LUMINESCENCE DATING OF CERAMICS FROM THE SINOP REGIONAL ARCHAEOLOGICAL PROJECT (SRAP), SINOP, TURKEY

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50 ceramic sherds from the Sinop promontory, northern Turkey, were luminescence dated as part of the Sinop Regional Archaeological Project. These luminescence dates provide an absolute chronology with which to anchor the stylistic typologies in development by Bauer and Gantos (in progress). Dates presented here allow for regional comparison of ceramic typologies and may provide insight into patterns of trade and exchange. Those sherds with low precision ages and/or discrepancies in luminescence characteristics will undergo additional analyses, as described below.

Methods I: Procedures for Thermoluminescence Analysis of Pottery

Sample preparation -- fine grain

The sherd is broken to expose a fresh profile. Material is drilled from the center of the cross-section, more than 2 mm from either surface, using a tungsten carbide drill tip. The material retrieved is ground gently by a corundum mortar and pestle, treated with HCl, and then settled in acetone for 2 and 20 minutes to separate the 1-8 µm fraction. This is settled onto a maximum of 72 stainless steel discs.

Glow-outs

Thermoluminescence is measured by a Daybreak reader using a 9635Q photomultiplier with a Corning 7-59 blue filter, in N_2 atmosphere at 1°C/s to 450°C. A preheat of 240°C with no hold time precedes each measurement. Artificial irradiation is given with a ^{241}Am alpha source and a ^{90}Sr beta source, the latter calibrated against a ^{137}Cs gamma source. Discs are stored at room temperature for at least one week after irradiation before glow out. Data are processed by Daybreak TLApplic software.

Fading test

Several discs are used to test for anomalous fading. The natural luminescence is first measured by heating to 450°C. The discs are then given an equal alpha irradiation and stored at room temperature for varied times: 10 min, 2 hours, 1 day, 1 week and 8 weeks. The irradiations are staggered in time so that all of the second glows are performed on the same day. The second glows are normalized by the natural signal and then compared to determine any loss of signal with time (on a log scale). If the sample shows fading and the signal versus time values can be reasonably fit to a logarithmic function, an attempt is made to correct the age following procedures recommended by Huntley and Lamothe (2001).

Equivalent dose

The equivalent dose is determined by a combination additive dose and regeneration (Aitken 1985). Additive dose involves administering incremental doses to natural material. A growth curve plotting dose against luminescence can be extrapolated to the dose axis to estimate an equivalent dose, but for pottery this estimate is usually inaccurate because of errors in extrapolation due to nonlinearity. Regeneration involves zeroing natural material by heating to 450°C and then rebuilding a growth curve with incremental doses. The problem here is sensitivity change caused by the heating. By constructing both curves, the regeneration curve can be used to define the extrapolated area and can be corrected for sensitivity change by comparing it with the additive dose curve. This works where the shapes of the curves differ only in scale (i.e., the sensitivity change is independent of dose). The curves are combined using the "Australian slide" method in a program developed by David Huntley of Simon Fraser University (Prescott et al. 1993). The equivalent dose is taken as the horizontal distance between the two curves after a scale adjustment for sensitivity change. Where the growth curves are not linear, they are fit to quadratic functions. Dose increments (usually five) are determined so that the maximum additive dose results in a signal about three times that of the natural and the maximum regeneration dose about five times the natural. If the regeneration curve has a significant negative intercept, which is not expected given current understanding, the additive dose intercept is taken as the best, if not fully reliable approximation.

A plateau region is determined by calculating the equivalent dose at temperature increments between 240° and 450°C and determining over which temperature range the values do not differ significantly. This plateau region is compared with a similar one constructed for the b-value (alpha efficiency), and the overlap defines the integrated range for final analysis.

Alpha effectiveness

Alpha efficiency is determined by comparing additive dose curves using alpha and beta irradiations. The slide program is also used in this regard, taking the scale factor (which is the ratio of the two slopes) as the b-value (Aitken 1985).

Radioactivity

Radioactivity is measured by alpha counting in conjunction with atomic emission for ^{40}K. Samples for alpha counting are crushed in a mill to flour consistency, packed into plexiglass containers with ZnS:Ag screens, and sealed for one month before counting. The pairs-technique is used to separate the U and Th decay series. For atomic emission measurements, samples are dissolved in HF and other acids and analyzed by a Jenway flame photometer. K concentrations for each sample are determined by bracketing between standards of known concentration. Conversion to ^{40}K is by natural atomic abundance. Radioactivity is also measured, as a check, by beta counting, using a Risø low level beta GM multicounter system. About 0.5 g of crushed sample is placed on each of four plastic sample holders. All are counted for 24 hours. The average is converted to dose rate following Bøtter-Jensen and Mejdahl (1988) and compared with the beta dose rate calculated from the alpha counting and flame photometer results.

Both the sherd and an associated soil sample are measured for radioactivity. Additional soil samples are analyzed where the environment is complex, and gamma contributions determined by gradients (after Aitken 1985: appendix H). Cosmic radiation is determined after Prescott and Hutton (1988). Radioactivity concentrations are translated into dose rates following Adamiec and Aitken (1998).

Moisture Contents

Water absorption values for the sherds are determined by comparing the saturated and dried weights. For temperate climates, moisture in the pottery is taken to be 80 ± 20 percent of total absorption, unless otherwise indicated by the archaeologist. Again for temperate climates, soil moisture contents are taken from typical moisture retention quantities for different textured soils (Brady 1974: 196), unless otherwise measured. For drier climates, moisture values are determined in consultation with the archaeologist.

<u>Methods II: Procedures for Optically Stimulated or Infrared Stimulated Luminescence of Fine-grained pottery.</u>

Optically stimulated luminescence (OSL) and infrared stimulated luminescence (IRSL) on fine-grain (1-8µm) pottery samples are carried out on single aliquots following procedures adapted from Banerjee et al. (2001) and Roberts and Wintle (2001). Equivalent dose is determined by the single-aliquot regenerative dose (SAR) method (Murray and Wintle 2000).

