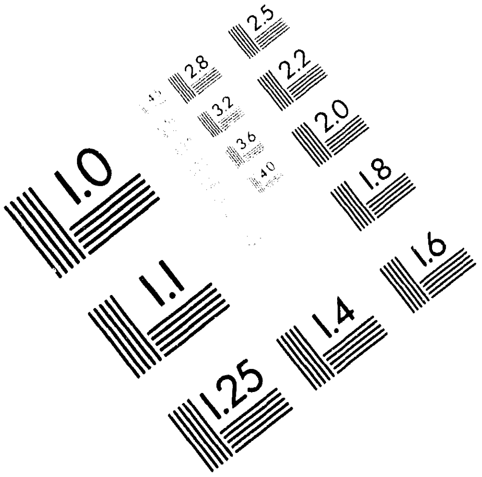

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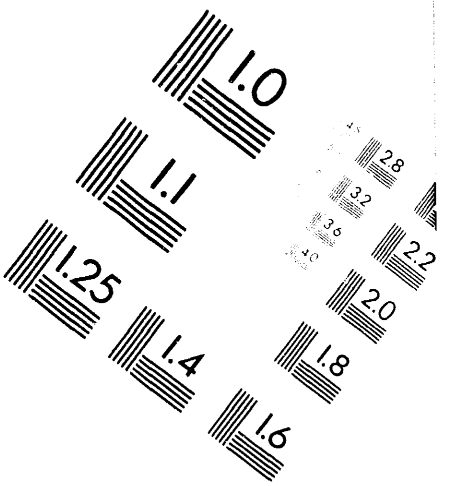

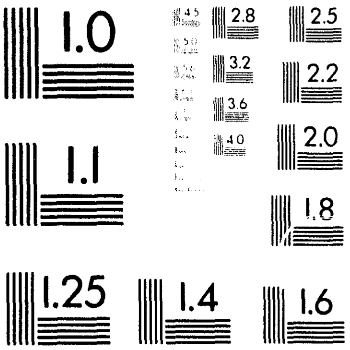

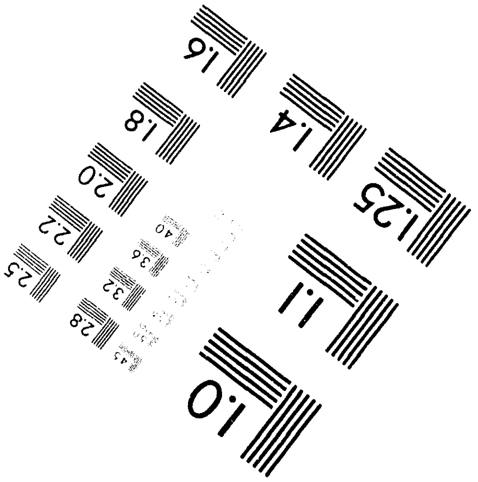

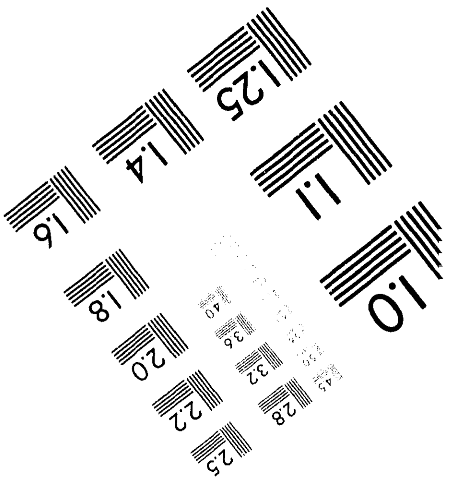

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Preliminary study of lead isotopes in the carbonate-silica veins of Trench 14, Yucca Mountain, Nevada

by

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Open-File Report 93-690

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CONTENTS

Abstract

The sub-vertical carbonate-silica veins filling the Bow Ridge Fault, where exposed in Trench 14 on the east side of Yucca Mountain, carry a lead isotopic signature that can be explained in terms of local sources. Two isotopically distinguishable—"silicate" and "carbonate"—fractions of lead are recognized within the vein system as well as in overlying surficial calcrete deposits. The acid-insoluble "silicate" fraction is contributed largely from the decomposing Miocene volcanic tuff, which forms the wall rock of the fault zone and is a ubiquitous component of the overlying soil. In addition to the opaline silica found abundantly in the veins, altered tuff, clays (including sepiolite), and iron oxides have been recognized in the insoluble residues. Lead contained in the "silicate" fraction ($^{206}Pb/^{204}Pb$ = 18.09-18.84 and $^{208}Pb/^{204}Pb$ = 38.51-39.16) approaches in isotopic composition that of the Miocene volcanic rocks of Yucca Mountain ($^{206}Pb/^{204}Pb$ = 18.12-18.35 and $^{208}Pb/^{204}Pb$ = 38.74-39.20), but diverges from it in some samples by being more enriched in uranogenic isotopes.

