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**DIALOGS BY JERRY SZYMANSKI REGARDING THE
YUCCA MOUNTAIN CONTROVERSY FROM
DECEMBER, 1990 TO MARCH, 1991**

VOLUME III

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State of Nevada

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MASTER

**Dialogs by Jerry Szymanski Regarding the Yucca Mountain Controversy from
December, 1990 to March, 1991**

Volume III

REPORT ORGANIZATION

PART 1

Letter to Z. E. Peterman and J. S. Stuckless

J. S. Szymanski

PART 2

Letter to J. S. Szymanski

Z. E. Peterman and J. S. Stuckless

PART 1

Letter to Z. E. Peterman and J. S. Stuckless

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WBS 1.2.9
QA: N/A

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TRANSMITTAL OF A CRITIQUE OF U.S. GEOLOGICAL SURVEY (USGS) PAPERS REGARDING
THE ORIGIN OF THE YUCCA MOUNTAIN HYDROGENIC DEPOSITS

Please be advised that, after publication and presentation of scientific papers by Stuckless et al. (1991) and Peterman et al. (1991), I have been interviewed by a number of reporters. Repeatedly, these reporters have asked me to state my personal opinion as to the soundness and scientific validity of the subject papers. In one instance, my response was a blunt "nonsense;" in another instance, I have characterized USGS rainwater conclusions as a "flat earth theory." Having publicly stated my viewpoints, I feel obligated to attempt to justify these viewpoints. Enclosed please find a critique I have prepared for these purposes.

Should you have any questions regarding this letter or desire further clarification, please do not hesitate to contact me at (702) 794-7941 or FTS 544-7941.

Jerry S. Szymanski

Technical Analysis Branch
Regulatory & Site Evaluation Division

RSED:JSS-1185

Enclosures:

1. Critical Evaluation of the USGS
Interpretations of the Origin
of the Yucca Mountain
Calcite-Opaline Silica Veins
2. General Summary and Overview

P.S.

Incidentally, you may have some interest in knowing what some other scientists think about the logic that underlies the isotopic "proof," as set forth by you. Enclosed please find the General Summary and Overview from Archambeau and Price, 1991. Of particular relevance are statements from pages 136 through 138.

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CRITICAL EVALUATION OF THE U.S. GEOLOGICAL (USGS) INTERPRETATIONS OF
THE ORIGIN OF THE YUCCA MOUNTAIN CALCITE-OPALINE SILICA VEINS

Notwithstanding the plentiful and persuasive facts to the contrary, some of the investigators employed by the USGS stubbornly keep insisting that, at Yucca Mountain, the majority of calcitic veins were precipitated from infiltrating rainwaters. Although it is now admitted that some of the vadose zone veins represent the epigenetic and hydrothermal mineralization processes (and must have been precipitated from upwelling geothermal solutions), the remaining calcitic veins are still regarded as the products of infiltrating rainwater, Whelan and Stuckless (1991), and Figures 2 and 3. Specifically, it is considered that, these veins owe their formation to the sensu stricto pedogenesis. In this process, infiltrating rainwaters dissolve mineral matter from eolian detritus and other mineral constituents of the soil zone, and acquire dissolved carbonate from biogenically respired carbon dioxide and decaying organic matter. Samples of such allegedly rainwater-produced veins yield both the low relative concentrations of uranium-234 and carbon-13 and the high relative concentrations of strontium-87 and oxygen-18, Figures 1 through 4. Two broad lines of clearly superficial evidence were put forth in support of the USGS rainwater interpretations. [By no stretch of the imagination, the observed by the USGS investigators isotopic affinity, between the calcretes and the surficial veins, may be regarded as a serious and valid evidence in favor of the rainwater story. However, the direct field observations alone are sufficient to confidently conclude that, at Yucca Mountain, both the calcretes and the veins reflect a common mineralization process. The observed isotopic affinity may be taken no further but to confirm that, indeed, this conclusion is valid, as both of the opaline silica

and calcite forms were precipitated from solutions that have carried identical stable and radiogenic isotopic contents. As far as the origin of these solutions is concerned, however, the isotopic affinity is of little assistance unless, of course, one alleges that, in the case of calcretes, the rainwater origin is an independently documented scientific fact. Because such is hardly the case, the USGS conclusion that the calcrete and vein isotopic affinity is supportive of the rainwater story is clearly based on circular logic, and must be rejected off-hand and, consequently, will not be considered any further in this critique.]

On the one hand, Stuckless et al. (1991) have correctly pointed out that, at Yucca Mountain, the isotopic characters of uranium + strontium dissolved in the contemporary fluid phases, from immediately below the water table, are different than those interpreted to have been dissolved in the parent fluids of the disputed calcitic veins. This correctly noted discrepancy led the USGS investigators to conclude that: (1) "the calcite could not have been precipitated from ground water," and (2) "the data are consistent with a surficial origin for the hydrogenic deposits", Stuckless et al. (1991). Both of these conclusions, in turn, erroneously were taken as indicating that, for the disputed calcretes and associated veins, the rainwater origin hypothesis is a sole viable alternative left. The USGS investigators do not seem to be aware that, for such to be the case, two conditions must be satisfied first. The first condition is that, at Yucca Mountain, either the fluid circulation depth is no greater than about 2.0 km (maximum depth of the explored section) or the isotopic compositions of the local subterranean fluids are

depth-invariant. The second condition is that, at Yucca Mountain and for time spans measured in tens of thousand of years, factors that control the isotopic compositions of the local fluids (i.e., temperature of isotopic exchange reactions, exchangeable solid medium, gas and fluid inputs from above and below, etc.) are time-invariant. Because it was neither demonstrated, nor could it have been demonstrated, that these conditions are satisfied, the genetic implications of the noted isotopic discrepancy, as advocated by the USGS investigators, must be rejected unless, of course, one is ready to certify the logical coherence of the statement "acquittal of a person falsely accused of murder amounts to resurrection of the victim." While attempting to find a more satisfying explanation for the noted isotopic discrepancy, a more inquisitive researcher would note that, in the vicinity of Yucca Mountain, the local hydrosphere consists of two contrasting thermodynamic configurations. These are: (1) the so-called hydraulic "source" regions, alternating with, (2) the so-called hydraulic "sink" regions, Szymanski (1991). This researcher would also note that, relative to the "sink" fluids and regions, the hydraulic "source" regions and fluids exhibit: (1) the depthward, increasing values of the hydraulic potentials; (2) roughly, a factor of two higher values of the geothermal gradient; and (3) on the average, a factor of ten higher concentration of the dissolved $\text{Cl}^- + \text{SO}_4^{--}$ anions. The inquisitive researcher would further note that, relative to the "sink" fluids, the hydraulic "source" fluids exhibit: (1) lower values of the $^{234}\text{U}/^{238}\text{U}$ ratio; (2) significantly higher values of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio; (3) markedly higher values of the $\delta^{13}\text{C}$ ratio; and (4) noticeably higher magnitudes of the "oxygen isotopic shift" and, consequently, higher relative concentrations of oxygen-18. Finally, with

satisfaction, the inquisitive researcher would note that, at Yucca Mountain, the interpreted isotopic compositions of the parent fluids, for the local calcretes and associated veins, display a close uranium + strontium + carbon + oxygen isotopic affinity with the observed hydraulic "source" fluids. If considered in light of the above observations, the isotopic discrepancy, as noted by Stuckless et al. (1991), is not at all harmful to the hydrothermal interpretations of the origin of the Yucca Mountain calcitic phases. Rather than negating these interpretations, the discrepancy in fact supports them. This is so because, by demonstrating that: (1) in the Yucca Mountain region, the local hydrosphere consists of the two contrasting thermodynamic configurations; (2) the isotopic compositions of the parent fluids, for the local calcitic phases, are incompatible with those of the local "sink" fluids; and (3) the isotopic compositions of the parent fluids, for the local calcitic phases, are compatible with those of the local "source" fluids, we are actually making three important points. These are: (1) in the Yucca Mountain region, the local hydrosphere behaves as a non-equilibrium dissipative system; (2) the currently observed self-organization produced macroscopic order is not a static, or frozen, feature; and (3) in enlarging time-space, for one reason or another, the system undergoes "sink" $\leftrightarrow$ "source" transformations, Nicolis and Prigogine (1977) and Stewart (1989).

