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URANIUM-THORIUM DATING OF QUATERNARY CARBONATE ACCUMULATIONS IN THE NEVADA TEST SITE REGION, SOUTHERN NEVADA

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ABSTRACT

A useful way to approach the problem of tectonic activity in an arid region is through study of the history of movement of faults and fractures and of the young alluvial material they displace. Easily datable materials are scarce in these deposits, but carbonates such as caliche, calcrete, travertine, calcite vein, and tufa are common. Several types of these carbonates from the Nevada Test Site area in the southern Great Basin have been collected and dated by the uranium-series method. A variety of geologic settings are represented.

The carbonate samples were subjected to a complex treatment process, and the resulting preparations were counted on an alpha spectrometer. Some of the samples from obviously closed systems yielded reasonable ages; others gave only a minimum age for a material or event. Many of the ages obtained agree well with estimates of age determined from dated volcanic units, fault-scarp morphology, and displaced alluvial units. Among the significant ages obtained were three dates of greater than 400,000 years on calcite-filling fractures above and below the water table in an exploratory drill hole for a possible candidate nuclear waste repository site at Yucca Mountain. Another date on calcrete from immediately below the youngest basalt in the region gave an age of 345,000 years, which agrees extremely well with the K-Ar age determined for the basalt of about 300,000 years. Undisturbed travertine that fills faults in several areas gave ages from about 75,000 years to greater than 700,000

years. Soil caliche and calcretes slightly displaced or broken by repeated movement on faults gave minimum ages in the range from more than 5,000 to more than about 25,000 years.

INTRODUCTION

Geologically precipitated carbonates occur in a variety of forms in surficial and subsurficial deposits in the Nevada Test Site (NTS) region. These carbonates accumulate in soil horizons in different physical forms depending upon their genesis and relative stages of development. They commonly fill fractures along faults, form dense, strongly cemented deposits in alluvium, and are precipitated by spring water. Dating these materials is important because it allows correlation of alluvial-fan deposits and permits a better understanding of the geomorphic processes affecting pediments and alluvial terraces. These dates are useful in the assessment of the chronology of Quaternary faulting, and help define paleoclimatic conditions during the Quaternary. All this information is essential to the evaluation of the NTS region for storage of radioactive wastes.

The carbonates were broadly classified into five groups. The hard, dense and finely crystallized carbonates precipitating from ground water are referred to as travertines. The softer and more porous forms of the precipitated carbonates are defined as tuffaceous travertines. The surficial conglomerates or rock fragments and minerals, strongly cemented by authigenic carbonates are called calcretes. The secondary accumulations of cementing carbonate in the host material of a soil environment are identified as soil caliches. Finally, the dense calcium carbonate in fractures in drill cores is referred to as calcite veins.

As is widely known, uranium is readily transported in ground water, both as a free ion or combined with organic or inorganic species, notably carbonate complexes. Thorium, on the other hand, hydrolyzes and precipitates, or can be readily adsorbed on the various matrix minerals through which the transporting medium passes. When calcium carbonate precipitates, uranium also present in solution will coprecipitate. Accordingly, pure carbonates may be dated by the uranium-series metnod provided that the samples represent a closed system; that is, there has been no postdepositional migration of uranium isotopes nor their in situ produced long-lived daughter, ^{230}thorium. However, most precipitated carbonates found in nature are composed of two distinct phases--original host or matrix material, minerals and rock fragments, and the cementing authigenic carbonate medium. The major problem with dating these samples is that the two phases cannot be completely separated by simple chemical or physical means, and clearly the two can exhibit widely differing ages.

Little data has been published on dating carbonates containing large amounts of cemented detrital material, mainly because of the difficulties involved in processing. Rosholt (1976) dated caliche rinds and travertine; the soluble and insoluble fractions of individual aliquots were separated by means of dilute acetic, nitric and hydrochloric acids. Ages were calculated by using $^{230}Th/^{232}Th$ versus $^{234}U/^{232}Th$ plots of the soluble and insoluble fractions. Ku and others (1979) reported dating of soil caliche rinds on pebbles. They leached the samples with dilute hydrochloric acid and analyzed both soluble and insoluble fractions. Ages were calculated from the analyses of the soluble component after applying a correction scheme for the detrital ^{230}Th contamination. Szabo and Butzer (1979) dated carbonates from playa deposits. They dissolved and analyzed an aliquot of the total sample; then another aliquot was leached by dilute acetic acid and the acid insoluble residue was also analyzed. Ages were calculated from the $^{230}Th/^{234}U$ versus $^{232}Th/^{234}U$ and $^{234}U/^{238}U$ versus $^{232}Th/^{238}U$ plots.

The ages of the samples in the present report are calculated by means of isochron plots of the respective acid soluble and acid insoluble residue pairs (Szabo and Sterr, 1978). The slope of the $^{234}U/^{232}Th$ versus $^{238}U/^{232}Th$ plot yields the $^{234}U/^{238}U$ activity ratio of the pure carbonate component (see fig. 1); the slope of the $^{230}Th/^{232}Th$ versus $^{234}U/^{232}Th$ plot yields the $^{230}Th/^{234}U$ activity ratio of the pure carbonate component (see fig. 2). From these isotopic ratios, isochron-plot ages of the various carbonate samples are calculated using a rearranged form (equation 2) of the standard radioative growth and decay equations:

$$(1)\quad {}^{230}Th = {}^{238}U\,[1-\exp(-\lambda_0 t)] + ({}^{234}U-{}^{238}U)\left[\frac{\lambda_0}{\lambda_0-\lambda_4}\right][1-\exp(\lambda_4 t-\lambda_0)]$$

$$(2)\quad {}^{230}Th/{}^{234}U = \frac{1}{{}^{234}U/{}^{238}U}\,[1-\exp(-\lambda_0 t)] + \left(\frac{{}^{234}U/{}^{238}U-1}{{}^{234}U/{}^{238}U}\right)\left[\frac{\lambda_0}{\lambda_0-\lambda_4}\right][1-\exp(\lambda_0 t-\lambda_0)]$$

Where ^{230}Th, ^{234}U and ^{238}U are measured activities in a sample; λ_0 and λ_4 represent the decay constants of ^{230}Th and ^{234}U, respectively; and t equals time (^{230}Th age).

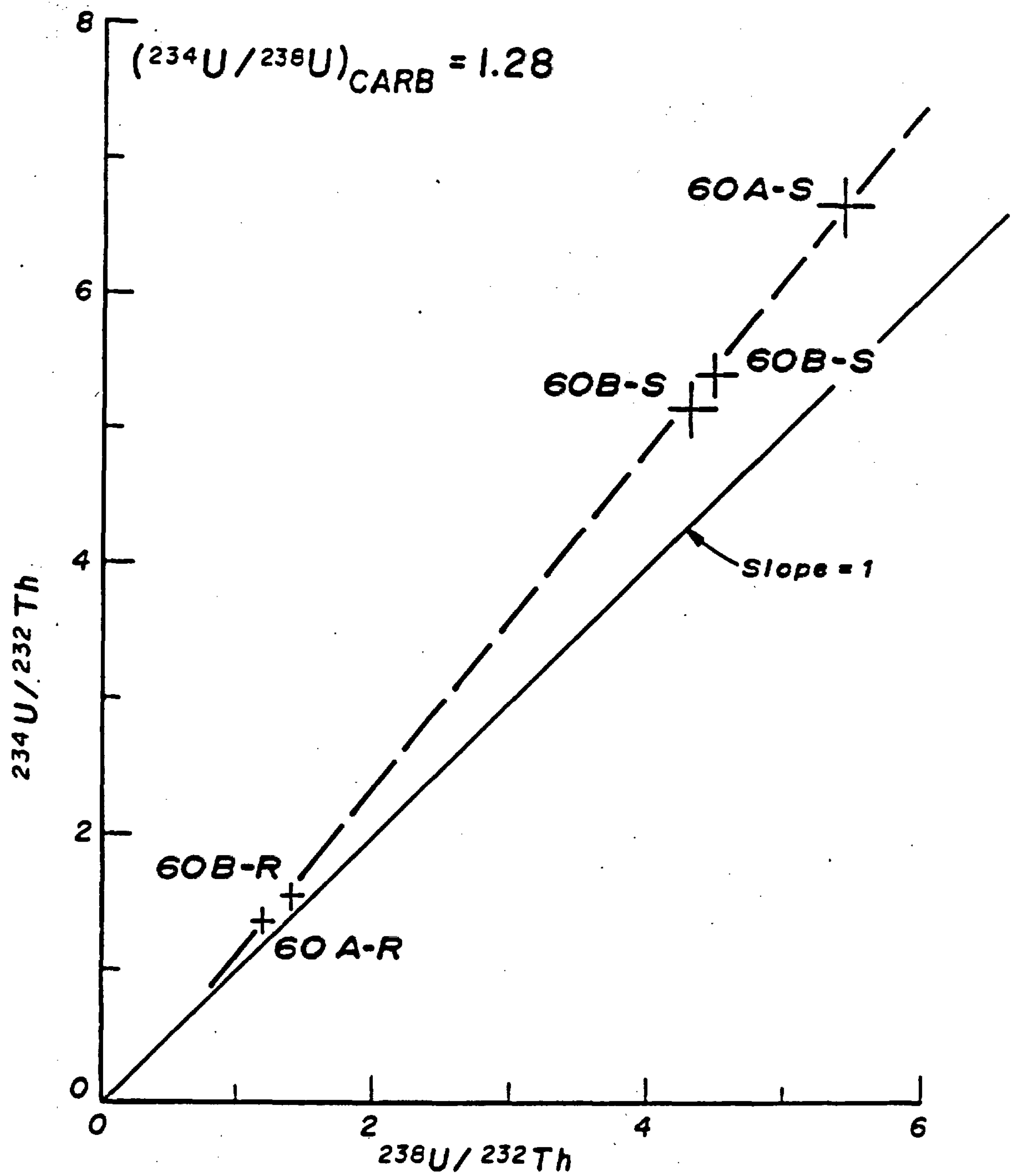


Figure 1.--$^{234}U/^{232}Th$ activity ratio.

