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Title of article Dating the Upper Cenozoic Sediments in Fisher Valley,
Southeastern Utah

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SAMPLING AND ANALYTICAL METHODS

Paleomagnetic Stratigraphy

The magnetic stratigraphy in (QTbl) was examined using standard sampling and analysis methods. Oriented samples were collected at 1-2-m intervals in 160 plastic cubes and cylinders (3.2 and 6.5 cm³, respectively) and 8 cores (10.9 cm³) were drilled from oriented-block samples of well-indurated sediments. To determine sample polarity, the cubes and cylinders were subjected to alternating-field demagnetization (peak fields: 10, 20, 40, and 60 milliteslas) and the cores were thermally demagnetized, in steps of 100°-200° C, to a maximum temperature of 680° C. Equal-area and orthogonal vector projections (Zijderveld, 1967) of sample remanence (measured in a spinner magnetometer during stepwise demagnetization) were used to classify samples as normal, normal?, reversed, reversed?, or indeterminant (N, N?, R, R?, I, respectively), according the criteria discussed by Colman and others (in press). Remanent directions of N and R samples and of N? and R? samples were within 30 angular degrees and from 30 to 60 angular degrees, respectively, of the geocentric axial dipole directions for Fisher Valley.

Normal and indeterminant polarities in parts of the Matuyama chronozone (fig. 5) indicate either (1) that these sediments were deposited during normal-polarity subchrons of the Matuyama, or (2) that the sediments locally contain a postdepositional chemical (CRM) or viscous (VRM) remanent magnetization, assuming that these sediments acquired a stable detrital remanence (DRM) when they were initially deposited. Indeterminant and conflicting polarities in sampled horizons near the top of the reversed-polarity zone probably reflect post-depositional remagnetization of the

sediments. Such remagnetization, if present, could result from either CRM or VRM, or some combination of the two. It is extremely difficult to identify the mineralogical sources of magnetic remanence in red sediments (Collinson, 1983), particularly in second-cycle red beds in which some of the magnetic minerals are chemically altered prior to deposition. The primary remanence in the sediments is apparently a DRM, carried by detrital specular hematite (Colman and others, in press), but alteration of other iron-bearing minerals (e.g., magnetite, biotite) identified in the sediments could result in a CRM component. Many samples in the reversed zone, regardless of their final polarity classification, showed evidence of normal polarity overprints during demagnetization (Colman and others, in press). Such secondary magnetic components and the lack of detailed, independent age control prevents correlation of the normal-polarity subzones in the reversed section with recognized normal subchrons of the Matuyama.

Uranium-Trend Analyses

Uranium-trend dating (Rosholt, 1985; Rosholt and others, 1985) is based on an open-system model, in contrast to an ideal closed system, in which no post-depositional migration of ^{238}U or of its in-situ daughter products ^{234}U and ^{230}Th occurs in the deposit. Open-system models impose no restrictions on post-depositional migration of these radioisotopes within and between deposits; the open-system model is therefore better for detrital deposits through which water moves.

The large number of geochemical variables in an open system precludes rigorous mathematical models for uranium migration; rather, an empirical approach is used to explain observed patterns of isotopic distribution. After deposition, detrital sediments interact with materials carried in pore waters

that move through the deposits. Waters that permeate deposits contain at least small amounts of uranium; this uranium decays, producing radioactive daughter products, some of which are readily adsorbed on solid matrix material, primarily of silt and finer size.

The very long-lived ^{238}U isotope (half-life of 4.5×10^9 years) produces long-lived daughter products, ^{234}U and ^{230}Th ; the half-life of ^{234}U is 248,000 yr, and this isotope has potential use as a geochemical tracer for about the past 900,000 yr. The half-life of ^{230}Th is 75,200 yr and because of its daughter-parent relation to ^{234}U , it is a key isotope used in nearly all uranium-series dating models (Ku, 1976).

For surficial deposits, the uranium-trend clock is started by the initiation of movement of water through the sediment. Isotopic equilibrium in the parent material is disturbed during sediment transport, and the process of readjustment towards a new equilibrium starts at the time of deposition. The empirical model incorporates a component called uranium flux, $F(0)$, whose actual physical significance is not well understood. $F(0)$ is related to the flux of mobile-phase uranium through a deposit, which in turn is related to both the flux of water through the deposit and the concentration of uranium in that water. The uranium flux appears to decrease exponentially with time (Rosholt, 1985), probably due to physical and chemical alteration of the deposit. As a result, $F(0)$ is expressed as the half-period of uranium flux.