On the other hand, Peterman et al. (1991) have correctly pointed out that, for the northwestern segment of Yucca Mountain, the calcitic veins carry values of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio that define a reasonable well expressed depth-gradient. As shown in Figure 4, samples of the calcitic veins (encountered in boreholes

USW G-1, G-2, G-3, G-4, and UE-25b #1) yield the depthward diminishing relative concentrations of the radiogenic strontium-87. Shallow samples, encountered within ~450m of the topographic surface, yield values of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio that overlap with those from samples of the calcretes and associated surficial veins. For the calcretes, the corresponding values range from 0.7112 to about 0.7130 (Figure 5), for the associated veins, these values range from 0.7118 to about 0.7128 (Figure 5). Deeper within the explored section (more than ~700m below the topographic surface), however, the calcitic veins carry markedly lower relative concentrations of strontium-87. Samples of such veins yield a narrow range of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio, from 0.7086 to about 0.7098, Figure 4. The transition between the differing populations of the calcitic veins appears to be fairly smooth and occurs near the contemporary water table. Importantly, the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio vs. depth gradient, as constructed based on samples of the calcitic veins, fairly accurately reflects the corresponding gradient constructed based on the whole-rock samples of ignimbrites encountered in boreholes USW G-1 and G-2. Similarity between the respective gradients may be observed by comparing Figures 4, 6, and 7. Clearly, for both the whole-rock ignimbrites and the calcitic veins, the observed $^{87}\text{Sr}/^{86}\text{Sr}$ ratio vs. depth gradients must be somehow related. There are two explanations that may be put forth, namely (1) either both the whole-rock ignimbrites and the calcitic veins have acquired their $^{87}\text{Sr}/^{86}\text{Sr}$ ratios from the same fluids, or (2) the parent fluids for the calcitic veins have acquired their $^{87}\text{Sr}/^{86}\text{Sr}$ ratios through dissolution of the host ignimbrites. While commenting on a possible meaning of the observed $^{87}\text{Sr}/^{86}\text{Sr}$ ratio vs. depth gradient, Peterman et al. (1991)

have implied that this gradient is consistent with, and supportive of, the rainwater hypothesis. These investigators have made the following statement. "Calcite fracture fillings within approximately 200m of the surface probably formed by infiltration of water which carried surficial Ca and Sr downward along fractures and faults. This conclusion supports the interpretation of Szabo and Kyser (1990) based on stable isotope systematics. Below the upper 200m, the $^{87}\text{Sr}/^{86}\text{Sr}$ values of calcite fracture fillings decrease systematically to an average value of 0.71098 immediately above the water table. This decrease probably reflects increasing rock/water interaction downward in the volcanic pile where the rock $^{87}\text{Sr}/^{86}\text{Sr}$ values also decrease systematically with depth." Also in this case, the USGS investigators do not seem to be aware that, prior to declaring the observed $^{87}\text{Sr}/^{86}\text{Sr}$ ratio vs. depth gradient as supportive of the rainwater hypothesis, two conditions must be satisfied first. The first condition is that, for the parent fluids of the calcretes and associated surficial veins, a source of the radiogenic strontium-87 should be reliably identified. In addition to supplying Sr, such a source must also be capable of providing Ca, and must be situated at or very near the topographic surface. A Paleozoic carbonates-derived wind blown dust, however, is of little assistance in that regard. Although such dust may be presumed to be a source of Ca, it may not be held accountable for providing the sufficiently high relative concentrations of strontium-87. The second condition is that, for the whole-rock ignimbrites, a determination must be made as to the relative antiquity of the observed $^{87}\text{Sr}/^{86}\text{Sr}$ ratio vs. depth gradient. In other words, a determination must be made that, for the whole-rock ignimbrites and the calcitic veins, the corresponding isotopic

gradients were developed at different times, in response to different processes, and do not reflect a Ca + Sr metasomatism of the host ignimbrites. Because neither of these conditions has been satisfied, the Peterman et al. (1991) conclusions must be viewed with skepticism.

To further expose the misleading character of the Peterman et al. (1991) conclusions, the following four points are put forth. First, the acceptance of the notion that, in the Yucca Mountain region, infiltrating rainwaters are typically and uniquely associated with the elevated relative concentrations of the radiogenic strontium-87 leads to the following three paradoxical conclusions. The first of such conclusions emerges if one recognizes that, for the Yucca Mountain calcretes and associated veins, values of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio are identical to those contained in the DH-2 (Devil's Hole) travertine vein, Figures 4 and 5. The observed isotopic similarities may be taken as indicating that, both the Yucca Mountain calcretes and associated veins and the DH-2 vein were precipitated from fluids with common intra-formational residence times and histories. The assumption that, for the Yucca Mountain calcretes and veins, the parent fluids were infiltrating rainwaters leads to a conclusion that the parent fluids for the DH-2 vein were also of similar character. For the DH-2 vein, however, we do know that such a conclusion is false. The second paradoxical conclusion arises if one recognizes that, for the parent fluids of the upper Yucca Mountain calcitic veins, values of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio are similar to those being carried by the evolved and mature fluids residing in the Paleozoic carbonates, Figures 4, 5, and 8. The observed isotopic similarities may be taken as indicating that, both the

parent fluids for the Yucca Mountain calcretes and associated veins and the Paleozoic carbonates-based fluids have acquired their relative concentrations of the dissolved strontium through ionic exchange reactions with a common solid material. The assumption that, for the Yucca Mountain calcretes and associated veins, the parent fluids were infiltrating rainwaters leads to a conclusion that the mature Paleozoic carbonates-based fluids are also of similar character. For the latter fluids, however, we do know that such a conclusion is false. The third paradoxical conclusion becomes apparent if one recognizes that, in addition to yielding the $^{87}\text{Sr}/^{86}\text{Sr}$ vs. depth gradient, the Yucca Mountain calcitic veins also yield the $\delta^{18}\text{O}$ vs. depth gradient, Figures 2 and 4. It is reasonable to assume that both varieties of the disputed calcitic veins (ones carrying the greatest relative concentrations of oxygen-18 and strontium-87) were precipitated from common parent solutions. Szymanski (1991) has demonstrated that all conceivable geothermal reconstructions (including those performed by Szabo and Kyser, 1990), made selectively using only samples with the highest values of the $\delta^{18}\text{O}$ ratio, yield values of the paleo-geothermal gradient that are a factor of 1.5-2.5 higher than the corresponding contemporary geothermal gradients, Figure 9. The assumption that the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio vs. depth gradient was caused by infiltrating rainwaters, leads to a conclusion that the elevated $\delta^{18}\text{O}$ vs. depth gradient, and with it the elevated paleo-geothermal gradient, must also have been caused by rainwater. For the latter gradient, however, we do know that such a conclusion is false. The above three-fold ad absurdum treatment of the rainwater hypothesis indicates, of course, that this hypothesis is **WRONG**.