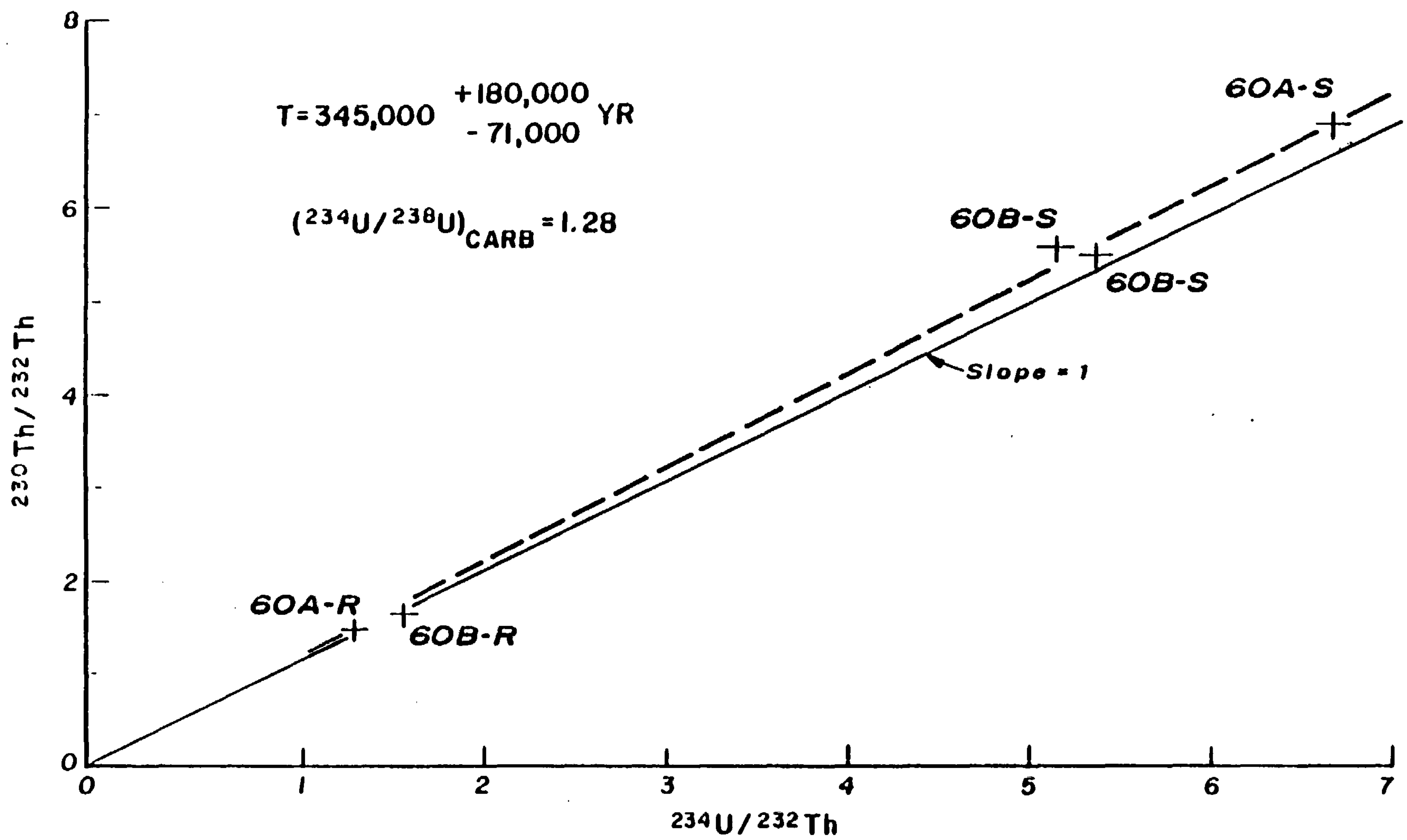


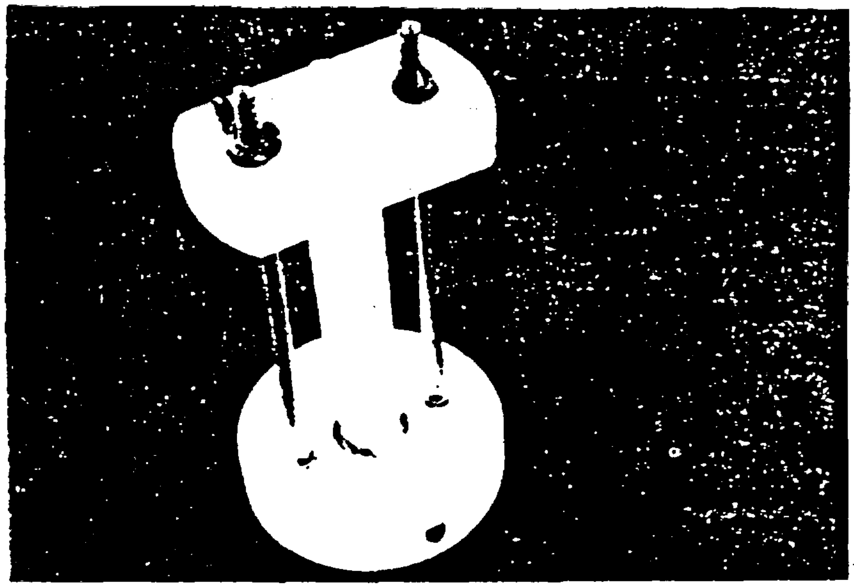
Figure 2.--^{230}Ta/^{234}V activity ratio.

EXPERIMENTAL PROCEDURES

The soft, poorly cemented samples of soil caliches were crushed and cleaned by sieving, by hand picking and removing the visible rock fragments. The dense, strongly cemented samples were crushed and ground to a fine powder. All samples were homogenized, passed through a 115-mesh screen, and ashed for a period of about 8 hours at 900°C to convert $CaCO_3$ to CaO. The accurately weighed sample was then carefully added to a dilute solution of nitric acid (0.1-0.5 F) in minute portions to assure that at no time was the solution allowed to turn basic. The final acidity of the slurry of detrital acid-insoluble material in the soluble component solution was adjusted to approximately pH=3 or lower. The soluble and insoluble fractions were separated by centrifuging and the solid fraction was dried and weighed. The separately labeled pairs thus obtained were treated in parallel fashion to obtain the points for the isochron plots. Both fractions were spiked with a standard solution of ^{236}U, the amount determined by the relative weights and a crude quick measurement of total activity, such that the ^{236}U activity was approximately equal to the ^{234}U and ^{238}U activities. Both fractions also were spiked with a standard solution of ^{228}Th and ^{229}Th, again the amount determined by the relative weights to best assure equivalent counting sensitivity.

Addition of concentrated NH_4OH to the acid soluble fraction generally coprecipitated the uranium and thorium with the naturally present iron and aluminum as hydroxides. If no precipitate had formed by the time the pH reached 6, the solution was reacidified, iron nitrate carrier added, and the procedure repeated. The precipitate was separated by centrifuging and washed with 1:20 NH_4OH. Then the precipitate was dissolved in minimal concentrated HNO_3 and the concentration adjusted to approximately 7F to permit maximum ion-exchange efficiency. A previously prepared and conditioned Dowex 1-X8 ion-exchange columnin the NO_3^- form selectively absorbs both uranium and thorium nitrate complexes, whereas most other metals pass directly through. Elution with highly dilute HNO_3 permits recovery, and great volume reduction can thus be accomplished via subsequent hot plate evaporation. In fact, the salts are taken to dryness and redissolved in 6F HCl to permit separation of the thorium and uranium on a previously prepared and conditioned Dowex 1-X8 Cl^- column. Thorium does not form stable chloride complexes and hence passes directly through, whereas the uranium chloride complexes are absorbed (Kraus and others, 1956). The uranium is recovered in a separate beaker via subsequent elution with highly dilute HCl. Both nitrate and chloride column separations can be used to further purify or reduce the volume of either the uranium or the thorium. The final tiny volume of solid is dissolved in a micro-drop of $HClO_4$, mixed with an NH_4Cl buffer, and the pH adjusted to approximately 4. This solution is then added to a specially designed teflong plating apparatus (see fig. 3) and electroplated onto a disc suitable for alpha spectrometer counting. The uranium plating requires roughly 1/2 hour at a current of $\sim$1 amp using a platinum disc. The thorium plating requires roughly 1 hour at a current of $\sim$1 amp using a titanium disc. It should be noted that some thorium samples were prepared for counting by solvent extraction and evaporation on an aluminum disc. This method involves identical procedures up to obtaining a final tiny volume of solid thorium salt. At this point, the solid is dissolved in a small amount of 0.1 F HNO_3 and extracted with an equally small volume of 0.4F thenoyltrifluoroacetone (TTA) in benzene. This organic solution was evaporated on a dimpled aluminum disc and the extraction procedure repeated. The dimple was reversed after drying and the disc placed in the alpha spectrometer for counting.

