

Chapter 14

URANIUM SERIES DATING OF ENAMEL, DENTINE, AND BONE FROM KABAZI II, STAROSELE, KABAZI V, AND GABO

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INTRODUCTION

One of the focal points of the joint Ukrainian/American project investigating the Middle Paleolithic of Western Crimea was to obtain as many absolute dates on Paleolithic sites in the region as possible. Beginning in 1992, a sequence of teeth from multiple Middle Paleolithic localities, including from the sites of Kabazi II, Kabazi V, GABO, and Starosele, was studied. Each year of the continuing project produced new documented samples from excavated squares. This paper is a review of the uranium series chronology of those localities.

The uranium series analysis of fossil teeth and bone began with Cherdyntsev (1956) who had attempted bone dating in the USSR, including at the site of Starosele, though the paper was not available in the West until later. In the West, Rosholt (1957) independently demonstrated that uranium series dating (USD) of bone was feasible. The dating of bone in general has been shown to produce minimum ages in most sites (Schwarcz and Blackwell 1992). The dating of teeth (enamel, dentine, and cementum) was not attempted systematically until the late 1970's with the work of McKinney (1977). Recently, the subject was re-examined by McKinney (1991), who demonstrated that tooth enamel was the best material in the skeleton for dating, using early uptake assumptions. Schwarcz and Blackwell (1992) have suggested that enamel may show greater variation in age quality beyond the range of radiocarbon dating, based on their assumptions of linear uptake used in electron spin resonance dating (ESR). The different and incompatible assumptions between USD and ESR were discussed by McKinney (1990), who argued that comparisons between radiocarbon and USD of tooth enamel had shown that early uptake of uranium was the primary mode, not continuous uptake (linear uptake), as assumed by ESR researchers.

The determination of uranium series ages is based on the decay of the long lived isotopes ^{238}U to ^{234}U to ^{230}Th with half-lives of 4.5×10^9 ; 250,000; and 75,200 years, respectively (fig. 14-1). For any absolute dating, closed-system conditions are necessary and must meet three conditions:

- (1) Uranium must be absorbed rapidly and then be sealed from further absorption or loss;
- (2) ^{230}Th must not be present and must accumulate only by production from the decay of ^{234}U ; and,
- (3) ^{230}Th is only lost via decay to daughter isotopes (Cherdyntsev 1956; Rosholt 1957; Ivanovich 1982).

In the environment, the soluble uranium becomes separated from insoluble thorium. Bone phosphate absorbs uranium readily from ground water after the death of the animal due to conditions generated by the organic decay process (McKinney 1977; Szabo 1980). Under these conditions, reduced uranium is absorbed into the phosphate; but on the completion of the organic loss, this absorption ceases. Tooth enamel has been shown to behave in a closed system manner in geochemically neutral spring environments (McKinney 1977, 1991), but

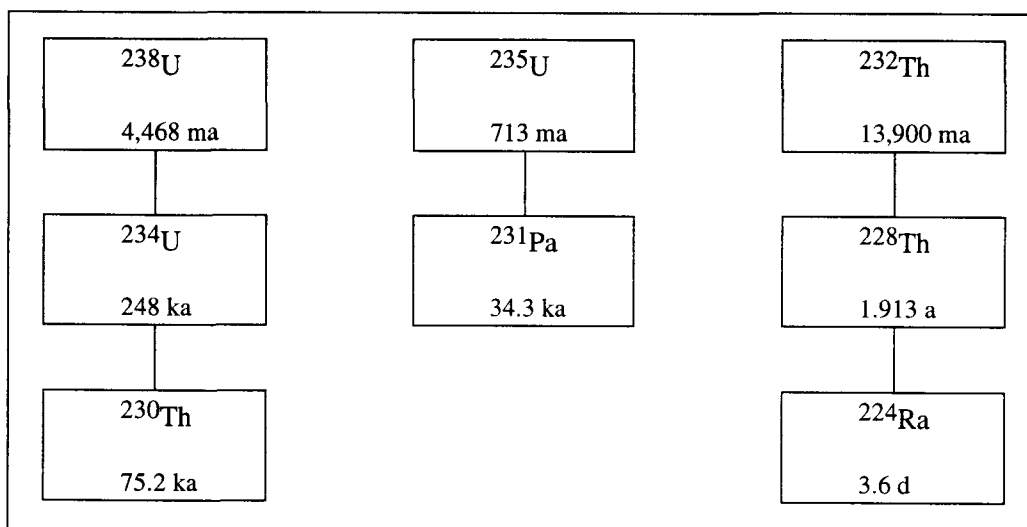


Fig. 14-1—Alpha emitting isotopes and their half-lives which are used in uranium-series dating (McKinney 1991).

produced inconsistent ages in active geochemically arid environments (McKinney 1992) and in interior cave environments (Bischoff and Rosenbauer 1981).