Second, in addition to the major elements metasomatism, the Yucca Mountain ignimbrites also exhibit a space-variant strontium metasomatism. Such a state of affairs may be identified by comparing Figures 6, 7, and 10. There are two spatio-temporal aspects of the locally evident strontium metasomatism. On the one hand, below a depth of ~800m, the whole-rock ignimbrites (encountered in boreholes USW G-1 and G-2) yield the anomalously high total concentrations of strontium and the low relative concentrations of the radiogenic strontium-87, Figure 7. The involvement of strontium metasomatism, in producing at least one of these features, may be identified by examining the total strontium concentrations, in stratigraphically equivalent rock units, but at differing locations. As shown in Figure 10, for the southernmost end of Yucca Mountain, the whole-rock samples of the Crater Flat Tuff yield the total strontium concentrations ranging from 50 to 66 ppm, for the Prow Pass Member, through 156-213 ppm, for the Bullfrog Member, to about 120-150 ppm, for the Tram Member. For the northernmost end of Yucca Mountain (boreholes USW G-1 and G-2), however, the whole-rock samples of the Crater Flat Tuff yield significantly higher values of the corresponding concentrations. As shown in Figures 6 and 7, these concentrations range from 122 to as much as 705 ppm. Fluids responsible for the strontium metasomatism, as observed in the deeper parts of the northwestern segment of Yucca Mountain, seem to have been carrying fairly high total concentrations of the dissolved strontium and, at the same time, fairly low relative concentrations of the dissolved strontium-87. Although such fluids could have been involved in the precipitation of the deeper and "coarsely crystalline" calcitic veins, they cannot be held responsible for the precipitation of shallower, more strontium

radiogenic, and micritic calcitic veins. It is imperative to reckon that, in the deeper parts of the northwestern segment of Yucca Mountain, the whole-rock ignimbrites (encountered in boreholes USW G-1, G-2, and G-3) also contain:

- (1) the predominantly sodic-potassic clinoptilolites, Figures 11a and 11b;
- (2) clinoptilolites and smectite-illite fractions carrying the K/Ar ages ranging from 9.5×10^6 to 11.0×10^6 years B.P., Figures 12 and 13; and (3) the relatively low concentrations of Ca + Mg, Figures 14a and 14b. Collectively, these three characteristics may be taken as indicating that, in the deeper parts of the northwestern segment of Yucca Mountain: (1) the degree of late Ca + Mg metasomatic zeolitization is relatively low, and (2) the observed epigenetic zeolitization occurred in association with the hydrothermal stages of activity of the Timber Mountain Caldera. It is possible that the most strontium-87 depleted calcitic veins, represented in Figure 4, record this alteration and mineralization episode. On the other hand, above a depth of ~800m below the topographic surface, the whole-rock ignimbrites (encountered in boreholes USW G-1 and G-2) yield the markedly lower total concentrations of strontium and the high relative concentrations of the radiogenic strontium-87, Figure 7. Importantly, the conspicuous $^{87}\text{Sr}/^{86}\text{Sr}$ ratio vs. depth gradient is present in both the whole-rock ignimbrites and the calcitic veins, Figures 4 and 7. It is imperative to reckon that, in the southeastern segment as a whole and in the shallow parts of the northwestern segment of Yucca Mountain, the whole-rock ignimbrites also contain: (1) the relatively high proportions of the calcic clinoptilolites, Figures 11a and 11b; (2) the clinoptilolite fractions carrying the K/Ar ages ranging from 6.94×10^6 to as little as about 2.0×10^6 years B.P., Figures 12 and 13; and (3) the increased concentrations of

Ca + Mg, Figure 14. Collectively, these three characteristics may be taken as indicating that, in the shallow parts of the northwestern segment of Yucca Mountain and in the whole southeastern segment: (1) the degree of late Ca + Mg metasomatic zeolitization is relatively high, and (2) the observed epigenetic zeolitization is the result of an episodically-ongoing hydrothermal alteration and mineralization process. It is evident that, both the most strontium-87 enriched calcitic veins and the younger calcic clinoptilolites record this process.

Third, for the northwestern segment of Yucca Mountain, the occurrence of the most strontium-radiogenic calcitic veins, selectively in the shallow parts, is a normal and readily understandable feature. By no stretch of the imagination, however, may one argue that this feature either requires or supports the paradoxical rainwater story. To find a logical and paradox-free explanation for the observed $^{87}\text{Sr}/^{86}\text{Sr}$ vs. depth gradient, it is useful to recognize two characteristics of the tectonically induced upwelling of geothermal fluids. On the one hand, it is totally inappropriate to envisage such upwelling as a spatially extensive and uniform increase in the upward fluid flux. Szymanski (1989) has pointed out that, for the upwelling to be effective in restructuring the hydraulic conductivity structure, and thus in raising the local water table, the fluid flux increase must necessarily be restricted to a "ruptured fault and a few adjacent fractures." In other words, at a depth of, say, 2.0 km, the fluid flux increase is narrowly focused around the causative fault, and forms an elongated upwelling center, Figure 15. It is imperative to reckon that, at Yucca Mountain, the younger

alteration center, one responsible for the Ca + Mg metasomatism and the corresponding zeolitization, is situated somewhere within the southeastern segment of Yucca Mountain, possibly along the trace of the Stage Coach Road fault. Such a state of affairs is indicated by the spatial distribution of both the alternation temperatures (Figure 16) and the calcic clinoptilolites (Figure 11). On the other hand, for deep-seated upwelling fluids, lateral diffusion away from the ruptured fault is controlled by the spatial distribution of hydraulic conductivity. The latter, in turn, is controlled by the in situ stress field developed around a yielding, and soon to be unstable, fault. Szymanski (1989) has pointed out that, prior to a fault rupture, the corresponding in situ stress field, and with it the local conductivity structure, is characteristically space-variant. Near the soon-to-be ruptured fault, the in situ stress enhancement of the hydraulic conductivity structure is relatively deep and large. Away from this fault, however, both the enhancement depth and the enhancement magnitude diminish gradually. In Figure 15, this effect is represented by the space-variant magnitude of the so-called depth $Z_{(x,y,t)}$. Keeping in mind both of the above conditions, it is possible to construct a logical explanation for the observed selective development of the most strontium-radiogenic calcitic veins. Such explanation is provided in Figure 15. In this figure, two reasonable points are emphasized. These are: (1) the parent fluids for the most strontium-radiogenic veins were ejected in the southeastern segment of Yucca Mountain, and (2) the fluid diffusion paths were controlled by the deformation-induced hydraulic conductivity gradients. For the northwestern segment (where boreholes USW G-1, G-2, G-3, and G-4 are located), the

penetration depth of the ejected fluids was about 500m below the topographic surface. The proposed explanation requires that, in the southeastern segment of Yucca Mountain, calcitic veins with the appropriate values of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio are present well below the contemporary water table. Undoubtedly, further exploration in this segment will establish that such is the case indeed.

Fourth, the isotopic characters of uranium + strontium + oxygen + carbon incorporated in the Yucca Mountain calcitic phases, if considered together with the spatio-temporal distribution of both the epigenetic zeolitization and the whole-rock metasomatism, lead to the establishment of a coherent understanding of the history of local hydrothermal activity. In accordance with such understanding, the Yucca Mountain ignimbrites contain two temporally distinct varieties of epigenetic alteration and mineralization phases. The older variety includes the calcitic veins that exhibit three isotopic characteristics. These are: (1) the relative concentrations of oxygen-18 are low, values of the $\delta^{18}\text{O}$ ratio range from +4.0 to, say, +15.0 per mil_{SMOW}, Figure 17; (2) the relative concentrations of carbon-13 are high, values of the $\delta^{13}\text{C}$ ratio range from +4.0 to, say, 0.0 per mil_{PDB}, Figure 17; and (3) the relative concentrations of strontium-87 are low, values of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio range from 0.7086 to, say, 0.7092, Figure 4. Both the low values of the $\delta^{18}\text{O}$ ratio and the high values of the $\delta^{13}\text{C}$ ratio clearly indicate that, the corresponding veins are of hydrothermal origin. Such veins are present both above and below the contemporary water table and, consequently, provide indisputable evidence as to the epigenetic hydrothermal