The SAR method measures the natural signal and the signal from a series of regeneration doses on a single aliquot. The method uses a small test dose to monitor and correct for sensitivity changes brought about by preheating, irradiation or light stimulation. SAR consists of the following steps: 1) preheat, 2) measurement of natural signal (OSL or IRSL), L(1), 3) test dose, 4) cut heat, 5) measurement of test dose signal, T(1), 6) regeneration dose, 7) preheat, 8) measurement of signal from regeneration, L(2), 9) test dose, 10) cut heat, 11) measurement of test dose signal, T(2), 12) repeat of steps 6 through 11 for various regeneration doses. A growth curve is constructed from the L(i)/T(i) ratios and the equivalent dose is found by interpolation of L(1)/T(1). Usually a zero regeneration dose and a repeated regeneration dose are employed to insure the procedure is working properly. For fine-grained ceramics, a preheat of 240°C for 10s, a test dose of 3.1 Gy, and a cut heat of 200°C are currently being used, although these parameters may be modified from sample to sample.

The luminescence, L(i) and T(i), is measured on a Risø TL-DA-15 automated reader by a succession of two stimulations: first 100 s at 60°C of IRSL (880nm diodes), and then 100s at 125°C of OSL (470nm diodes). Detection is through 7.5mm of Hoya U340 (ultra-violet) filters. The two stimulations are used to construct IRSL and OSL growth curves, so that two estimations of equivalent dose are available. Anomalous fading usually involves feldspars and only feldspars are sensitive to IRSL stimulation. The rationale for the IRSL stimulation is to remove most of the feldspar signal, so that the subsequent OSL signal is free from anomalous fading. However, feldspar is also sensitive to blue light (470nm), and it is possible that IRSL does not remove all the feldspar signal. Some preliminary tests in our laboratory have suggested that the OSL signal does not suffer from fading, but this may be sample specific. The procedure is still undergoing study.

Alpha efficiency will surely differ among IRSL, OSL and TL on fine-grained materials. It does differ between coarse-grained feldspar and quartz (Aitken 1985). Research is currently underway in the laboratory to determine how much b-value varies according to stimulation method. Results from several samples from different geographic locations show that OSL b-value is less variable and centers around 1.0. IRSL b-value is more variable and is higher than that for OSL. TL b-value tends to fall between the OSL and IRSL values. We currently are measuring the b-value for IRSL and OSL by adding two alpha regeneration points to the SAR sequence. The slopes of the beta regeneration growth curve and that of the alphas are compared to determine b-value. This procedure is also undergoing study.

Results

Fifty ceramic sherds were analyzed for luminescence dating from the Sinop Regional Archaeological Project. The sherds, from surface surveys of the Sinop Promontory, had typological estimates of age ranging from the Neolithic to the Hellenistic periods. The samples and their provenience (including an estimate of age based on stylistic typology) are given in Table 1.

Table 1: Sample Provenience

UW lab number	Specimen number	Site/Locus	Typological Age	Burial depth (m)
UW1126	L03.07.1	Abdaloğlu	3rd Mill.BC or 4th c BC	0
UW1127	L03.07.2	Abdaloğlu	3rd Mill.BC or 4th c BC	0
UW1549	Sin06-1-1	Abdaloğlu	3rd Mill.BC or 4th c BC	0
UW1572	Sin06-2-3	Abdaloğlu	3rd Mill.BC or 4th c BC	0
UW1573	Sin06-2-4	Abdaloğlu	3rd Mill.BC or 4th c BC	0
UW1603		Güllüavlu	MB 2100-1700 BC	0
UW1604		Güllüavlu	4th Mill BC	0
UW1130	L03.09.1	Karapınar	Late Chalcolithic/EBA	0
UW1574		Karapınar	Late Chalcolithic/EBA	0
UW1120	T03.01.1	Kayanın Başı	EBA, 3rd Mill. BC	0
UW1121	T03.01.2	Kayanın Başı	EBA, 3rd Mill. BC	0
UW1122	T03.92.1	Kayanın Başı	EBA, 3rd Mill. BC	0
UW1123	T03.02.2	Kayanın Başı	EBA, 3rd Mill. BC	0
UW1124	T03.02.3	Kayanın Başı	EBA, 3rd Mill. BC	0
UW1125	T03.02.4	Kayanın Başı	EBA, 3rd Mill. BC	0
UW1486	L03.04.1	Kayanın Başı	EBA, 3rd Mill. BC	0
UW1487	L03.04.2	Kayanın Başı	EBA, 3rd Mill. BC	0
UW1488	L03.04.3	Kayanın Başı	EBA, 3rd Mill. BC	0
UW1128	L03.08.1	Kocagöz	EBA 2800-2200BC	0
UW1129	L03.08.2	Kocagöz	EBA 2800-2200BC	0
UW1483	L03.08.1	Kocagöz	EBA 2800-2200BC	0
UW1484	L03.08.2	Kocagöz	EBA 2800-2200BC	0

UW lab number	Specimen number	Site/Locus	Typological Age	Burial depth (m)
UW1485	L03.08.3	Kocagöz	EBA 2800-2200BC	0
UW1489	T03.07	Kocagöz	EBA 2800-2200BC	0
UW1490	T03.14	Kocagöz	EBA 2800-2200BC	0
UW1491	L03.08x	Kocagöz	EBA 2800-2200BC	0
UW1131	L03.11.1	Köşk Höyük	LBA/Iron 1600-700 BC	0
UW1132	L03.11.2	Köşk Höyük	LBA/Iron 1600-700 BC	0
UW1517	96.74.78	Köşk Höyük	LBA/Iron 1600-700 BC	0
UW1516	L98.29.13	Maltepe Hacıoğlu	Late Chalc., 4^{th} Mill. BC	0
UW1568	Sin06-1-2	Maltepe Hacıoğlu	Late Chalc., 4^{th} Mill. BC	0
UW1569	Sin06-1-4	Maltepe Hacıoğlu	Late Chalc., 4^{th} Mill. BC	0
UW1570	Sin06-2-2	Maltepe Hacıoğlu	Late Chalc., 4^{th} Mill. BC	0
UW1571	Sin06-2-3	Maltepe Hacıoğlu	Late Chalc., 4^{th} Mill. BC	0
UW1552	Sin06 1-1	Maltepe Tepealtı	Early 1^{st} Mill. BC	0
UW1575	Sin06-1-2	Maltepe Tepealtı	Early 1^{st} Mill. BC	0
UW1542	Sin06-1-1	Mezarlıktepe	5^{th} Mill. BC	0
UW1544	Sin06-3-1	Mezarlıktepe	5^{th} Mill. BC	0
UW1545	Sin06-4-1	Mezarlıktepe	5^{th} Mill. BC	0
UW1546	Sin06-5-1	Mezarlıktepe	5^{th} Mill. BC	0
UW1563*	Sin06-2-3	Mezarlıktepe	5^{th} Mill. BC	0
UW1564	Sin06-4-2	Mezarlıktepe	5^{th} Mill. BC	0
UW1566	Sin06-5-2	Mezarlıktepe	5^{th} Mill. BC	0
UW1567	Sin06-5-3	Mezarlıktepe	5^{th} Mill. BC	0
UW1590	Sin06-1-5	Mezarlıktepe	5^{th} Mill. BC	0
UW1557	Sin06-1-1	Nohutluk	Early 1^{st} Mill. BC	0
UW1559	Sin06-3-1	Nohutluk	Early 1^{st} Mill. BC	0
UW1581	Sin06-2-2	Nohutluk	Early 1^{st} Mill. BC	0
UW1555	Sin06-4-1	Tıngır Tepe	7^{th}-4^{th} cen. BC	150
UW1576	Sin06-1-2	Tıngır Tepe	7^{th}-4^{th} cen. BC	150
UW1579	Sin06-2-3	Tıngır Tepe	7^{th}-4^{th} cen. BC	150

