 1991.

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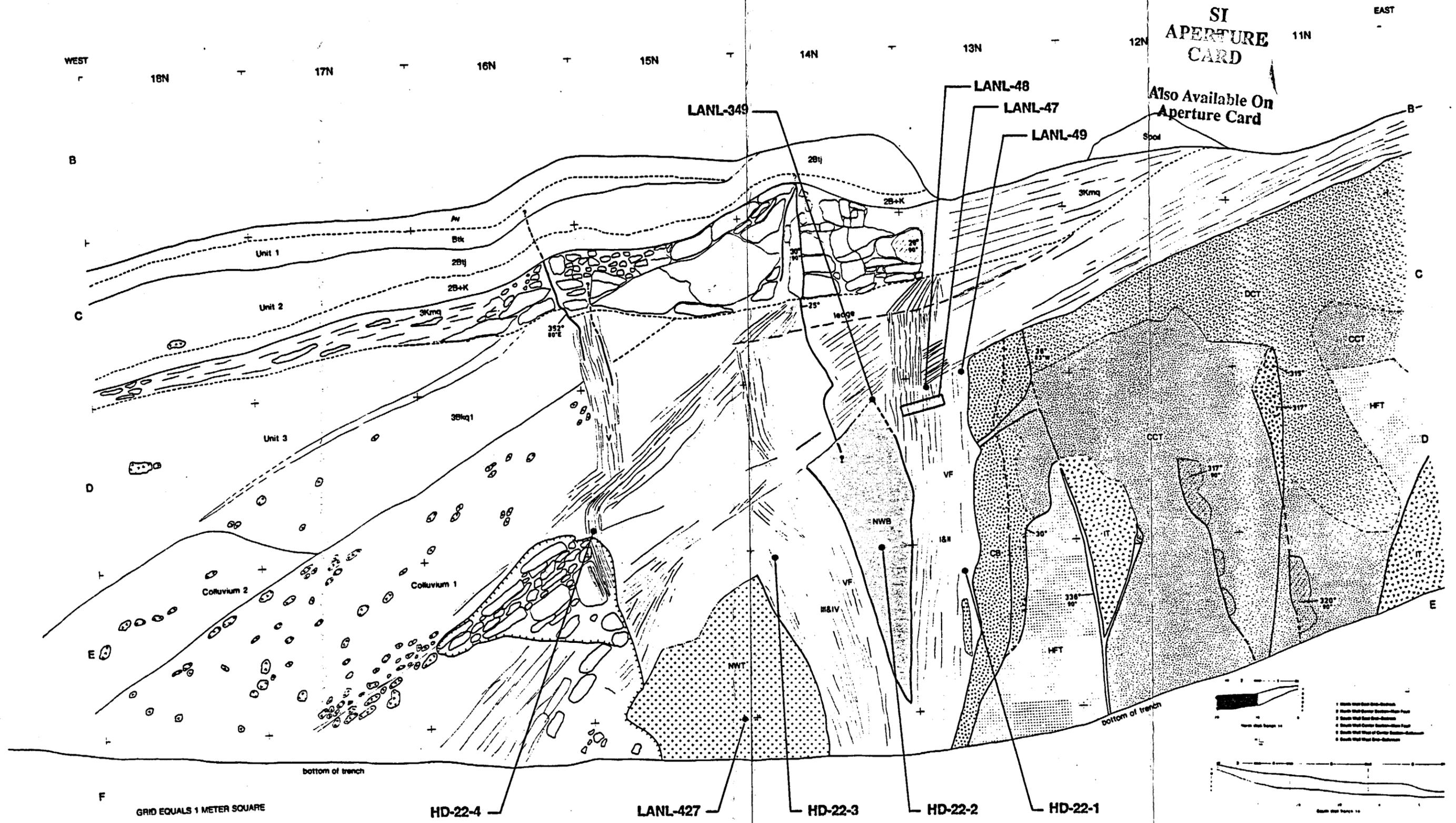


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A. Geologic Section Showing Bedrock Exposed on the North Wall, East of Trench 14 on the Bow Ridge Fault at Exile Hill, Nye County, Nevada