The "carbonate" fraction of lead in both vein and calcrete samples resides dominantly in the HCl- and CH_3COOH-soluble calcite. HCl evidently also attacks and removes lead from silicate phases, but the milder CH_3COOH dissolution procedure oftentimes identifies a significantly more radiogenic lead in the calcite ($^{206}Pb/^{204}Pb$ = 18.11-20.21 and $^{208}Pb/^{204}Pb$ = 38.60-39.34). Probably this radiogenic "carbonate" lead was transported into the vein system by the downward percolation of calcite-precipitating meteoric water that had previously interacted with surficial calcretes. Wind-blown particulate matter brought to the area from Paleozoic and Late Proterozoic limestones in surrounding mountains may be the ultimate source of the calcite. Several samples, however, including two from a vein incorporating a thin zone of basaltic ash, contain a "carbonate" lead that is only slightly different from their "silicate" lead. These isotopically more uniform samples suggest that locally the basaltic ash and other volcanic rock have contributed most of the lead to both fractions of the vein system.

The isotopically heterogeneous lead that is presumed to characterize the underlying Paleozoic and Late Proterozoic sedimentary rocks and Middle Proterozoic crystalline rocks remain a candidate for at least some of the lead in the Trench 14 veins. An important finding of this study, however, is that the data do not require the more exotic mechanisms or origins that have been proposed for the veins. Instead, the remarkably similar lead isotopic properties of the veins to those of the soil calcretes support their interpretation as a surficial, pedogenic phenomenon.

Introduction

Over the past several years controversy has arisen over the carbonate-silica veins filling the Bow Ridge Fault, where exposed in Trench 14 on the east side of Yucca Mountain (Taylor and Huckins, 1986; Szymanski, 1989). Problems associated with interpreting this geologic feature are the subject of several companion papers (Taylor, unpubl. report; Muhs and others, unpubl. report; Whelan and Stuckless, unpubl. report; Marshall and others, unpubl. report). The preliminary lead isotopic results reported herein complement these other studies, especially the strontium isotopic study of Marshall and others (unpubl. report), from which all of our samples from Trench 14 and Busted Butte have been obtained.

The prominent carbonate-silica veins occurring in the sub-vertical fault zone raise some major questions about the origin of such hydrogenic deposits and their implication for the integrity of the proposed repository. If the vein material is precipitated from meteoric waters percolating down through the soil into the fractured volcanic rocks along the fault, it may be considered a special type of pedogenic deposit. If, instead, it represents a spring or hydrothermal deposit formed from ascending ground water, the possibility that a recurrence of the phenomenon could breach the potential repository must be considered. Various possible scenarios, including a wetter climate, seismic pumping, and circulation of heated water, have been proposed to explain the hypothesized rise of fluid substantially above the present water table.

Acknowledgements

All of the samples analyzed for lead isotopes were provided by Zell Peterman, who, along with Brian Marshall, Richard Spengler, John Stuckless, and Emily Taylor, introduced the authors to the geology of Yucca Mountain and the fascinating hydrogenic deposits of Trench 14.

Strategy of Investigation

A considerable effort is being expended to characterize the carbonate-silica veins, including their detailed mapping, mineralogy, chemistry, and isotopic composition (Taylor, unpubl. report; Muhs and others, unpubl. report; Whelan and Stuckless, unpubl. report; Marshall and others, unpubl. report; Quade and Cerling, 1990). These workers generally favor a pedogenic origin for the veins, akin to that producing the abundant surficial calcretes of this arid area. Nonetheless, the discovery of some component of the veins uniquely derived from deeper strata would demand its upward conveyance, and extensive searches are being conducted for such exotic components. Underlying Paleozoic and Late Proterozoic sedimentary rocks and Middle to Early Proterozoic crystalline basement have been suggested as candidates for supplying this evidence. Of course, dissolution and precipitation during transport by a fluid is likely to afford us with only a chemical or isotopic expression of any far-traveled material, so any meaningful search must be able to see through its reconstituted form.

Radiogenic and stable isotopes offer an opportunity to identify an exotic component should it bear an isotopic label different from any local source. In order to employ this isotope fingerprinting technique, however, one must characterize both the vein itself and possible source materials from which it may have been derived. Constraints can then be placed upon the source material(s) that actually have contributed to the formation of the vein. In particular, if all local material is thereby eliminated as the sole source, one must look elsewhere for at least some of the element under investigation.

The several chemical elements (Sr, Nd, Pb, O, C) that lend themselves to isotopic fingerprinting are generally distributed differently among the phases of the vein system. Unlike strontium, which is contained dominantly in the carbonate and behaves as an analog of calcium, lead occurs in significant amounts in both the carbonate and silica phases of the vein and calcrete samples. It also became evident at the onset of our study that the lead residing in these separate phases is not isotopically identical, but reflects at least two contributing source materials. Clearly, the carbonate and silica—hereafter referred to as silicate, itself being a mixture of opaline silica, altered rhyolitic tuff, clays (including sepiolite), and iron oxides—phases have not isotopically equilibrated, and the vein material cannot be interpreted solely as a precipitate from an aqueous solution.

