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IN REPLY REFER TO:

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Memorandum

To: S.J. Brocoum, U.S. Department of Energy, Assistant Manager for Licensing, Yucca Mountain Project

Robert W. Craig

From: R.W. Craig, U.S. Geological Survey, Chief, Yucca Mountain Project Branch

Subject: Review of reports relating to hydrothermal activity and modeling of potential water table rise at Yucca Mountain, Nevada by TRAC-NA on behalf of the Nevada Nuclear Waste Project Office

The TRAC materials given to the NWTRB at the February 1997 meeting in Pahrump, Nevada, consisted of a statement of objectives of research, 11 titles and summaries of research and two letters to Congress (attachment 1). The summaries of research have been reviewed by Dr. John Stuckless, Dr. William Dudley and Dr. Silvio Pezzopane who provide the comments below.

Nothing in the package represents truly new findings or directions of research, but the migration of the large hydraulic gradient to the south constitutes a new variant on an older theme which we shall treat in more detail than the other summaries. For the most part, nothing is presented in sufficient detail to permit (or even merit) careful review. In a few cases, we have been able to obtain the reports from which the abstracts were taken. For the others, we have assumed that the data base is what we have seen before or the same as we have for the same materials. All of the information relating to the origin of opal/calcite deposits has been presented previously in the article by Hill *et al.* (1994). A brief summary is included in the hand-out materials, and the entire article was attached at the end of the handout. Attached to this memo is our response refuting each of their arguments (attachment 2). This has been reviewed and approved by the Director of the U. S. Geological Survey and has been accepted by Environmental Geology for publication.

The summary of the "thermodynamic evolution and present state of the lithosphere at Yucca Mountain, Nevada" claims that a large set of data leads to the conclusion that heat transport has evolved from predominantly advective (13 Ma to 9 Ma) to predominantly conductive (<9 Ma). Supposedly, the earlier regime, one of "relatively shallow, multi-path, and long-lasting circulations" has changed over time to one of "deep-seated, energetic, hydrothermal plumes which can be triggered by tectonic events." In the present, conductive regime, the hydrologic system is described as thermally unstable with a large potential for hydrothermal eruptions in the next 10-100 Ka. The "findings" that apparently lead to these conclusions are (1) an almost illegible reproduction of Rick Blakely's Curie isotherm map of Nevada (Blakely, 1988), which the authors credit as demonstrating a vertical temperature gradient as great as 40°C/km and a lateral gradient of 3.2°C/km, and on which the authors significantly mis-locate the Yucca Mountain area; and (2) the presence of two distinct facies of epigenetic, "hydrothermal" minerals in the tuffs. The authors insinuate that the thermal gradients are extreme, but no comparisons with other areas are offered to show that they are in fact extreme or to support the authors' claim of thermal instability. Additionally, there is no apparent consideration of the relation of actual temperature measurements to Blakely's map, which shows the depths to magnetic basement calculated from the magnetic map of Nevada; the relation is, in fact, somewhat questionable. We certainly agree that the mineralogical suite that formed during emplacement of the tuffs and within the tuffs during the subsequent cooling period is demonstrably different from that formed later by chemical precipitation from infiltrating water or by low-temperature alteration in the presence of infiltrating water.

The summary of "Chemical heterogeneity of the clinoptilolite-heulandite fraction at Yucca Mountain, Nevada: Evidence for polygenetic, hydrothermal alteration" appears to be based on Project data and a false premise. The authors assume that the zeolites must have a similar composition to the unaltered tuffs; there is an abundance of published literature to the contrary. The authors imply that the project would like the same origin for the zeolites and the calcite/opal deposits, which is not true, but having implied that, the authors then conclude that the origins are different. There is also a reliance on apparent ages obtained at Los Alamos by Giday WoldeGabriel. None of us believe that these apparent ages represent any real event, but rather open-system behavior by materials that don't meet the criterion of retaining argon generated by the decay of potassium; this is especially true for zeolites from the unsaturated zone (Woldegabriel, 1995; Woldegabriel and others, 1996).

The summary of "hydrochemical accessory minerals in tuffs, breccias, and calcite/opal veins at Yucca Mountain: evidence for Plio-Quaternary hydrothermal eruptions" appears to be heavily flawed. Firstly, we have been unable to find any reported occurrences of either sphene or zircon as hydrothermal minerals. Furthermore, Charles Naeser and Schon Levy have reported geochronologic results for zircons from near-surface breccias in a project report (DOE, 1993). The ages for 12 individual zircons range from about 60 to 5 million years. The older, rounded zircons are obviously of detrital origin having originally crystallized from the Cretaceous igneous event. The younger, euhedral zircons are from the last ash-flow event. If the breccia deposits had been affected by solutions hot enough to grow zircons, all ages for any existing zircons would have been reset to the age of the hydrothermal event. But none of the zircons analyzed yield ages younger than their crystallization age, and thus, there is no evidence of a hydrothermal event younger than the tuffs. The project has also sampled a large volume of the Tiva Canyon Tuff for any evidence of disturbance of the oxygen isotope system (Marshall and others, 1996). Extensive studies of mineralized Tertiary granites from the western United States have shown that extremely large volumes of rock become strongly depleted in ^{18}O when the granites are subjected to epithermal alteration (Criss and Taylor, 1986). No such depletion was found, and thus, there is no evidence for large hydrothermal systems that have affected the Yucca Mountain area at any time since deposition of the Tiva Canyon tuff. (Note that the abstract says submitted to GSA, but the paper was never presented.)

The summary of "Fluid inclusions in calcite from the Yucca Mountain Exploratory Tunnel: evidence for hydrothermal origin of the calcite" is apparently based on data collected by TRAC personnel, though the number of samples and their locations are unknown. There is also no clear distinction between results from the ESF and those from drill core. All sampling within the ESF is supposed to be documented by a placard at the locality from which the samples are taken. There is no such documentation in the ESF of sampling by TRAC, so even if the samples were collected there, the samples have no traceability. Nonetheless, we have similar findings except that we find two-phase inclusions to be extremely rare. Geometric and age relations are some of the critical information not reported by TRAC. The evidence of methane and higher temperatures is found only in the oldest materials, which our few dates show to be at least as old as the youngest tuffs (>9 Ma). Also, the calcites are restricted to floors of cavities and footwalls of fractures, a geometry consistent only with unsaturated zone genesis.

The article on stable isotope gradients does not contain enough information to evaluate it, but the variation reported on oxygen and carbon is within the range seen at any one pedogenic exposure and can be explained by precipitation in variable climates. We have looked at the alleged spring deposit at WT-7 with members of the National Academy of Sciences panel. The panel concluded that the deposits originally formed during the last stages of volcanism, and some calcite was infilled much later (NAS, 1992, p. 46) . The minerals cited as proving a hydrothermal spring origin may have formed during the initial synvolcanic event. Alternatively, they are also common accessory minerals in the near-by tuffs and soils, and they may have washed in during the pedogenic infilling of calcite. We conclude that the starting material, referred to in the article as feeder 1, is best explained as pedogenic material.

If the assumption is made that the deposits were formed by flowing water, the explanation for increasing isotopic weight of carbon and oxygen in calcite with distance due to evaporation and degassing of CO_2 is reasonable. However, we note that the two sources of water must be isotopically very distinct in spite of their close spatial association. A complete evaluation of just how different the postulated two feeders are is not possible because no analysis of feeder 2 is provided and data for only 11 of the 15 sample points are plotted, but the two waters apparently mix at sample site 7 or further along the flow path (depending upon which sites have no data). As drawn, there is no reason why the two sources should not mix closer to feeder 1, but at site 7, any water from feeder 2 would have to have flowed at least 500 m before mixing with the water from feeder 1. By analogy with the isotopic composition of water from feeder 1, both carbon and oxygen in the water from feeder 2 should have become heavier by at least 1 per mil. This would work for carbon as long as nearly all the carbon in the combined system was from feeder 2. But the mixed oxygen (at site 7) is nearly 2 per mil lighter that the starting composition of feeder 1 and about 4 per mil lighter than the water in flow path 1. If calcite had been analyzed at feeder 2, it would have to have been at least as light as -15 or -16 per mil (as compared with -10.2). Such a large difference in discharging waters so close together does not seem reasonable, especially when the difference is observed in oxygen but not in carbon. (Again this paper was not presented at GSA.)

The abstract on "Sr-, C-, and O-isotopic profiles from the USW VH-2 borehole, Crater Flat, Nevada: Evidence for intermittancy (sic) of hydrothermal discharges and the Plio-Quaternary age of ^{87}Sr metasomatism at Bare Mountain" has no obvious connection to Yucca Mountain. The first paragraph starts with a confused description of the borehole lithology in which calcrete is mis-equated to calclithite. There is also a completely unfounded assertion that cementation of units occurred by as a result of "fluids discharged from faults cutting Bare Mountain." The authors identify two isotopically distinct "facies", but they never describe what these are geologically. We presume that they are some sort of carbonates because the authors report carbon isotopic compositions and because carbonate material is common throughout the drillhole, especially at the depths shown in the plot for their samples. The older facies is asserted (no age evidence is given) as "equivalent in age to the Timber Mountain Caldera", but according to the lithologic log (Carr and Parish, 1985) the sampling depth would correspond to breccias and blocks derived from the Paleozoic carbonates. Both the strontium and carbon isotopes match well with data for these geologic units. However, the authors, for no apparent reason, equate their samples to carbonates from >800 m depth at Yucca Mountain. The "younger facies" (Mio-Pliocene) is asserted to be less than 10 Ma, but again, no data are presented to support the age, and the lowermost samples of this facies appear to have been collected stratigraphically below a 10 Ma basalt. It is interesting to note that the authors say that their younger phase is isotopically equivalent to "calcite-opal veins which are present in the interior of Yucca Mountain, at a depth of less than 1,250 m" and to "Late Quaternary Spring deposits from southern Crater Flat and from the Amargosa Basin." Note that there is a 450 m overlap in the depth of veins at Yucca Mountain; the second set of compositions would more properly be described as shallower that 700 m. More importantly, these shallower samples from Yucca Mountain tend to have lighter carbon than the samples from VH-2 and are less radiogenic (with respect to strontium) than the spring deposits from southern Crater Flat and from the Amargosa Basin. Thus the VH-2 samples cannot be isotopically equivalent to both. The abstract closes with 4 assertions from another paper by Szymanski that don't even relate to the data presented for VH-2. (Again, this paper, contrary to the claim, was not presented at GSA.)