Radioactivity was measured on both the sherds and the sediments associated with each sherd (Table 2). The associated sediment radioactivity of some sherds is represented by an average value from the locus, as indicated. Table 2 also gives the beta dose rate calculated in two ways, one by direct beta counting and one by derivation from the alpha counting, assuming secular equilibrium, and also taking into account the K content from flame photometry. These are in statistical agreement for most samples; those samples not in agreement (UW1122, UW1488, UW1490, UW1516, UW1567, UW1568, UW1570, UW1572, UW1575, UW1579, and UW1603) are likely the result of disequilibrium conditions. The direct beta counts were used to determine the beta dose rate for those samples, while the sample in agreement used the more precise alpha counting/flame photometry. Moisture contents, reflecting the arid environment, were assumed to be 70 ± 30 % of saturated value for the ceramics and 20 ± 6% for the sediments.

Table 2: Radioactivity

Sample	^{232}Th (ppm)	^{238}U (ppm)	K (%)	Beta dose rate (Gy/ka)	
				ß-counting	α-counting/ flame photometry
UW1120	5.990±0.897	2.320±0.164	1.309±0.063	1.630±0.120	1.550±0.061
Sed	4.540±0.825	0.700±0.090	0.578±0.026		
UW1121	8.770±1.118	2.900±0.207	1.355±1.025	1.750±0.120	1.750±0.050
Sed	4.540±0.825	0.700±0.090	0.578±0.026		
UW1122	5.760±0.862	1.250±0.115	1.173±0.037	1.410±0.110	1.280±0.042
Sed	4.540±0.825	0.700±0.090	0.578±0.026		
UW1123	18.500±1.872	2.170±0.245	2.110±0.040	2.410±0.200	2.510±0.070
Sed	4.540±0.825	0.700±0.090	0.578±0.026		
UW1124	9.540±1.170	1.990±0.181	0.726±0.016	1.120±0.090	1.160±0.060
Sed	4.540±0.825	0.700±0.090	0.578±0.026		
UW1125	7.290±1.111	2.830±0.199	1.626±0.023	1.850±0.160	1.920±0.050
Sed	4.540±0.825	0.700±0.090	0.578±0.026		
UW1126	8.630±1.167	0.860±0.135	0.940±0.009	1.060±0.230	1.120±0.040
Sed	7.440±1.002	1.090±0.122	1.050±0.024		
UW1127	36.060±2.697	2.640±0.376	2.813±0.075	3.420±0.270	3.630±0.110
Sed	7.440±1.002	1.090±0.122	1.050±0.024		
UW1128	5.870±1.000	2.870±0.190	1.457±0.031	1.698±0.110	1.748±0.046
Sed	6.880±1.080	2.360±0.190	1.254±0.058		
UW1129	49.590±3.670	4.190±0.530	2.741±0.048	4.010±0.240	4.165±0.132
Sed	6.880±1.080	2.360±0.190	1.254±0.058		
UW1130	18.780±1.870	1.600±0.220	1.034±0.036	1.442±0.110	1.576±0.067
Sed	6.880±1.080	2.360±0.190	1.254±0.058		
UW1131	8.590±1.200	2.590±0.200	1.604±0.014	1.734±0.125	1.900±0.045
Sed	4.550±0.776	1.640±0.124	1.326±0.016		
UW1132	8.480±1.170	1.450±0.140	1.229±0.014	1.390±0.090	1.429±0.040
Sed	4.550±0.776	1.640±0.124	1.326±0.016		
UW1483	6.470±1.050	2.780±0.193	1.357±0.014	1.642±0.122	1.671±0.041
Sed	8.890±1.120	1.940±0.177	1.195±0.040		
UW1484	7.670±1.040	2.410±0.179	1.620±0.025	1.839±0.118	0.691±0.043
Sed	8.890±1.120	1.940±0.177	1.195±0.040		
UW1485	5.090±0.869	2.780±0.181	1.361±0.014	1.626±0.114	1.637±0.037
Sed	8.890±1.120	1.940±0.177	1.195±0.040		
UW1486	8.640±1.110	2.060±0.169	1.533±0.042	1.969±0.170	1.969±0.180
Sed	5.450±0.921	0.940±0.111	0.770±0.043		
UW1487	4.060±0.741	1.950±0.135	1.671±0.061	1.904±0.177	1.736±0.057
Sed	5.450±0.921	0.940±0.111	0.770±0.043		
UW1488	4.960±0.864	1.820±0.138	1.481±0.010	1.860±0.157	1.590±0.032
Sed	5.450±0.921	0.940±0.111	0.770±0.043		
UW1489	10.740±1.330	1.010±0.148	1.140±0.022	1.389±0.138	1.355±0.046
Sed	5.450±0.921	0.940±0.111	0.770±0.043		
UW1490	6.910±1.050	1.310±0.130	1.197±0.009	1.554±0.138	1.340±0.035
Sed	8.200±1.160	1.500±0.150	0.950±0.019		
UW1491	11.080±1.050	2.400±0.202	0.797±0.006	1.284±0.111	1.292±0.041
Sed	8.890±1.120	1.940±0.177	1.195±0.040		
UW1516	4.400±0.796	2.310±0.155	0.945±0.026	1.389±0.123	1.216±0.038
Sed*	8.145±1.069	1.398±0.146	1.108±0.028		
UW1517	4.160±0.807	1.865±0.136	1.429±0.028	1.619±0.139	1.539±0.140