The purpose of this study is to gain information about the source materials that have contributed to the Trench 14 carbonate-silicate veins based on a lead isotope characterization of the vein and other rocks from which the lead may have been derived. The results will be shown to be compatible with an entirely local derivation of lead in both the carbonate and silicate phases. Combined with other isotopic, geochemical, and geologic investigations, our data provide additional supportive evidence that the Trench 14 veins need not contain an exotic, deep component, but are, in fact, best interpreted as a pedogenic phenomenon.

Analytical procedure

All new lead isotopic analyses reported in this paper were performed on samples of carbonate-silicate material and volcanic rock that have been previously studied by other investigators. A detailed cross-section of Trench 14, which includes a grid for locating the vein and calcrete samples, is given in the companion paper of Taylor (Fig. 2 and 3, unpubl. report). An additional vein and a rhizolith sample from Busted Butte have been described by Marshall and others (unpubl. report). Composite samples from drill-hole USW-G1 core that were originally prepared for radioelement measurement (Bush and others, 1983) together with four surface samples of the Tiva Canyon Formation—two from Trench 14A (Marshall and others, unpubl. report) and two from the crest of Yucca Mountain (Z. E. Peterman, U.S. Geological Survey, oral communication, 5/89)—are used to characterize the local Miocene volcanic rocks.

Powdered samples of carbonate-silicate rock were first leached in either HCl or CH_3COOH (acetic acid) to dissolve the carbonate and separate it from admixed silicates. After centrifuging the reacted sample, the supernatant liquid was separated from the residue, taken to dryness, redissolved in HCl, and basified with NH_4OH. The precipated hydroxides, which contain the U, Th, and Pb, were then chemically processed similarly to dissolved silicates (see below).

Initially, the same chemical procedure as that used by Marshall and others (unpubl. report) for the analysis of strontium isotopes was employed, whereby the carbonate is dissolved in 1.5N HCl and decanted from the silicate residue. A change to 0.8N CH_3COOH was necessitated, however, because the HCl was found to also remove significant amounts of U, Th, and Pb from non-carbonate phases of the sample. Although a lack of reproducibility between duplicate sample analyses involving the more reactive HCl served to identify the isotopically heterogeneous nature of the vein and calcrete material, subsequent analyses have sought to make a cleaner separation of the calcite from the silicate phases. There is no proof that the CH_3COOH produces a completely pure separation, either, but the results obtained with it are reproducible and reveal a lead generally more enriched in uranogenic isotopes for the calcite than the corresponding HCl leach.

The silicate analyses have been performed by procedures similar to those described by Tatsumoto and others (1972) with modifications by Arden and Gale (1974) and Zartman and others (1986). The volcanic rocks and the silicate residues from the leached carbonate-silicate material lend themselves to a straightforward application of these techniques. Approximately 50 to 100 mg of sample, to which HF, HNO_3, and $HClO_4$ have been added, are digested in enclosed teflon containers in a microwave oven. A separate aliquot of the sample is spiked with isotopic tracers and submitted to a parallel chemistry. After the dissolved sample is evaporated to dryness and converted to bromide-anion form, lead is removed by ion-exchange chromatography. The solution retained from the spiked lead ion-exchange separation is then evaporated to dryness, converted to nitrate-anion form, and subjected to ion-exchange chromatography for recovery of uranium and thorium.

The Pb, U, and Th blanks for the total analytical procedure are 0.5 ± 0.2 nanograms, 0.02 ± 0.01 nanograms, and 0.02 ± 0.01 nanograms, respectively. Based on sample weights of 80-150 milligrams, these blank levels have a minor to negligible effect on the concentration and lead isotope composition determinations. Nevertheless, such corrections have been applied to the raw data, and are included in the tabulated results. The Pb analysis most affected, the acetic acid leached "carbonate" fraction of sample HD-31-2 vein, is reduced by about 1 percent in concentration but changes less than 0.1 percent in isotopic composition by the blank correction.

All isotopic analyses were carried out on a VG Micromass 54E 12-inch, solid-source mass spectrometer operating in an automated mode. Raw measured lead ratios have been corrected for mass discrimination by application of normalizing factors obtained from analyzing the NBS 981 lead standard. The reported lead ratios are accurate to within ± 0.05 percent per atomic mass unit (95 percent confidence level), and U, Th, and Pb concentrations obtained by isotope dilution measurement are accurate to ± 1 percent (95 percent confidence level). For this preliminary study only the Pb-isotope composition has been measured on the volcanic rocks, and we rely on published U and Th concentrations (Bush and others, 1983) and approximately Pb chemical yields (5-20 ppm) to support our assertion of negligible postcrystallization growth of radiogenic lead.