alteration and mineralization of ignimbrites comprising the Yucca Mountain vadose zone. The spatial association of some veins from the older variety (specifically, ones that carry the low values of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio) with the oldest clinoptilolite and smectite-illite fractions (yielding the K/Ar ages ranging from 9.5×10^6 to about 11.0×10^6 years B.P.) indicates that, partially, these veins record the stationary-longevous hydrothermal system driven by the concentrated Timber Mountain Caldera heat source. Two general characteristics may be inferred to have been associated with this system. On the one hand, it may be presumed that the prolonged circulations of hydrothermal solutions have caused the extensive heating of the local ignimbrites. Consequently, the corresponding veins record low values of the oxygen isotopic fractionation factor (brought about by the elevated precipitation temperature) and yield the observed low values of the $\delta^{18}\text{O}$ ratio. On the other hand, it may also be presumed that, during early stages of extension and thinning of the local lithosphere, the fluid circulation depth was relatively small. Consequently, the parent fluids for the corresponding veins have acquired their dissolved strontium + carbon, predominantly, through dissolution of the shallow Paleozoic carbonates. These veins, therefore, carry the strontium + carbon isotopic signatures that are typical of the Paleozoic carbonates. The younger variety includes several generations of the epigenetic calcitic veins. These veins exhibit the following four isotopic characteristics: (1) the relative concentrations of uranium-234 are low, values of the $^{234}\text{U}/^{238}\text{U}$ ratio range from 1.0 to 1.5, Figure 1; (2) the relative concentrations of oxygen-18 are high, values of the $\delta^{18}\text{O}$ ratio range from, say, +12.0 to +22.0 per mil_{SMOW}, Figures 2 and 17; (3) the relative concentrations of carbon-13 are low, values

of the $\delta^{13}\text{C}$ ratio range from, say, -3.0 to -8.0, Figures 3 and 17; and (4) the relative concentrations of strontium-87 are high, values of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio range from, say, 0.7112 to 0.7130, Figures 4 and 5. For the corresponding veins, the hydrothermal or geothermal origin is given away by four isotopic characteristics. These are: (1) the observed low values of the $^{234}\text{U}/^{238}\text{U}$ ratio, such values not only are identical to those contained in the local travertine veins (Figures 18a and 18b) but also are characteristic of geothermal fluids in general, see for example, Osmond and Cowart (1982); (2) the observed high values of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio, such values not only are identical to those contained in the local travertine veins (Figure 5a) but also are characteristic of the local geothermal fluids (Figure 8); (3) the observed values of the $\delta^{13}\text{C}$ ratio, such values not only are significantly higher than those associated with the local infiltrating rainwaters (Figures 19a through 19d) but also are typical of hydrothermal fluids (Figures 20 and 21); and (4) the observed values of the $\delta^{18}\text{O}$ vs. depth gradient, such values yield the paleo-geothermal gradient that is a factor 1.5-2.5 greater than the contemporary geothermal gradient (Figure 9). The spatial association of the younger calcitic vein variety with the younger clinoptilolites (carrying the K/Ar ages ranging from 8.47×10^6 to 1.99×10^6 years B.P.) indicates that this variety records an intermittently ongoing alteration and mineralization process. The metasomatic character of this process further confirms the independently evident hydrothermal origin of the disputed veins. It is entirely reasonable to conclude that, at Yucca Mountain, both the metasomatic zeolitization and the younger epigenetic carbonatization record the ephemeral activity of the diffuse heat source

hydrothermal system. Two general characteristics may be inferred to be associated with this system. On the one hand, it may be presumed that the episodic convective bursts are of relatively short duration, and do not cause the spatially extensive heating of the local ignimbrites. The resulting calcitic veins, therefore, contain the observed high values of the $\delta^{18}\text{O}$ ratio, and record only modest increases of the paleo-geothermal gradient. On the other hand, it may also be presumed that during more advanced stages of extension and thinning of the local lithosphere, the fluid circulation depth is greater. As far as the isotopic characters of the dissolved strontium + carbon are concerned, the increased circulation depth has important implications. It causes that, with time, the circulating fluids may acquire increasingly more strontium from the highly radiogenic reservoir of strontium, which is the Precambrian basement. Being precipitated from such fluids, the youngest Yucca Mountain calcretes and veins carry the abnormally high values of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio. Similarly, the increasing fluid circulation depth causes that the dissolution of CO_2 , provided by deep-seated igneous sources, occurs at the progressively greater depth and temperature. Because the carbon isotopic fractionation factor decreases with the increasing temperature (Figure 22), the increasing CO_2 dissolution temperature causes that, with time, the resulting solutions carry progressively smaller relative concentrations of the dissolved carbon-13. Being produced from such solutions, the youngest Yucca Mountain calcretes and veins do carry the observed negative values of the $\delta^{13}\text{C}$ ratio. Although too high for the local infiltrating rainwaters (Figures 19a through 19d), these values are identical to those observed in association with many hydrothermal ore deposits, Figures 20 and 21.

The interpretation that, for the Yucca Mountain hydrothermal solutions, the increasing fluid circulation depth is reflected through the time-variant relative concentrations of strontium-87 and carbon-13 may be verified by tracking down the temporal evolution of fluids that are and were residing in the Paleozoic carbonates. Although the currently available data are scarce in that regard, they are sufficient to make two important points. On the one hand, based on values of both the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio and the $\delta^{13}\text{C}$ ratio, as observed for the Yucca Mountain ignimbrites altered and mineralized during the Timber Mountain Caldera hydrothermal episode (boreholes USW G-1, G-2, and G-3, below a depth of ~700m, Figures 12, 17, and 4), it may be inferred that the corresponding veins were precipitated from fluids upwelling from the Paleozoic carbonates. Importantly, these fluids have carried the relative concentrations of strontium-87 and carbon-13 that are identical to those expected for fluids equilibrated with marine limestones of Paleozoic age. For the latter fluids, the expected values of the $\delta^{13}\text{C}$ ratio and the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio are -1.0 to, say, 2.0 per mil_{PDB}, and 0.7082 to, say, 0.7090, respectively (Hoefs, 1987 and Faure, 1986). On the other hand, based on the currently observed values of the $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{13}\text{C}$ ratios in the Amargosa Desert area, it is clear that, at the present time, the isotopic characters of strontium + carbon dissolved in the Paleozoic carbonates-based fluids are abnormal and markedly different from those expected. The observed values of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio range from 0.7123 to as much as 0.7190, Figures 8 and 23; for the $\delta^{13}\text{C}$ ratio, the observed values range from -4.6 to -5.2 per mil_{PDB}, Winograd and Pearson (1976). Clearly, in the Amargosa Desert area, the Paleozoic carbonates-based fluids did not acquire the dissolved strontium +

carbon through ionic and isotopic exchange reactions solely with their host rocks. For these fluids, the host rock isotopic inputs are evidently being augmented by strontium + carbon from some other sources. No such augmentation, however, is evident at Yucca Mountain during times corresponding to the hydrothermal stages of activity of the Timber Mountain Caldera. One explanation for the noted discrepancy is that, since the Timber Mountain Caldera times, the fluid circulation depth has been substantially increased. The increasing involvement of both the Pre-Cambrian basement and the higher CO₂ dissolution temperatures causes that, for fluids residing in the Paleozoic carbonates, the relative concentrations of the dissolved strontium-87 increase and the relative concentrations of the dissolved carbon-13 decrease.

In summary, while performing their interpretations of the origin of the Yucca Mountain calcretes and associated veins, based on the uranium + strontium + oxygen + carbon isotopic data, the USGS investigators make four cardinal errors and, consequently and by any standards, the resulting conclusions must be considered as devoid of any scientific merit. First, notwithstanding plentiful and persuasive facts to the contrary, the USGS investigators keep regarding the Yucca Mountain geodynamic system as a linear or equilibrium dynamic system. For this system, the controlling factors (both the conductivity structure and the boundary conditions) are erroneously assumed to be perpetually fixed. By definition, the envisaged system is asymptotically stable, such that if subjected to perturbations, it is always driven back to the point-attractor reference state. This myopic and groundless perception, expressing a wish for a predictable and reversible world, may be adequate for

solving a variety of short-term groundwater supply and management problems. However, for the purposes of developing a high-level nuclear waste repository, this "nothing happens-perception" is clearly inadequate. It must be replaced by a perception that makes allowances for the intrinsically evolving character of natural systems.