Sample	^{232}Th (ppm)	^{238}U (ppm)	K (%)	Beta dose rate (Gy/ka)	
				ß-counting	α-counting/ flame photometry
Sed*	8.145±1.069	1.398±0.146	1.108±0.028		
UW1542	8.580±1.090	2.250±0.177	1.178±0.049	1.586±0.290	1.508±0.056
Sed*	9.162±0.869	1.470±0.110	1.397±0.011		
UW1544	8.110±1.200	3.080±0.220	1.436±0.032	1.844±0.160	1.823±0.053
Sed	9.162±0.869	1.470±0.110	1.397±0.011		
UW1545	4.720±0.910	3.050±0.190	1.780±0.017	2.020±0.187	2.002±0.040
Sed	8.300±1.175	1.780±0.169	1.390±0.013		
UW1546	8.660±1.230	2.820±0.208	1.240±0.013	1.685±0.151	1.643±0.046
Sed	10.200±1.290	1.220±0.150	1.410±0.018		
UW1549	7.920±0.697	1.490±0.134	1.597±0.018	1.765±0.158	1.715±0.031
Sed	7.250±1.060	0.720±0.400	0.968±0.018		
UW1552	9.380±1.190	2.950±0.214	1.640±0.012	2.123±0.190	2.002±0.046
Sed	11.450±1.148	2.070±0.201	1.666±0.065		
UW1555	5.580±0.950	1.690±0.140	1.579±0.007	1.744±0.120	1.666±0.033
Sed	10.200±1.290	1.220±0.150	0.918±0.043		
UW1557	7.610±1.150	3.090±0.210	1.572±0.042	2.017±0.181	1.920±0.055
Sed*	9.840±1.296	2.040±0.182	1.303±0.041		
UW1559	8.420±1.230	3.570±0.240	1.111±0.026	1.627±0.150	1.642±0.053
Sed	9.840±1.296	2.040±0.182	1.303±0.041		
UW1563	4.800±0.924	3.360±0.290	0.998±0.024	1.393±0.220	1.422±0.044
Sed	9.162±0.869	1.470±0.110	1.397±0.011		
UW1564	11.600±1.430	2.500±0.214	0.897±0.011	1.397±0.130	1.401±0.051
Sed	8.300±1.175	1.780±0.169	1.390±0.013		
UW1566	4.420±0.791	2.460±0.161	1.417±0.021	1.797±0.150	1.617±0.036
Sed	10.200±1.290	1.220±0.150	1.410±0.018		
UW1567	4.270±0.740	2.050±0.140	1.242±0.026	1.627±0.135	1.412±0.036
Sed	10.200±1.290	1.220±0.150	1.410±0.018		
UW1568	6.330±0.909	3.850±0.233	0.633±0.015	1.085±0.084	1.243±0.044
Sed	10.240±1.273	1.220±0.154	1.024±0.025		
UW1569	5.360±0.850	2.040±0.150	1.695±0.044	1.893±0.180	1.804±0.048
Sed	10.240±1.273	1.220±0.154	1.024±0.025		
UW1570	2.840±0.630	2.210±0.140	0.794±0.011	1.223±0.092	1.037±0.028
Sed	14.350±1.579	1.230±0.181	1.292±0.022		
UW1571	8.130±1.100	2.600±0.191	1.450±0.025	1.834±0.170	1.765±0.046
Sed	14.350±1.579	1.230±0.181	1.292±0.022		
UW1572	17.160±1.852	2.909±0.027	2.909±0.026	3.782±0.315	3.227±0.055
Sed	8.490±1.090	0.960±0.120	1.046±0.025		
UW1573	6.110±1.020	2.740±0.190	1.076±0.007	1.481±0.157	1.430±0.040
Sed	8.490±1.090	0.960±0.120	1.046±0.025		
UW1574	8.690±1.290	4.460±0.280	1.427±0.018	2.115±0.190	2.033±0.056
Sed	8.320±0.510	2.060±0.168	1.131±0.014		
UW1575	6.100±0.990	1.840±0.150	1.972±0.059	2.319±0.205	2.017±0.059
Sed	11.450±1.418	2.070±0.201	1.666±0.065		
UW1576	4.330±0.844	2.560±0.169	1.631±0.064	2.020±0.183	1.800±0.060
Sed*	8.530±1.142	1.880±0.173	1.306±0.044		
UW1579	4.080±0.732	1.850±0.131	1.608±0.013	2.024±0.160	1.672±0.030
Sed	5.610±0.865	1.690±0.145	0.945±0.022		
UW1581	7.420±1.020	2.610±0.185	1.341±0.062	1.770±0.169	1.660±0.063
Sed	12.990±1.500	1.100±0.175	1.182±0.015		

Sample	^{232}Th (ppm)	^{238}U (ppm)	K (%)	Beta dose rate (Gy/ka)	
				ß-counting	α-counting/ flame photometry
UW1590	7.750±1.140	2.150±0.173	2.241±0.067	2.491±0.204	2.323±0.067
Sed	9.162±0.869	1.470±0.110	1.397±0.011		
UW1603	7.080±1.130	3.250±0.270	1.124±0.007	1.393±0.120	1.570±0.050
Sed*	8.153±1.071	1.410±0.150	1.110±0.030		
UW1604	10.480±1.330	2.420±0.200	0.991±0.014	1.393±0.130	1.435±0.048
Sed*	8.153±1.071	1.410±0.150	1.110±0.030		

*Averaged values from nearby samples.

Equivalent dose was determined by thermoluminescence (TL), optically stimulated luminescence (OSL), and infrared stimulated luminescence (IRSL), as explained above. To account for lower alpha efficiency, a b-value was also determined for all three, being much lower for OSL than for the others, as is commonly the case. The TL yielded good data in terms of having broad plateaus and low scatter in the growth curves. A test for anomalous fading was conducted for TL on all sherds with sufficient material. The majority of the measured sherds showed evidence of fading, although some sherds did not have significant fading. The OSL signal, which is not affected much by fading, therefore provides a better age. The IRSL may also fade (though this was not measured); and is considered an underestimation of the age when appropriate. Table 3 gives the equivalent dose and b-value for each sherd, while Table 4 shows some additional TL parameters, including plateau and fading values.