Results

This work draws upon a data base consisting of both new and published determinations of lead isotopic composition for a variety of materials in and outside the possible repository area at the Yucca Mountain Site. To date, we have included in the lead isotope study only samples previously analyzed for strontium isotopes (Marshall and others, unpubl. report; Z. E. Peterman, U.S. Geological Survey, written communication, 10/89). The analytical results for "carbonate" and "silicate" fractions of the Trench 14 veins and calcrete, and for selected volcanic rocks from Yucca Mountain are presented in Tables 1 and 2, respectively. The pertinent isotopic ratios are also shown graphically as plots of $^{206}Pb/^{204}Pb$ vs. $^{207}Pb/^{204}Pb$ and $^{206}Pb/^{204}Pb$ vs. $^{208}Pb/^{204}Pb$ in

Figure 1 with the lines joining together the "carbonate" and "silicate" fractions of individual samples. Preliminary analyses, which used HCl to dissolve the carbonate from bulk vein and calcrete samples, confirmed the presence of at least two separate isotopic components of lead. In order not to lose this additional information, a chemical procedure whereby vein and calcrete samples are divided into CH_3COOH-soluble ("carbonate") and insoluble ("silicate") fractions was employed during most of the study. An x-ray diffraction examination of the bulk sample and the dried insoluble fraction following leaching suggests that we have been largely successful in removing the carbonate—determined to be quite pure calcite—while leaving the silicate phases essentially intact.

The resulting isotopic ratios determined on the "carbonate" and "silicate" fractions demonstrate appreciable variability both within and among samples (Table 1 and Figure 1). For all but one sample (HD-42-10 vein), the $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ values increases in the order: "silicate" fraction, "carbonate" fraction leached by HCl, "carbonate" fraction leached by CH_3COOH. The "silicate" fractions cluster around $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ of 18.4 ± 0.2 and 39.0 ± 0.2, respectively, and 5 out of 13 of the "carbonate" fractions leached by CH_3COOH cluster around $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ of 20.0 ± 0.2 and 39.25 ± 0.08, respectively. Most of the remainder of the "carbonate" fractions leached by CH_3COOH and those leached by HCl assume intermediate values.

Fourteen analyses of the Miocene volcanic rocks, which comprise most of the bedrock of Yucca Mountain, are reported in Table 2 and shown on Figure 1. Important to this study is the relatively tight grouping of the lead isotopic ratios ($^{206}Pb/^{204}Pb$ = 18.12-18.25 and $^{208}Pb/^{204}Pb$ = 38.74-39.20) for all the rocks, although note is made of the gross inverse correlation observed between $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ for the suite as a whole. Additionally, the lead isotopic composition of three Quaternary hawaiites from Crater Flat west of Yucca Mountain has recently been published by Farmer and others (1989). Ordinarily, these outlying cinder cones might be considered as insignificant compared to the extensive area of Miocene volcanic rocks, but the presence of basaltic ash layers within the Trench 14 vein system raises special interest in these nearby young basalts (for example, see discussion of the effect of this basaltic ash on the strontium isotopes, Marshall and others, unpubl. report). Thus, the Crater Flat basalt analyses, which differ only slightly in lead isotopic composition from the Miocene rocks, are also shown plotted on Figure 1.

A compilation of published rock lead isotopic composition (Doe, 1976) has been used to characterize other potential source materials in lieu of new analyses on local rocks. Specifically, the isotope fields of Paleozoic and Proterozoic sedimentary rocks and Proterozoic metamorphic and igneous rocks are defined from this worldwide data set (Figure 2). Although demonstrating the extremely wide range in lead isotopic composition possible for these types of rocks, this broad characterization of the upper crust does not permit the fingerprinting of individual lithologic units in the area. On the other hand neither does it rule out some average sample of such older rocks as an ultimate source of the lead constituting one component of the veins and soil calcretes. As we shall discuss, however, the question of ultimate source, while scientifically interesting, probably lies beyond the scope of this investigation. Not available at this initial stage of the study are analyses of the lead contained in ground water underlying the design repository area.

Some comments about the abundances of U, Th, and Pb in the analyzed samples are relevant to the interpretation of the isotopic data. In every instance for which both "carbonate" and "silicate" fractions of vein and calcrete samples have been analyzed, the latter fraction (1.1-63.2 ppm Pb) contains a higher concentration of Pb—by a factor of 2-6 for CH_3COOH-leached carbonate—than the former (0.5-10.9 ppm Pb). Also, higher Pb abundances occur and, usually, a greater proportion of the sample is removed in the HCl- as compared to CH_3COOH-leached "carbonate" fractions. Together with the trend in isotopic ratios, material balance calculations based on Pb concentrations support our contention that the lead in the vein and calcrete samples generally can be best understood as mixtures of two components, an acid-soluble "carbonate" and a residual "silicate".

Although some similarity to the Pb behavior is also shown by the U and Th, these two elements exhibit additional complexities not fully decipherable with the present limited data. The partitioning of these radioactive elements, as revealed by their highly variable abundances and U/Th, appears to be quite complicated. In comparing the "silicate" fractions (Table 1) with the volcanic rocks (Table 2), one observes U contents in the "silicate" fractions equal to or higher by as much as a factor of 3, and Th contents lower by a factor of 2 to 20 than the volcanic rocks. Possibly the explanation involves an overall reduction in abundances due to a diluting effect of the opaline silica combined with selective absorption of U on some (clay or opaline silica?) silicate phase. Estimated modal composition of the "silicate" fractions (D.T. Vaniman, Los Alamos National Laboratory, written communication, 3/90), however, reveals no obvious correlation between their mineralogy and U, Th, or Pb concentrations.