Second, notwithstanding plentiful and persuasive facts to the contrary, the USGS investigators keep insisting that the Yucca Mountain hydrologic system is a shallow-gravity driven flow system, classically consisting of the high-ground recharge areas and the low-ground discharge areas. It is erroneously assumed that for this system, deeply penetrative fluid and gas circulations and vertical motions are of no importance. Furthermore, it is assumed that the circulating fluids acquire their isotopic characteristics through modifications of the original isotopic inputs via isotopic and ionic exchange reactions with rocks situated along a horizontal flow path. Because the aquifer rocks do not change much, the resulting isotopic characteristics also do not change significantly, neither in space nor in time. For the corresponding fluids, these characteristics may be used to uniquely identify the intraformation time and history. In volcanically and tectonically active regions (such as the Yucca Mountain region), however, common sense alone is sufficient to tell us that the deeply penetrating fluid and gas circulations are important. In addition to ionic and isotopic exchange reactions with reservoir rocks, the corresponding fluids acquire their isotopic characteristics through spatio-temporally varying, yet incessant, intermixings of various fluid and gas phases. For multi-component solutions, this causes

that: (1) the isotopic characteristics may not be regarded as unique indicators of the respective fluid intraformation time and history, and (2) for a given point in space, the isotopic characteristics are time-variant. The latter expectation is particularly relevant for developing a paradox-free and thus provisionally correct understanding of the isotopic characteristics, as observed for the Yucca Mountain calcretes and associated veins.

Third, in addition to working with the inapplicable thermodynamic and hydrologic concepts, the USGS investigators consider only selected parts of the available data base. Specifically, these investigators ignore both the chemical composition data as developed and reported by Broxton et al. (1986), and the K/Ar radiometric data, as developed and reported by WoldeGabriel (1991). The former data allow for a comparison of the chemical compositions of the local volcanic glasses with the corresponding compositions of the devitrified ignimbrites, Figures 24a through 24c. The detailed comparison (not included herein), in turn, reveals that, relative to the volcanic glass, the corresponding altered ignimbrites are enriched in a number of major and trace elements, including calcium, magnesium, aluminum, iron, titanium, etc. The latter data allow for appreciation of youthfulness and persistency of the locally evident metasomatism. Specifically, the K/Ar ages from samples of the metasomatic clinoptilolites indicate that, at Yucca Mountain, the calcic zeolitization: (1) occurred during a time span from 8.47×10^6 to 1.99×10^6 B.P., and (2) is an episodically ongoing process. The spatial correspondences between the alteration and mineralization phases, in turn, indicate that the calcitic veins record the carbonatization aspects of this process, and the

calcic clinoptilolites record the associated zeolitization aspects.

Fourth, consistently and predictably, the USGS investigators dismiss and ignore isotopic data and interpretations that contradict and, taken

collectively, invalidate the rainwater hypothesis. The following five

examples are put forth in support of this accusation. While performing the

interpretations of values of the $^{234}\text{U}/^{238}\text{U}$ ratio, from samples of the Yucca

Mountain calcretes and associated veins (Figure 25a), the USGS investigators

point out that the observed values are significantly lower than the

corresponding values from the DH-2 travertine vein (Figure 25b). The

well-known fact that the Yucca Mountain $^{234}\text{U}/^{238}\text{U}$ ratios are identical to

those from the Furnace Creek and Amargosa Basin travertine veins, however, is

completely ignored, Figures 18 and 25. While performing the interpretations

of values of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio, as observed in the Yucca Mountain vadose

zone (Figure 4), Peterman et al. (1991) have made the following statement,

"Calcite fracture filling within approximately 200m of the surface probably formed by infiltration of water which carried surficial CO_2 and Sr downward

along fractures and faults. This conclusion supports the interpretation of

Szabo and Kyser (1990) based on stable isotope systematics." The implied

rainwater origin of the corresponding veins ignores three well known facts.

These are: (1) the Yucca Mountain $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are identical to those

contained in the DH-2 travertine vein, Figures 4 and 5; (2) the Yucca Mountain

$^{87}\text{Sr}/^{86}\text{Sr}$ ratios are identical to those contained in the local geothermal

fluids, Figures 4 and 8; and (3) samples of both the metasomatically altered

ignimbrites (containing calcic clinoptilolites with K/Ar ages ranging from

8.47×10^6 to 1.99×10^6 years B.P.) and the spatially corresponding calcitic

veins yield similar $^{87}\text{Sr}/^{86}\text{Sr}$ ratio vs. depth gradients, Figures 4 and 7. While performing the interpretations of the $\delta^{18}\text{O}$ ratio vs. depth gradient, as observed from samples of the vadose zone calcitic veins, Szabo and Kyser (1990) and Peterman et al. (1991) have considered that the reconstructed paleo-geothermal gradient is similar to the corresponding contemporary geothermal gradient. A comparison of the both spatially equivalent gradients, however, reveals that such is hardly the case. As shown in Figure 9, relative to the contemporary geothermal gradient, the gradient reconstructed by Szabo and Kyser is strongly divergent. The observed discrepancy indicates that, at Yucca Mountain, the precipitation of the calcitic veins was accompanied by a substantial warming of the basal parts of the vadose zone and may hardly be regarded as caused by infiltrating rainwaters. While performing the interpretations of the $\delta^{13}\text{C}$ ratios, as observed from samples of the Yucca Mountain veins situated in the upper 1 km of the topographic surface (Figure 3), Whelan and Stuckless (1991) have categorically stated that "the isotopically light $\delta^{13}\text{C}$ of the UZ calcite reflects the interaction of the UZ fluids with organic material and pedogenic carbonate in the soil zone prior to infiltration." This conclusion again ignores three well known facts. These are: (1) the vadose zone interstitial fluids, samples of which were centrifuged out of cores extracted in the Yucca Mountain borehole UE-25 UZ #4, carry values of the $\delta^{13}\text{C}$ ratio ranging from -20.05 to -26.70 per mil_{PDB}, Yang (1989); (2) the isotopic character of carbon incorporated in the known Yucca Mountain calcitic veins is isotopically "heavier" than that expected to be contained in veins produced by the local infiltrating rainwaters, Figures 19a through 19d; and (3) the isotopic character of carbon incorporated

in the known Yucca Mountain calcitic veins is identical to that incorporated in many hydrothermal ore deposits and veins, Figures 20 and 21. Finally, and perhaps least excusably, while performing the interpretations of the uranium + strontium + oxygen + carbon isotopic data, the USGS investigators completely ignore the U/Th radiometric data, from samples of the Yucca Mountain calcretes and associated veins. The means of these data display a fairly suspicious looking correspondence with the means of the K/Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ laser fusion radiometric ages from samples of the local alkali basalts and hawaiites. This correspondence is depicted in Figure 26. Is it not eminently reasonable to suspect that, the evident spatio-temporal correspondence may be telling us that, at Yucca Mountain, both the mafic magmatism and the pedogenic developments are linked via cause-effect relationship? Are the papers in Science, and the special GSA session, sufficient to denounce and ignore such linkage? I think not.

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a) isotopic character of strontium contained in the Devil's Hole calcitic vein. From Marshall et al. (1990).

b) isotopic character of strontium contained in the Yucca Mountain calcretes and veins. From Stuckless (1990).

Note:

- a) the Devil's Hole vein has been precipitated from the local thermal fluids - these calcium-magnesium fluids are known to carry abnormally high values of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio; and
- b) the phrase "pedogenic carbonate" is used to denote the Yucca Mountain calcretes.

Isotopic character of strontium contained in samples of the Yucca Mountain calcretes and associated veins.