METHODS

The procedures for alpha spectrometry and associated chemical techniques are reviewed in Ivanovich and Harmon (1982, 1992). Briefly, the sample is cleaned of any dirt or preservative by hand. The enamel and dentine must be separated, since dentine contains 10 to 100 times the uranium content of enamel (McKinney 1977, 1991). The separation can be accomplished by hand, or a finely crushed sample may be separated using heavy liquids such as bromoform by density differences between enamel (sp. gr. 3.1) and dentine (sp. gr. 2.5). Density separation is most successful with dentine and enamel that have uranium contents of less than 10 : 1. The bromoform-soaked enamel is cleaned with acetone and dried. The dry enamel is weighed, then ashed at 800° Celsius for about eight hours. The fired sample is re-weighed to determine weight loss on ignition. The dissolution of the sample in 8 N nitric acid and 10% hydrogen peroxide occurs after it is combined with $^{232}\text{U}/^{228}\text{Th}$ or $^{236}\text{U}/^{229}\text{Th}$ spikes—whose concentrations are known so that yields can be calculated (the yield must be determined because uranium and thorium behave differently chemically and will have different proportions at the end of the procedure). The nitric acid and hydrogen peroxide oxidize any remaining organic residues, and, to ensure that uranium is in the +four state, the solution is heated and allowed to dry to equilibrate the various spikes with the sample.

By using a combination of ion exchange and co-precipitations, the uranium and thorium isotopes are separated and purified (Rosholt 1957). The dried mixture is dissolved in 8 N hydrochloric acid, and the uranium and thorium are separated by passing the solution through an anion exchange column (dowex 1, 100 to 200 mesh). The procedure is repeated for uranium, whereas the thorium is collected in solution with 8 N hydrochloric acid prepared for co-precipitation with zirconium pyrophosphate. The thorium solution is evaporated to about 15 to 25 mls and diluted to 200 mls with distilled water. After heating to boiling, 20 to 30 mgs of zirconium are added to co-precipitate the thorium with pyrophosphate created during the firing procedure. The precipitate, collected and washed in distilled water, is dissolved in oxalic acid. The oxalic solution is brought to a boil. The thorium is dissolved in 7.5 N nitric acid and passed through a second anion exchange column to remove the remaining non-

thorium elements. For some samples, an iron carrier is added to produce iron hydroxides, co-precipitating the thorium. This step is inserted to remove non-thorium elements not eliminated by the anion exchange step. The purified thorium is ready for plating by extracting from 0.1 N nitric acid into 2-thenoyltrifluoroactone (TTA) in benzene (1 ml). The drop of TTA is evaporated on a steel planchette. The uranium is processed using the same procedure after the second anion exchange step. The discs are placed in a vacuum and are counted by an alpha spectrometer. The spectra indicate the total number of alpha counts (400 to 20,000) for each isotope for an interval of time (five to 10 days). These data are reduced to activity ratios, and, from these ratios, the age, concentrations, and yield are calculated.

After the absorption of uranium, the isotopes begin to build toward equilibrium by building the missing daughters in the chain isotopes. By measuring the radioactivity of each isotope, each can be compared (equal activity indicates equilibrium, whereas unequal activity indicates the opposite). Comparisons are made by creating isotopic ratios of adjacent daughters in the chain. Uranium ratios ($^{234}\text{U}/^{238}\text{U}$) that are greater or lesser than one approach equilibrium with a half-life of 250,000 years. Thorium ratios ($^{230}\text{Th}/^{232}\text{Th}$) are used to determine the level contamination from pre-existing ^{230}Th in association with natural ^{232}Th in the sample (low ratio <50 contamination is significant, >50 is not significant). The presence of ^{232}Th indicates some contamination. Age ratios ($^{230}\text{Th}/^{234}\text{U}$) are assumed to start at zero and grow with a half life of 75,200 years to one. The age ratio ($^{230}\text{Th}/^{234}\text{U}$) is calculated using the spike concentration to eliminate distortions caused by differences in elemental yields during chemical procedures. Since uranium-series dating depends on multiple decaying and growing isotopes, ages are calculated using $^{234}\text{U}/^{238}\text{U}$ and $^{230}\text{Th}/^{234}\text{U}$ ratios (fig. 14-2) with the UTAGE3 computer program (Ivanovich and Harmon 1982). The isotopic error is added or subtracted to the isotopic ratio and an age is calculated. The difference provides the error range for the date (the plus error is always larger than the minus error).