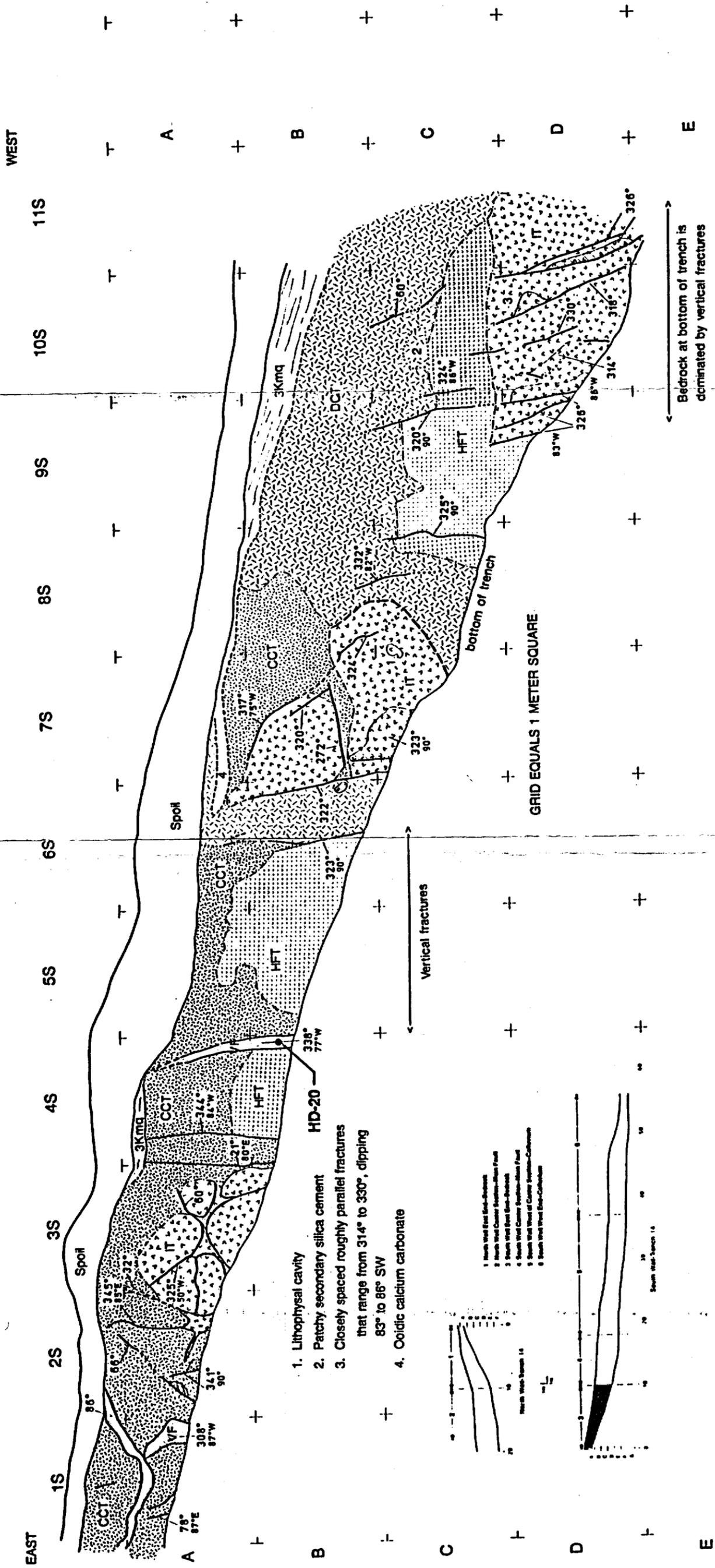


B. Geologic Section Showing the Main Fault Exposed on the North Wall, Center Section of Trench 14 on the Bow Ridge Fault at Exile Hill, Nye County, Nevada