The summary on "Epithermal mineralization, alteration, and spring deposits at Yucca Mountain, Nevada - thermodynamic evolution of the geologic system" is a weak rehash of the Hill et al. (1994) article for which a rebuttal is enclosed. Note that the trends in isotopic composition with depth were first noted by the project personnel in 1985 (Szabo and Kyser, 1985) and a thorough discussion and explanation for the data was presented in 1992 (Whelan and Stuckless, 1992). Briefly, within the unsaturated zone, the carbon isotopic composition scatters over a range of compositions that reflect changing climatic conditions during at least the Quaternary and consequent changes in the plant community at the surface (i.e., c-3 and c-4 type plants). The oxygen isotopic composition varies about a line, the slope of which reflects precipitation of calcite at increasing temperatures with depth. The breadth of scatter about that line reflect changes in composition of rainfall or snow as a function of changing climate. This trend continues into the saturated zone, but the carbon composition changes fairly abruptly to heavier values which seem to reflect an ultimate source of the underlying Paleozoic carbonate rocks. A few samples of what appear to be early, possibly higher temperature calcites add some scatter to trends for both oxygen and carbon data.

The summary on "Carbonate deposits at Yucca Mountain (Nevada, USA) and the problem of high-level nuclear waste repository" contains no information not discussed above.

"Geohydrologic models and earthquake effects at Yucca Mountain, Nevada" presents a slightly new twist on an earlier theory, and we will, therefore, treat it in more detail than the other summaries. The earlier theory of water-table rise in response to earthquakes proposed by Szymanski and his colleagues was examined by a National Academy of Sciences panel and was found to be without merit. Our comments on the modified theory are based on the summary and a preprint of the same title with the caveat that these materials may not represent the final thoughts of the authors. Nonetheless, several general comments can be made. (1) Neither the summary nor the preprint contain sufficient information about underlying assumptions, model input, and boundary conditions to allow a rigorous evaluation of the model. As a consequence, one must accept the author's results "on faith," because they have not presented their analysis completely. This is true, for example, for such things as the elastic strain changes or dilatancy models used to support claims of hydrologic changes. (2) Much important detail is ignored. For example, data from various drillholes are compared without regard for the fact that different units were tested in different drillholes or that the geologic (and consequently hydrologic) character of a single unit changes drastically as a function of where it is sampled in a lateral sense. (3) The preprint contains many citation inaccuracies. Data are attributed to sources that contain no such data, and the data or postulates of some authors are misrepresented. As an example of the former case, Open-File Report 93-170 is cited as a source of data for the water table response to the Little Skull Mountain earthquake, but that report, by Prudick and others (1993), is only a conceptual model of the large-scale hydrology of the Great Basin with no data pertaining to the Little Skull Mountain earthquake. As an example of the latter case, Fridrich and others (1994) proposed a relatively short fault (8 km) as a drain, not a 100 km long fault, nor did they postulate that the fault might be a barrier to flow as claimed by Davies and Archambeau.

The claimed geographic coincidence of the regional zone of large hydraulic gradient with the perimeter of the Timber Mountain caldera is not well justified. In general, the large gradient occurs within well-faulted terranes beyond the edge of the caldera. The gradient zone correlates much better with the edge of the Paleozoic-carbonate domain, or its contact with contiguous regional aquitards, as explained in Fridrich et al. (1994). That "...a boundary between media of high and low conductivity can produce the large hydraulic gradient..." is hardly a revelation; Winograd and Thordarson (1968, 1975) demonstrated the relationship at Nevada Test Site almost three decades ago based on hydrogeologic principles that were commonly understood long before then. What is noteworthy is that the authors choose to explain the gradient near the Yucca Mountain site in terms of stress differences but do not address the consistency of this explanation with the other localities along the regionally extensive large hydraulic gradient.

Figure 1 of the summary (which is figure 2 of the pre-print), claims significance for discrete (single-value) fracture-opening water pressures as revealed by slug tests in wells. The claim that the data for USW G-1 and USW G-2 were obtained from slug-test analyses is false simply because these holes, which were small-diameter core holes, were not hydraulically tested by the straddle-packer, slug-injection technique. In-situ stresses were measured in these holes, however, by the hydrofrac technique (Stock and Healy, 1988). Note that the results for hydrofrac stress tests in other holes (USW G-3 and UE-25p#1) reported by Stock and Healy (1988) are not included on the present authors' figures, but without explanation. In addition, the fracture-opening pressures *per se* are meaningless unless they are normalized in some consistent way, preferably to a common vertical stress (overburden pressure). Note that Stock and Healy (1988, page 89) report least horizontal stresses (S_h, presumably comparable to fracture-opening pressures) for USW G-2 ranging from 5.1 to 12.0 MPa (about 50 to 120 bars), correlating with vertical (S_v, greatest stress in this tectonic setting) stresses of about 6.1 to 25.5 MPa at depths of 295 to 1210 m. Furthermore, in the hydrofrac technique, a new fracture is induced, theoretically normal to S_h and demonstrably so in the context of other evidence; then, S_h is measured as the pressure at which reopening is initiated. In contrast, fractures that are dilated during high-pressure slug tests may or may not be normal to S_h. In fact, if the dominant direction of fracturing in the northern part of the site area parallels the northwest-trending structural grain, the fractures that are most available to a randomly placed slug test would be approximately normal to the greatest horizontal stress, S_H. Finally, the authors give no indication that they have considered the likelihood that several fractures at different orientations participate in the dilatory response of a tested interval that is tens of meters long.

Several processes, mechanisms, cause-and-effect relations, and possible, but unlikely, conditions are treated as though they are rather well understood and neatly predictable. This is not the case! Similarly, earthquake scaling and historical analogs stated in the preprint are not consistent with the sizes and types of prehistoric earthquakes that have occurred at Yucca Mountain. Prehistoric earthquakes have been studied (Pezzopane and others, 1996) through determination of the height of paleoearthquake scarps along the flank of the ranges, the sizes of displacements recorded in trenches, and the maximum lengths of mapped faults (indicates the maximum potential fault rupture length). The strain changes discussed on p. 4 (10^{-5} to 10^{-6} at 5 km distance, 10^{-8} at 40 km) are about what one expects for a 2-m displacement event such as the Mw 6.8 Borah Peak, Idaho, earthquake. However, this range-bounding fault rupture is larger than the largest of the Yucca Mountain paleoearthquakes, which is a 1.2 m displacement on the 18 km-long Solitario Canyon fault (Ramelli and others, 1996). The authors provide scaling relations for "a magnitude 6 earthquake failure zone" as having a length of 15 km, a displacement of 2-3 m, and rupture extending to the surface from 10 km depth. The authors are modeling an event more like the 1954 Mw 6.8 Dixie Valley, Nevada, earthquake or those examples that they mention. The point is that earthquakes at Yucca Mountain have been smaller in size than those the authors model and describe in the preprint. This is especially true of the Bow Ridge fault (which is presumably the "Bowridge Canyon fault" cited in the preprint). Furthermore, the maximum length of that fault is 10 km (not 15) and does not display Quaternary movement along its total length (Pezzopane, 1996)

The analysis of ground-water response to the June 29, 1992 Little Skull Mountain earthquake is badly flawed. The responses reported in Figure 4 of the preprint for two wells in Jackass Flats (J-11 and J-12) and two in the southern Amargosa Desert (AD-11 and AD-16) are puzzling, but the inaccuracy of the source citations is deplorable. The data are attributed to two sources : (1) O'Brien, 1994, USGS Open-File Report 93-170, and (2) Lehman and Brown, 1994, presentation at a meeting of the Nuclear Waste Technical Review Board. Hand-written notes in the draft text indicate that the second citation is to be withdrawn, leaving the first as the represented source. However, USGS OFR 93-170 is "Conceptual Considerations of Regional Ground-Water Flow in the Carbonate-Rock Province of the Great Basin, Nevada, Utah, and Adjacent States" (Prudick and others, 1993) which is not a YMP paper and is unrelated to the effects of the Little Skull Mountain earthquake. O'Brien (1993) did, however, author Open-File Report (93-73), which was not cited by Davies and Archambeau; it reports responses of instrumented wells H-3, H-5, H-6, and UE-25p#1 to the subject earthquake but does not discuss the Jackass Flats and Amargosa Desert wells, which were not instrumented but rather were measured manually on an approximately monthly basis.

O'Brien and others (1995) report essentially unchanged water levels, varying less than 0.1 m, at both J-11 and J-12 from May through September of 1992. The hydrographs presented by Davies and Archambeau are erroneous and may indeed have been provided by Lehman and Brown, who may have failed to recognize or properly correct for a change of measurement reference point.

Based on the map location and general water-level altitude, the Davies/Archambeau well AD-16 is apparently the same as AD-12 (La Camera and Westenburg, 1994). The hydrograph for AD-16 is a reasonable representation of the USGS data for well AD-12. However, the paper provides no basis for assuming that the water-level rise between measurements on June 15 and July 20, 1992, are correctly attributed to the June 29 earthquake; it is merely asserted by the authors.

Again based on the map location and the general water-level altitude, the Davies/Archambeau well AD-11 is apparently the same as AD-10 (La Camera and Westenburg, 1994). The water levels shown on the hydrograph after June 1992, declining from about 2184 ft to about

2183 ft, agree approximately with the August - December monthly measurements reported by the USGS. There are no May and June measurements. However, the USGS data show four measurements and a relatively stable level of 2181.8 ±0.1 ft from January through April, whereas Davies and Archambeau portray six measurements at about 2168 ft. The official data indicate a 2-ft net rise during the mid-April to mid-August period, whereas Davies and Archambeau portray a 16-ft rise in a shorter period tailored to bracket the time and aftermath of the earthquake!