Discussion

It is immediately apparent from Figure 1 that the veins have a lead isotopic composition essentially indistinguishable from that of the pedogenic calcretes. For those samples where a difference in isotopic composition was determined between "silicate" and "carbonate" fractions, the latter is always more enriched in its uranogenic isotopes than the former. Although all of the "silicate" and "carbonate" pairs do not show isotopically identical patterns, a clustering of the data does occur, which we will interpret as end-member isotopic compositions. In terms of these end-members, the "silicate" fraction has a $^{206}Pb/^{204}Pb$ of 18.4 ± 0.2, and the "carbonate" fraction has a distinctly more uranogenic $^{206}Pb/^{204}Pb$ of 20.0 ± 0.2. The "carbonate" fraction end-member is also distinguished by having a slightly higher $^{208}Pb/^{204}Pb$ of 39.25 ± 0.08, compared to 39.0 ± 0.2 for the "silicate" fraction end-member. Such a pattern common to both the veins and calcretes can be readily explained (1) if the "silicate" fraction originated largely from the Miocene volcanic rocks and their alteration products, and (2) if the calcite, comprising the dominant phase of the "carbonate" fraction, was precipitated from a surficial aqueous solution.

Several conspicuous exceptions to this pattern of end-member mixtures exist, however, which do demand a special explanation. Samples HD-42-10 and HD-42-12 show very little isotopic difference between their "silicate" and "carbonate" fractions, the latter of which is only slightly displaced from the volcanic rock field. When the proximity of these two samples to a thin basaltic ash layer within the same vein sample (Marshall and others, unpubl. report) is taken into consideration, the close agreement of their isotopic composition to the two Crater Flat basalt analyses becomes especially noteworthy. We may speculate that locally the basaltic ash has contributed most of the lead to both fractions of the vein material. A similar homogenization of "silicate" and "carbonate" lead is found in vein samples HD-22-2 and HD-28-2, and, perhaps more surprisingly, calcrete sample HD-9 and rhizolith sample HD-63-3. In these latter cases, however, the Miocene volcanic rocks rather than basaltic ash, which is unknown in the vicinity of these samples, seems more likely to be the primary contributor of the lead. With the limited data presently available, it cannot be determined how often the "carbonate" fraction of either vein material or calcrete will deviate from the suggested end-member isotopic composition.

The dominance of tuffaceous, rhyolitic rocks in local outcrops, their identification as a major clastic component of the veins and calcrete, and the similarity in isotopic composition make them the prime candidate for contributing most of the lead to the "silicate" fractions. Although inconsistencies in U and Th abundances argue against a purely mechanical mixing of volcanic rock into the vein and calcrete samples, the survival of its isotopic fingerprint despite profound chemical modification demonstrates the power of the isotopic technique. In one instance, however—that of the "silicate" fraction in vein sample HD-54-5—another source component, in addition to the volcanic rock and the "carbonate" fraction, must be entertained to explain its unusually low $^{208}Pb/^{204}Pb$. Presently, that low $^{208}Pb/^{204}Pb$ component has not been identified, but the anomalous ratio has been confirmed by a duplicate analysis.

The radiogenic lead characterizing the calcite, which is the dominant phase in all of the "carbonate" fractions, can be explained as a constituent of intermittent meteoric water that has been in contact with surficial minerals. Repeated dissolution and precipitation of soluble salts almost certainly contributes the calcium and carbonate that give rise to the ubiquitous calcretes of this arid desert region. It is perhaps not too surprising, then, that this water occasionally would also percolate downward into the porous or even open fault zone to precipitate the vein calcite. Frequent interaction between water and soluble salts, which will promote the mixing of ionic species over an area commensurate with water movement, could account for the general isotopic homogeneity of the calcite. A common origin for the carbonate phase of the veins and calcretes was also suggested on the basis of their similar strontium isotopic composition (Marshall and others, unpubl. report).

The ultimate source of this radiogenic lead is as yet unknown, but it may accompany an eolian contribution to the soils derived from exposed Paleozoic and Late Proterozoic carbonate rocks in surrounding mountains. Recent measurements of the flux of fine-grained, wind-blown particulates in the vicinity of Yucca Mountain attest to the importance of this mechanism in transporting surficial matter over large distances (Marith Reheis, U.S. Geological Survey, oral communication, 4/90). The continuing ablation of exposed carbonate bedrock that is implicit in the eolian process could well provide the initial material for making the soil calcretes and the vein calcite. Marshall and others (unpubl. report) point out the dissimilarity in strontium isotopic composition between that found in the veins and soil and that expected for Paleozoic and Late Proterozoic marine limestones. However, impure and metamorphosed carbonate rocks, might have elevated $^{87}Sr/^{86}Sr$ compared to the marine value, cannot be excluded as possible source materials. The sparse lead isotopic data that we have on Paleozoic carbonate rocks from southwestern United States (Figure 2) is certainly permissive of such an origin for the "carbonate" fraction.