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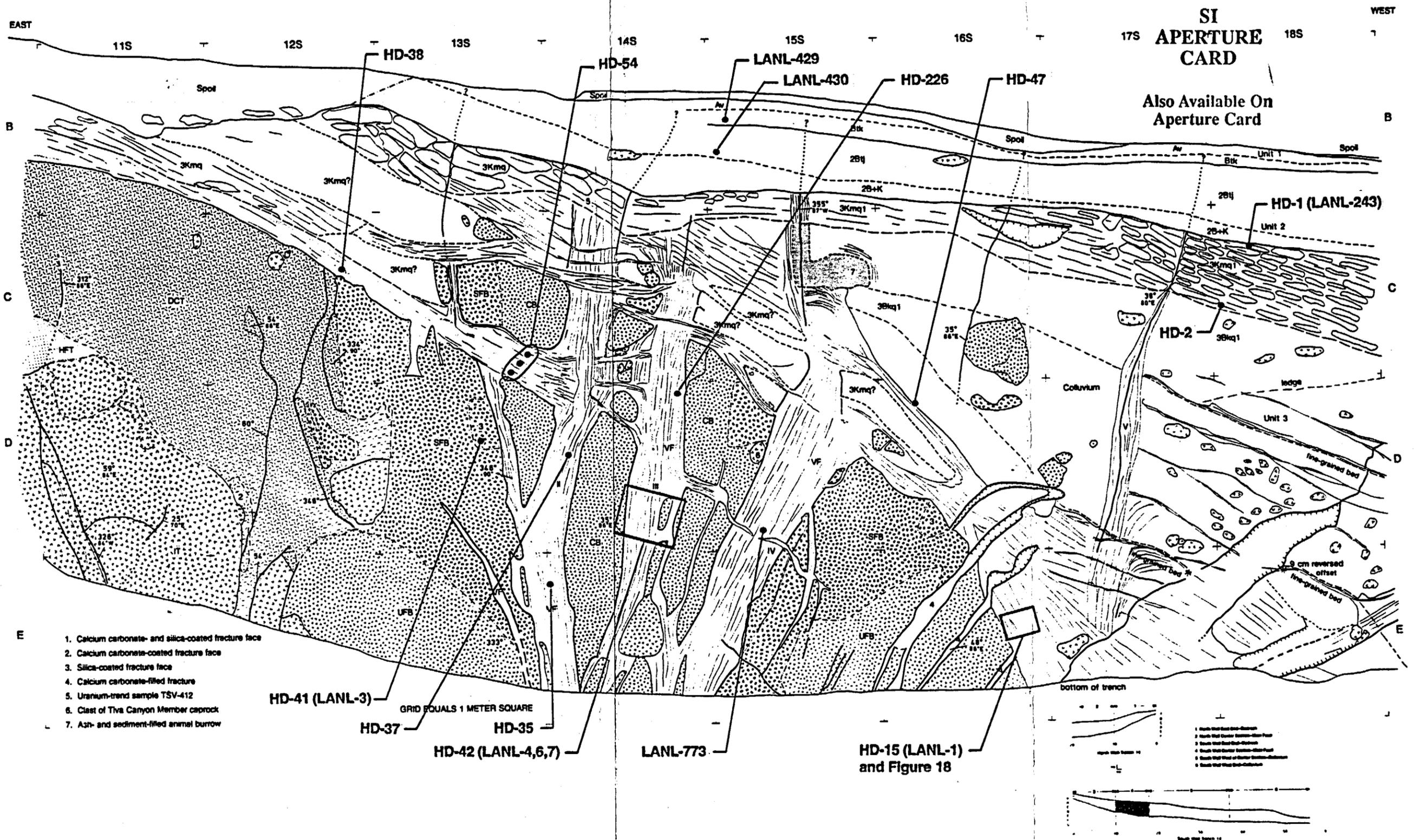


1. Lithophysal cavity
2. Patchy secondary silica cement
3. Closely spaced roughly parallel fractures that range from 314° to 330°, dipping 83° to 86° SW
4. Ooidic calcium carbonate

- 1 North Wall East Bed-Block
- 2 North Wall Center Bed-Block
- 3 North Wall East Bed-Block
- 4 North Wall Center Bed-Block
- 5 South Wall West of Center Bed-Block
- 6 South Wall East Bed-Block

9309230133-03

C. Geologic Section Showing Bedrock Exposed on the South Wall, East of Trench 14 on the Bow Ridge Fault at Exile Hill, Nye County, Nevada