	Mb	Sr	Y	Zr	Mb	Rb/Sr	Ma	$^{87}\text{Sr}/^{86}\text{Sr}$ IR(Sr)
	Parts per million							
Tiva Canyon								
MD-18	192	24	36	187	32	8.00	12.9	0.71574
MD-29	222	10	25	64	30	22.20	12.9	0.72024
MD-32-1	208	49	29	67	33	4.24	12.9	0.71353
MD-34	148	44	37	326	24	3.36	12.9	0.71267
Yucca Mt. 2AA-6	175	31	34	193	32	5.65	13.0	0.71495
Topopah Spring(12)	176	22	26	109	22	8.07	13.4	0.71603
2AA-5(upper)	146	57	25	320	21	2.56	13.4	0.71231
2AA-3 (bas. vit.)	192	58	22	118	25	3.31	13.4	0.71239
2AA-1(basal)	204	63	28	104	24	3.24	13.4	0.71345
Calico Hills(4)	159	66	24	91	19	2.41	13.4	0.71328
2A-1-1	85	77	10	53	12	1.10	13.4	0.71239
2A-1-2	158	92	18	99	18	1.72	13.4	0.71239
Prow Pass(2)	155	52	30	148	27	2.99	13.5	0.71172
3A-7	116	196	21	93	19	0.59	13.5	0.71139
Bullfrog(16)	139	124	29	135	24	1.12	13.5	0.70953
3A-6 (upper)	159	122	26	108	20	1.30	13.5	0.70976
3A-4 (ba. vit.)	165	239	27	177	31	0.69	13.5	0.70879
3A-3 (ba. vit.)	151	464	27	251	26	0.33	13.5	0.70834
3A-2 (basal)	169	118	25	131	23	1.43	13.5	0.70944
Air Fall 31-1	144	149	29	204	31	0.97	13.5	0.71012
Tram(11)	131	196	20	149	19	0.67	13.6	0.70974
4A-1	219	705	27	179	32	0.31	13.6	0.71026
4B-4	161	178	21	108	17	0.90	13.6	0.71042
4B-6	149	79	17	113	20	1.89	13.6	0.71105
Flow Breccia(4)	103	729	32	331	17	0.14	13.7	0.70928
Lithic Ridge(6)	131	240	24	165	21	0.55	13.8	0.70909
IC-3	151	144	19	128	26	1.05	13.8	0.70947
Unit A(6)	157	161	25	151	27	0.98	14.0	0.70955
Unit B(1)	131	183	26	186	23	0.72	14.0	0.70921
Unit C(7)	130	511	23	244	17	0.25	14.0	0.70888
Yucca Flat 1C-1	108	105	32	177	32	1.03	14.0	0.71013
								0.70955

Explanation:

- - major cations content from samples of clinoptilolites;
- - major cations content from whole-rock samples;

bar indicates range of values for either $^{87}\text{Sr}/^{86}\text{Sr}$ or Sr concentrations, whole-rock samples; and

Tpc - the Tiva Canyon Member, Tpy - the Yucca Mountain Member, Tpt - the Topopah Spring Member, Thl - the Tuffs of Calico Hills, Tcp - the Prow Pass Member, Tcb - the Bullfrog Member, Tct - the Tram Member, and Tlr - the Lithic Ridge Tuff.

Depth comparison - the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, the Sr concentrations, and the major cation concentrations, samples of the alteration products (whole-rock and clinoptilolites).

Note:

- for the K+Na carrying fluids, total number of samples is 11; and
- for the mature Ca+Mg carrying fluids, total number of samples is 14.

A comparison of the isotopic characters of strontium dissolved in the sodium-potassium and calcium-magnesium fluids phases.

Comparison between the contemporary geothermal gradient and the paleo-geothermal gradients, as reconstructed based on the $d\delta^{18}O/dz$ gradient from samples of the calcite-silica deposits and using various assumptions.

Whole-rock concentrations of strontium, southernmost end of Yucca Mountain. From Peteman et al. (1991).

Note:

- mol % of exchangeable cations, as determined by electron microprobe analyses, are from Broxton et al., (1986); and
- the calcic series zeolites have been identified in boreholes J-13 (heulandite + chabazite), UE-25p#1 (heulandite + laumontite + erionite), UE-25a#1 (heulandite + erionite) and G-4 (heulandite), Carlos et al. (1990) and Bish and Chipera (1989).

Chemical composition of the Yucca Mountain clinoptilolites, expressed as mol % of exchangeable cations, as a function of depth.

Note:

- mol % of exchangeable cations, as determined by electron microprobe, are from Broxton et al. (1986); and
- calcic series zeolites were identified in boreholes USW G-2 (heulandite + stellerite, at a depth from 1447 to 1687 feet), USW G-1 (heulandite + stellerite, at a depth from 1156 to 1356 feet), and USW G-3 (heulandite + erionite, at a depth of 1189 feet), Carlos et al. (1990).

Chemical composition of the Yucca Mountain clinopitilites, expressed as mol % of exchangeable cations, as a function of depth.

Explanation:

- - sample represents clinoptilolites from the vadose zone;
- - sample represents clinoptilolites from below the water table;
- + - sample represents illite/smectites with the RO type of interstratification; and
- ⊕ - sample represents illite/smectite with the R1 and $R \geq 3$ type of interstratification.

K/Ar ages of clinoptilolites and hydrothermal clays as a function of depth, Yucca Mountain. From Aronson and Bish (1987) and WaldeGarbiel (1991).

Note:

- mol % of exchangeable cations are from Broxton et al. (1986);
- K/Ar ages are from WaldeGabriel (1990);
- Carlos et al. (1990) have reported that, in borehole USW G-4, heulandite occurs at a depth from 1254 to 1381 feet; evidently, the Ca+Mg zeolite zone extends, at least, to a depth of 1254 feet; and
- the representative Ca+Mg cations content is given by the mol % vs. depth curve.

K/Ar ages of the Yucca Mountain clinoptilolites, as a function of depth and mol % of exchangeable cations.

Note:

- a) mol % of exchangeable cations [as determined employing a combination of x-ray fluorescence, atomic absorption, and plasma-source emission spectrophotometry] are from Broxton et al. (1986).

Chemical composition of the Yucca Mountain ignimbrites (whole-rock samples), expressed as mol % of exchangeable cations, as a function of depth.

Note:

- a) mol % of exchangeable cations [as determined employing a combination of x-ray fluorescence, atomic absorption, and plasma-source emission spectrophotometry] are from Broxton et al. (1986).

Chemical composition of the Yucca Mountain ignimbrites (whole-rock samples), expressed as mol % of exchangeable cations, as a function of depth.

a) schematic diagram showing principal elements of the future upwelling.

b) spatial distribution of the upward fluid flux increase - $\Delta q_{(x)}$.

c) spatial distribution of the fluid diffusion path.

Explanation for the selective development of the most strontium-radiogenic calcite veins.

Explanation:

- - USW G-1 borehole;
- - USW G-2 borehole;
- ◐ - USW H-5 borehole;
- - contemporary geothermal gradient in USW G-1, from Sass et al. (1987).

Paleo-geothermal reconstructions, based on the observed zonation of zeolitization and illitization, northwestern Yucca Mountain.

Explanation:

- - J-13 well;
- - UE-25p#1 borehole;
- - UE-25a#1 borehole;
- ⊕ - USW G-3 borehole; and
- - - contemporary geothermal gradient in UE-25p#1

Note:

- a) Chemistry of the zeolitic assemblage from the southeastern sector differs from that of zeolitic assemblage from the northwestern sector. The former zeolites tend to be more calcic in composition; the latter zeolites tend to be more of sodic-potassic composition. Also, the former zeolites include more exotic calcic species, such as: laumontite, heulandite, erionite, and chabasite.

Paleo-geothermal reconstructions, based on the observed zonation of zeolitization and illitization, southeastern Yucca Mountain.