The acid insoluble fraction was totally dissolved by repeated heating with concentrated HF and $HClO_4$ or HNO_3 mixtures. Depending upon the material,



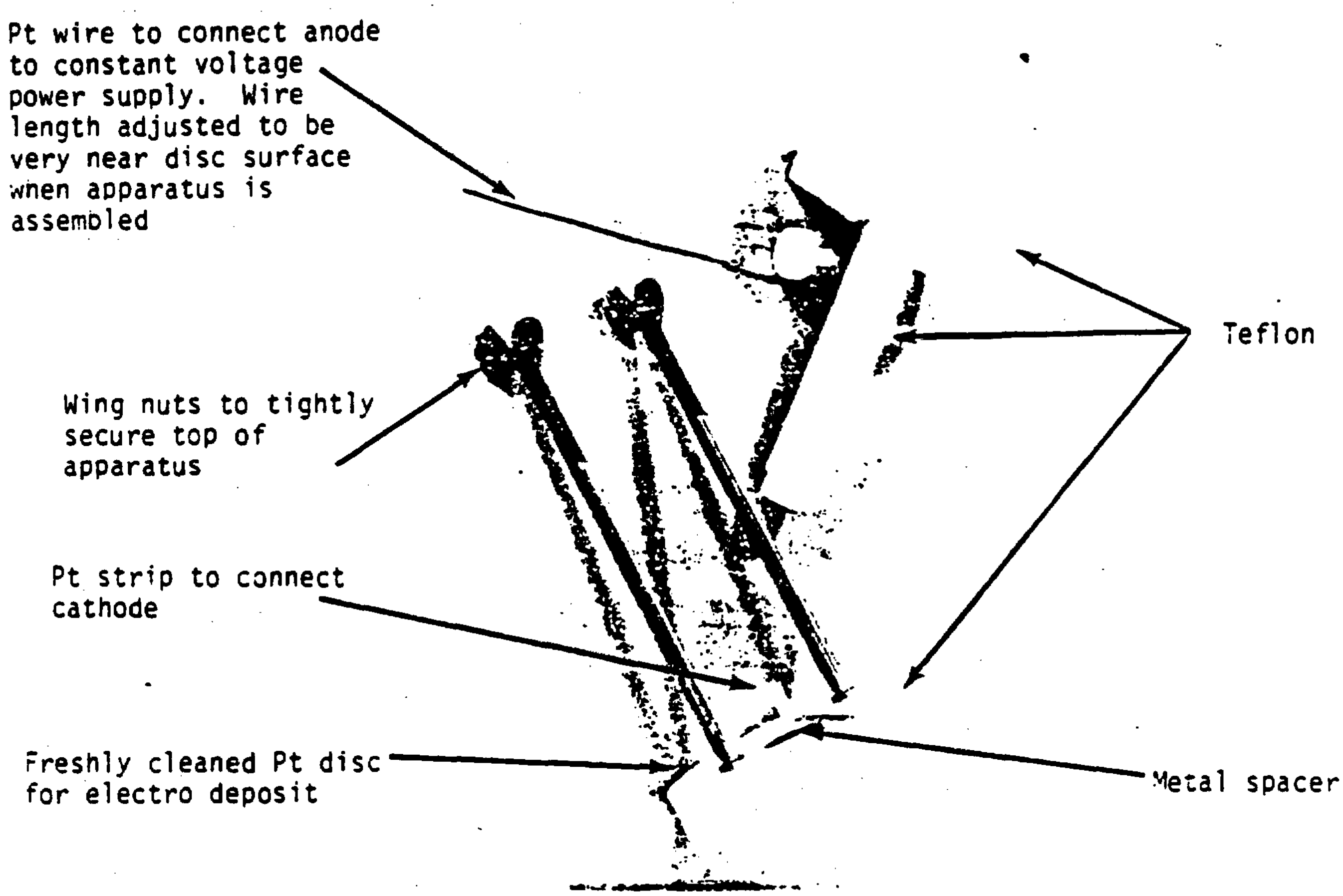


Figure 3.--Teflon electroplating apparatus.

extended refluxing was sometimes necessary to effect complete solution. The uranium and thorium isotopes were concentrated and separated as indicated previously using anion exchange, and so forth. On occasion, concentration of the uranium via hexone extraction was believed to be preferable. This procedure involved dissolving the uranium-containing fraction in 6F HNO_3, addition of about 25 milliliters of hexone in a separatory funnel and shaking for about 5 minutes. The hexone phase was back extracted with 25 milliliters of water, repeated, and then the aqueous phase, containing the uranium, evaporated to dryness. Plate preparation was the same as for the soluble fractions.

Plates were counted for at least about 10,000 counts in an Ortec alpha spectrometer. Figure 4 is a typical cathode-ray tube trace for uranium and figure 5 is a representative trace for thorium.

RESULTS AND DISCUSSION

The analytical data and calculated ages of samples from eight general areas of the NTS region (fig. 6) are listed in table 1. The results of the analysis of the calcite recovered from fractures in welded tuff of a drill core at Yucca Mountain are shown in table 2.

Listed in tables 3 and 4 are the material description, locality, general geologic setting, age and brief interpretation of the dated material. The following discussion highlights several of the sampled localities, attempts to relate some of them, and provides details of the settings.

Before discussing the ages obtained, the Quaternary alluvial stratigraphy in the NTS area must be outlined briefly. The general stratigraphic column is shown on figure 7. The alluvium is readily divisible into the three main groups as shown. Roughly equivalent eolian sandy phases are recognized for Holocene and Pleistocene units. Three important time-stratigraphic markers are present in the southwestern NTS area. Two basalts, one about 300,000 years old, the

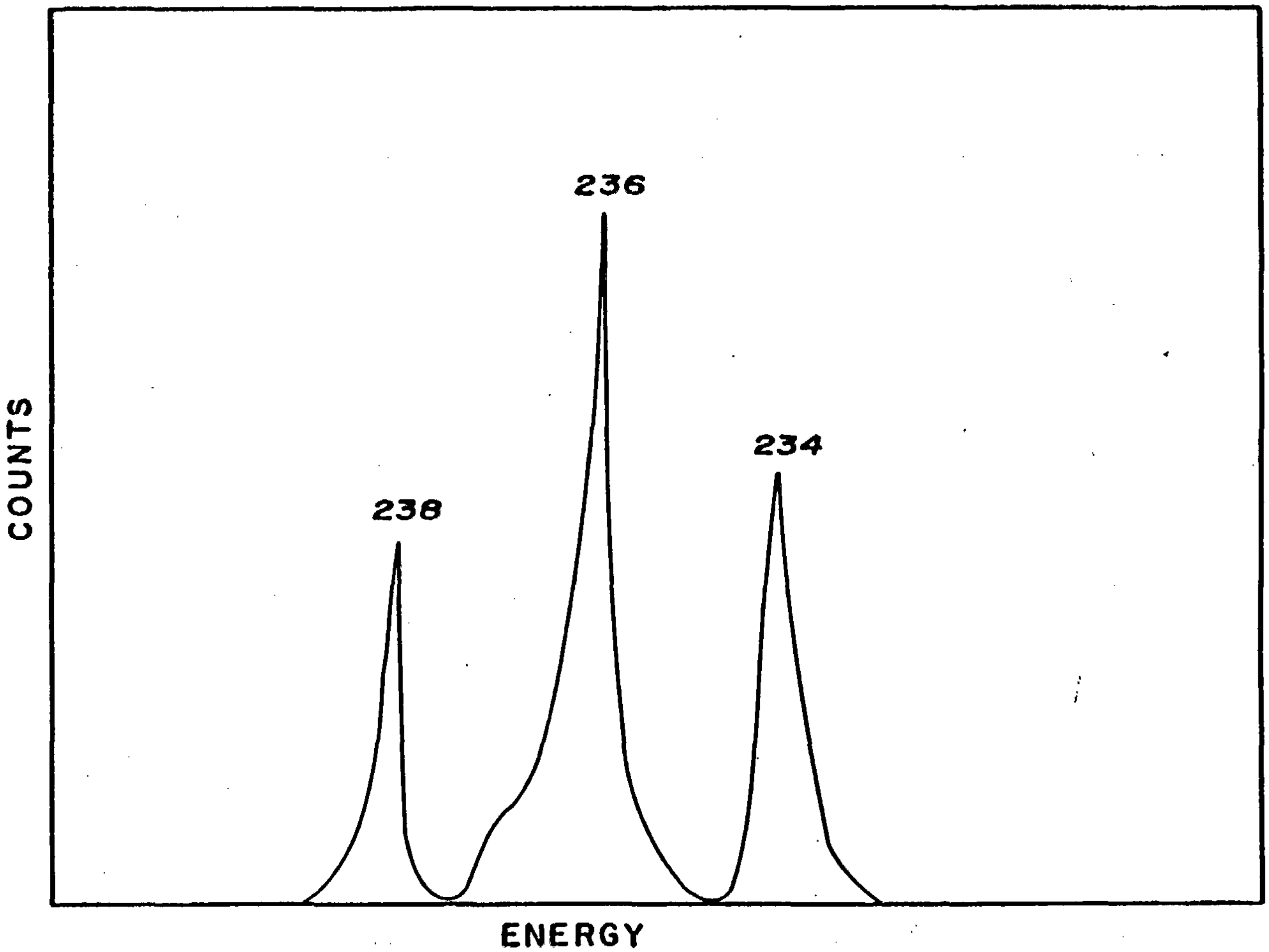


Figure 4.--Typical cathode-ray tube presentation of uranium isotope results.