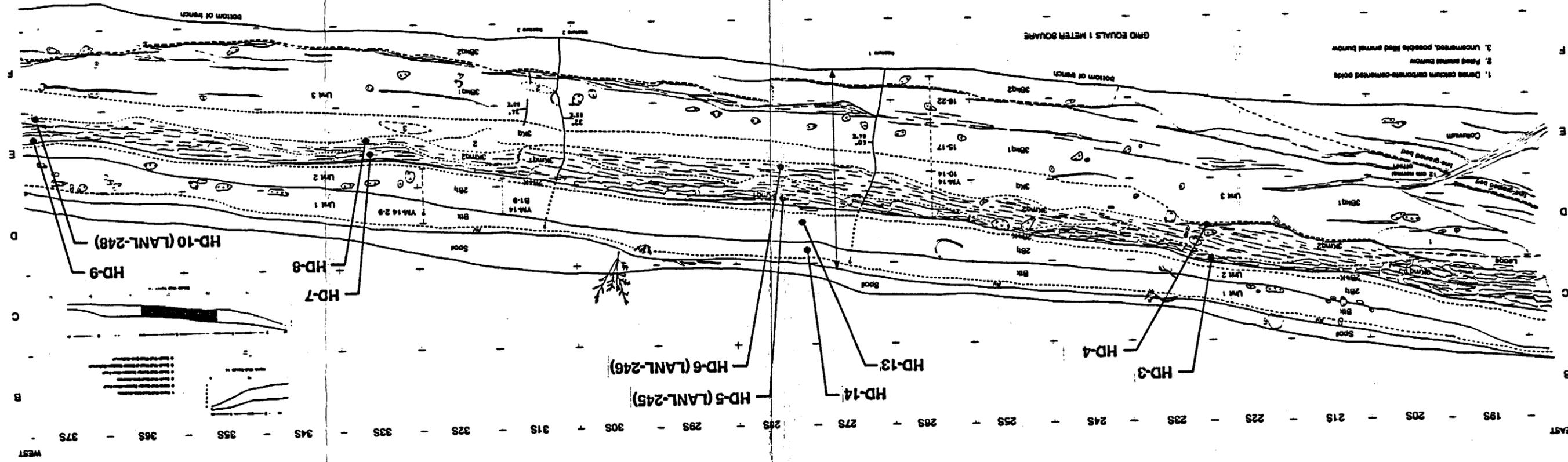


D. Geologic Section Showing the Main Fault Exposed on the South Wall, Center Section of Trench 14 on the Bow Ridge Fault at Exile Hill, Nye County, Nevada

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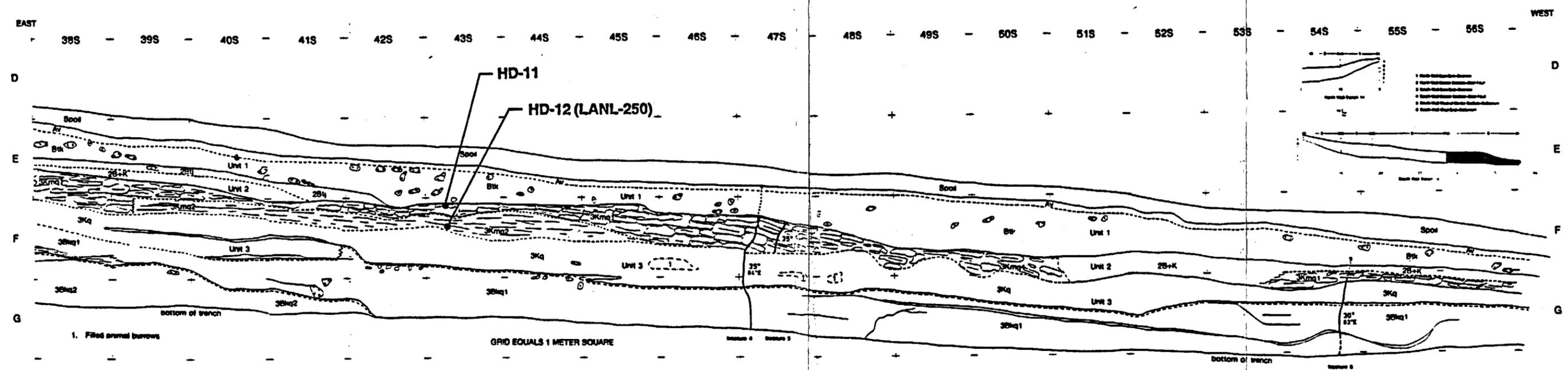
E. Geologic Section Showing the Slope-Wash Alluvium Exposed on the South Wall, West of the F. Center Section of Trench 14 on the Bow Ridge Fault at Exile Hill, Nye County, Nevada

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F. Geologic Section Showing the Slope-Wash Alluvium Exposed on the South Wall at the West End of Trench 14 on the Bow Ridge Fault at Exile Hill, Nye County, Nevada