Distribution of the alteration temperatures at a depth of 3000 feet, Yucatan Mountain.

Isotopic characters of carbon and oxygen contained in the Yucca Mountain subsurface veins. From Whelan and Stuckelss (1991).

Sample No.	Uranium (ppm)	Thorium (ppm)	Activity Ratios		
			$\frac{^{234}\text{U}}{^{238}\text{U}}$	$\frac{^{230}\text{Th}}{^{232}\text{Th}}$	$\frac{^{230}\text{Th}}{^{234}\text{U}}$
Total Dissolution					
1	0.564 ±0.011	0.75 ±0.04	1.07 ±0.02	2.05 ±0.06	0.868 ±0.035
2	0.668 ±0.013	0.86 ±0.04	1.08 ±0.02	2.00 ±0.06	0.793 ±0.032
3	0.609 ±0.012	0.88 ±0.04	1.09 ±0.02	1.84 ±0.06	0.819 ±0.033
4	0.693 ±0.014	1.05 ±0.05	1.11 ±0.02	1.82 ±0.06	0.859 ±0.034
Carbonate Leach					
3	0.39 ±0.02	0.57 ±0.06	1.11 ±0.02	1.79 ±0.05	0.733 ±0.037
4	0.68 ±0.03	0.71 ±0.07	1.07 ±0.02	1.97 ±0.06	0.691 ±0.035
Acid-Insoluble Residue					
3	0.74 ±0.04	0.95 ±0.10	1.03 ±0.02	1.90 ±0.05	0.769 ±0.038
4	1.06 ±0.05	3.7 ±0.4	0.811 ±0.024	1.63 ±0.05	2.41 ±0.12

Uranium concentrations and activity ratios, the travertine veins from the Furnace Creek Wash area. From Szabo and O'Malley, 1985.

Sample No.	Uranium (ppm)	Activity Ratios		
		$\frac{^{234}\text{U}}{^{238}\text{U}}$	$\frac{^{230}\text{Th}}{^{232}\text{Th}}$	$\frac{^{230}\text{Th}}{^{234}\text{U}}$
Caliche Nodules - Main Hectorite Whiting Pit				
79-3-7P ¹	1.51	1.196	213	0.921
	±0.03	±0.012	±64	±0.027
80-10-20F ¹	0.431	1.206	55	0.952
	±0.015	±0.009	±11	±0.038
Travertine Vein ²				
81-3-19F ³	1.25	1.522	176	1.11
	±0.02	±0.022	±53	±0.03
AM-9 ⁴	1.24	1.486	242	1.13
	±0.02	±0.022	±50	±0.03

¹ Collected by R. L. Hay, 3.2 km south of IMV Plant, near center; east of edge SE 1/4 Sec. 6, T. 26N., R. 5 E., (Calif. part of Ash Meadows 15 min. Quad.).

² Vein location is SW 1/4, NW 1/4, sec. 23, T. 17S, R. 50E.

³ Collected by K. Kyser.

⁴ Collected by I. J. Winograd.

fluids produced through leaching of the Nevada Test Site soils.

observed very shallow fluids from alluvium and tuff "pile".

soil fluids produced through dissolution of the observed CO_2 .

parent fluids for the Yucca Mountain calcretes and veins

Note:

a) the isotopic data used in constructing this figure are explained and referenced in Figures 19b through 19d.

Carbon isotopic analyses of the origin of the authigenic breccia cements and the associated lithofacies.

Note:

- the observed range for the $\delta^{13}\text{C}$ ratio, from samples of the Yucca Mountain calcretes and surficial veins, is from -3.0 to -7.5 per mil_{permil}; isotopic data are from Whelan and Stuckless, 1990.
- for precipitation temperature $T=15^\circ\text{C}$, the equilibrium fractionation factor $10^3 \ln \alpha_{\text{CaCO}_3 - \text{HCO}_3} = 1.75$ per mil_{permil}; and
- the interpreted range for the $\delta^{13}\text{C}$ ratio, for the parent fluids of the Yucca Mountain calcretes and surficial veins, is from -4.75 to -9.25 per mil_{permil}.

Carbon isotopic analyses of the origin of the authigenic breccia cements and the associated lithofacies.

- o A mean value of the $\delta^{13}\text{C}$ ratio for the CO_2 gas respired from the vadose zone, as observed at Yucca Mountain and Amargosa Narrows, is $\delta^{13}\text{C} = -18.36$ and -20.0 per mil_{PDB}, respectively, Yang et al., 1986, Thorstenson et al., 1989, and White and Chuma, 1987 - the Yucca Mountain value is based on samples that carry PMC > 100 percent and were collected at a depth ranging from 0 to 12.8m.
- o A mean value of $\delta^{13}\text{C}$ ratio for soil gas, as observed at various locations throughout the Nevada Test Site, is $\delta^{13}\text{C} = -20.5$ per mil_{PDB}, Boughton, 1986.
- o The equilibrium isotopic fractionation factor $10^3 \ln \alpha_{\text{HCO}_3 - \text{CO}_2(\text{g})} = 9.483 \cdot 10^3 \cdot T^{-1} - 23.89$, Turi (1986) - for 15°Celsius, the fractionation factor is ~9 per mil_{PDB}.
- o Dissolution of the CO_2 gas respired from the vadose zone, with the observed range from -18.36 to -20.5 per mil_{PDB}, may be expected to yield the *per descensum* pedogenic fluids with the $\delta^{13}\text{C}$ ratios ranging from -9.36 to -11.5 per mil_{PDB}.
- o A mean value for the $\delta^{13}\text{C}$ ratio from samples of shallow alluvium - based fluids, as observed around Amargosa Narrows, is $\delta^{13}\text{C} = -11.3$ per mil_{PDB} (range of the observed values is from -9.59 to -13.05 per mil_{PDB}), White and Chuma (1987).
- o A value of the $\delta^{13}\text{C}$ ratio from samples of shallow tuff "pile" - based fluids, as observed in the Yucca Mountain borehole UE-29a#2 (depth to the water table is 29m, and PMC ranges from 60 to 62.3 percent), is $\delta^{13}\text{C} = -13.0$ per mil_{PDB}, Benson and McKinley, 1985.
- o A value of the $\delta^{13}\text{C}$ ratio for the Nevada Test Site soil water, as interpreted based on laboratory soil-leaching experiments, is $\delta^{13}\text{C} = -12.0$ per mil_{PDB} (the observed range for leached water is from -9.6 to -16.4 per mil_{PDB}), Spencer (1990).

Carbon isotopic analyses of the origin of the authigenic breccia cement and the associated lithofacies.

The $\delta^{13}\text{C}$ range from -4.75 to -9.45 per mil_{PDB}, interpreted for the parent fluids of the Yucca Mountain calcretes and surficial veins, is too "heavy" to permit genetic association with the local *per descensum* pedogenic fluids alone.

Note:

- a) Quade and Cerling (1990) have proposed that, the Yucca Mountain calcite-silica deposits were precipitated during the glacial maxima, when the local climate was cooler than the contemporary climate;
- b) the postulated climate was analogous to that presently encountered at altitudes 750 - 790m higher, in the lower pinyon-juniper-sagebrush zone;
- c) it may reasonably be assumed that, during precipitation of the Yucca Mountain calcite-silica deposits, the local biomass could have contained higher proportion of plants with the C-3 metabolic pathway and, consequently, the biogenically derived CO_2 was isotopically "lighter" than the contemporary CO_2 ; and
- d) the depicted in Figure 19a carbon isotopic discrepancy, between the parent fluids for the Yucca Mountain deposits and the local *per descensum* pedogenic fluids, represents a minimum value.