For each sample, the concentrations of ^{238}U , ^{234}U , and ^{230}Th are determined on <2-mm-size subsamples by radioisotope-dilution techniques and alpha-spectrometer measurements. The isotopic composition of the deposit is expressed as two ratios, $(^{234}\text{U}-^{238}\text{Th})/^{238}\text{U}$ and $(^{238}\text{U}-^{230}\text{Th})/^{238}\text{U}$. For individual deposits, plots of these two ratios yield straight lines, so that the relations can be expressed as the slope and intercept of the line. The

empirical open-system model thus contains four components: the slope of the uranium-trend line, its intercept, the half-period of uranium flux, and time.

The uranium-trend model has been calibrated by data from several deposits of known age that encompass the time range defined by the model. Time calibrations at 12,000, 150,000, 600,000, and 730,000 yr, are provided by radiocarbon and K-Ar dating (Rosholt and others, 1985). The respective depositional units are (1) loess of late Wisconsin age in Minnesota; (2) glacial till and loess of Bull Lake age near West Yellowstone, Montana, and till of Bull Lake age near Pinedale, Wyoming; (3) altered Lava Creek Ash from Lake Tecopa, California; and (4) altered Bishop Ash also from Lake Tecopa.

The isotopic abundances of ^{238}U , ^{234}U , and ^{230}Th are used to construct uranium-trend plots similar to those in figure 6. The slope of the linear regression (U-trend slope) and the intercept on the X-axis (X intercept) in table 1 are calculated from these plots. The half periods of $F(0)$ are obtained from a calibration curve (Rosholt and others, 1985) developed from deposits of known age.

SOIL DEVELOPMENT

The amounts of secondary calcium carbonate and clay in the Fisher Valley soils was used as a quantitative measure of soil development. Carbonate and clay contents were calculated from weight percents multiplied by bulk densities. Primary contents of carbonate and clay were estimated from samples of the lowest, least altered C horizons and scattered samples of sediments that were not in soil profiles (Colman and others, in press). Secondary carbonate and clay contents of each soil horizon were multiplied by the horizon thickness and summed to produce the estimated total mass of each material in a 1-cm^2 column of each soil.

The genesis of calcareous soils in the arid and semi-arid western United States has been controversial, but recent studies have shown that pedogenic (secondary) carbonate accumulates in such soils primarily by aerosolic addition and by redistribution of aerosolic and primary carbonate in the soils (Gile and others, 1981; Machette, 1985). Groundwater and calcium-rich silicate rocks are thought to be negligible sources of calcium carbonate. Analogous processes are probably responsible for much of the secondary clay in arid and semi-arid soils (Gile and others, 1981; Colman and others, in press). This is especially true in Fisher Valley, where the semi-arid climate and quartz-rich sediments are deterrents to clay formation by weathering.

The rates calculated using the two age datums are essentially identical ($0.15 \text{ g/cm}^2/10^3 \text{ yr}$ for carbonate and $0.11 \text{ g/cm}^2/10^3 \text{ yr}$ for clay); only rates derived from the Brunhes-Matuyama boundary are shown in fig. 7.

Amino Acid Analyses

Two fractions of each soil sample (100 mg of <69 micron size) from Fisher Valley were analyzed for amino acids : (1) the soluble fraction, that is, soluble in 6N HCl at room temperature and (2) the sediment fraction, which was released from the residue of the soluble fraction during pyrolysis in 6N HCl for 22 hours at 110°C . Some of the sediment-fraction samples were also treated with NaOH to remove dissolved metallic ions (mostly iron) that interfere with the ion-exchange separation of the amino acids. Total concentrations of amino acids in both fractions were determined, as were the concentrations of several individual amino acids. For all samples, isoleucine epimerization (the ratio of D-alloisoleucine to L-isoleucine, or alle/Ile) was also determined. Amino acid concentrations were measured using standard ion-exchange liquid chromatography techniques. Total amino acid concentrations

and alle/Ile ratios for samples of soils in Fisher Valley are summarized in Table 2.

Most of the amino acids in the soluble fraction are probably incorporated with secondary calcium carbonate that was precipitated in the soils in Cca and K horizons; most of the amino acids in the sediment fraction are probably sorbed or tied to the surface of detrital sediment grains, although clay-sized material, which is most abundant in the B horizons, probably includes amino acids bound in lattice sites within mineral structures.