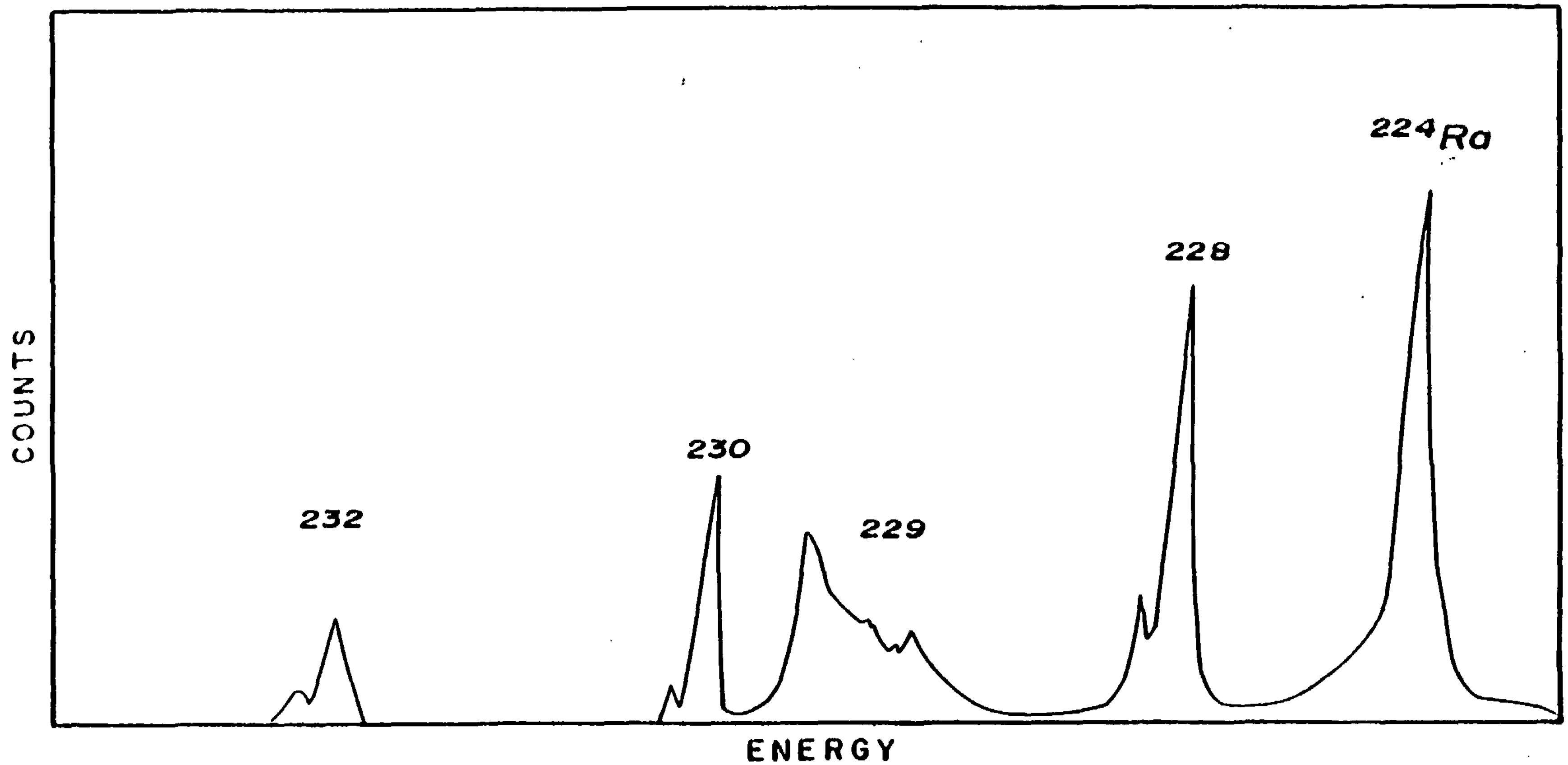


Figure 5.--Typical cathode-ray tube presentation of thorium isotope results.

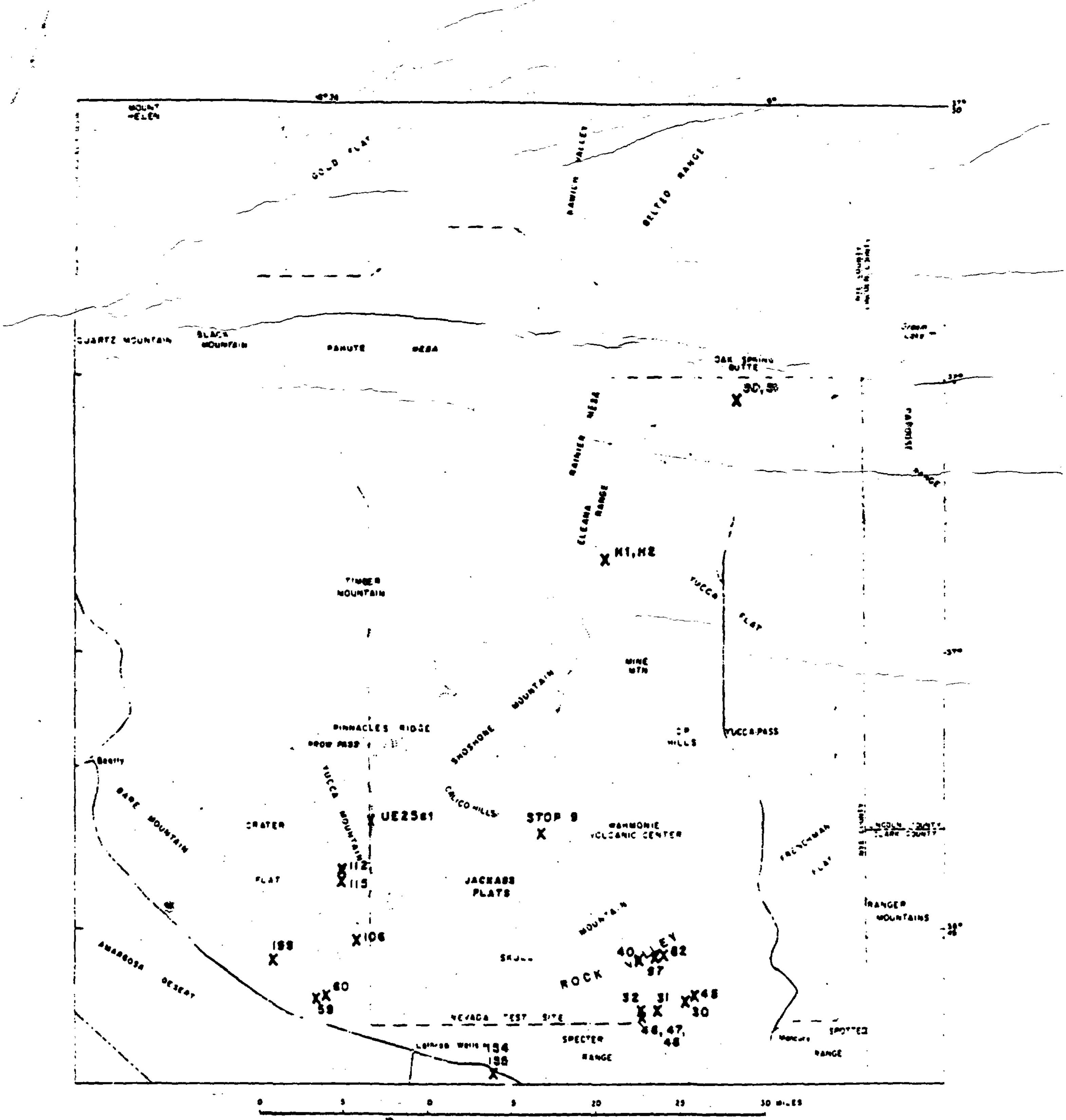


Figure 6.--Index map of southern Nevada Test Site area, showing sample localities mentioned in the text.

TABLE 1. Analytical data and uranium-series ages of carbonate at the Nevada Test Site
[Trav travertine; TTrav, tufaceous travertine; Calcr, calcrete; SC, soil caliche; S, acid soluble solution; R, acid insoluble residue]

Sample No.	Material	Percent residue	Fraction	Uranium (ppm)	$^{234}U/^{238}U$	$^{230}Th/^{232}Th$	$^{230}Th/^{234}U$	Uranium-series age (years)
				MERCURY VALLEY AREA				
30-A[1]	Trav	0	S	0.038 ± 0.001	1.00 ±0.02	43. ±10.	0.844 ±0.042	>700,000
30-B[2]	Trav	0	S	[illegible] ± 0.001	0.987 ±0.030	77. ±15.	0.992 ±0.040	> [illegible]
32	Trav	0	S	0.016 ± 0.002	1.00 ±0.05	4.05 ± 0.41	1.12 ±0.11	>700,000
[illegible][3]	Trav	0	[illegible]	0.495 ± 0.007	0.981 ±0.015	6.92 ± 0.21	1.00 ±0.03	>700,000
45-C[4]	Trav	5	S	1.10 ± 0.17	0.999 ±0.015	10.2 ± 0.3	1.06 ±0.03	>700,000
			R	0.52 ± 0.05	0.95 ±0.09	5.5 ± 0.6	1.21 ±0.18	
47-A[5]	Trav		S	4.71 ± 0.07	1.12 ±0.02	5.03 ± 0.15	0.846 ±0.025	104,000 ± 8,000
			R	2.84 ± 0.09	0.980 ±0.015	2.20 ± 0.07	1.58 ±0.05	
47-B[5]	Trav	22	S	3.16 ± 0.05	1.17 ±0.02	5.37 ± 0.16	0.957 ±0.029	97,000 ± 8,000
			R	2.51 ± 0.05	1.00 ±0.05	3.42 ± 0.10	1.42 ±0.07	
43	Calcr	18	S	3.17 ± 0.05	1.06 ±0.02	7.65 ± 0.23	0.730 ±0.022	100,000 - 150,000
			R	21.1 ± 0.3	1.01 ±0.02	16.7 ± 0.5	1.08 ±0.03	
46	TTrav	23	S	5.19 ± 0.08	1.04 ±0.02	38.2 ± 1.5	0.999 ±0.030	>70,000
			R	10.6 ± 0.9	1.05 ±0.02	34.0 ± 1.4	1.15 ±0.12	
31-A[7]	Calcr	70	S	19.7 ± 0.03	1.45 ±0.02	13.1 ± 0.4	0.750 ±0.030	102,000 ± 8,000
			R	5.61 ± 0.08	1.37 ±0.02	4.38 ± 0.13	1.16 ±0.05	