Table 3: Equivalent Dose and b-Value

Sample	# OSL/IRSL Aliquots	Equivalent dose (Gy)			b-value (Gy μm^2)		
		TL	IRSL	OSL	TL	IRSL	OSL
UW1120	7	3.361±0.233	4.415±1.165	4.930±0.433	1.001±0.182		
UW1121	5	5.762±1.000	13.493±1.306	11.723±0.355	1.019±0.156	1.973±0.358	0.671±0.034
UW1122	8	24.306±2.085	18.455±1.027	18.316±0.623	1.445±0.333		
UW1123	6	18.554±1.256	25.309±1.839	26.809±2.187	1.246±0.077	1.123±0.139	1.531±0.087
UW1124	4	12.905±2.893	21.645±3.666	19.942±1.661	2.193±0.273	1.275±0.306	0.761±0.038
UW1125	2	4.050±0.317	6.229±1.172	12.187±1.128	1.496±0.122	1.620±0.337	1.189±0.154
UW1126	4	12.865±0.939	No signal	11.656±0.593	1.754±0.119		0.651±0.045
UW1127	4	46.346±4.338	No signal	32.166±1.935	1.400±0.128		1.077±0.084
UW1128	6	23.393±1.015	14.089±1.059	15.308±0.668	2.012±0.147	1.978±0.295	1.593±0.093
UW1129	4	31.871±4.093	35.809±3.208	36.388±2.241	1.443±0.097	0.922±0.090	0.653±0.029
UW1130	4	21.389±1.378	14.979±1.035	18.145±2.038	2.630±0.191	2.114±0.216	2.388±0.288
UW1131	3	15.550±0.326	No signal	13.904±3.638	1.623±0.094		3.072±0.854
UW1132	6	11.272±0.634	No signal	11.171±0.537	1.257±0.089		0.883±0.062
UW1483	5	15.003±1.520	10.297±1.012	12.149±0.325	1.093±0.452	1.179±0.188	0.815±0.043
UW1484	2	20.540±4.340	14.348±1.515	26.000±1.420	0.516±0.316	1.707±0.273	1.144±0.105
UW1485	5	9.880±0.983	12.247±0.650	12.665±0.298	1.850±0.127	1.169±0.146	0.934±0.047
UW1486	4	12.759±0.807	5.653±1.116	10.933±1.926	1.388±0.186		
UW1487	4	7.420±1.060	4.833±0.307	3.696±0.125	1.906±0.121	2.881±0.386	2.428±0.167
UW1488	4	3.667±0.331	4.981±0.442	4.988±0.148	1.620±0.132	1.475±0.465	2.760±0.279
UW1489	6	2.934±0.262	5.611±0.446	7.186±0.207	1.164±0.091	1.784±0.344	3.233±0.240
UW1490	4	8.460±0.281	4.513±0.621	6.491±0.273	1.95±0.233	1.679±0.674	1.837±0.102

Sample	# OSL/IRSL Aliquots	Equivalent dose (Gy)			b-value (Gy µm^2)		
		TL	IRSL	OSL	TL	IRSL	OSL
UW1491	3	8.232±0.599	13.409±0.897	13.288±0.383	1.185±0.053	0.979±0.891	0.670±0.032
UW1516	3	17.700±1.12	16.586±1.102	17.609±0.539	2.333±0.733	0.970±0.902	2.131±0.114
UW1517	3	12.050±1.120	18.500±1.797	12.983±0.290	1.316±0.075	1.141±0.131	0.716±0.036
UW1542	6	11.871±0.514	12.316±0.913	13.285±0.565	1.600±0.096	1.136±0.230	1.611±0.104
UW1544	6	12.180±3.013	11.899±0.401	15.005±0.462	2.558±0.772	1.235±0.096	1.609±0.076
UW1545	5	7.689±0.299	13.296±1.769	10.042±0.497	1.670±0155	1.330±0.338	0.543±0.060
UW1546	5	14.420±0.750	11.927±0.544	13.237±0.289	2.388±0.269	1.889±0.151	2.977±0.145
UW1549	5	11.410±0.468	11.519±0.812	12.955±1.584	0.923±0.051		
UW1552	1	5.175±0.279	9.342±0.672	18.992±2.744	1.591±0.100	1.391±0.243	0.699±0.155
UW1555	4	8.704±0.820	11.54±0.755	12.328±0.417	1.972±0.194	1.448±0.187	2.443±0.135
UW1557	3	4.789±0.411	6.598±0.874	6.171±0.243	0.907±0.057	1.240±0.390	0.497±0.048
UW1559	5	19.451±0.650	14.831±0.951	18.452±0.707	1.661±0.169	1.119±0.163	2.883±0.347
UW1563	6	10.668±0.681	11.401±0.663	10.070±0.170	1.231±0.066	1.148±0.145	0.531±0.021
UW1564	7	10.0775±0.301	13.690±1.266	10.316±0.320	1.533±0.072	1.565±0.455	3.032±0.266
UW1566	5	11.6188±0.597	7.722±0.642	9.434±0.254	1.226±0.142	1.065±0.154	2.859±0.317
UW1567	4	16.965±0.845	10.481±0.452	11.727±0.318	1.941±0.272	1.584±0.147	2.127±0.113
UW1568	5	6.637±0.693	18.959±1.537	16.795±0.348	0.934±0.096	0.840±0.148	0.686±0.038
UW1569	5	20.529±0.437	18.684±1.992	15.383±0.649	1.047±0.063	0.987±0.254	1.162±0.110
UW1570	4	16.33±2.385	18.006±2.855	22.983±0.523	0.935±0.142	0.932±0.213	0.440±0.018
UW1571	6	14.299±0.479	15.369±0.981	14.841±0.482	0.677±0.063	1.285±0.203	1.478±0.113
UW1572	3	23.697±1.250	16.422±1.728	30.548±1.646	1.27±0.146	1.688±0.395	1.704±0.136
UW1573	3	4.078±0.501	3.739±1.257	4.191±0.473	2.228±0.262	2.164±1.187	2.735±0.277
UW1574	6	10.959±0.301	7.310±0.621	6.909±0.150	2.082±0.139	1.872±0.223	0.898±0.042
UW1575	6	5.484±0.511	14.112±1.879	No signal	1.160±0.100		
UW1576	5	13.723±1.025	10.590±0.500	13.143±0.441	1.781±0.227	1.514±0.219	1.497±0.102
UW1579	5	7.5945±0.717	8.785±0.771	9.594±0.983	0.720±0.066	2.642±0.798	0.834±0.082
UW1581	3	11.343±0.797	12.049±0.945	16.933±1.365	1.304±0.115	1.165±0.161	0.802±0.074
UW1590	5	11.693±0.600	11.718±1.359	6.278±0.526	0.435±0.043		
UW1603	3	14.492±1.367	11.404±0.601	10.045±0.273	1.249±0.010	0.857±0.080	0.555±0.024
UW1604	4	16.480±0.900	11.198±1.011	11.283±0.366	2.521±0.269	0.903±0.165	0.766±0.047