The discussion on page 6 of the preprint regarding the residual stress effects of the 10-Ma Timber Mountain caldera contradicts extensive previous experience in the region of the Nevada Test Site (Stock and others, 1985). This composite experience is compiled from 14 sources reporting results from diverse methods including hydraulic fracturing, overcoring stress measurements, earthquake focal mechanisms, borehole breakouts, orientations of explosion-produced fractures, and study of Quaternary faults and cinder-cone alignments. These studies show a reasonably uniform direction of extension between NW and W, with a mixed potential-slip regime of normal faulting (mainly for shallow indicators) and strike-slip faulting (mainly for deep indicators). The Davies and Archambeau discussion is also inconsistent with actual stress measurements in G-2 as reported by Stock and Healy (1988), which is cited by the current authors, though erroneously, as a source of "slug-test" data. Stock and Healy (1988) characterize G-2 as being within the same ("combined normal and strike-slip") faulting regime as that indicated by the results from the three holes that they tested south of the large gradient. In fact, based on the stress measurements in the four holes, the tendency for strike-slip faulting is greatest in the southeastern hole, UE-25p#1, not in the northern Yucca Mountain area where G-2 is located as Davies and Archambeau propose. The actual data do not support a residual stress effect from the Timber Mountain caldera, do not support a modern stress field changing from strike-slip in northern Yucca Mountain to normal south of the hydraulic gradient, and do not support a southward decrease of the least principal stress.

The discussion of hydraulic conductivities and transmissivities on page 7 of the preprint hinges principally on results from USW H-1, representing the purportedly less permeable northern sector, and from UE-25p#1, representing the presumably more permeable southern sector. In order to support this classification, the authors omit data for the upper sections of H-1 tested in the Crater Flat Group, which provided a transmissivity of 152 m^2/day (Luckey and others, 1996). The transmissivity for the same stratigraphic interval in UE-25p#1 (in the supposedly more permeable southern sector) was about 20 m^2/day. By truncating the H-1 data set, the authors assign a transmissivity of 5 m^2/day to the northern area, contrasting with the 370 m^2/day that they selected to represent the southern area.

Interestingly, USW H-1 has a water-table altitude of 730 m, which is characteristic of the area south of the large gradient, that is, of the area having the extremely small gradient, to which the authors elsewhere assign a small least principal stress. However, H-1 is indeed the farthest north of the wells that were tested by hydrologic techniques that provide transmissivity values, apparently leaving the authors little choice but to make do by truncating the test results.

In actuality, we do not disagree that the area north of the large gradient is less transmissive than the area to the south-southeast. However, we hold that the difference stems from durable differences of lithology, alteration history, and structural deformation, and not from a transient state of stress.

A casual reading without systematic verification of the citations nonetheless reveals several significant errors:

> On Page 1 and again on page 7, citations of Blankennagel and Weir (1973) suggest that they worked at Yucca Mountain, but they actually described the results of hydraulic tests at Pahute Mesa.
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> As noted above, Fridrich and others (1994) are cited on Pages 2 and 3 as proposing a fault of 100 km length as an impermeable barrier to flow, but these authors actually proposed a buried fault 8 km in length that could provide a permeable pathway to drain water downward to the Paleozoic aquifer.
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> Again as noted previously, Stock and Healy (1988) did not report on slug-injection tests, as the authors claim on Pages 6 and 7. However, there are numerous reports providing slug-test results from the holes discussed by Davies and Archambeau, but these authors do not acknowledge most of the original work.
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> Robison (1984) did not report hydraulic conductivities as the authors claim on Page 7, nor did he infer from his potentiometric data that hydraulic conductivity decreases to the north.

Based on this sampling, and the significant errors in the citations regarding the effects of the Little Skull Mountain earthquake and reported transmissivities and hydraulic conductivities, it seems likely that a rigorous reference-verification exercise would show much of the basis for this paper to be misrepresentation of the data and interpretations of others. We have no confidence that anything in the paper, whether reporting results attributed to others or those from the authors' analysis, can be taken at face value.

We agree generally with the conceptual model for the stepped slug-injection recovery curve as proposed in the abstract "Analysis of High-Pressure Fluid Flow in Fractures with Applications to Yucca Mountain, Nevada, Slug Test Data". However, we have not seen the full publication, presumably published in *Tectonophysics* in 1996, nor have we had the opportunity to evaluate their analysis of the full set of slug-test data. The abstract does state that the fracture reopening pressure "has been taken equal to the minimum principal stress". As stated earlier, this interpretation is justified only if the preexisting fracture that is dilated by water pressure is normal, or nearly so, to the least principal stress.

In a much earlier review (Attachment to letter of November 16, 1993 from Larry R. Hayes, USGS, to J. Russell Dyer, DOE), we identified problematic assumptions regarding test geometry, fracture permeability and rock-matrix storativity that seemed potentially to affect an early version of Davies' model for slug-test analysis.

References

Blakely, R.J., 1988, Curie temperature isotherm analysis and tectonic implications of aeromagnetic data from Nevada: Journal of Geophysical Research, v. 93, p. 11,817-11,832.

Blankennagel, R.K., and Weir, J.E., Jr., 1973, Geohydrology of the eastern part of Pahute Mesa, Nevada Test Site, Nye County, Nevada: U.S. Geological Survey Professional Paper 712-B, 35 p.

Criss, R.E., and Taylor, H.P., Jr., 1986, Meteoric hydrothermal systems, *in* Valley, J.W., Taylor, H.P., Jr., and O'Neil. J.R., eds., Stable Isotopes in high temperature geologic processes, Mineralogic Society of America, Reviews in Mineralogy, v. 16, p. 373-424.

Department of Energy, 1993, Report on the Origin of Calcite-Silica Deposits at Trench 14 and Busted Butte and Methodologies Used to Determine Their Origin: Yucca Mountain Site Characterization Report YMP/93-11-R, 64 p.

Fridrich, C.J., Dudley, W.W., Jr., and Stuckless, J.S., 1994, Hydrologic analysis of the saturated-zone ground-water system under Yucca Mountain, Nevada: Journal of Hydrology, v, 154, p. 133-168.

Hickman, S., Sibson, R.H. and Bruhn, R., 1994, eds., Proceedings of Workshop LXIII -- The Mechanical Involvement of Fluids in Faulting: U.S. Geological Survey Open-File Report 94-228, 615 p.

Hill, C.A., Dublyansky, Y.V., Harmon, R.S., and Schluter, C.M.,1995, Overview of calcite/opal deposits at or near the proposed high-level nuclear waste site, Yucca Mountain, Nevada, USA: Pedogenic, Hypogene, or Both?: Environmental Geology, v. 26, p. 69-88.

La Camera, R.J., and Westenburg, C.L., 1994, Selected ground-water data for the Yucca Mountain Region, Southern Nevada and Eastern California, through December 1992: U.S. Geological Survey Open-File Report 94-54, 161 p.

Luckey, R.R., Tucci, P., Faunt, C.C., Ervin, E.M., Steinkampf, W.C., D'Agnese, F.A., and Patterson, G.L., 1996, Status of understanding of the saturated-zone ground-water flow system at Yucca Mountain, Nevada, as of 1995: U.S. Geological Survey Water-Resources Investigations Report 96-4077, 71 p.

Marshall, B.D., T.K. Kyser, and Z.E. Peterman,1996, Oxygen Isotopes and Trace Elements in the Tiva Canyon Tuff, Yucca Mountain and Vicinity, Nye County, Nevada: U.S. Geological Survey Open-File Report 95-431, 49 p.

Muir-Wood, R., and King, G.C.P,. 1993, Hydrological signatures of earthquake strain: Journal of Geophysical Research, v. 98, p. 22035-22068.

National Research Council, 1992, Ground Water at Yucca Mountain: How High Can It Rise?, Final Report of the Panel on Coupled Hydrologic/ Tectonic/Hydrothermal Systems at Yucca Mountain, National Academy Press, Washington, D.C., 231 p.

O'Brien, G.M., 1993, Earthquake induced water-level fluctuations at Yucca Mountain, Nevada, June 1992: U.S. Geological Survey Open-File Report 93-73, 12 p.

O'Brien, Tucci, P., and D. J. Burkhardt, D.J., 1995, Water Levels in the Yucca Mountain Area, Nevada, 1992: U.S. Geological Survey Open-File Report 94-311, 74 p.

Pezzopane, S.K., 1996, Relevant Earthquake Sources, *in* Seismotectonic Framework and Characterization of Faulting at Yucca Mountain, Nevada: Synthesis Report by the U.S. Geological Survey to the U.S. Department of Energy, Chapter 11, p 11-1 to 11-44. (GS960783117361.002)

Pezzopane, S.K., Whitney, J.W., and Dawson, T.E., 1996, Models of Earthquake Recurrence and Preliminary Paleoearthquake Magnitudes at Yucca Mountain, *in* Seismotectonic Framework and Characterization of Faulting at Yucca Mountain, Nevada: Synthesis Report by the U.S. Geological Survey to the U.S. Department of Energy, Chapter 5, p. 5-1 to 5-100. (GS960783117361.003)

Prudick, D.E., Harrill, J.R., and Burbey, T.J., 1993, Conceptual Considerations of Regional Ground-Water Flow in the Carbonate-Rock Province of the Great Basin, Nevada, Utah, and Adjacent States: U.S. Geological Survey Open-File Report 93-170,

Ramelli, A.R., Oswald, J.A., Vadurro, G., Menges, C.M., and Paces, J.B., 1996, Quaternary faulting on the Solitario Canyon fault, *in* Seismotectonic Framework and Characterization of Faulting at Yucca Mountain, Nevada: Synthesis Report by the U.S. Geological Survey to the U.S. Department of Energy, Chapter 4.7, p. 4.7-1 to 4.7-56. (GS961083117361.010)

Robison, J.H., 1984, Ground-water level data and preliminary potentiometric maps, Yucca Mountain and Vicinity, Nevada: U.S. Geological Survey Water-Resources Investigations Report 84-4197, 8 p.

Sibson, R.H., 1994, Geological evidence for fluid involvement in the rupture process of crustal earthquakes: U.S. Geological Survey Open-File Report 94-228, p. 31-38.

Smith D.L., and Evans, B., 1984, Diffusional crack healing in quartz: Journal of Geophysical Research, v. 89, p. 4125-4135.

Stock, J.M., Healy, J.H. Hickman, S.H., and Zoback, M.D., 1985, Hydraulic Fracturing Stress Measurements at Yucca Mountain, Nevada, and Relationship to the Regional Stress Field: Journal of Geophysical Research, Vol. 90, No. B10, p. 8691-8706.

Stock, J.M., and Healy, J.H., 1988, Stress Field at Yucca Mountain, Nevada, *in* Carr, M.D., and Yount, J.C., eds., Geologic and Hydrologic Investigations of a Potential Nuclear Waste Disposal Site at Yucca Mountain, Southern Nevada: U.S. Geological Survey Bulletin 1790, p. 87-94.