TABLE 1. Analytical data and uranium-series ages of carbonate at the Nevada Test Site--continued
[Trav, travertine; TTrav, tufaceous travertine; Calcr, calcrete; SC, soil caliche; S, acid soluble solution; R, acid insoluble residue]

Sample No.	Material	Percent Residue	Fraction	Uranium (ppm)	$\frac{^{234}U}{^{238}U}$	$\frac{^{230}Th}{^{232}Th}$	$\frac{^{230}Th}{^{234}U}$	Uranium-series age (years)
31-B[7]	Calcr	75	S	2.21 ± 0.03	1.10 ±0.02	4.66 ±0.14	0.751 ±0.030	96,000 ± 8,000
			R	1.86 ± 0.03	1.07 ±0.02	1.45 ±0.04	1.79 ±0.07	
				ROCK VALLEY FAULT AREA				
154	TTrav	55	S	2.23 ± 0.03	1.17 ±0.02	5.03 ±0.13	1.72 ±0.09	([8])
			R	0.630 ± 0.010	1.03 ±0.02	2.48 ±0.07	1.98 ±0.10	
155	TTrav	80	S	4.96 ± 0.07	1.27 ±0.02	9.73 ±0.29	0.650 ±0.033	70,000 - 110,000
			R	18.8 ± 0.3	1.31 ±0.02	23.4 ±0.7	0.790 ±0.040	
40	Calcr	45	S	6.90 ± 0.10	1.13 ±0.02	16.4 ±0.7	0.435 ±0.013	≥20,000
			R	12.3 ± 0.2	1.13 ±0.02	11.8 ±0.4	0.824 ±0.025	
82	SC	62	S	3.79 ± 0.06	1.41 ±0.02	1.81 ±0.07	0.0747 ±0.0022	>5,000
			R	3.02 ± 0.05	1.24 ±0.02	1.10 ±0.04	1.06 ±0.04	
97	SC	48	S	1.19 ± 0.02	1.35 ±0.02	1.33 ±0.05	0.119 ±0.004	>5,000
			R	2.91 ± 0.04	1.20 ±0.02	1.22 ±0.05	1.44 ±0.06	
				JACKASS FLATS				
Stop-9	SC	90	S	4.75 ± 0.06	1.34 ±0.02	3.28 ±0.10	0.240 ±0.010	~24,000
			R	2.79 ± 0.04	1.17 ±0.02	0.961 ±0.029	1.14 ±0.05	

TABLE 1. Analytical data and uranium-series ages of carbonate at the Nevada Test Site--continued
[Trav, travertine; TTrav, tufaceous travertine; Calcr, calcrete; SC, soil caliche; S, acid soluble solution; R, acid insoluble residue]

Sample No.	Material	Percent Residue	Fraction	Uranium (ppm)	$^{234}U/^{238}U$	$^{230}Th/^{232}Th$	$^{230}Th/^{234}U$	Uranium-series age (years)
				LATHROP WELLS AREA				
60-A	Calcr	35	S	5.32 ± 0.08	1.23 ±0.21	6.98 ±0.21	1.05 ±0.03	345,000 + 180,000 - 71,000
			R	3.73 ± 0.06	1.06 ±0.02	1.46 ±0.04	1.14 ±0.03	
60-B	Calcr	46	S	5.37 ± 0.08	1.20 ±0.02	5.62 ±0.17	1.09 ±0.03	345,000 + 180,000 - 70,000
			S	5.03 ± 0.10	1.20 ±0.02	5.53 ±0.17	1.03 ±0.05	
			R	6.11 ± 0.09	1.10 ±0.02	1.62 ±0.05	1.04 ±0.03	
59	SC	47	S	2.14 ± 0.03	1.53 ±0.02	1.99 ±0.06	0.425 ±0.013	25,000 ± 10,000
			R	1.94 ± 0.03	1.21 ±0.02	1.13 ±0.03	1.72 ±0.05	
				YUCCA MOUNTAIN AREA				
113	Calcr	75	S	2.78 ± 0.04	1.03 ±0.02	0.687 ±0.027	0.146 ±0.006	>5,000
			R	4.17 ± 0.06	0.986 ±0.015	0.620 ±0.002	0.337 ±0.025	
115	Calcr	80	S	10.6 ± 0.2	1.46 ±0.03	16.7 ±1.7	0.422 ±0.017	>20,000
			R	9.44 ± 0.14	1.51 ±0.02	22.4 ±0.9	1.19 ±0.04	
106	Ttrav	70	S	9.53 ± 0.14	1.26 ±0.19	4.53 ±0.14	0.660 ±0.025	78,000 ± 5,000
			R	3.66 ± 0.05	1.33 ±0.02	2.43 ±0.07	0.860 ±0.034	
				CRATER FLAT				
199	TTrav	30	S	1.31 ± 0.03	2.16 ±0.03	2.57 ±0.09	0.290 ±0.012	>30,000
			R	1.58 ± 0.02	1.17 ±0.02	2.61 ±0.08	1.47 ±0.06	

TABLE 1. Analytical data and uranium-series ages of carbonate at the Nevada Test Site--continued
[Trav, travertine; TTrav, tufaceous travertine; Calcr, calcrete; SC, soil caliche; S, acid soluble solution; R, acid insoluble residue]

Sample No.	Material	Percent Residue	Fraction	Uranium (ppm)	$^{234}U/^{238}U$	$^{230}Th/^{232}Th$	$^{230}Th/^{234}U$	Uranium-series age (years)
				ELEANA RANGE				
H-1	SC	45	S	6.51 ± 0.10	1.21 ±0.02	2.95 ±0.09	0.877 ±0.026	128,000 ± 20,000
			R	4.09 ± 0.06	1.10 ±0.02	1.37 ±0.04	1.18 ±0.04	
H-2	SC	40	S	16.8 ± 0.3	1.34 ±0.02	2.90 ±0.09	0.0806 ±0.0024	>5,000
			R	11.4 ± 0.2	1.35 ±0.02	1.82 ±0.06	0.331 ±0.010	
				BOUNDARY FAULT AREA				
50	SC	40	S	6.21 ± 0.09	1.37 ±0.02	11.2 ±0.5	0.242 ±0.007	>24,000
			R	4.36 ± 0.07	1.34 ±0.02	4.56 ±0.14	0.279 ±0.008	
51	SC	31	S	4.77 ± 0.07	1.37 ±0.02	1.62 ±0.05	0.164 ±0.005	>8,000
			R	3.50 ± 0.50	1.20 ±0.02	1.07 ±0.03	0.587 ±0.018	

[1]The outside, oldest part of travertine vein TSV-30.

[2]The center, youngest part of travertine vein TSV-30.

[3]The outside, oldest part of travertine vein TSV-45.

[4]The center, youngest part of travertine vein TSV-45.

[5]Sample represents 1/3 of full vein width of sample TSV-47.

[6]Sample represents 2/3 of full vein width of sample TSV-47.

[7]Different aliquots of calcrete cement sample TSV-31.

[8]Age cannot be calculated.

[9]Inner part of dense carbonate rind growing on cobbles.

[10]The softer and porous outer part of the same rind as 9 (above).

Table 2. Analytical data of calcite veins and fault gouge in fractures in cores from drill hole UE25a-1 at Yucca Mountain, Nevada Test Site

Sample depth (m)	Uranium (ppm)	$^{234}U/^{238}U$	$^{230}Th/^{232}Th$	$^{230}Th/^{234}U$	Age (years)
34	1.37 $\pm$0.03	1.17 $\pm$0.02	2.37 $\pm$ 0.07	1.02 $\pm$0.04	>400,000
87	5.18 $\pm$0.10	1.09 $\pm$0.02	0.989 $\pm$ 0.030	1.06 $\pm$0.04	(1)
283	8.98 $\pm$0.18	1.47 $\pm$0.02	22.2 $\pm$ 0.7	1.04 $\pm$0.04	>400,000
611	6.12 $\pm$0.12	1.29 $\pm$0.02	72 $\pm$ 3	1.19 $\pm$0.05	>400,000

[1]Fault gouge sample; age cannot be calculated.