Table 4: Additional TL Parameters

Sample	Plateau (°C)	Fit to growth curves	1st glow/2nd glow ratio	Fading (g, tc =2)
UW1120	280-360	linear	1.000	Test failed poor data
UW1121	250-425	linear	4.000±0.551	12.548±1.611
UW1122	250-420	linear	1.000	3.393±1.053
UW1123	250-370	linear	1.540±0.075	No fading
UW1124	250-440	quadratic	2.740±0.339	1.621±10.878
UW1125	290-360	linear	No 2nd glow	18.300±6.393
UW1126	290-390	quadratic	1.000	4.888±0.284
UW1127	250-420	linear	1.950±0.183	5.813±1.706
UW1128	250-400	quadratic	1.000	2.074±1.130
UW1129	250-400	quadratic	1.450±0.109	No test conducted
UW1130	270-380	linear	1.290±0.073	2.703±1.362
UW1131	250-370	linear	1.000	3.455±1.371
UW1132	250-400	linear	1.320±0.084	12.273±2.372
UW1483	250-380	linear	1.000	14.975±2.383
UW1484	250-390	linear	1.000	0.887±3.701

Sample	Plateau (°C)	Fit to growth curves	1st glow/2nd glow ratio	Fading (g, tc =2)
UW1485	250-360	linear	2.330±0.136	29.910±6.181
UW1486	250-390	linear	0.558±0.075	No fading
UW1487	250-300	linear	1.320±0.095	19.728±17.422
UW1488	280-330	linear	No 2nd glow	5.254±3.370
UW1489	260-330	linear	1.000	No fading
UW1490	310-360	linear	1.000	12.892±17.480
UW1491	250-310	linear	1.000	No fading
UW1516	250-390	linear	1.000	10.314±3.428
UW1517	250-390	linear	1.890±0.123	No test conducted
UW1542	250-320	linear	1.000	8.577±1.749
UW1544	250-430	linear	No 2nd glow	12.541±0.281
UW1545	250-390	quadratic	1.000	8.346±2.525
UW1546	250-410	linear	1.000	5.053±1.465
UW1549	270-310	linear	1.000	0.845±3.786
UW1552	280-330	quadratic	1.000	9.317±3.781
UW1555	250-410	linear	2.233±0.202	13.011±1.637
UW1557	300-360	linear	0.852±0.051	11.594±4.347
UW1559	260-370	linear	1.000	3.913±2.120
UW1563	250-420	linear	1.620±0.106	4.657±1.857
UW1564	250-310	linear	1.000	12.504±1.593
UW1566	250-330	linear	1.000	No fading
UW1567	250-380	linear	1.000	8.972±1.437
UW1568	250-350	linear	3.160±0.367	17.257±2.917
UW1569	290-320	linear	1.000	10.801±1.513
UW1570	250-420	linear	1.800±0.272	9.442±3.294
UW1571	310-350	linear	1.000	5.411±1.678
UW1572	250-320	linear	2.742±0.501	3.766±3.632
UW1573	270-360	linear	0.195±0.023	No fading
UW1574	250-350	quadratic	1.000	10.751±1.720
UW1575	290-330	linear	0.707±0.060	6.504±3.841
UW1576	250-390	linear	1.000	4.845±1.107
UW1579	280-400	linear	0.572±0.052	0.814±1.564
UW1581	260-410	linear	1.000	5.418±2.578
UW1590	330-360	linear	0.740±0.039	10.892±1.666
UW1603	250-410	linear	1.250±0.101	No test conducted
UW1604	310-430	linear	1.000	No test conducted

*TL fading age not significantly different from uncorrected TL age or cannot be corrected

Derived ages are given in Tables 5a-5k. Under ideal circumstances, ages derived from TL, OSL, and IRSL for any given sample will be equivalent (within error terms) and thereby amenable to the use of weighted averaging. Weighting averaging produces an age wherein the statistical areas of overlap are most likely to be the 'true' age, reducing the error terms associated with the age value. Samples U1121, U1487, U1488, U1491, U1516, U1545, U1563, U1573, U1603, and U1604 represent a weighted average of TL, OSL, and IRSL, though no fading test was done for U1129, U1603 and U1604. For U1120, U1124, U1125, U1127, U1128, U1129, U1485, U1542, U1544, U1549, U1555, U1557, U1564, U1567, U1568, U1571, and U1575 the age is based only on OSL and/or IRSL. The TL for these samples is either spurious or fades demonstratively, and attempts to correct for the fading produce an age that is unreasonably old. For U1122, U1132, U1483, U1489, U1490, U1549, U1566, U1569, U1576, and U1579 the OSL age agrees with that from the uncorrected TL, suggesting fading for these samples is not significant. For U1126, U1130, U1131, U1546, U1559, U1572, and U1581 the age is based on a weighted average of OSL and the TL corrected for fading. The age for U1517 is also based on the weighted average of OSL and TL, but no fading test was done. Such agreement suggests that any fading in this sample is probably not significant either. For U1484, U1552, and U15770 the TL age agrees with the IRSL, without significant fading. Lastly, four samples have ages derived only from TL (U1123, U1486, U1574, and U1590) which are currently viewed as preliminary ages.

Convergence (*i.e*. agreement) between the luminescence and typological ages, when present, is an outcome of independent methods of analysis; no weighting (*i.e*. bias) of typological age was used in the derivation of luminescence age. Table 6 provides the justification for each derived age. The samples range in age from 9.3 to 1.2 ka.