Whether the processes of formation of the veins and the soil calcrete occurred simultaneously or sequentially cannot be answered solely from the lead isotopes. The preliminary uranium disequilibrium analyses reported by Muhs and others (unpubl. report) indicate a considerably older age for some vein carbonate than the presently mantling platy K soil horizon, but one strongly suspects that still older but similar soils previously overlaid the fault. Probably, the veins have been derived wholly or in part from the reworking of surficial pedogenic material, which was carried in solution and/or as particulate matter down into open spaces of the fractured rock. In that case, however, the retention of separate lead isotopic identities between the "silicate" and "carbonate" fractions demands that the lead was not all transported in a single, homogenized solution. Introduction of the precipitated phases, such as the calcite and opaline silica, by descending meteoric water and incorporation of a more locally derived clastic component from the adjacent wall rock is currently our preferred scenario for forming the Trench 14 carbonate-silicate veins.

Because the lead isotopic fields defined by the vein material are virtually identical to those of the soil calcrete, one need not look any further to explain the observed lead isotopic data. Admittedly, such evidence, while strongly suggestive of a surficial origin for these hydrogenic deposits, cannot be used to absolutely rule out the presence of a more exotic component to the system. The foreign component might, for example, contain a negligible amount of lead or coincidentally have an isotopic composition identical to the local soils. Nevertheless, when taken together with other evidence indicating that the veins represent a low-temperature infilling into the locally fractured rocks of the Bow Ridge Fault of carbonate and silicates, one finds in this lead isotopic study no support for a more unusual origin. Certainly, the extreme isotopic variability observed for Paleozoic and Late Proterozoic sedimentary rocks or the Early to Middle Proterozoic crystalline basement (Figure 2) is not found in the vein material.

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Figure Captions

Figure 1. (A) $^{206}Pb/^{204}Pb$ vs. $^{208}Pb/^{204}Pb$ and (B) $^{206}Pb/^{204}Pb$ vs. $^{207}Pb/^{204}Pb$ diagrams showing lead isotopic ratios from calcrete (circle), rhizolith (triangle), and Trench 14 and Busted Butte vein (square), and volcanic rocks (cross). Also shown are three Quaternary hawaiites from Crater Flat (X) analyzed by Farmer and others (1989). The tie lines join "carbonate" (open symbol - leached by CH_3COOH; stippled symbol - leached by HCl) and "silicate" (solid symbol) fractions from same sample.

Figure 2. $^{206}Pb/^{204}Pb$ vs. $^{208}Pb/^{204}Pb$ diagram showing isotopic fields of the upper and lower continental crust drawn to contain 80% of the data compiled by Doe (1976). Fields extend a considerable distance beyond the border of the diagram. Paleozoic carbonate rock (triangle) and Proterozoic crystalline rock (square) from southwestern United States are plotted individually.

Table 1. U, Th, and Pb concentration and lead isotopic composition of carbonate-silicate veins and calcrete from Yucca Mountain, Nevada. HD-1 and -2, and HD-9 and -10 are paired samples from the top and bottom, respectively, of the mantling platy K soil horizon. [Except as noted, carbonate and silicate fractions are the dissolved and residue portions of the sample after leaching in 0.8N CH_3COOH for 2 hours. Percent silicate and, by difference, carbonate is calculated by weighing total and residue portions of samples.]

Sample[1]	U, ppm	Th, ppm	Pb, ppm	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
TRENCH 14						
HD-1 Calcrete						
Carbonate - 44%	1.13	2.14	4.61	20.15	15.78	39.30
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[2] - 58%	(1.9)	(3.7)	(3.9)	18.73	15.65	39.17
Carbonate - 53%	1.25	1.30	2.11	18.81	15.66	39.19
Silicate - 47%	7.56	5.41	7.50	18.52	15.63	39.08
HD-10 Calcrete						
Carbonate[2] - 58%	(1.5)	(0.9)	(1.0)	18.80	15.70	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%	9.90	3.18	2.49	18.38	15.58	39.05
HD-22-2 Vein						
Carbonate[2] - 69%	(0.6)	(3.0)	(4.3)	18.35	15.60	39.10
Carbonate - 47%	0.85	3.48	4.08	18.40	15.56	38.89
Silicate - 53%	3.17	2.80	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

HD-31-2 Vein						
Carbonate[2] - 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[2] - 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[2] - 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
BUSTED BUTTE						
HD-56-6 Vein						
Carbonate[2] - 58%	(1.3)	(3.8)	(3.7)	18.62	15.63	39.18
Carbonate - 40%	0.57	1.27	2.10	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%	1.26	2.16	9.49	18.67	15.63	38.60
Silicate - 82%	5.75	8.81	15.2	18.49	15.60	38.95

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[1] For sample locations, see Fig. 2 of Taylor (unpubl. report).