Table 3.--Dated calcretes, soil caliches, and spring deposits, Nevada Test Site area

Sample No.	Material description and locality	Interpretation	Age, years
31	Massive calcrete, overlapping fault scarp, head of Mercury Valley.	Fault has not moved after about 100,000 years ago. Agrees well in age with similar sample 48.	≥99,000 ± 8,000
48	Massive calcrete, head of Mercury Valley. Is cut by adjacent faults containing dated travertine samples 46 and 47.	Agrees with field relations; that is, gives age slightly older than material in faults that displace it. Minimum age for old alluviam (QTa).	100,000 - 150,000
51	Laminar caliche, similar to samples 82 and 97. In trench on Boundary fault that displaces samples material.	Fault may have moved a little as recently as 8,000 years ago, but calcrete in fault (sample 50) gives age of ≥24,000 years.	>8,000
59	Caliche from base of loess overlying basalt cinder cone near Highway 95 northwest of Lathrop Wells.	Caliche is derived from leaching of loess layer. Age represents minimum for loess and cinder cone. Gives same as as caliche of sample Stop 9, which it may correlate (unit Q2).	25,000 ± 10,000
60	Stalactitic laminated calcrete in cavities between boulders, immediately beneath basalt flow.	Agrees nicely with age of 290,000 years obtained by K-Ar dating on overlying basalt lava.	≥345,000
82	Laminar caliche, base of soil zone in older alluvium (QTa) trench No. 2 across Rock Valley fault (fig. 9).	Zone of dated caliche is offset several inches to possibly as much as a foot by Rock Valley fault. Age does not agree with obviously mature age of fault scarp, nor with apparent ages of associated soil. See fig. 9.	>5,000
97	Same material as 82, but from trench No. 1.	See remarks for sample 82.	>5,000

Table 3.--Dated calcretes, soil caliches, and spring deposits, Nevada Test Site area (Continued)

Sample No.	Material description and locality	Interpretation	Age, years
106	Seep-deposited tufa or calcrete intercalated in Q2 alluvium. Shows some evidence of spring-water deposition.	Gives approximate minimum age of Q2 alluvium.	78,000 ± 5,000
199	Nodular tufa spring deposit, south end of Crater Flat.	Suggested spring activity was at altitude of about 838 m as late as 30,000 yrs. ago. Present water table is about 120 m lower (Winograd and Thordarson, 1975, pl. 1).	[1]30,000
H-1	Caliche possibly deposited by seepage. East flank Eleana Range.	Age predates adjacent valley; minimum age of alluvium (Qta).	128,000 ± 20,000
H-2	Laminar caliche formed by redeposition at top of zone represented by H-1 sample.	Age postdates adjacent valley.	>5,000
Stop 9	Soil caliche in trench, northeast Jackass Flats, Unit #2.	Age is in general agreement with estimated soil age; represents probably a minimum age.	~24,000

[1]Average of two sample splits.

[2]Samples of inner and outer parts of caliche "stalactite" gave the same age (table 1).

Table 4.--Dated fault and fracture filling carbonates, Nevada Test Site area

Sample No.	Material description and locality	Interpretation	Age, years
30	Calcite vein, head of Mercury Valley, in limestone bedrock.	Little or no movement has occurred on fault within last 700,000 years.	>700,000
32	Unbroken calcite crystal filling in fault between alluvium and limestone bedrock; ridge between Mercury and Rock Valleys.	No movement has occurred within last 700,000 years.	>700,000
40	Calcrete in fracture in tuff breccia, Rock Valley. Fills fracture adjacent to Rock Valley fault.	Age suggests minor fault movement and reopening of fracture no later than about 20,000 years ago.	$\gtrsim$20,000
45	Undisturbed travertine vein in limestone ridge between Mercury Valley and Rock Valley.	Essentially unfractured fault filling indicates no significant movement post-700,000 years.	>700,000
46	Undisturbed travertine vein in alluvium, head of Mercury Valley.	Sample is unfractured filling in fault near, and parallel to, fault sampled by No. 47. Ages of 46 and 47 are in general agreement and indicate no opening of fault after about 70,000 years ago.	$\gtrsim$70,000
47A	Undisturbed travertine; represents one-third of total vein width.	Sample is unfractured filling in fault near and parallel to fault sampled by No. 46. Ages agree with sampling; that is, two-thirds vein width is slightly younger.	104,000 $\pm$ 8,000
47B	Same, but represents two-thirds of total vein width.		97,000 $\pm$ 8,000
50	Calcrete in Boundary fault, northwest edge Yucca Flat.	Sample fills opening in fault; slightly crushed and some slippage evident. Gives an older age than caliche (sample 51) offset by fault.	$\gtrsim$24,000
113	Calcrete in fault between welded tuff and alluvium, west side of Yucca Mountain.	Sample was unfractured by fault, so last movement is greater than about 5,000 years ago.	>5,000

Table 4.--Dated fault and fracture filling carbonates, Nevada Test Site area--Continued

Sample No.	Material description and locality	Interpretation	Age, years
115	Same as 113.	Sample was unfractured by fault; last movement on fault is greater than about 20,000 years ago.	>20,000
154	Nodular calcrete in fault where Rock Valley Wash crosses U.S. 95.		Did not yield an age.
155	Same locality as 154, but from a parallel branch of the fault. Slip surfaces are present within dated calcrete.	Fault has moved a little after about 100,000 years.	70,000 - 110,000
UE25a-1, -34, -283, and -611 meter depths.	Drill hole at Yucca Mountain; calcite in filled fractures in core.	Fractures have probably not been reopened in last 400,000 years.	[1]>400,000

[1]All three sample exceeded the age of resolution of the method.

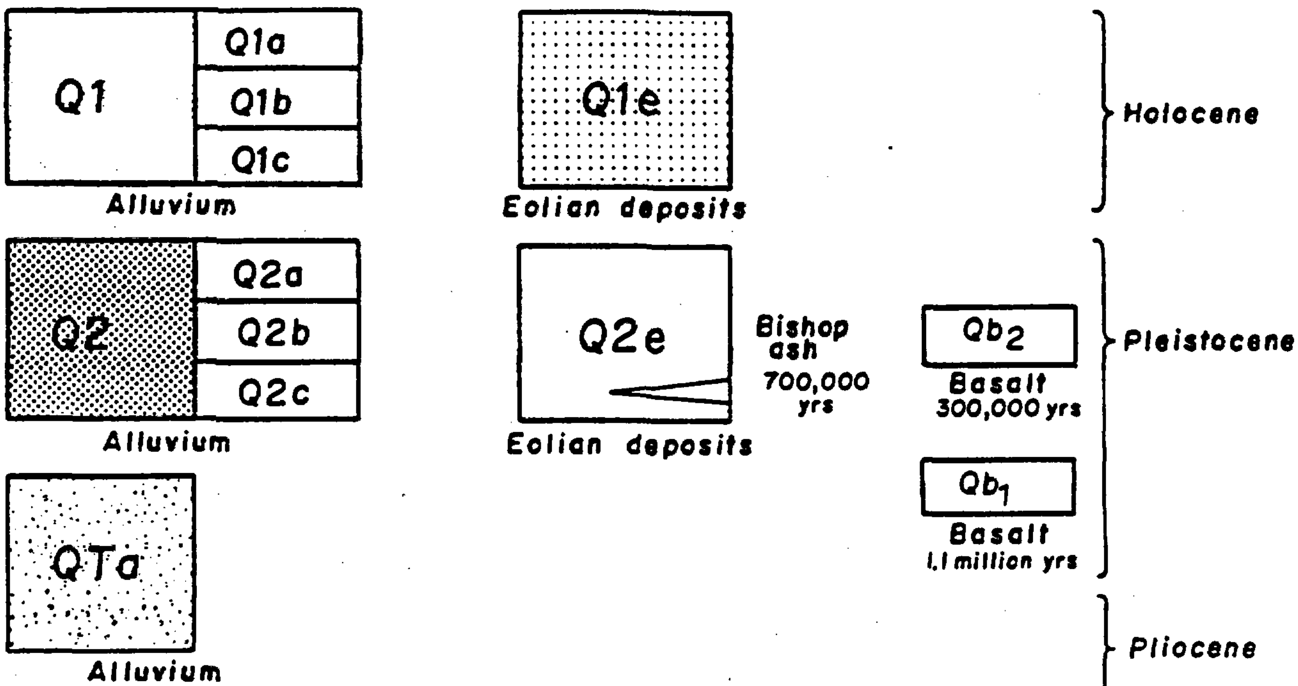


Figure 7.--Generalized alluvial stratigraphy, Nevada Test Site area.

other about 1.1 m.y. old, are useful age markers in the Crater Flat area. Several occurrences of Bishop ash (700,000 years old) have been found, mostly in the eolian phase of unit Q2. Thus, the age of the alluvium section is roughly calibrated by volcanic units.

First, we will discuss calcretes, soil caliches and spring deposits (table 3). Two massive calcretes were dated (samples 31 and 48) near the head of Mercury Valley. Both are developed on older alluvium (QTa) and both give similar ages--about 100,000 years. This calcrete is dense and permeability is now relatively low. It was probably derived, in part at least, by leaching of carbonate from sand dunes, now largely removed. The calcrete contains noticeable windblown frosted sand grains. The original dunes could have been blown into the area largely from the lake beds of probable late Pliocene age in the Amargosa Valley to the west. Another example of carbonate formed from leaching of windblown material is sample 59, which is a thin, soft, porous carbonate layer at the base of a loess layer, which has a maximum thickness of 0.5 m. Holocene sand dunes overlie the loess and basalt in places (fig. 8). The loess rests on highly porous basalt cinders that provide an extremely permeable system. The age resulting from uranium-series dating is about 25,000 years; the underlying basalt lava flow is about 300,000 years old as determined by K-Ar dating (R. J. Fleck and W. J. Carr, U.S. Geol. Survey, oral commun., 1979). Obviously, the caliche gives only a minimum possible age for the loess and cinder cone. Immediately beneath the basalt lava flow, massive stalactitic calcrete was analyzed as sample TSV-60 (fig. 8). The material encrusts boulders of welded tuff and displays well-developed laminae, so the sample was split into inner and outer parts. Both parts gave the same uranium-series age, suggesting rapid deposition of the calcrete. The age of 345,000 years agrees with the age of the overlying basalt and suggests that formation of the calcrete was ended abruptly by emplacement of the basalt.