Each sample is also assigned a qualitative grade based on a series of quantitative tests of the luminescence data for empirical sufficiency. Eight aspects of the luminescence data are evaluated: the inclusion in radioactivity analysis of an associated sediment, the relative sorting of b-values (high to low) from IRSL to TL to OSL, an error of less than 15% for the OSL equivalent dose, an error of less than 15% for the TL equivalent dose, a TL plateau of greater than 90 degrees Celsius, correction for TL fading (if possible), agreement between the OSL and TL ages, and equivalency of beta dose-rate calculations from alpha and beta measurement. Those samples that receive full marks, i.e., pass each of the eight standards, are given a grade of A, those that pass all but one (or two related measures) are given a B, etc. In this way, when discussing the age of a site based on several luminescence dates with varying grades, one can give greater credence to those ages that have qualitatively better luminescence data. Derived ages presented in Tables 5a-5k are sorted by grade.

Table 5a: Derived Ages for Abdaloğlu. Expected age (based on typology) during the 3rd millennium BC or the 4th century BC.

Sample	Basis for age	Age (ka)	% error	Calendar years	Agreement with Typology	Grade
UW1126	TL, OSL	6.366 ± 0.372	5.8	4360 ± 372 BC	Lum. Earlier	A
UW1573	TL, OSL, IRSL	1.164 ± 0.108	9.3	862 ± 108 AD	Lum. Later	A
UW1549*	TL, OSL	4.441 ± 0.247	5.6	2437 ± 247 BC	Statistical agreement	B
UW1572	TL, OSL, IRSL	5.142 ± 0.423	8.2	3136 ± 423 BC	Statistical agreement	B
UW1127	OSL	5.242 ± 0.394	7.5	3236 ± 394 BC	Statistical agreement	C
	**Date is preliminary; additional analyses in progress*			*b-values used in age calculation are statistical estimates*		

Table 5b: Derived Ages for Güllüavlu. Expected age (based on typology) during the Middle Bronze Age (2100-1700 BC) for U1603 and the 4th millennium BC for U1604.

Sample	Basis for age	Age (ka)	% error	Calendar years	Agreement with Typology	Grade
UW1603*	TL	4.574 ± 0.214	4.7	2568 ± 214 BC	Lum. Earlier	C
UW1604*	TL, OSL, IRSL	4.317 ± 0.214	5.0	2311± 214 BC	Lum. Later	C
	**Dates are preliminary; additional analyses in progress*			*Samples lack associated sediments for radioactivity measurement*		

Table 5c: Derived Ages for Karapınar. Expected age (based on typology) during the Late Chalcolithic to Early Bronze Age, 3rd to 4th millennium BC.

Sample	Basis for age	Age (ka)	% error	Calendar years	Agreement with Typology	Grade
UW1130*	TL, OSL	5.196 ± 0.538	10.4	3192 ± 538 BC	Statistical agreement	A
UW1574	TL	5.335 ± 1.249	23.4	3329 ± 1249 BC	Statistical agreement	C
	**Date is preliminary; additional analyses in progress*			*b-values used in age calculation are statistical estimates*		

Table 5d: Derived Ages for Kayanın Başı. Expected age (based on typology) during the Early Bronze age, 3rd millennium BC.

Sample	Basis for age	Age (ka)	% error	Calendar years	Agreement with Typology	Grade
UW1121	TL, OSL	4.394 ± 0.230	5.2	2388 ± 230 BC	Statistical agreement	B
UW1122*	TL, OSL	8.975 ± 0.670	7.4	6969 ± 670 BC	Lum. Earlier	B
UW1124	IRSL, OSL	9.306 ± 0.804	8.6	7300 ± 804 BC	Lum. Earlier	B
UW1487*	TL, OSL, IRSL	1.363 ± 0.082	6.0	643 ± 82 AD	Lum. Later	B
UW1488*	TL, OSL, IRSL	1.428 ± 0.087	6.1	576 ± 87 AD	Lum. Later	B
UW1120	TL, OSL, IRSL	2.039 ± 0.334	16.4	35 ± 334 BC	Lum. Later	C
UW1125	OSL	4.136 ± 0.456	11.0	2130 ± 456 BC	Statistical agreement	C
UW1486*	TL	2.504 ± 0.395	15.8	498 ± 395 BC	Lum. Later	C
UW1123*	TL	4.430 ± 0.349	7.9	2426 ± 349 BC	Statistical agreement	C
	**Dates are preliminary; additional analyses in progress*			*b-values used in age calculation are statistical estimates*		

Table 5e: Derived Ages for Kocagöz. Expected age (based on typology) during the Early Bronze Age, ca. 2800-2200 BC.

Sample	Basis for age	Age (ka)	% error	Calendar years	Agreement with Typology	Grade
UW1491	TL, OSL, IRSL	5.883 ± 0.266	4.5	3877 ± 266 BC	Lum. Earlier	A
UW1128	OSL, IRSL	4.374 ± 0.231	5.3	2368 ± 231 BC	Statistical agreement	B
UW1129	OSL, IRSL	5.371 ± 0.319	5.9	3365 ± 319 BC	Lum. Earlier	B
UW1483	TL, OSL	4.520 ± 0.228	5.0	2514 ± 228 BC	Statistical agreement	B
UW1485	IRSL, OSL	4.498 ± 0.186	4.1	2492 ± 186 BC	Statistical agreement	B
UW1489*	TL, OSL	2.797 ± 0.143	5.1	791 ± 143 BC	Lum. Later	B
UW1484	TL, IRSL	4.099 ± 0.378	9.2	2093 ± 378 BC	Statistical agreement	C
UW1490*	TL, OSL	3.102 ± 0.215	6.9	1096 ± 215 BC	Lum. Later	C
	**Dates are preliminary; additional analyses in progress*			*b-values used in age calculation are statistical estimates*		

Table 5f: Derived Ages for Köşk Höyük. Expected age (based on typology) during the Late Bronze Age to Early Iron Age, ca. 1600 – 700 BC.

Sample	Basis for age	Age (ka)	% error	Calendar years	Agreement with Typology	Grade
UW1132	TL, OSL	4.439 ± 0.210	4.7	2433 ± 210 BC	Lum. Earlier	B
UW1517	TL, OSL	5.903 ± 0.249	4.2	3897 ± 249 BC	Lum. Earlier	B
UW1131*	TL, OSL	5.107 ± 0.470	9.2	3101 ± 470 BC	Lum. Earlier	B

Sample	Basis for age	Age (ka)	% error	Calendar years	Agreement with Typology	Grade
	**Date is preliminary; additional analyses in progress*			*b-values used in age calculation are statistical estimates*		

Table 5g: Derived Ages for Maltepe Hacıoğlu. Expected age (based on typology) during the Late Chalcolithic, ca. 4th millennium BC.