[2] Dissolved in 1.5N HCl after 2 hours. For these samples percent carbonate is calculated from CO_2 loss assuming pure $CaCO_3$, and resultant concentrations shown in parentheses are accurate to only +/- 10%.

Table 2. U and Th concentration and lead isotopic composition of volcanic rocks from Yucca Mountain, Nevada. [Pb concentration estimated from chemical yields to be 5-20 ppm.]

Sample	U, ppm[1]	Th, ppm[1]	$^{206}\text{Pb}/^{204}\text{Pb}$	$^{207}\text{Pb}/^{204}\text{Pb}$	$^{208}\text{Pb}/^{204}\text{Pb}$
Tiva Canyon					
HD-29[2]	nd	nd	18.120	15.563	39.033
HD-32-1[2]	nd	nd	18.123	15.555	39.014
5-4-89D[3]	nd	nd	18.160	15.565	39.039
5-4-89F[3]	nd	nd	18.231	15.573	39.042
Topopah Spring					
Composite (12)[4]	4.4	24.5	18.147	15.564	39.074
Calico Hills					
Composite (4)[4]	4.5	23.0	18.225	15.590	39.016
Prow Pass					
Composite (2)[4]	5.1	22.2	18.342	15.578	38.742
Bullfrog					
Composite (16)[4]	4.0	20.7	18.319	15.597	38.890
Tram					
Composite (11)[4]	4.2	20.3	18.354	15.579	38.907
Flow Breccia					
Composite (4)[4]	3.4	17.4	18.243	15.578	39.197
Lithic Ridge					
Composite (6)[4]	2.7	18.3	18.249	15.581	39.079
Unit A					
Composite (6)[4]	3.6	20.0	18.271	15.577	39.045
Unit B					
Composite (1)[4]	4.3	20.0	18.244	15.564	39.015
Unit C					
Composite (7)[4]	2.9	16.9	18.178	15.587	39.167

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[1] Average U and Th concentrations for each composite calculated from individual core sample analyses reported in Table 1 of Bush and others (1983).

[2] Tuff from Trench 14A (see Table 4 of Marshall and others, unpubl. report).

[3] Tuff from crest of Yucca Mountain.

[4] Composite from core samples of Bush and others (1983); number of individual samples indicated in parentheses.

nd - Not determined.