Szabo, B.J. and Kyser,T.K., 1990, Uranium thorium isotopic analyses and uranium series ages of calcite and opal, and stable-isotope compositions of calcite from drill cores UE-25a-1, USW G-2, and USW G-3/GU-3, Yucca Mountain area, Nevada: U.S. Geological Survey Open-File Report 85-224, 25 p.

Whelan, J.F. and Stuckless, J.S., 1992, Paleohydrologic implications of the stable isotopic composition of secondary calcite within the Tertiary volcanic rocks of Yucca Mountain, Nevada: Proc of the Third International Meeting on High Level Radioactive Waste Management, American Nuclear Society, v. 2, p.1572-1581.

Winograd, I.J. and W. Thordarson, 1975, Structural control of ground water movement in miogeosynclinal rocks of south-central Nevada, in E.B. Eckel, ed., Nevada Test Site: Geological Society of America Memoir 110, p. 35-48.

Winograd, I.J. and W. Thordarson, 1975, Hydrogeologic and Hydrochemical Framework, South-Central Great Basin, Nevada-California, with Special Reference to the Nevada Test Site: U.S. Geological Survey Professional Paper 712-C, 126 p.

Woldegabriel, Giday, 1995, K/Ar dating of clinoptilolite, mordenite, and coexisting illite/smectite from Yucca Mountain, Nevada, *in* Natural zeolites '93 occurrence, properties, and use: Ming, D.W., and Mumpton, F.A. eds., Int. Comm. natural zeolites, Brockport, New York, p. 141-156.

Woldegabriel, Giday, Broxton, D.E., and Byers, F.M., Jr., 1996, Mineralogy and temporal relations of coexisting authigenic minerals in altered silicic tuffs and their utility as potential low-temperature dateable minerals: Journal of Volcanology and Geothermal Research, v. 71, 155-165.

Attachment 1

Materials Prepared by TRAC-NA and reviewed by the USGS

- The Thermodynamic Evolution and Present State of the Lithosphere at Yucca Mountain, Nevada
  by J. S. Szymanski and C. B. Archambeau

- Chemical Heterogeneity of the Clinoptilolite-Heulandite Fraction at Yucca Mountain, Nevada: Evidence for Polygenetic, Hydrothermal Alteration
  by D. E. Livingston and J. S. Szymanski

- Hydrochemical Accessory Minerals in Tuffs, Breccias, and Calcite/Opal Veins at Yucca Mountain: Evidence for Plio-Quaternary Hydrothermal Eruptions
  by A. V. Chepizhko, Y. V. Dublyansky, and J. S. Szymanski

- Overview of Calcite/Opal Deposits at or Near the Proposed High-Level Nuclear Waste Site, Yucca Mountain, Nevada, USA: Pedogenic, Hypogene, or Both?
  by C. A. Hill, Y. V. Dublyansky, R. S. Harmon and C. M. Schluter

- Fluid Inclusions in Calcite from the Yucca Mountain Exploratory tunnel: Evidence for Hydrothermal Origin of the Calcite
  by Y. V. Dublyansky, V. Reutsky, and N. Shugurova

- Stable Isotope Gradients in Slope Calcretes at Yucca Mountain, Nevada: Evidence for the Involvement of Carbonic Gases in the Hydrothermal Discharges
  by J. S. Szymanski and Y. V. Dublyansky

- Sr-, C-, and O-Isotopic Profile from the USW VH-2 Borehole, Crater Flat, Nevada: Evidence for the Intermittancy of the Hydrothermal Discharges and the Plio-Quaternary Age of the ^{87}Sr Metasomatism at Bare Mountain
  by J. S. Szymanski, Y. V. Dublyansky, and D. E. Livingston

- Epithermal Mineralization, Alteration, and Spring Deposits at Yucca Mountain, Nevada - Thermodynamic Evolution of the Geologic System
  by J. S. Szymanski

- Carbonate Deposits at Yucca Mountain (Nevada, USA) and the Problem of High-Level Nuclear Waste Repository
  by Y. V. Dublyansky and J. S. Szymanski

- Geohydrological Models and Earthquake Effects at Yucca Mountain, Nevada
  by J. B. Davies and C. B. Archambeau

- Analysis of High-Pressure Fluid Flow in Fractures with Applications to Yucca Mountain, Nevada, Slug Test Data
  by J. B. Davies and C. B. Archambeau

Attachment 2

Comments on "Overview of calcite/opal deposits at or near the proposed high-level nuclear waste site, Yucca Mountain, Nevada, USA: pedogenic, hypogene, or both" by C.A. Hill, Y.V. Dublyansky, R.S. Harmon, and C.M. Schluter

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Comments on "Overview of calcite/opal deposits at or near the proposed high-level nuclear waste site, Yucca Mountain, Nevada, USA: pedogenic, hypogene, or both" by C.A. Hill, Y.V. Dublyansky, R.S. Harmon, and C.M. Schluter

J.S. Stuckless[1], B.D. Marshall[1], D.T. Vaniman[2], W.W. Dudley[1], Z.E. Peterman[1], J.B. Paces[1], J.F. Whelan[1], E.M. Taylor[1], R.M. Forester[1], and D.W. O'Leary[1]

The stated objective of the paper by Hill and others (1995, p. 70) is "to show that the geologic and geochemical evidence does not preclude a hypogene origin for the COD" [calcite/opal deposits located in and near faults at Yucca Mountain]. In order to champion this objective, the paper contains several misstatements of fact, some important omissions of pertinent and readily available information, and some misleading generalizations that together bias the reader toward the erroneous conclusion that the hypogene model remains viable.

In describing the regional geology, for example, the perception of a tectonically formidable environment is promoted by the statement on page 70, "Quaternary volcanism, active faulting and seismicity, high heat flow, and thermal springs characterize the region." To be sure, Quaternary volcanism and faulting have occurred at several localities within 10 km of the Yucca Mountain site, though at relatively small rates for the Great Basin. Similarly, using the nongenetic definition that "thermal springs" discharge water warmer than the mean annual surface temperatures at their locales, there indeed are thermal springs 25 km west of Yucca Mountain at Oasis Valley (41°C; White 1979). However, the stated 43°C temperature and its attribution (Hill and others 1995, p. 71) to Winograd and Pearson (1976), who did not discuss Oasis Valley, are both erroneous. Winograd and Pearson (1976, Fig. 3) show the temperature of Devils Hole, which is about 40 km south of Yucca Mountain, to be 33°C rather than the 34°C attributed to them by Hill and others (1995, p. 71), although Dudley and Larson (1976)

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do report temperatures as great as 34.5°C for some springs near Devils Hole. Even allowing for considerable cooling as deep, regional flow paths rise toward these discharge areas, these temperatures are consistent with ground-water flow to depths of only 1 to 2 km, which is the expected pattern of flow in large regional flow systems developed in thick transmissive rocks (e.g., Mifflin 1988). Plate 1 of Garside and Schilling (1979) clearly demonstrates the absence of spring temperatures greater than 41°C south of latitude 38°30' in Nevada, whereas spring flows exceeding 65°C, even exceeding 90°C, are common north of this latitude.

The assertion of "high heat flow" (paragraph above) and the subsequent statement on page 71, "Heat flow is as high as 130 mW m^{-2}, which is significantly above basin and range heat-flow averages of 80-100 mW m^{-2} (Sass and others 1980)", are clearly misleading in describing the Yucca Mountain site. Sass and others (1980) addressed two boreholes: UE-25a #1, at Yucca Mountain, and UE-25a #3, in the Calico Hills more than 10 km east of the site. For the borehole at Yucca Mountain, they reported a calculated heat flow at least 30 mW m^{-2} *less* than the Basin and Range average. The value chosen by Hill and others (1995) to characterize the Yucca Mountain area is that for the Calico Hills hole. Sass and others (1980, p. 15) also suggest caution in interpreting the heat-flow values: "Data like those discussed in this report may or may not have regional significance; it is certain, however, that they do contain information on local hydrology." The paper under discussion subsequently cites the later, more comprehensive work of Sass and others (1988; mis-cited as 1987) for other purposes, but it fails to mention that the heat flows reported for 33 boreholes at and adjacent to Yucca Mountain range from 29 to 74 mW m^{-2} and average 47.3 ± 13.5 mW m^{-2}, which is significantly below the ~90 mW m^{-2} Basin and Range average. In fact, Sass and others (1988) propose a tentative southward extension of the Eureka Low (originally defined by Sass and others 1971) to encompass the Yucca Mountain area, suggesting alternatively that it may be a geographically closed heat-flow low. Thus, heat-flow at Yucca Mountain is anomalous, not because it is high but, rather, because it is low.

The following discussion critiques several topical aspects of the Hill and others (1995) paper that pertain to the origin of the calcite-opal deposits. This is followed by an evaluation of the data base that is cited repeatedly by the authors, emphasizing the manner in which the data are used. The discussion is not exhaustive; many other, though generally less important, shortcomings could be addressed.

In discussing the field relationships of the controversial calcite/opal veins, the report notes on page 71: "These veins narrow towards the base but thicken and split out into multiple veins near (within a few meters of) the sand-ramp ground surface (Fig. 3). Such a splayed geometry is typical of epithermal mineral deposits (Department of Energy 1993)." The referenced citation states: "This splaying up of a major vein at depth over a vertical range of several hundred meters into smaller ones closer to the surface contrasts with the relationships found at trench 14." Hill and others (1995) have overlooked the referenced depth scale. The splayed geometry is typical of near-surface hanging-wall collapse against a downward-flattening normal fault. Collapse is caused by the tensile stress that is exerted because of friction during lateral translation of the hanging wall over the footwall.

The article strongly implies that previous authors erred in collection of pedogenic calcites used in comparisons.: "Past studies supporting a pedogenic hypothesis have *assumed* [emphasis originally added] that COD [defined as calcite/opal deposit] slope calcretes are pedogenic in origin (*e.g.* Quade and Cerling 1990; Marshall and others 1990)." In fact, the authors of both of the cited studies took great care to collect unequivocal samples from modern pedogenic materials. The former study is based on Quade and others (1989), in which sampling was restricted to Holocene, stage 1 carbonates from four different mountain ranges. The latter study, which was preliminary, was subsequently expanded to include samples from terrace and pediment deposits and even dust deposits within foundations of a ghost town (Marshall and others 1991). Further on in the paper, Hill and others (1995, p. 78) note that a decrease in $\delta^{13}C$ and $\delta^{18}O$ with increasing elevation has been reported by others for true pedogenic carbonates, but that no such change is evident in the COD at Yucca Mountain. The change reported by Quade and others (1989) occurs over an elevation differential of 2200 m, whereas samples from Yucca Mountain represent an elevation range of only a few tens of meters. Furthermore, any trend as a function of elevation would exist only for a constant set of climatic conditions, whereas the samples from Yucca Mountain span much of the Quaternary period as demonstrated by the authors' Figure 18. These samples represent formation under a variety of climatic conditions and would not have a simple relationship with elevation.