Thermoluminescence

The method of measuring thermoluminescence (TL) described here, called the R-T method, is designed to determine the radiation dose that the sample has received since the last exposure to sunlight, even if this exposure was of relatively short duration (e.g., 1 hour) or was through an absorbing medium (e.g., silty water). The method attempts to determine the component of the TL that arises from electron traps that are highly light-sensitive and thus would have been emptied at the time of sediment deposition. This method was introduced by Wintle and Huntley (1980) and is described in detail by Huntley (1985). This method can measure equivalent doses of <5 Gy (1 Gy = 1 Joule/kg or 100 rads) for modern river silts; this ED corresponds to less than 2000 yr (Huntley and others, 1983; Huntley, 1985). For such sediments, zero-point errors are not significant on a time scale of 10^5 years.

Sample preparation and measurements were generally those described in Wintle and Huntley (1980); the standard light exposure was 24 hours under a Sylvania 275 watt sunlamp using a Corning 3-73 filter (420 nm cutoff) to remove the ultraviolet TL component. The TL measurements were nonlinear functions of dose, as expected for total doses over ~ 100 Gy. Both quadratic

and exponential fits were made for the extrapolations to zero dose; because these fits did not always yield the same result, the equivalent doses (ED) quoted are given uncertainties that include both possibilities (Table 3).

Radiocarbon

All samples were treated with 2N NaOH at 100°C for 30 minutes, and with 2N HCl at room temperature for 48 hours. Samples were repeatedly washed, filtered, and cleaned of obvious impurities such as rootlets. Carbon-14 activities were measured using standard liquid-scintillation techniques. Resulting dates are summarized in Table 4.

Unit Qa was sampled in stream cuts at two localities, each of which contained two thin, charcoal-bearing horizons. At C81-38, the two horizons were 1.0 and 1.7 m below the surface of a low fluvial terrace along Fisher Creek; at C82-06, the two horizons were 1.3 and 3.6 m below the surface of a similar terrace on Onion Creek. The samples consisted of charcoal and partially burned wood, which appeared to be roots and stems of sagebrush or other woody plants. Scattered rootlets were present in all the bulk samples, but visible roots were removed. Two subsamples of sample C82-06A were hand picked, one for wood and one for charcoal, and were processed separately.

Samples of unit Qas were obtained from a steep, eroding hillside exposure. The samples consist of peaty sand and organic-rich silt, which contained numerous rootlets. The two samples are identical except for different treatments to remove the roots. One sample (C81-44A) was treated according to the methods described above, including hand-removal of visible roots; this sample yielded a date of 8360±110 yr B.P. (Table 4). The second sample was dispersed in sodium pyrophosphate, washed with water, and decanted to remove floating roots; it was also sieved through a 125-micron screen before other pretreatments; no evidence of remaining roots was seen under 30-

times magnification. The sample subjected to the extra treatment (C81-44B) yielded a date of 9330 ± 155 yr B.P. (Table 4). These data suggest that sample C81-44A was contaminated to some degree by modern roots. However, the pretreatments performed on sample C81-44B and the amount of modern material necessary to significantly affect dates within this range (Grootes, 1983) suggest that the date for this sample is close to its true age.

Table A.--Uranium-trend model parameters and ages of deposition units,
Fisher Valley, Utah

Sample	U-trend slope	X intercept	Half period of F(0) (10^3 yr)	Age (10^3 yr)
SJ	0.069	0.758	73	9 ± 11
SI upper part (1-4)	0.363	-0.180	460	210 ± 40
SI lower part (5-11)	0.267	0.038	660	240 ± 35
SI average				230 ± 40
SC	-0.865	-0.014	690	530 ± 70

Table B.--Amino acid data for Fisher Valley soils

[<, below resolution limit; ND, concentration below detection limit; -, not analyzed or not applicable, *, probably contaminated (high serine/glutamic acid ratio). Total amino acid concentrations are expressed in picomoles/mg dry sediment weight]