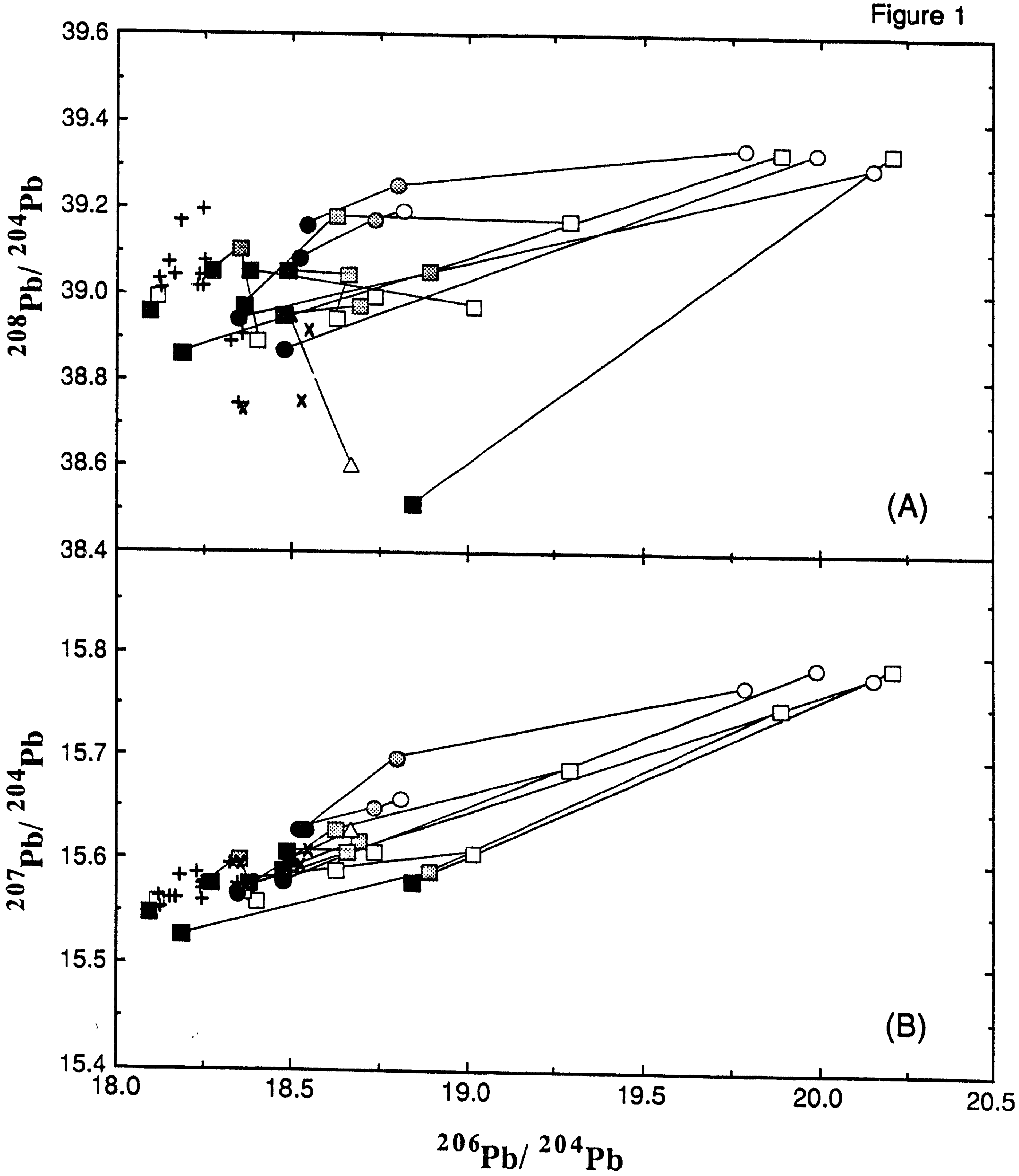
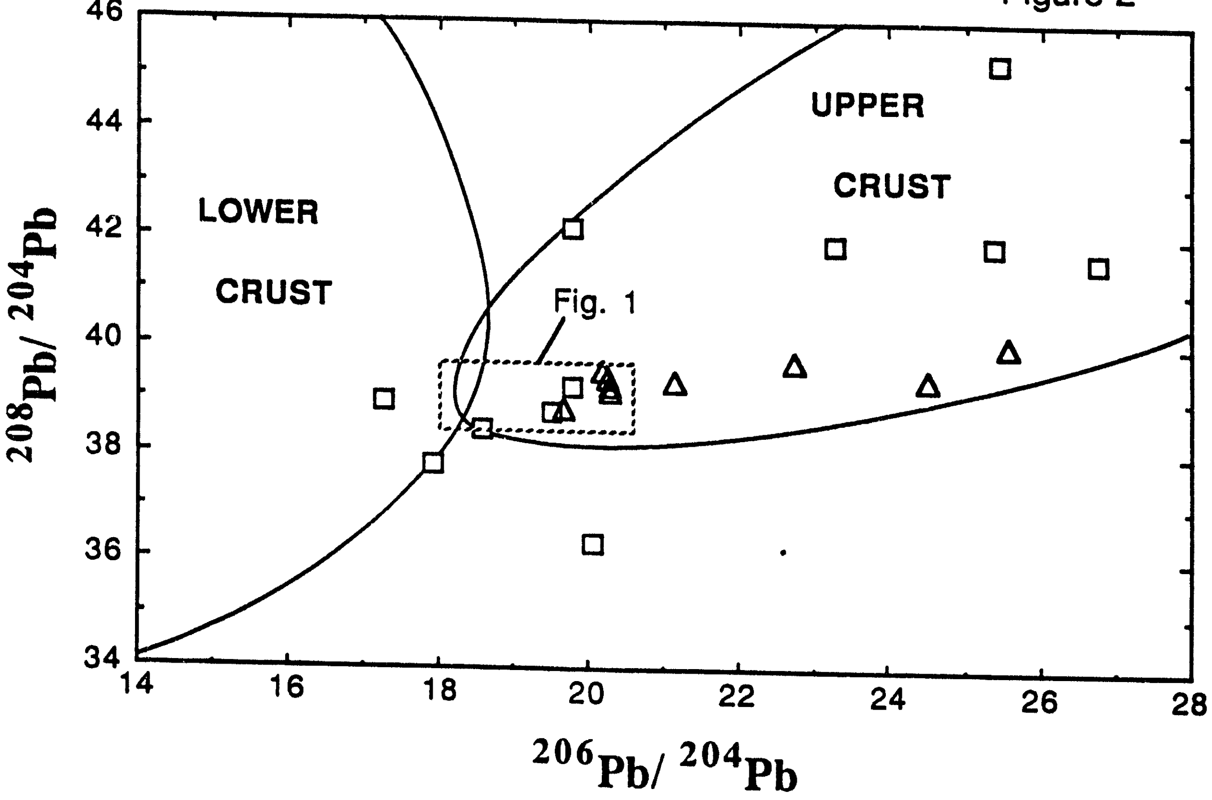


Figure 1
39.6
39.4
39.2
39.0
38.8
38.6
38.4
$^{208}Pb/^{204}Pb$
(A)
15.8
15.7
15.6
15.5
15.4
$^{207}Pb/^{204}Pb$
(B)
18.0
18.5
19.0
19.5
20.0
20.5
$^{206}Pb/^{204}Pb$

Figure 2


LOWER
CRUST
UPPER
CRUST
Fig. 1
46
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^{208}Pb/ ^{204}Pb
^{206}Pb/ ^{204}Pb

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