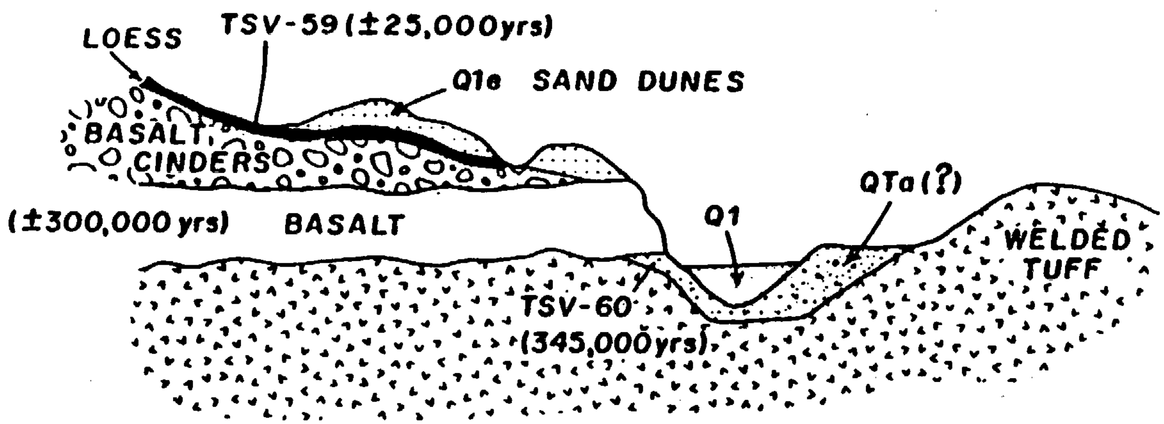


Figure 8.--Geologic relations at basalt center, 11 miles northwest of Lathrop Wells, Nevada Test Site.

Samples 82 and 97 were collected from similar soil caliche in unit Q2 in the walls of two trenches dug across the Rock Valley fault (fig. 9). At both localities, which are 500 m apart, the caliche and a B soil zone appear to have been disturbed and offset as much as 0.5 m by the fault. This apparently young displacement is in contrast to the lack of a youthful scarp at the surface; in fact, the maximum slope measured on the scarp at the trenches is 8° and scarp height ranges from about 1.5 to 2 m. At least two episodes of movement are demonstrated by the scarp and the exposures in the trenches. The work of Bucknam and Anderson (1979, p. 14) suggests that on the basis of the relationship between scarp-slope and height, the Rock Valley fault scarp is older than about 12,000 years. The latest event, the one that displaced the dated caliche about 0.5 m, is thus probably younger than 12,000 years, but the surface scarp has been obliterated. Perhaps such a small scarp can disappear in 10,000 years or so. However, at several locations from 1 to 2 miles west of the trenches along the Rock Valley fault system, scarps that displace intermediate-age (Q2) alluvium 1-2 m extend across Holocene (Q1) alluvium as faint but discernible lines with no scarps. Thus, evidence is strong for a major earthquake on the Rock Valley fault zone prior to about 12,000 years ago, which was followed by a smaller event sometime in early Holocene time, probably between 5,000 and 12,000 years ago.

A somewhat similar caliche was dated from a trench dug in intermediate alluvium (Q2) in northeastern Jackass Flats (stop-9). The age obtained on the caliche, approximately 24,000 years, is much younger than the age of the deposit which J. N. Rosholt (U.S. Geol. Survey, written commun. 1980) dated at 145,000 years by the uranium-trend method (Rosholt, 1978). Probable reasons for this discrepancy are discussed later in the summary.

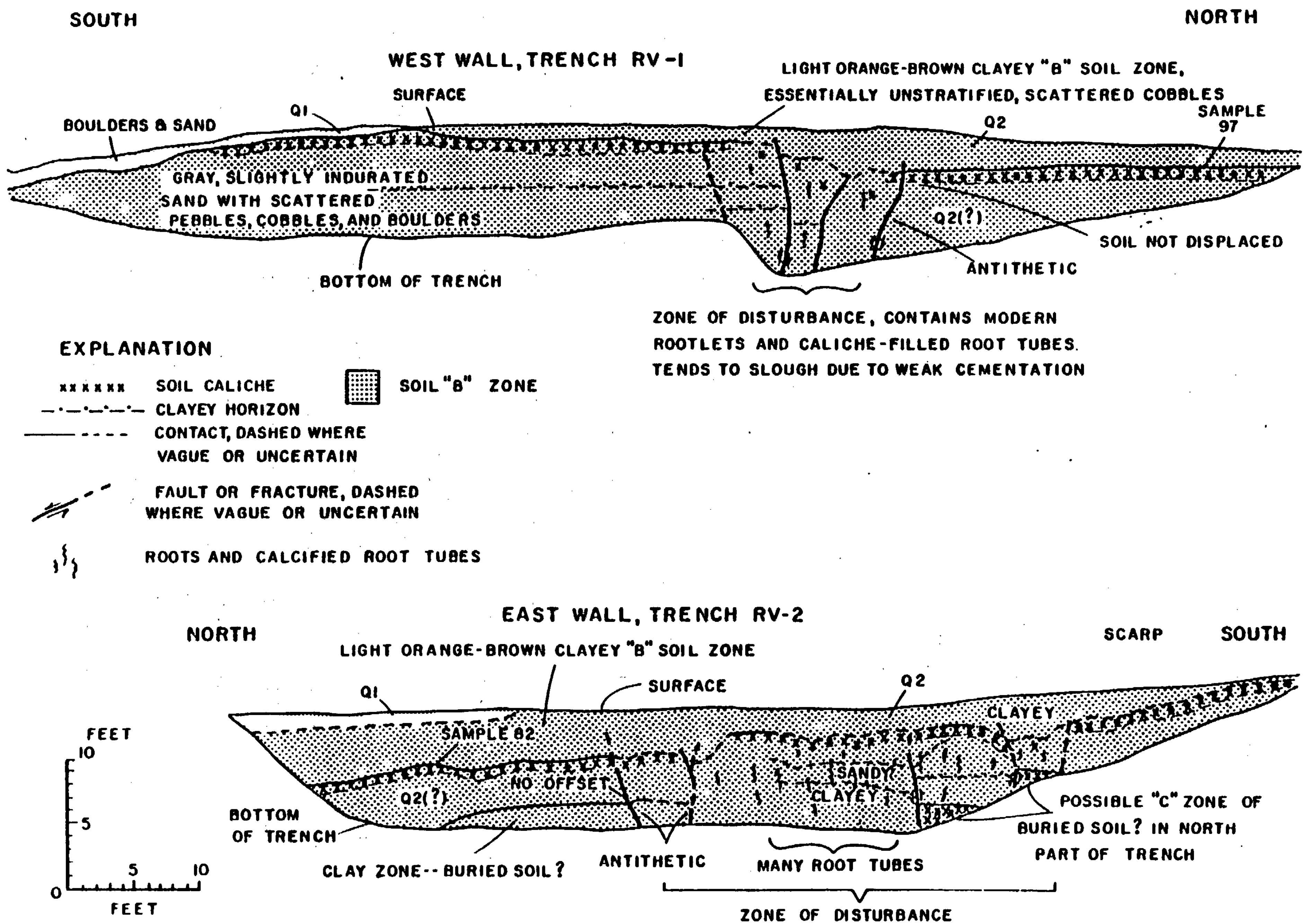

SOUTH
NORTH
WEST WALL, TRENCH RV-1
LIGHT ORANGE-BROWN CLAYEY "B" SOIL ZONE, ESSENTIALLY UNSTRATIFIED, SCATTERED COBBLES
SURFACE
Q1
BOULDERS & SAND
Q2
SAMPLE 97
GRAY, SLIGHTLY INDURATED SAND WITH SCATTERED PEBBLES, COBBLES, AND BOULDERS
Q2(?)
SOIL NOT DISPLACED
ANTITHETIC
BOTTOM OF TRENCH
ZONE OF DISTURBANCE, CONTAINS MODERN ROOTLETS AND CALICHE-FILLED ROOT TUBES. TENDS TO SLOUGH DUE TO WEAK CEMENTATION
EXPLANATION
SOIL CALICHE
SOIL "B" ZONE
CLAYEY HORIZON
CONTACT, DASHED WHERE VAGUE OR UNCERTAIN
FAULT OR FRACTURE, DASHED WHERE VAGUE OR UNCERTAIN
ROOTS AND CALCIFIED ROOT TUBES
EAST WALL, TRENCH RV-2
NORTH
SCARP
SOUTH
LIGHT ORANGE-BROWN CLAYEY "B" SOIL ZONE
SURFACE
Q1
Q2
CLAYEY
SAMPLE 82
NO OFFSET
SANDY?
CLAYEY
Q2(?)
FEET
10
5
0
5
10
FEET
BOTTOM OF TRENCH
POSSIBLE "C" ZONE OF BURIED SOIL? IN NORTH PART OF TRENCH
CLAY ZONE--BURIED SOIL?
ANTITHETIC
MANY ROOT TUBES
ZONE OF DISTURBANCE

Figure 9.--

Two caliche samples (H1 and H2) from old alluvium (QTa) exposed by a trench (fig. 10) on the flank of the Eleana Range also gave relatively old (128,000 ± 20,000 yrs.) and relatively young (>5,000 yrs.) ages. The young caliche is similar to caliche of samples 82 and 97 from Rock Valley and stop 9 in Jack. .s Flats, and is in general, related to the present topography. The older caliche dips into the present topography about 12° and predates the adjacent valley.

Yet another laminar caliche (sample 51) similar to the previously discussed examples was taken from a trench dug across the Boundary fault in northwestern Yucca Flat. It is obviously displaced by the fault, and it too gave a young minimum age of >8,000 years, whereas the calcrete from the fault zone itself (sample 50) gave an age of about 24,000 years. The calcrete in the fault appeared to be crushed and jostled somewhat by subsequent movements. The general situation is similar to that at the Rock Valley fault where the age of the offset caliche appears to be somewhat younger than the age of the fault as estimated from other evidence. In both instances, faulting clearly has occurred after deposition of most of the laminar soil caliche. The morphology of the Boundary fault scarp suggests younger significant offset than on the Rock Valley fault, yet the calcrete in the Boundary fault gives an age that is apparently older than the scarp. Rough ages based on scarp-slope relationships determined by Wallace (1977, p. 1275) for north-central Nevada suggests that the Boundary fault scarp formed about 10,000 years ago, which is in fairly good agreement with the age of >8,000 years determined on the offset caliche.