The article briefly cites Fe/Sc ratios, which reflect the detrital component of the deposits, and concludes that the chemical data probably reflect contamination from the tuffs (the wall rock to the veins), providing evidence only for a near-surface origin. The authors do not mention the more important evidence, *abundances*, from which it can be shown that the detritus in the calcite/opal veins at Trench 14 comes not from the adjacent tuff walls but from the overlying soil horizons (Vaniman and others 1994, 1995). Both iron and scandium are enriched during the soil-forming process such that the soils, and ultimately the calcite-opal veins, have similar Fe/Sc ratios, but several of the vein samples have abundances of these two elements that are as great as those of the tuffs. Because the Fe-Sc-bearing detritus is volumetrically minor in the calcite-opal deposits, it must be derived from the strongly enriched overlying soils and not from the vein wall rock, which is Fe-Sc poor. (This interpretation has been strengthened recently by the identification of characteristic low-Mn detrital hematite grains in the calcite/opal deposits, derived from the overlying soil horizons and distinctly different from the high-Mn hematites of the wall-rock tuffs (Vaniman and others 1995)).

One of the most definitive lines of evidence for pedogenic origin is the presence throughout the calcite/opal deposits of structures and forms that are specifically pedogenic in origin. It is discouraging to see the authors assert on page 74 that "Vesicular texture (Fig. 9) is suggestive of gas cavities created by the degassing of fluids out of which the COD precipitated." We have closely examined many such "gas cavities" and find unequivocal evidence that they are tubular cavities left by roots. These cavities are lined by opaline fossil root walls and often contain *needle-fiber calcites* and *calcified filaments* that are specific indications of root and fungal associations in pedogenesis (Vaniman and others 1994). In particular, Vaniman and others (1994) point out that these extremely delicate calcite forms can be found throughout the calcite/opal deposits, including the oldest deposits (determined by the sequence of unconformities in fault-disrupted vein deposits), and would not be preserved if spring flow (let alone disruptive epigenetic eruptions) had ever occurred. This, however, is not the most serious problem facing the epigenetic/spring discharge proposal. Hill and others (1995) make no attempt to explain the absence of features (such as tufa mounds) that should be present if spring discharges had ever occurred.

The discussion on page 77 of accumulation rates for pedogenic carbonate presents selective, thus misleading rates leading to erroneous inferences. The authors state that "eolian dust supplies only 0.35 - 0.55 g m^{-2} yr^{-1}", which excludes the two highest of 7 numbers (both of which are 1.3 g m^{-2} yr^{-1}) in their cited reference (Gile and others 1981). They correctly note that Gile and others (1981) report an even larger wet-fall component of 1.5 g m^{-2} yr^{-1}; however, they fail to state that this is in addition to the dry-fall component such that the combined total exceeds 2 g m^{-2} yr^{-1}. Furthermore, Machette (1985) and Reheis and others (1992) have measured total accumulation rates of 0.3 to 5.5 g m^{-2} yr^{-1} in the desert southwest. In addition, accumulation of calcite in some vertical veins is greatly enhanced where there is relatively impermeable bedrock upslope of the veins such that a catchment area for dust and rain provides a concentrated source, thereby creating rates of accumulation much greater than measured in these studies. Hill and others (1995, p. 77) imply that there are pedogenic deposits "as young as ~30 ka" that are "meters-thick". In fact, the youngest ages cited in their article are for spring deposits, and the thick slope-parallel deposits are, at least in part, hundreds of thousands of years old. The authors' discussion is based on the erroneous assumption that the deposits contain "carbonate ranging from ~ 20% to 75% and silica from ~25% to 80%" (Hill and others 1995, p. 73). In fact, both K horizon calcretes (Taylor and Huckins 1995) and near-surface vertical veins, such as at Trench 14 (Vaniman and others 1994), contain only about 50% calcite, a feature common to pedogenic calcretes but uncommon to both hot and cold spring deposits. The slope-parallel deposits are in fact true K horizons that transition upward into normal B and vesicular A horizons (Taylor and Huckins

1995).

The article correctly notes (for example, p. 72 and p. 80) that many calcite occurrences are related to a hydrothermal event (probably the synvolcanic Timber Mountain event, 9 - 11 ma). To our knowledge, all of these occurrences have been found only at great depth (such as those discussed on p. 84), but other hydrothermal minerals formed during this event are found closer to the modern surface (for example, p. 80). These outcrops contain minerals crystallized from both hydrothermal and pedogenic events, but they are treated as monogenetic. Although we have looked for and not found pyrite/chalcopyrite at one of the cited localities (we did find oxybiotite), such an association does exist elsewhere. In these places, the evidence shows a clear temporal distinction between at least two episodes of deposition. The first appears to relate to an early, possibly synvolcanic age, with the latter being a clearly later, low-temperature overgrowth. Note too that the authors assume that pyrite and chalcopyrite indicate high temperature (for example, p. 77); however, both minerals are known to form in low-temperature sedimentary environments, such as the copper shales (kupferschiefer) of the Mansfield District of Germany or as precipitates on abandoned tools in old mine workings.

Attempts to use a quartz-calcite geothermometer (p. 85) are unlikely to be valid because the two phases did not crystallize together from a single solution and, therefore, are not known to be in equilibrium with each other. Hill and others (1995) apparently recognize this source of error but nonetheless, favor the resulting high temperature of crystallization, as high as 238°C. Recent temperature estimates for the formation of opal recovered from drill core range from 18 to 51° C for water with $\delta^{18}O$ = -10.5 or 10 to 40° C for water with $\delta^{18}O$ = -13 (Whelan and others 1994).

Hill and others (1995, p. 84) discuss the data in their Table 2 apparently with the assumption that the two ages are representative of the ages of the fluid inclusions. The ages listed are ^{14}C apparent ages for the outermost growth bands of calcite, whereas the fluid inclusions examined and reported by Roedder and others (1994) were from the crystal interiors although those authors did not state the inclusion locations explicitly. Hill and others (1995) thus fail to recognize that the age difference is potentially very significant because of the probable low rate of calcite growth. Additional problems associated with the temperatures reported in Table 2 and the associated text are discussed below.

The discussion on page 84 dealing with fluid-inclusion temperatures reports information from original sources quite selectively. First, Bish (1989) did not state that the inclusions yielding temperatures of 94-238°C were in *vein* calcite; rather, he describes (p. 26) the mineral only as secondary calcite in the context of association with secondary chlorite and fluorite. He clearly attributes this secondary mineralization to the Timber Mountain episode of hydrothermal alteration at about 11 ma (p. 5 & 31). Hill and others (1995, p. 84) also fail to acknowledge the additional evidence cited by Roedder and others (1994) (vapor at about atmospheric pressure; the presence of all-liquid inclusions and absence of two-phase inclusions in the upper 300 m of USW G-1; the presence of methane and CO_2 in the gas phase of vapor inclusions) that indicate formation of the calcite in unsaturated fractures at near-surface temperatures rather than at the absolute maxima reported by Hill and others (1995). Additionally, the depth (178 m) reported for sample HD-359 on Table 2 of Hill and others (1995) should be 262 m (Whelan and others 1994); correcting the resulting mis-plot of the data on Figure 19 diminishes the credibility of the paleothermal gradient inferred by Hill and others (1995) from the fluid-inclusion temperatures.

The discussion of temperatures calculated for calcites (p. 85) lists several minor assumptions made in the calculations, but it fails to note that the anomalously high inferred temperatures are possible only if an unrealistically heavy isotopic composition is assumed for the water. The paper incorrectly attributes the first attempt to calculate a paleo-thermal gradient to an unpublished 1993 report by Szymanski; Szabo and Kyser (1990), who are cited by Hill and others (1995), reported a thermal gradient of 34° C km^{-1} on the basis of oxygen isotopic data. This agrees well with gradients based on modern temperature measurements in the unsaturated zone, which range from 15° C km^{-1} to 60° C km^{-1} (Sass and others 1988, tab 6), not 20 to 24° C km^{-1} as was attributed by Hill and others (1995) to Sass and others (1988). Note that rising thermal waters would be highly unlikely to equilibrate with the surrounding rocks and thus preserve a record of the paleothermal gradient in precipitated calcite. Also, if all of the re-equilibration trends shown on Figure 13 operated in the past, any thermal gradient calculated from calcites would be of questionable meaning. Presumably the "$\delta^{13}O$" shown on Figure 13 should be $\delta^{18}O$.

The discussion of strontium isotopes (p. 80 - 82) relies on erroneous data and generalizations that obfuscate relationships. The article correctly notes a large range in values of strontium isotopic composition in ground water within the broad region of southern Nevada and adjacent California, but it fails to note that values in the specific area beneath Yucca Mountain fall into a narrow range that is markedly less radiogenic than that found for the veins whose origin is in question. The correct range for ground water from the Tertiary aquifer beneath Yucca Mountain and the area immediately up-gradient is 0.7093 to 0.7115. Furthermore, the least radiogenic of these values for the Tertiary aquifer is up-gradient from Yucca Mountain and, therefore, further from the compositions of the calcite veins. These spatial relationships are not presented by the authors. Both pedogenic and vein carbonates range from 0.7116 to 0.7128. Thirty-seven analyses of pedogenic carbonate yield an average of 0.71233 $\pm$ 0.00028, and 39 analyses of vein carbonate yield an average of 0.71238 $\pm$ 0.00026 (Marshall and others 1991). Thus the strontium isotopic data eliminate ground water as a possible source for the veins at and near Yucca Mountain and show a nearly perfect match between the pedogenic carbonate and vein carbonate.