RESULTS

The results for each site are presented in Tables 14-1 through 14-4. At Kabazi II and Starosele, a number of the major archeological units were dated, but dates at Kabazi V and GABO are from a single stratigraphic unit each (fig. 14-3). The sample codes represent the spiking number-sample number-material type (enamel=E, dentine=D) -series (1, 2, and 3). The last indicates multiple analysis. The results shown represent complete sets of uranium and thorium data. Samples that were incomplete by not having either a uranium or thorium spectrum, or having low yields (<5%), or low count rates (< one count per six hours), are not presented because of their very high uncertainties.

DISCUSSION

In this study, multiple analyses were conducted on different teeth from each archeological unit and level. The results produced surprises and unexpected problems. The problems were primarily with contamination from tiny amounts of dentine that remained on the enamel and persistent low isotope yields during chemical separations. The contamination can be graphically removed if ^{232}Th is present to provide a tracer; ^{232}Th indicates outside thorium has entered the system since ^{230}Th is always present with natural thorium. Any material that contains thorium that is incorporated into the sample can be graphically removed by plotting the $^{230}\text{Th}/^{232}\text{Th}$ and $^{234}\text{U}/^{232}\text{Th}$ activity ratios of each. Samples in related groups will produce linear associated samples, the slope of which indicates the corrected $^{230}\text{Th}/^{234}\text{U}$ age ratio. The corrected uranium ratio is produced by plotting the $^{234}\text{U}/^{232}\text{Th}$ and $^{238}\text{U}/^{232}\text{Th}$ and taking the slope of those points. Low levels of ^{232}Th contamination were found in many