Note:

- relict fluids entrapped in fluid inclusions from samples of the carbonate gangue minerals, associated with various hydrothermal ore deposits, yield values of the $\delta^{13}\text{C}$ ratio ranging from -4 to about -10 per mil_{PDB};
- for individual ore deposits, the different generations of the carbonate gangue minerals are arranged from early to late, as shown by arrows;
- the observed trend toward the isotopically "heavier" carbon (with decreasing age of the carbonate gangue minerals) may be taken to indicate that, as the volcanic activity and the resulting geothermal circulations decay, the contribution of CO_2 from the deep-seated igneous sources also decays; and
- observation that the hydrothermal ore forming fluids carry values of the $\delta^{13}\text{C}$ ratio ranging from -2 to about -10 per mil_{PDB} may be taken to indicate the deep-seated (igneous) origin of the dissolved carbon, Hoefs (1987).

The isotopic character of carbon contained in samples of the carbonate gangue minerals associated with various hydrothermal ore deposits. From Hoefs (1987).

		Rock (‰)		Water (‰)		Temperature		
		$\delta^{13}\text{C}$	$\delta^{18}\text{O}$	$\delta^{13}\text{C}$	$\delta^{18}\text{O}$	measured	^{13}C	^{18}O
Spring travertine								
Reds Meadow Spring		+1.7	+15.8	-3.6	-14.7	48	76	15
Hot Creek		+1.5	-7.2	-1.5	-15.8	92	113	54
Dome Spring A		+2.6	+15.9	-5.7	-15.7	58	42	11
Dome Spring B		+1.8	+15.9	-5.7	-15.7	58	50	11
Mammoth Rock Spring		-0.3	+14.2	-9.7	-14.9	18	31	25
Layton Spring A		+3.5	—	-9.3	-13.7	33	6	—
Layton Spring B		+1.9	—	-9.3	-13.7	33	17	—
Layton Spring C		+1.3	—	-9.3	-13.7	33	22	—
Little Hot Creek		-0.7	—	-3.4	-15.2	83	119	—
Big Alkali Lake Spring		-0.3	+13.2	-6.0	-15.8	50	70	22
Colton Spring		+0.1	+14.4	-3.0	-14.2	93	112	24
Little Alkali Lake Spring		—	+16.7	-4.9	-15.9	48	—	7
Vein calcite in the hydrothermal reservoir								
RDO-8	317 m	-5.3	-5.4	-4.9	-14.3	164	205	211
	405 m	-7.0	-7.1	-4.9	-14.3	175	307	251
	503 m	-4.1	-3.3	-4.9	-14.3	173	167	173
	521 m	-3.2	-2.0	-4.9	-14.3	171	146	154
	541 m	-6.1	-8.4	-4.9	-14.3	198	244	288
	547 m	-5.8	-7.6	-4.9	-14.3	200	229	264
	568 m	-6.5	-8.5	-4.9	-14.3	196	268	292
	611 m	-4.6	-3.9	-4.9	-14.3	198	182	183
	613 m	-5.7	-7.4	-4.9	-14.3	189	222	259
44-16	2500 m	-3.0	-1.9	-4.8	-14.9	205	230	125

Isotopic character of carbon contained in the Long Valley travertines and hydrothermal calcitic veins. White et al. (1990).

Note:

- a) the fractionation equation is from Turi (1986);
- b) mean value of the $\delta^{13}\text{C}$ ratio, for the sub-lithospheric mantle indigenous CO_2 , may be taken as ~ -6 per mil_{PDB}, Hoefs (1987);
- c) depending upon reaction temperature, dissolution of the sub-lithospheric mantle indigenous CO_2 may be expected to produce fluids with values of the $\delta^{13}\text{C}$ ratio ranging from $+1.45$ ($T = 20^\circ\text{Celsius}$) to -10 per mil_{PDB} ($T = 200^\circ\text{Celsius}$); and
- d) the expected range of the $\delta^{13}\text{C}$ ratio, for fluids produced through dissolution of the sub-lithospheric mantle indigenous CO_2 , is similar to that observed for the Nevada Test Site geothermal fluids.

Plausibility assessment - hypothesis that the abnormally low values of the $\delta^{13}\text{C}$ ratio, for the Paleozoic carbonates based "source" fluids, may be reflecting influx of the sub-lithospheric mantle indigenous CO_2 .

Location	Sampling site	$^{87}\text{Sr}/^{86}\text{Sr}$	Source
Chemically and isotopically immature fluids			
Spring Mtns	spring	0.7084	Stuckless(1990)
Spring Mtns	spring	0.7088	do
Indian Sprg Val	spring	0.7100	do
Indian Sprg Val	spring	0.7096	do
mean: 0.7092			
Chemically and isotopically mature thermal fluids			
northern NTS	UE-15d	0.7135	Stuckless(1990)
Yucca Flat	C-1	0.7149	do
Yucca Mtn	UE-25p#1	0.7118 (?)	do
south of Mercury	16S/51E	0.7117	do
Ash Meadows	spring	0.7127	do
do	spring	0.7125	do
do	spring	0.7123	do
do	spring	0.7124	do
do	spring	0.7124	do
do	spring	0.7124	do
do	spring	0.7125	do
do	spring	0.7170	do
do	spring	0.7190	do
Greenwtr Range	well	0.7165	do
mean:0.7136			

Isotopic character of strontium dissolved in the calcium-magnesium type of subsurface fluids, region around Yucca Mountain.

Explanation:

FIELD OF COMPOSITIONS FOR THE
PAH CANYON MBR. (n = 3)
TOPOPAH SPRING MBR. (n = 40)
TUFF OF CALICO HILLS (n = 25)
PROW PASS MBR. (n = 5)

FIELD OF COMPOSITIONS FOR THE
TIVA CANYON MBR. (n = 17)
YUCCA MOUNTAIN MBR. (n = 1)

n = NUMBER OF ANALYSIS

Triangular diagram showing relative alkali metal and alkali earth elements compositions, samples of glasses from various Yucca Mountain ignimbrites. From Broxton et al. (1986).

Triangular diagram showing relative alkali metal and alkali earth elements compositions, whole-rock samples of the Yucca Mountain ignimbrites. From Broxton et al. (1980).

Triangular diagram showing the alkali metal and the alkali earth elements compositions, samples of the Yucca Mountain clinoptilolites.
From Broxton et al. (1986).

$^{234}\text{U} / ^{238}\text{U}$ vs. $^{230}\text{Th} / ^{234}\text{U}$ ratios, samples of Yucca Mountains calcretes, surficial veins and subsurface veins.

$^{234}\text{U}/^{238}\text{U}$ vs. $^{230}\text{Th}/^{234}\text{U}$ ratios, samples of the travertine veins from Devil's Hole, Amargosa Basin, and Furnace Creek Wash.

Explanation:

- - the U-series age, bar indicates value of the experimental error, and
- - actual U-series age exceeds value shown.

Note:

The U-series ages suggest that, during the last 400×10^3 years B.P. the precipitation of calcites occurred in association with, at least, four distinct hydro-tectonic episodes.

The U-series ages from sample of the Yucca Mountain calcretes, surficial calcitic veins, and subsurface calcitic veins.

The mean $^{40}\text{Ar}/^{39}\text{Ar}$ and K/Ar ages of the local igneous events.

The mean U/Th ages of precipitation of the calcretes and the vadose zone veins.

The interpreted history of formation of the Yucca Mountain calcretes and the vadose zone veins, based on radiometric ages of the local igneous events, and the corresponding carbonatization events.

PART 2

Letter to J. S. Szymanski

United States Department of the Interior

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BOX 25046 M.S. _____
DENVER FEDERAL CENTER
DENVER, COLORADO 80225

IN REPLY REFER TO:

Dec. 18, 1991

Dear Mr. Szymanski,

Thank You for your communication of Dec. 9, 1991. What with all the high-powered technical matter and heavy load of programmatic and quality assurance reading we have to do, your pedagogic satire on the scientific method provided a most refreshing change of pace.

Sincerely Yours,

Zell E. Peterman

John S. Stuckless