Sample	Basis for age	Age (ka)	% error	Calendar years	Agreement with Typology	Grade
UW1516*	TL, OSL, IRSL	6.892 ± 0.561	8.1	4886 ± 561 BC	Lum. Earlier	B
UW1568	IRSL, OSL	7.379 ± 0.364	4.9	5373 ± 364 BC	Lum. Earlier	C
UW1569	TL, IRSL	7.181 ± 0.315	4.4	5175 ± 315 BC	Lum. Earlier	C
UW1570	TL, IRSL	7.319 ± 0.845	11.5	5313 ± 845 BC	Lum. Earlier	C
UW1571	IRSL, OSL	4.215 ± 0.191	4.5	2209 ± 191 BC	Lum. Later	C
	**Date is preliminary; additional analyses in progress*			*b-values used in age calculation are statistical estimates and sample lacks associated sediment for radioactivity measurement*		

Table 5h: Derived Ages for Maltepe Tepealtı. Expected age (based on typology) during the early 1st millennium BC.

Sample	Basis for age	Age (ka)	% error	Calendar years	Agreement with Typology	Grade
UW1552	TL, IRSL	2.656 ± 0.271	10.2	650 ± 271 BC	Statistical agreement	B
UW1575*	IRSL	3.351 ± 0.516	15.4	1345 ± 516 BC	Statistical agreement	C
	**Poor data*			*IRSL only, no OSL, poor TL data*		

Table 5i: Derived Ages for Mezarlıktepe. Expected age (based on typology) during the 5th millennium BC.

Sample	Basis for age	Age (ka)	% error	Calendar years	Agreement with Typology	Grade
UW1545	TL, OSL, IRSL	3.718 ± 0.237	6.4	1712 ± 237 BC	Lum. Later	A
UW1546*	TL, OSL	4.608 ± 0.462	10.0	2602 ± 462 BC	Lum. Later	A
UW1563	TL, OSL, IRSL	4.311 ± 0.159	3.7	2304 ± 159 BC	Lum. Later	A
UW1544	OSL	4.129 ± 0.226	5.5	2123 ± 226 BC	Lum Later	B
UW1566*	TL, OSL	4.088 ± 0.251	6.1	2081 ± 251 BC	Lum. Later	B
UW1542	OSL, IRSL	4.254 ± 0.237	5.6	2248 ± 237 BC	Lum Later	C
UW1564*	IRSL, OSL	3.997 ± 0.470	11.8	1990 ± 470 BC	Lum. Later	C
UW1567	OSL, IRSL	3.634 ± 0.180	5.0	1628 ± 180 BC	Lum. Later	C
UW1590**	TL	3.843 ± 0.270	7.0	1837 ± 270 BC	Lum. Later	D
	**Dates are preliminary; additional analyses in progress*			*b-values used in age calculation are statistical estimates*		
	***Poor data*			*Treat date as a minimum age*		

Table 5j: Derived Ages for Nohutluk. Expected age (based on typology) during the early 1st millennium BC.

Sample	Basis for age	Age (ka)	% error	Calendar years	Agreement with Typology	Grade
UW1559*	TL, OSL	6.169 ± 0.712	11.5	4163 ± 712 BC	Lum. Earlier	A
UW1581	OSL, TL	5.862 ± 0.500	8.5	3856 ± 500 BC	Lum. Earlier	A
UW1557	OSL, IRSL	2.194 ± 0.125	5.7	188 ± 125 BC	Statistical agreement	B
	**Date is preliminary; additional analyses in progress*			*b-values used in age calculation are statistical estimates*		

Table 5k: Derived Ages for Tıngır Tepe. Expected age (based on typology) during the 7th – 4th century BC.

Sample	Basis for age	Age (ka)	% error	Calendar years	Agreement with Typology	Grade
UW1576	TL, OSL	3.981 ± 0.182	4.6	1975 ± 182 BC	Lum. Earlier	B
UW1579	TL, OSL	3.061 ± 0.254	8.3	1055 ± 254 BC	Statistical agreement	B
UW1555	OSL, IRSL	3.504 ± 0.164	4.7	1498 ± 164 BC	Lum. Earlier	C

Discussion

Any discussion of the comparison of luminescence to typologically derived dates must begin with the acknowledgement that both methods represent an effort to learn the *true* age of an artifact. Luminescence dating offers a quantitative approach; typological methods are often more qualitative. In discussing the luminescence ages described in this paper, there are five alternatives for each site: the luminescence and typological ages are in full agreement, the luminescence ages are older than the expectation from typology, the luminescence ages are younger than the expectation from typology, the luminescence ages suggest a multi-component site, or the situation is ambiguous. In assessing each site, samples with the best grades are given substantially more weight in the final interpretation.

Those sites for which the luminescence and typological ages are in agreement include Karapınar and Maltepe Tepealtı. Those sites for which the luminescence ages are older than expected are Kocagöz, Köşk Höyük, Maltepe Hacıoğlu, Nohutluk, and Tıngır Tepe. The luminescence ages are younger than expected at Mezarlıktepe. Kayanın Başı has luminescence ages that suggest a multi-component occupational history, with nodes of occupation during the 8th millennium BC, the 5th millennium BC, and the 5th century AD. Interestingly, typologically the expectation was that Güllüavlu would be a multi-component site; the luminescence ages cluster very tightly in the 3rd millennium BC. Lastly, the Abdaloğlu luminescence ages appear ambiguous. While there is some tendency toward agreement with the typology, the agreement comes from the samples with the poorest grades. The sherds with the two best grades bracket the typological expectation by roughly 2000 years.

In sum, five sites present as older than expected, two sites agree with the typological expectation, and the remainder are either multi-component or require additional data. These results suggest that the use of luminescence dating – an absolute dating technique that provides accurate calendar dates – has significant utility in revising regional ceramic chronologies in areas with inadequately developed typological methods. As we continue to gather more data (from the continued compilation of data for samples listed in this paper and from the inclusion into the study of additional samples) greater resolution will result.

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For a general review of luminescence dating by the director of this laboratory, see:

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