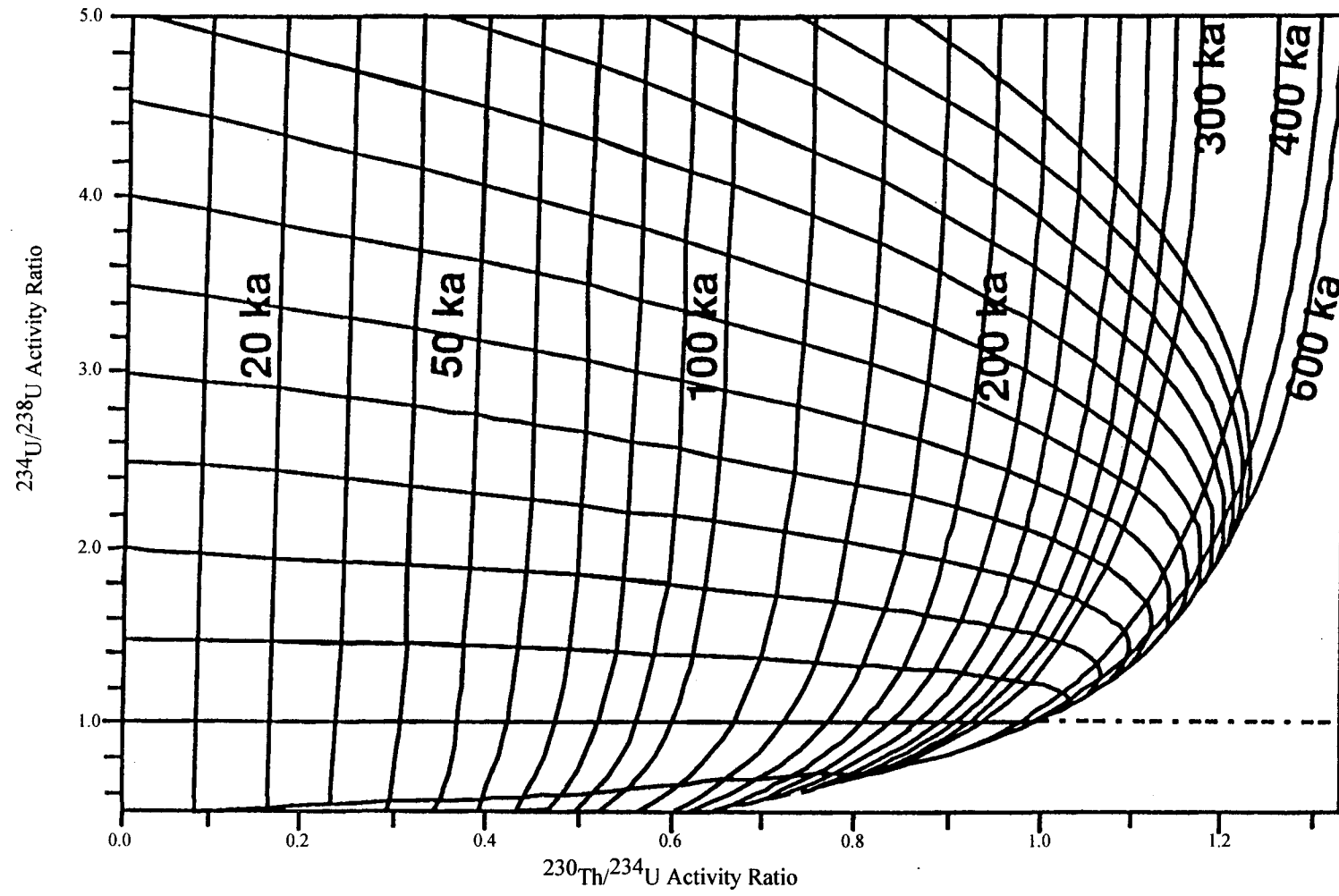


Fig. 14-2—Graph for determining uranium-series ages (McKinney 1991).

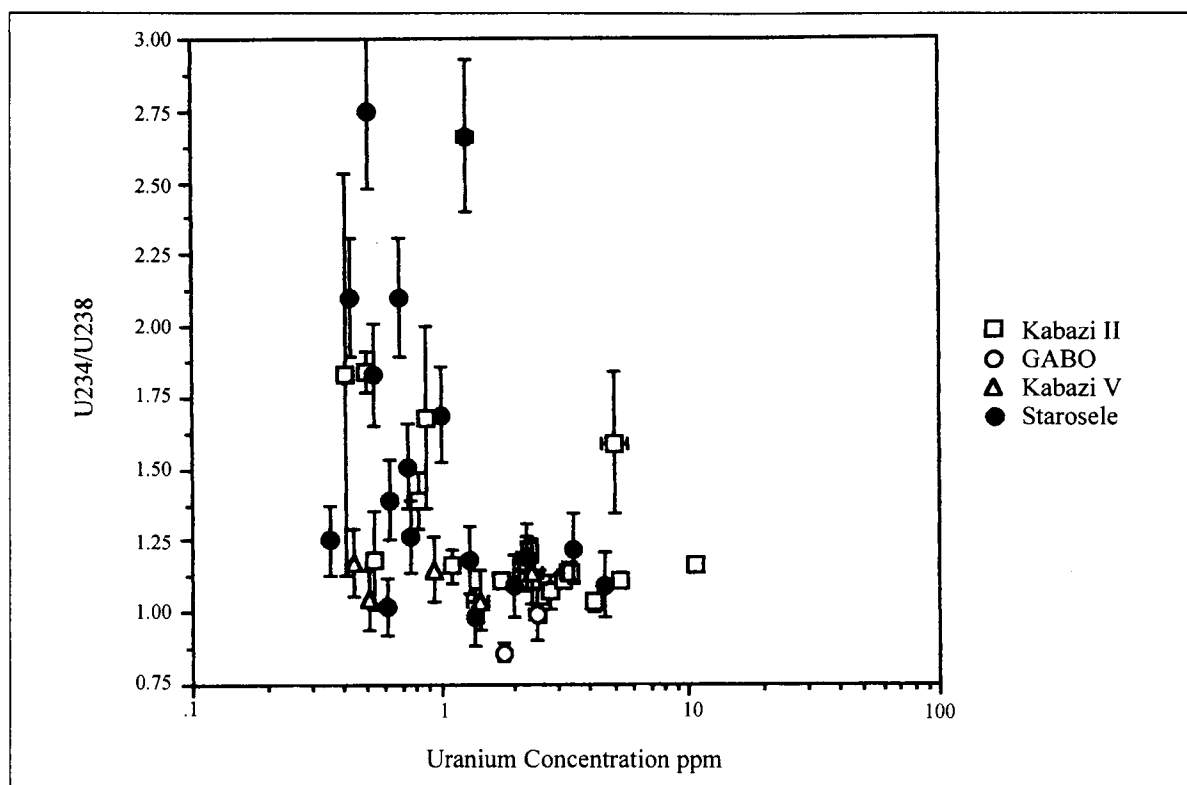


Fig. 14-3—Distribution of samples by their uranium content and uranium ratio for each site.

samples. Generally, low levels of ^{232}Th ($^{230}\text{Th}/^{232}\text{Th} > 50$) are not considered significant and corrections are not made. In the Crimean samples, dentine can be treated as contamination that contains ^{232}Th but has greater effect of higher uranium than clastic contaminants that are ubiquitous in carbonate deposits. The other problem of low yields was corrected by adjusting the chemical procedures and reanalyzing the samples. Most of the first and second series were lost because of these problems. The third series was the most successful and produced the bulk of the data in this report.