There are a number of minor errors in the discussion of uranium and thorium isotopes, such as the assertion on page 82 that incorporation of detrital material leads to open-system behavior or that U-series ages must represent maximum ages (p. 83). A more serious error is introduced by attempting to compare uranium isotopes in brines with the dilute ground waters of Yucca Mountain. Stuckless and others (1991) did not claim that all ground water had anomalously large $^{234}U/^{238}U$ values, but rather that this anomaly was a characteristic of waters beneath Yucca Mountain (p. 82). Brines, or any other waters with high uranium concentrations, would never be expected to have large $^{234}U/^{238}U$ values because purely chemical processes would obscure the minor effect of α-recoil or preferential leaching of radiation-damaged sites. Finally, we question the validity of the four samples shown in Figure 17 for Busted Butte and Trench 14. There are now hundreds of analyses of vein and slope-parallel soil and calcite deposits for the Yucca Mountain area by several different analysts (Szabo and others 1981; Szabo and Rosholt 1982; Swadley and others 1984; Rosholt and others 1985; Szabo and O'Malley 1985; Rosholt and others 1988; Muhs and others 1990; Stuckless and others 1991; Department of Energy 1993; Paces and others, 1993; 1994; 1995; and Peterson and others, 1995). None of these uranium analyses yield values close to those shown for these four samples.

On page 83, the article states "These dates show that some of the COD are very young (~30 ka) and thus are unlikely to represent pedogenic horizons that should be hundreds of thousands of years (or more)." It is true that the young ages do not represent old deposits, but there is no reason that all of the pedogenic carbonate should be old. In fact, as noted above, Quade and others (1989), who were cited by Hill and others (1995, p. 78) in a different context, restricted their study of pedogenic carbonate to Holocene deposits. In fact, the paucity of young ages is actually somewhat surprising given that most of the data base is from the Yucca Mountain Project, which has had a primary focus on identifying and characterizing the youngest climatic and tectonic events.

Note that Figure 18 incorrectly identifies site 106, which is at the base of Yucca Mountain, as a spring deposit. In spite of a diligent search, no spring deposits have been found this close to Yucca Mountain.

In addition to the arguments for a pedogenic origin, there are several arguments against a hypogene origin. The near-surface vein and slope-parallel deposits are devoid of aquatic microfossils (Stuckless and others 1991) common at current and paleo discharge sites (Quade and others 1995). The slope-parallel deposits continue uphill past the intersection of faults and alleged feeder veins with the surface (Taylor and Huckins 1995). Contrary to the assertion by the authors (p. 71) that the COD are localized along faults, slope-parallel CODs are located on the east side of Busted Butte and at site 106, both of which are unfaulted areas. As noted earlier, the isotopic composition of ground water over a broad region of southern Nevada and adjacent California is strongly heterogeneous. In contrast, the pedogenic and vein calcites are isotopically, fairly homogeneous. Most of the variability in strontium isotopic composition can be accounted for by minor contributions from adjacent bedrock or entrained detrital material (Stuckless 1991). Lead isotopes in the deposits of Trench 14 show clear evidence for the average isotopic composition being the result of mixing of at least two end-members with the minor component being very similar to the host volcanic rock (Zartman and Kwak 1993).

Unless restricted to very insignificant flow and little or no mineral deposition, springs leave definitive evidence of past activity in their deposits. Distinct features such as tufa mounds are unmistakable and should be expected along fault discharge zones, but even if such mounds have eroded away, there should remain some smaller-scale structures (e.g., microterraces; Viles and Goudie 1990) that remain as evidence of past spring activity. No such distinctive spring-deposit features have been found at Yucca Mountain. Even if the gross constructional evidence of spring discharge were to be eroded completely away and perfectly overprinted by pedogenic soil horizon development, it is very doubtful that the *microscopic* evidence of deposition from a spring source would be lost. Hill and others (1995; Table 2; p. 78) acknowledge site 199, near Yucca Mountain, as a site of spring discharge and deposition. Plant fossils at this site have microtextures that are distinctly different from those of the calcite/opal deposits; the fossil plant microstructures at this spring site are much more poorly preserved because of overprinting by *bacterial clumps* (Chafetz and Folk 1984), radial clusters of calcite crystals around bacterial precipitates characteristic of spring deposits. If the substantial calcite/opal deposits at Yucca Mountain were of spring origin, bacterial clumps rather than fine-scale root and fungal fossils should be found. Additionally, Vaniman and others (1995) have shown that deposition is characterized by dolomite and high-Mg calcite without opal, unlike the low-Mg calcite and abundant opal of the calcite/opal deposits.

In addition to the errors cited above in arguments for a hypogene origin or against a pedogenic origin by Hill and others (1995), the data base used (repeatedly cited as Hill and Schluter 1994) appears to be incomplete and inconsistent with some of the conclusions. Inspection of Hill and Schluter (1994) data base shows that most of the data come from the U.S. Geological Survey (USGS) or Los Alamos National Laboratory (LANL). The compilation was incomplete and did not include much of the data available at the time the compilation was made; many of the entries were in error; and some of the data did not agree with the figures presented in Hill and others (1995). For example, the first five entries listed in the "Data Chart" as U-series ages for surface calcite veins from Trench 14 (originally reported by Swadley and others 1984) are actually U-trend ages (a less reliable technique) for soils. These were obtained by taking channel samples through soils, not by analyzing "surficial calcite veins" as stated in the "Data Chart". Hill and Schluter (1994) also cite ages from Vaniman and Whelan (1994), but that article reports no age determinations. Hill and others (1995) plot three ages from Trench 8 on their Figure 18, but their data base (Hill and Schluter 1994) reports only one age, 70 $\pm$ 5 ka; the two ages of <50 ka plotted on their Figure 18 are not in the data base, and their origins are not cited. In fact, if the erroneous ages are excluded from Figure 18 and the large number of ages from their own data base are included, the hyperbolic curve no longer exists.

The majority of the entries in the Hill and Schluter (1994) would be impossible for most readers to check because they are referenced to USGS (or DOI) monthly highlights and status reports. None of us routinely reports analytical data in these monthly reports, and until recently, only a single master copy of these reports was kept on file. Checking our file copies, we do not find the data attributed to these sources. The sample numbers and analytical data do match those published by one or more of us elsewhere. The correct references where the isotopic data were originally presented and/or discussed include Marshall and others (1990), Whelan and Stuckless (1990), Marshall and others (1991), Marshall and Mahan (1991), Stuckless and others (1991), Peterman and others (1992), Marshall and others (1992), Whelan and Stuckless (1992), Stuckless and others (1992), Marshall and others (1993), Peterman and others (1993), Peterman and Stuckless (1993), Zartman and Kwak (1993), Ludwig and others (1993), Marshall and Mahan (1994), Vaniman and Whelan (1994), Peterman and others (1994), Whelan and others (1994), and Marshall and others (1994). We are disappointed by the failure to properly credit the published work.

The strontium analyses best exemplify the selective use and/or misuse of data. Figure 1 presents a comparison of the plotted data ranges in Hill and others (1995, Figure 15) with the actual data points we believe belong in each sample category. We have taken the data from Hill and Schluter (1994), identified the samples that were plotted and the samples that should have been excluded. We did not plot the Precambrian range and samples because a realistic range for Precambrian rock is as great as the entire scale of either their or our diagram.

The ranges shown by Hill and others (1995) for Paleozoic carbonates and Tertiary volcanic rocks are essentially correct. However, it should be kept in mind that the sampling is biased to altered samples; the vast majority of carbonate outcrop in the region is unaltered and has $^{87}Sr/^{86}Sr$ between 0.708 and 0.709. Also, Paleozoic carbonate encountered in a drill core closely adjacent to Yucca Mountain has $^{87}Sr/^{86}Sr = 0.709$ (Peterman and others 1994).

The range shown for the Tertiary volcanic rocks is taken from the Raven Canyon reference section (Peterman and others 1993), and represents unaltered rock as these samples were leached with hydrochloric acid (Peterman and others 1993). As such, the identification of some of these samples as altered on Figure 15 of Hill and others (1995) is erroneous. It should be noted that the Raven Canyon reference section extends upward only into the base of the Topopah Spring Tuff and therefore does not include the uppermost parts of the volcanic section at Yucca Mountain.

The range shown by Hill and others (1995) for eolian dust includes three residues from hydrochloric acid leaching used to remove the abundant carbonate fraction. These samples are identified as residues in Hill and Schluter (1994); there is no justification for including them here, especially inasmuch as there is abundant evidence that the silicate detritus contributes little or no strontium to the carbonate in the soils (Stuckless and others 1991; Marshall and Mahan 1994). The range for eolian material is drastically reduced when these samples are eliminated (Fig. 1).

Figure 15 (Hill and others 1995) is misleading in that it is drawn at two different scales such that any values shown to the left on the fine scale could be repeated to the right on the coarse scale. However, only the values for altered Paleozoic Carbonates and those labeled as "spring and wells, Yucca Mountain" are repeated on the right-hand side of the diagram. This has the effect of making the ranges appear larger than they really are. The range of strontium isotopic compositions for waters from "spring and wells, Yucca Mountain" greatly exceeds any measurements cited in Hill and Schluter (1994) or known to us. The correct range for the isotopic composition of well water from on or near Yucca Mountain is shown by the hatch marks on our Figure 1. (The label "spring and wells, Yucca Mountain" is erroneous because there are no springs on or near Yucca Mountain; the water table ranges from approximately 500 m to 700 m below the surface.)

The range for drill-hole calcite is accurate as shown. However, the use of a single bar to show the range obscures the fact that there are two distinct fields: those for samples from above the current water table, and those from below (Fig. 1). We are puzzled by the designations of deep-seated and shallow samples as Timber Mountain and Stagecoach Road calcites on Figure 15 of Hill and others (1995) because the terminology is not explained, and it certainly is not as germane to the data as the terms used by the authors cited above who collected the data.

The range shown for the calcite/opal deposits category is substantially correct, except that it does not extend far enough to the more radiogenic values. The four samples with the smallest

$^{87}Sr/^{86}Sr$ ratios (shown as outliers by Hill and others (1995)) are acid residues and are not representative of carbonate material.

The "groundwater spring deposit" category has two outliers as shown by Hill and others (1995, Fig. 15). The least radiogenic one is from the Wahmonie Mound, which is underlain by a different aquifer from the main aquifer at Yucca Mountain. Furthermore, its age and origin are unknown, but it probably represents a old hot spring deposit. The other outlier is data for an acid residue, and not representative of carbonate material. The range for the spring deposits category is further reduced by excluding samples from Devils Hole, which is not in the flow system that underlies Yucca Mountain. Thus we are left with 13 samples of spring deposits representing three sites south (and downgradient) of Yucca Mountain (Marshall and others 1993).