Two carbonate samples of spring or probably spring origin were dated (samples 106 and 199). These gave ages of 78,000 ± 5,000 and about 30,000 years. Spring deposits at both localities are overlain by Q2 alluvium, but, particularly in the deposit of the 30,000-year-old material, relationships

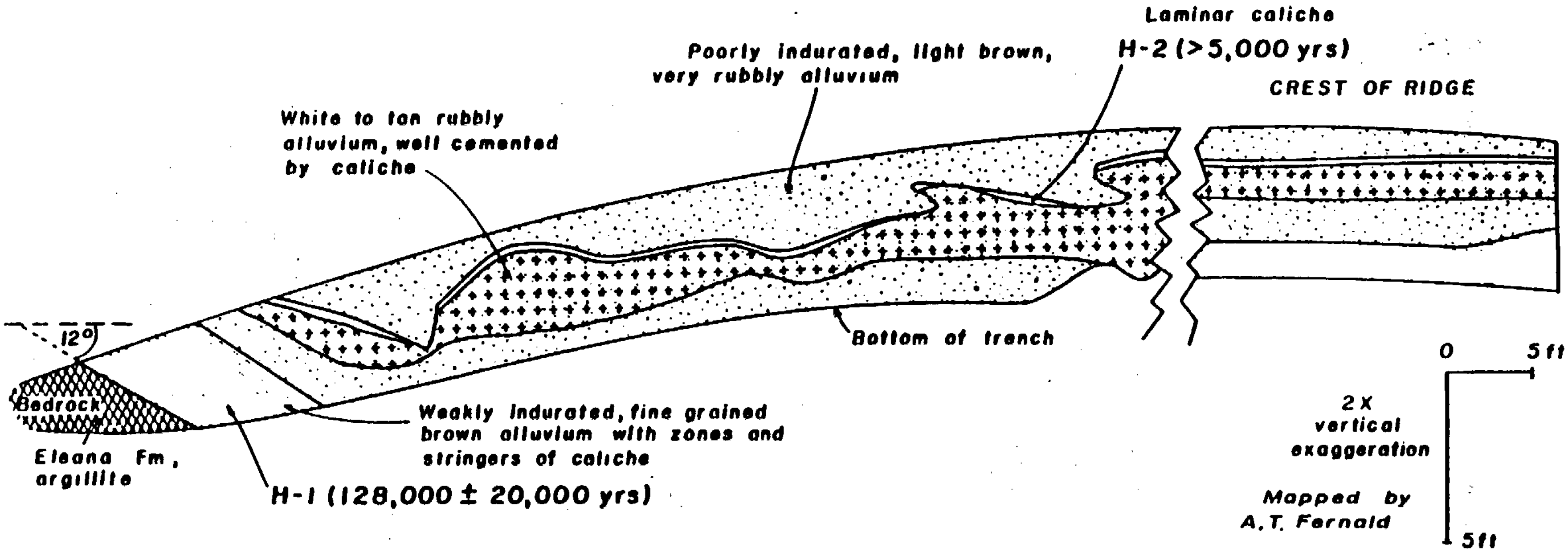


Figure 10.--Trench in alluvium, east flank of Eleana Range.

suggest that the spring activity continued after deposition of the intermediate alluvium. The deposit dated at about 78,000 years has been fractured and cut by a few minor faults.

Young caliches associated with the Rock Valley and Boundary faults have been previously described. Several other faults and fracture fillings were also dated (table 4), including calcite or travertine veins along faults in the Paleozoic limestone and dolomite bedrock between Mercury and Rock Valleys. These east-northeast to northeast-trending faults are fairly prominent on aerial photographs, but, in general, the youngest material they cut appears to be older alluvium (QTa), and in some instances the older alluvium is merely deposited against the scarps in bedrock. In three samples (30, 32, and 45), undisturbed fault-filling material gave ages older than 700,000 years.

Another group of samples (46, 47) from two adjacent parallel faults at the head of Mercury Valley gave ages in the general range of 100,000 years. These fault fillings are clearly undisturbed, but the faults cut older alluvium (QTa). The age of the latest fault movement there seems well controlled at earlier than about 100,000 years ago. The virtual absence of scarps in the older alluvium suggests that the actual age of the latest fault movement was probably even older, possibly 1 m.y. or so. However, no great difference in age was found between the inner and outer parts of one of the veins, suggesting fairly rapid filling of the opening along the fault.

On the west side of Yucca Mountain, a prominent Basin-Range fault that drops old alluvium (QTa) against welded tuff bedrock contains unfractured calcrete veins. The undisturbed calcretes gave ages of >5,000 and >20,000 years (sample 113 and 115, table 4). The highly siliceous nature of this material prevents a better resolution of age, but based on scarp morphology and age of alluvium affected, it is fairly certain that the last movement on the fault occurred prior to 20,000 years ago and probably before several hundred thousand years ago. About 7 km farther north, the same fault zone contains a small unfractured basalt dike dated by K-Ar at 10 m.y. (R. F. Marvin, U.S. Geol. Survey, written commun., 1979).

Calcrete was also dated from a northeast-trending fault zone in limestone bedrock in the lower part of Rock Valley. It gave an age of 70,000-110,000 years (sample 155, table 4), but another sample (154) from a parallel splay of the fault failed to yield an age. The calcrete is clearly crushed and slip surfaces within it display slickensides, so that some movement has occurred after about 100,000 years. Along the trend of the fault, to the north across U.S. Highway 95, is a small subtle fault scarp in old alluvium; this scarp could be the remnant of a small surface displacement corresponding to that recorded in the caliche. Significantly, a swarm of about 20 earthquakes occurred in this area in a short time in 1976 (A. M. Rogers, U.S. Geol. Survey, written commun., 1978).

A series of samples of calcite-filling fractures in drill core of welded tuff at Yucca Mountain (UE25a-1, tables 2 and 4) gave consistent ages of >400,000 years. The deepest sample (611 m) was from below the water table. These significant ages give assurance that reopening of these fractures has not occurred in at least 400,000 years, indicating relative stability for this structural block.

SUMMARY

Quaternary tectonic activity in arid regions may be assessed through the study of the history of movement of faults by dating carbonates that are deposited in fractures or carbonates cementing young alluvial materials that these faults displace. Carbonates, such as caliche, calcrete, travertine, calcite veins and tufas, are common in the NTS area, southern Great Basin, and all types of these carbonates have been collected and dated by the uranium-series method from a variety of geologic settings. Many of the samples have yielded reasonable results that agree well with estimates of ages determined by K-Ar and (or) fission-track dated volcanic units, fault scarp morphology, and geomorphic considerations. Other samples gave only minimum age for a material or event.

Dating of impure carbonates that are heterogeneous mixtures of materials with different ages is still tentative because there must be more experimental work to document the validity of the acid leaching approach used in this study. Some generalizations concerning the reliability of these uranium-series dates can be made at this time, however, Nearly all the travertines and calcite crystals or veins appear to yield reasonable ages, probably because these samples were deposited under conditions that closely resemble the "closed system" assumption necessary for the calculations. Tufaceous travertines may occasionally form open systems with respect to uranium and thorium, and hence those results may indicate minimum ages only. Calcretes, likewise, have some degree of uncertainty wherein determined ages may reflect minimum ages, but under favorable conditions, can yield reasonable ages for the time of cementation of the deposits.

The results for samples classified as soil caliches were found to be questionable using this procedure. Most samples yielded ages that are too young, but which can be considered as minimum ages. These too-young ages can readily be explained by recognizing that the soil carbonates may be dissolving and reprecipitating continuously while converting from a less mature to a more mature state. A different treatment of the samples and data using the uranium-trend method developed by Rosholt (1978) migh permit better age determinations, as these soil caliches resemble, in many ways, the soils he successfully dated.

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No 51595

URANIUM-SERIES DATING OF FAULT-RELATED FRACTURE- AND CAVITY-FILLING CALCITE AND OPAL IN DRILL CORES FROM YUCCA MOUNTAIN, SOUTHERN NEVADA

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Yucca Mountain in southern Nevada is currently being investigated as a possible site for geologic disposal of radioactive waste. Tertiary ash-flow tuffs with various degrees of welding are the predominant rock types. Three of the exploratory cores chosen for this study had fracturing at about 30-160 m, 170-370 m, and about 600 m depths. The fractures and other spherulitic cavities at these depths had been coated and occasionally completely filled with calcite and opal. These minerals are presumed to be precipitated from percolating ground water that leached wall rocks and fault-gouged materials and became super-saturated in calcite and silica. The purpose of this study was to attempt uranium-series dating of these calcite and opal infillings in order to bracket ages of possible recent tectonic activities.

Altogether, 14 calcite and 4 opal samples have been dated mostly by the conventional uranium-series technique. The uranium concentrations in the calcite samples vary between about 0.1 and 3.0 ppm, except for one sample that has 33 ppm of uranium. The uranium contents of the dated opal samples vary between 13 and 54 ppm, and the samples emit yellow-green light under ultraviolet stimulus. The obtained uranium-series dates group at about 28,000±3,000, 170,000±30,000, and 280,000±50,000 years B.P. All four opal samples and four of the calcites are measured to be older than 400,000 years B.P. Generalizing on a limited data base, the results suggest at least four episodes of recent recurrent faulting at the Yucca Mountain area.