Soil Sample Horizon	aIle/Ile									Total		Percent Soluble
	Soluble			Sediment								
	Mean	St. Dev.	N	Mean	St. Dev.	N	Sed	Sol				
C81-40												
J	SJ2	A12	.12	.01	3	0.038	0.001	2	23900	812	3	
J	AAJ	Clca	<.032	-	1	.021	-	1	7900	750	9	
I	SI1	B21t	.076*	.013	3	.20	.01	3	7800	780	9	
I	SI2	B22tca	ND	-	-	.27	.01	2	6200	-	-	
I	SI3	B23tca	.20	.05	2	.30	.01	3	6300	810	11	
I	SI4	B3ca	.20	.05	2	.28	.02	3	5300	880	14	
I	AAI1	K1	.061	-	1	.44	-	2	11500	2600	18	
I	AAI2	K21	.045	-	1	.040	-	1	7250	2000	22	
I	AAI3	K22	.067	.01	2	.036	-	1	4850	1300	21	
I	AAI4	Clca	.035	-	1	ND	-	-	5950	800	12	
H	SH1	B21t	.053	.002	4	.13*	.01	3	2900	620	18	
H	SH2	B22tca	.11	.01	3	.076	.001	3	-	1800	-	
G	SG1	B2tca	.037*	.001	3	.047*	.003	3	6100	1200	16	
G	AAG	2Clca	.18	.01	3	.047	.02	3	2000	1200	38	
F	SF2	B22tca	.11	.01	2	.16*	.00	3	1300	620	32	
F	SF4	B2t	.057*	.003	2	.48	.02	3	2800	810	24	
F	AAF1	Clca	.13	.04	2	.42	.02	3	820	560	41	
F	AAF2	Clcab	.18	.01	3	.15	.01	3	1000	710	42	
E	SE2	2B21t	.11	-	1	.023	.01	2	5800	2500	30	
E	SE3	2B22tca	.13	.01	3	.055	.002	3	1900	1100	37	
E	AAE	2Clca	.19	.01	3	.10	.01	2	1100	880	44	
C	AAC1	B21tca	.13	-	1	.11*	-	1	2200	320	13	
C	AAC2	B22tca	ND	-	-	ND	-	-	370	220	37	
C	AAC3	Clca	.20	.05	4	ND	-	-	870	710	45	
C	AAC4	C2ca	ND	-	-	ND	-	-	250	250	50	
A	C82-8A	B21t	.25	.01	2	.051*	.002	2	1200	260	18	
A	-8B	B22t	ND	-	-	.74	.02	3	540	ND	-	
A	-8C	Clca	.61	.04	2	.35	.02	2	1200	290	19	
C81-45 (equivalent to soil I, above)												
-	AA1	K1	.058	-	1	-	-	-	-	3150	-	
-	AA2	2K21m	.039	-	1	.037	.007	2	37500	6800	15	
-	AA3	2K22m	.037	-	1	.03	.02	1	1900	1500	44	

Table C.--Thermoluminescence analyses of Fisher Valley sediments

Sample	Equivalent Dose (Gy)	$\Delta(a)$	K_2O (weight percent)	alpha count rate		a-value(b)	Calculated dose rate(c) (Gy/ka)	Known Age (ka)
				$\lambda_U + \lambda_{Th}$ ($ks^{-1} cm^{-2}$)	λ_{Th} ($ks^{-1} cm^{-2}$)			
Qa	200 \pm 40	0.06	2.28	0.46 \pm .01	0.14 \pm .02	0.09 \pm .02	3.7	<0.2
SI	230 \pm 70	0.04	2.44	0.69 \pm .02	0.31 \pm .06	0.11 \pm .02	5.0	-
LC	750 \pm 350	0.09	3.01	0.80 \pm .02	0.37 \pm .07	0.07 \pm .02	4.9	610

(a) Δ = Weight of water/weight of dry sample.

(b) Relative alpha/gamma TL sensitivity as defined by Aitken and Bowman (1975).

(c) Includes a cosmic contribution of 0.20 Gy/ka for A and C.

Table D.--Radiocarbon dates for Fisher Valley deposits

Laboratory number	Field number	Unit	Material	Weight of carbon (g)	Age (years before 1950)	Analytical error (years)
DIC-2525	C81-38A	Qa	charcoal	0.28	20	190
DIC-2536	C81-38B	Qa	charcoal	0.42	120	165
DIC-2537A	C82-06A	Qa	wood	0.79	0	85
DIC-2537B	C82-06A	Qa	charcoal	1.80	80	65
DIC-2538	C82-06B	Qa	charcoal	0.20	0	185
DIC-2526	C81-44A	Qas	peaty silt	1.36	8360	110
DIC-2527	C81-44B	Qas	peaty silt	1.18	9330	155