We are intrigued by the selection of samples deemed by Hill and others (1995) to be "true pedogenic". None of the samples were analyzed by the USGS; however, an almost identical range of $^{87}Sr/^{86}Sr$ ratios was obtained by Marshall and Mahan (1994) on carbonate surface coatings and cements as noted in Hill and Schluter (1994). Also, in Hill and Schluter (1994) the average values for pedogenic carbonate from Trench 14 and Busted Butte are included in their "true pedogenic" category!

In summary, if all of the errors and selective use of data are eliminated from the "Overview" presented by Hill and others (1995), the conclusion, that a hypogene model remains viable, is untenable. There are no thermal data to support hydrothermal activity in the vicinity of Yucca Mountain within the last several million years. The chemical data require infilling of the vertical veins from above, and petrographic data and the lack of microfossils preclude any sort of spring activity. Strontium and uranium isotopic data preclude involvement of any water from beneath Yucca Mountain (the postulated addition of radiogenic strontium from a Precambrian source deep beneath both the thick Paleozoic and thick Tertiary sections such that mixing proportions consistently produce a near-constant isotopic composition is preposterous).

The match between carbon, strontium, and lead isotopes for pedogenic and vein carbonates is strongly suggestive of a common source for most of the material, and finally, the veins intersect slope-parallel carbonates that continue up-slope from the intersection.

Hill and others (1995) stated on page 70 that their intent was "to show that the geologic and geochemical evidence does not preclude a hypogene origin for the COD." Our examination shows that this objective might appear to some to be achieved, but only if a small and inherently ambiguous data set is analyzed in isolation from the larger body of evidence. An excellent example is the interpretation that Fe/Sc ratios in the detrital component of the calcite/opal veins probably reflect contamination, possibly of upwelling hypogene fluids, from the tuff wall rock, whereas consideration of the abundances requires that the source be the overlying, Fe-Sc-enriched soils rather than the Fe-Sc-poor wall rock. The unusually large and diverse body of geologic, mineralogic, isotopic, morphologic, and paleontologic evidence that has been developed provides an overwhelming convergence toward the conclusion that the calcite/opal deposits at Yucca Mountain originated from downward-percolating water, rather than hypogene fluids, within and beneath the zone of soil-forming processes.

REFERENCES

Bish DL (1989) Evaluation of past and future alterations in tuff at Yucca Mountain, Nevada, based on clay mineralogy of drill cores USW G-1, G-2, and G-3. Los Alamos National Laboratory Report LA-11497-MS, 40 p

Chafetz HS and Folk RL (1984) Travertines -- Depositional morphology and the bacterially constructed constituents. Journal of Sedimentary Petrology, 54:289-316

Department of Energy (1993) Report on the origin of calcite-silica deposits at Trench 14 and Busted Butte and methodologies used to determine their origin. Yucca Mountain Site Characterization Report YMP/93-11-R, 64 p

Dudley WW Jr., and Larson JD (1976) Effect of irrigation pumping on desert pupfish habitats in Ash Meadows, Nye County, Nevada. U.S. Geological Survey Professional Paper 927, 52 p

Garside LJ and Schilling JH (1979) Thermal waters of Nevada. Nevada Bureau of Mines and Geology Bulletin 91, 163 p

Gile LH, Hawkey JW and Grossman RB (1981) Soils and geomorphology of the basin and range area of southern New Mexico -- Guidebook to the Desert Project. New Mexico Bureau of Mines and Mineral Resources, Memoir 39, 222 p

Hill CA, Dublyansky YV, Harmon RS and Schluter CM (1995) Overview of calcite/opal deposits at or near the proposed high-level nuclear waste site, Yucca Mountain, Nevada, USA: Pedogenic, Hypogene, or Both? Environmental Geology, 26:69-88

Hill CA and Schluter CM (1994) Data chart, Yucca Mountain and vicinity: Updated June 1994: Data chart to Nuclear Waste Project Office, State of Nevada, Carson City, 60 p

Ludwig KR, Peterman ZE, Simmons KR and Gutentag ED (1993) $^{234}U/^{238}U$ as a ground-water tracer, SW Nevada-SE California. Proc. of the fourth International Meeting on High Level Radioactive Waste Management, American Nuclear Society, 2:1567-1572

Machette MN (1985) Calcic soils of the southwestern United States: in Soils and Quaternary geology of the southern United States, Special Paper 203, Weide DL ed., Las Vegas, Nevada University of Nevada, Las Vegas, Nevada, p 1-21

Marshall BD and Mahan SA (1991) A model for the formation of pedogenic carbonate based on strontium isotope data from southwest Nevada [abs.]. Geological Society of America Abstracts with Programs, 23:A118

Marshall BD and Mahan SA (1994) Strontium isotope geochemistry of soil and playa deposits near Yucca Mountain, Nevada. Proc. of the Fifth International Meeting on High Level Radioactive Waste Management, American Nuclear Society, 4:2685-2691

Marshall BD, Peterman ZE, Futa K, Stuckless JS, Mahan SA, Downey JS, and Gutentag ED (1990) Origin of carbonate deposits in the vicinity of Yucca Mountain, Nevada-- preliminary results of strontium isotope analyses. Proc of the First International Meeting on High Level Radioactive Waste Management, American Nuclear Society, 2:921-923

Marshall BD, Peterman ZE, Futa K, and Stuckless JS (1991) Strontium isotopes in carbonate deposits at Crater Flat, Nevada. Proc of the Second International Meeting on High Level Radioactive Waste Management, American Nuclear Society, 2:1423-1428

Marshall BD, Peterman ZE, and Stuckless JS (1993) Strontium isotopic evidence for a higher water table at Yucca Mountain. Proc of the Fourth International Meeting on High Level Radioactive Waste Management, American Nuclear Society, 2:1948-1952

Marshall BD, Peterman ZE, and Stuckless JS (1994) Paleohydrology from strontium isotopes at Yucca Mountain, Nevada [abs.], in Lanphere MA, Dalrymple GB and Turrin BD (eds). Abstracts of the Eighth International Conference on Geochronology, Cosmochronology and Isotope Geology. U.S. Geological Survey Circular 1107, p 203

Marshall BD, Whelan JF, Peterman ZE, Futa K, Mahan SA, and Stuckless JS (1992) Isotopic studies of fracture coatings at Yucca Mountain, Nevada. in: Water-Rock Interaction, 7th [Proc]. Park City, Balkema, p 737-740

Mifflin MD (1988) Region 5, Great Basin. in Back W, Rosenshein JS and Seaber PR (eds) Hydrogeology: Geological Society of America, The Geology of North America, O-2: 69-78

Muhs DR, Whitney JW, Shroba RR, Taylor EM, and Bush CA (1990) Uranium-series dating of secondary carbonates near Yucca Mountain, Nevada -- application to tectonic, paleoclimatic and paleohydrologic problems. Proc of the First International Meeting on High Level Radioactive Waste Management, American Nuclear Society, p 924-929

Paces JB, Mahan SA, Ludwig KR, Kwak LM, Neymark LA, Simmons KR, Nealey LD, Marshal BD, and Walker A (1995) Progress report on dating Quaternary surficial deposits: U.S. Geological Survey 1995 milestone report 3GCH510M, 36 p (36 tables, 56 figures).

Paces JB, Menges CM, Widmann B, Wesling JR, Bush CA, Futa K, Millard HT Jr, Matt PB, and Whitney JW (1994) Preliminary U-series disequilibrium and thermoluminescence ages of surficial deposits and paleosols associated with Quaternary faults, eastern Yucca Mountain. Proc of the Fifth International Meeting on High Level Radioactive Waste Management, American Nuclear Society, 4: 2391-2401

Paces JB, Taylor EM, and Bush CA (1993) Late Quaternary history and uranium isotopic compositions of ground water discharge deposits, Crater Flat, Nevada. Proc of the Fourth International Conference on High Level Radioactive Waste Management. American Nuclear Soc. 1573-1580

Peterman ZE, Spengler RW, Singer FR, and Dickerson RP (1993) Isotopic and trace element variability in altered and unaltered tuffs at Yucca Mountain, Nevada. Proc of the Fourth International Meeting on High Level Radioactive Waste Management, American Nuclear Society, 2:1940-1947

Peterman ZE, and Stuckless, JS (1993) Isotopic evidence of complex ground water flow at Yucca Mountain, Nevada. Proc of the Fourth International Meeting on High Level Radioactive Waste Management, American Nuclear Society, 2:1559-1566

Peterman ZE, Stuckless JS, Marshall BD, Mahan SA, and Futa K (1992) Strontium isotope geochemistry of calcite fracture fillings in deep core, Yucca Mountain, Nevada -- A progress report. Proc of the Third International Meeting on High Level Radioactive Waste Management, American Nuclear Society, 2:1582-1586

Peterman ZE, Widmann BL, Marshall BD, Aleinikoff JN, Futa K, and Mahan SA, (1994) Isotopic tracers of gold deposition in Paleozoic limestones, southern Nevada. Proc of the Fifth International Meeting on High Level Radioactive Waste Management, American Nuclear Society, 4:1316-1323

Peterson FF, Bell JW, Dorn RI, Ramaelli AR, and Ku TL (1995) Late Quaternary geomorphology and soils in Crater Flat, Yucca Mountain area, southern Nevada. Geological Society of America Bulletin, 107:379-395

Quade J and Cerling TE (1990) Stable isotopic evidence for a pedogenic origin of fracture-filling carbonates in Trench 14 near Yucca Mountain, Nevada. Science, 250:1549-1552

Quade J, Cerling TE, and Bowman JR (1989) Systematic variations in the carbon and oxygen isotopic composition of pedogenic carbonate along elevation transects in the southern Great Basin, United States. Geological Society of America Bulletin, 101:464-475

Quade J, Mifflin MD, Pratt WL, McCoy W, and Burckle L (1995) Fossil spring deposits in the southern Great Basin and their implications for changes in water-table levels near Yucca Mountain, Nevada, during Quaternary time. Geological Society of America Bulletin, 107:213-230

Reheis MC, Sowers JM, Taylor EM, McFadden LD, and Harden JW (1992) Morphology and genesis of carbonate soils on the Kyle Canyon fan, Nevada, U.S.A.: Geoderma 52:303-342

Roedder EW, Whelan JF, and Vaniman DT (1994) Fluid inclusion studies of calcite veins from Yucca Mountain, Nevada, tuffs -- environment of formation. Proc of the Fifth International Conference on High Level Radioactive Waste Management, American

Nuclear Society, p 1854-1860

Rosholt JN, Bush CA, Carr WJ, Hoover DL, Swadley WC, and Dooley JR Jr (1985) Uranium-trend Dating of Quaternary Deposits in the Nevada Test Site Area, Nevada and California. U.S. Geological Survey Open-File Report 85-540, 72 p

Rosholt JN, Swadley WC, and Bush CA (1988) Uranium-trend dating of fluvial and fan deposits in the Beatty area, Nevada. in Carr MD and Yount JC (eds) Investigations of a Potential Nuclear Waste Disposal Site at Yucca Mountain, Southern Nevada. U.S. Geological Survey Bulletin 1790:129-147

Sass JH, Lachenbruch AH, Dudley WW Jr, Priest SS, and Munroe RJ (1988) Temperature, thermal conductivity, and heat flow near Yucca Mountain, Nevada -- some tectonic and hydrologic implications. U.S. Geological Survey Open-File Report 87-649, 118 p

Sass JH, Lachenbruch AH, and Mase CW (1980) Analysis of thermal data from drill holes UE25a-3 and UE25a-1, Calico Hills and Yucca Mountain, Nevada Test Site. U.S. Geological Survey Open-File Report 80-826, 25 p

Sass JH, Lachenbruch AH, Munroe RJ, Greene GW, and Moses TH Jr (1971) Heat flow in the western United States: Journal of Geophysical Research, 76:6376-6413.

Stuckless JS (1991) An evaluation of evidence pertaining to the origin of vein deposits exposed in Trench 14, Nevada Test Site, Nevada. Proc of the Second International Meeting on High Level Radioactive Waste Management, American Nuclear Society, 2:1429-1438

Stuckless JS, Peterman ZE, Forester RM, Whelan JF, Vaniman DT, Marshall BD, and Taylor EM (1992) Characterization of fault-filling deposits in the vicinity of Yucca Mountain, Nevada. Waste Management '92 Conference Proc, p. 929-935

Stuckless JS, Peterman ZE, and Muhs DR (1991) U and Sr isotopes in ground water and calcite, Yucca Mountain, Nevada--evidence against upwelling water. Science, 254:551-554.

Swadley WC, Hoover DL, and Rosholt JN (1984) Preliminary report on Late Cenozoic faulting and stratigraphy in the vicinity of Yucca Mountain, Nye County, Nevada. U.S. Geological Survey Open-File Report 84-788, 42 p

Szabo BJ, Carr WJ, and Gottschall WC (1981) Uranium-Thorium dating of quaternary carbonate accumulations in the Nevada Test Site Region, Southern Nevada. U.S. Geological Survey Open-File Report 81-119, 35 p

Szabo BJ and Kyser TK (1990) Ages and stable-isotope compositions of secondary calcite and opal in drill cores from Tertiary volcanic rocks of the Yucca Mountain area, Nevada. Geological Society of America Bulletin, 102:1714-1719

Szabo BJ and O'Malley PA (1985) Uranium-deries dating of secondary carbonate and silica precipitates relating to fault movements in the Nevada Test Site region and of caliche and travertine samples from the Amargosa Desert. U.S. Geological Survey Open-File Report 85-47, 12 p

Szabo BJ and Rosholt JN (1982) Surficial continental sediments. in Ivanovich M and Harmon R S (eds) Uranium Series Disequilibrium -- Applications to Environmental Problems. Oxford, England, Claredon Press, p 246-267

Taylor ET and Huckins HE (1995) Lithology, fault displacement, and origin of secondary calcium carbonate and opaline silica at Trenches 14 and 14D on the Bow Ridge Fault at Exile Hill, Nye County, Nevada. U.S. Geological Survey Open-File Report 93-477, 38 p

Vaniman DT, Chipera SJ, and Bish DL (1994) Pedogenesis of siliceous calcretes at Yucca Mountain, Nevada. Geoderma. 63:1-17

Vaniman DT, Chipera SJ, and Bish DL (1995) Petrography, Mineralogy, and Chemistry of Calcite-Silica Deposits at Exile Hill, Nevada, in Comparison with Local Spring Deposits. Los Alamos National Laboratory Report LA-13096-MS, 70 p

Vaniman DT and Whelan JF (1994) Inferences of paleo-environment from petrographic, chemical and stable-isotope studies of calcretes and fracture calcites. Proc of the Fifth International Conference on High Level Radioactive Waste Management, American Nuclear Society, 4:2730-2737

Viles HA and Goudie AS (1990) Reconnaissance studies of the tufa deposits of the Napier Range, N. W. Australia. Earth Surface Processes and Landforms, 15:425-443

Whelan JF and Stuckless JS (1990) Reconnaissance $\delta^{13}C$ and $\delta^{18}O$ data from Trench 14, Busted Butte, and drill hole G-4, Yucca Mountain, Nevada Test Site. Proc of the First International Meeting on High Level Radioactive Waste Management, American Nuclear Society, 2:930-933

Whelan JF and Stuckless JS (1992) Paleohydrologic implications of the stable isotopic composition of secondary calcite within the Tertiary volcanic rocks of Yucca Mountain, Nevada. Proc of the Third International Meeting on High Level Radioactive Waste Management, American Nuclear Society, 2:1572-1581

Whelan JF, Vaniman DT, Stuckless JS and Moscati RJ (1994) Paleoclimatic and paleohydrologic records from secondary calcite, Yucca Mountain, Nevada. Proc of the Fifth International Conference on High Level Radioactive Waste Management, American Nuclear Society, 4:2738-2745

White AF (1979) Geochemistry of ground water associated with tuffaceous rocks, Oasis Valley, Nevada. U.S. Geological Survey Professional Paper 712-E, 25 p

Winograd IJ and Pearson FJ Jr (1976) Major carbon 14 anomaly in a regional carbonate aquifer -- possible evidence for megascale channeling, south central Great Basin. Water Resources Research, 12:1125 - 1143

Zartman RE and Kwak LM (1993) Preliminary study of lead istopes in the carbonate-silica veins of Trench 14, Yucca Mountain, Nevada. U.S. Geological Survey Open-File Report 93-960, 18 p

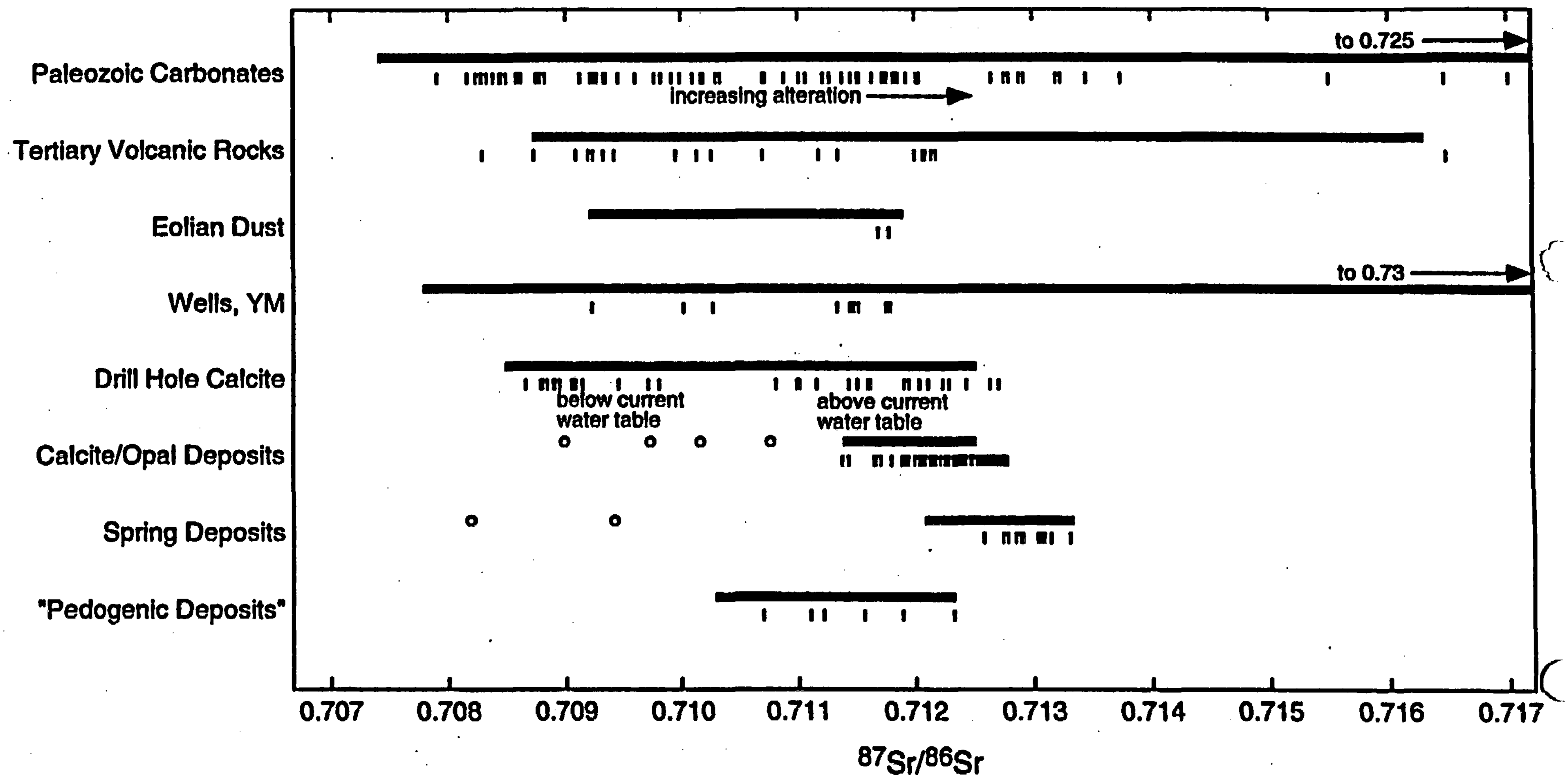

Figure 1. Dot plot showing $^{87}Sr/^{86}Sr$ ratios for different types of calcite deposits and possible parent materials or contaminants. Individual hatch marks plotted for each sample in Hill and Schluter (1994) considered valid (see text). Bars and circles are ranges and outliers as plotted in Hill and others (1995).