KABAZI II

The uranium series results from each stratigraphic zone show that the Middle Paleolithic cultural deposits at Kabazi II range in age between 35 and 55,000 years BP. Kabazi II is divided into five units, each containing several archaeological levels and horizons. Uranium concentrations ranged from 0.3 to 10 ppm, without any pattern indicating progressive uranium uptake (linear or continuous). Progressive absorption of uranium over time with enamel that shares the same environment should show older enamel having higher uranium contents than younger enamels. At Kabazi II, uranium ratios ($^{234}\text{U}/^{238}\text{U}$) consistently are less than 1.2, except for a group of similar tooth enamels in Level II/7F8 and Level III/2 that are distinct from all other samples, with uranium contents lower than average, and uranium ratios greater than 1.2. Assuming some contamination from uncleanable dentine, the sample data were plotted by level to determine if any distortions occurred. The results indicate that Kabazi II is a closed system, since average ages and ages produced by the plots are very similar.

Kabazi II, Level I/3

Two tooth enamels and a dentine were processed from Level I/3 (221-281-E-3; 224-289-E-3; 127-289-D-1). In most environments, dentine is unreliable for dating, because of rapid and

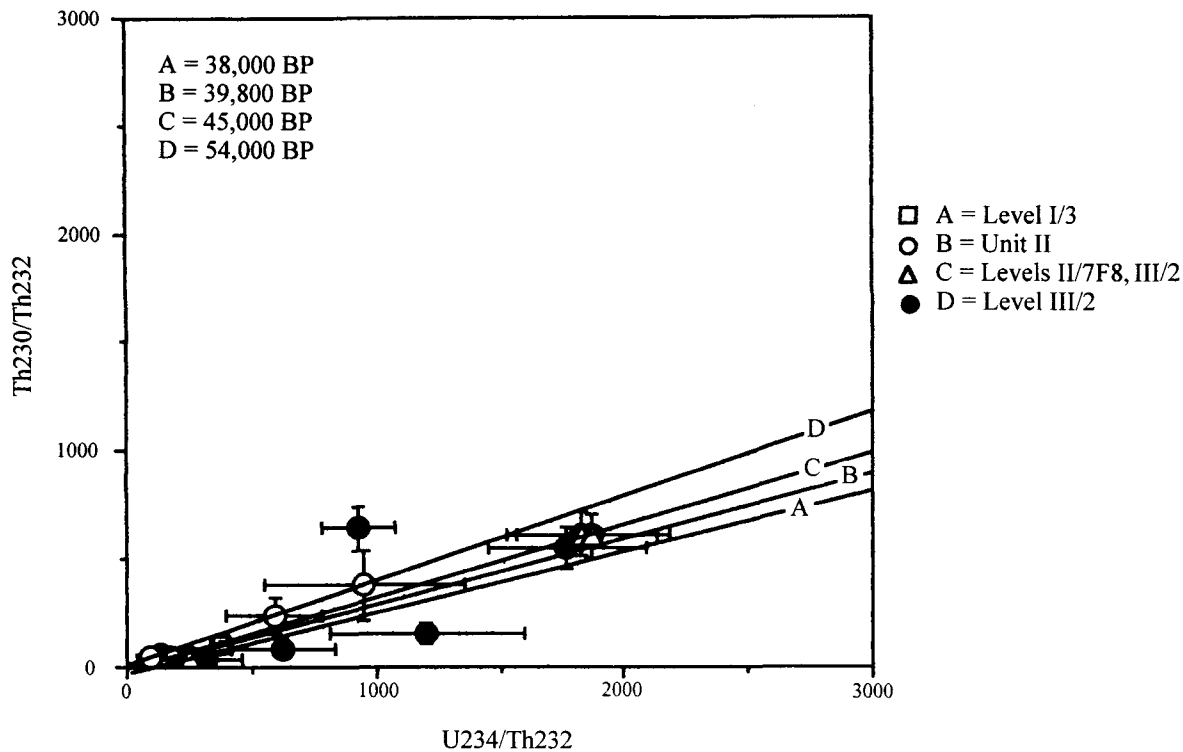


Fig. 14-4—Kabazi II, Plot of $\text{Th}^{230}/\text{Th}^{232}$ and $\text{U}^{234}/\text{Th}^{232}$.

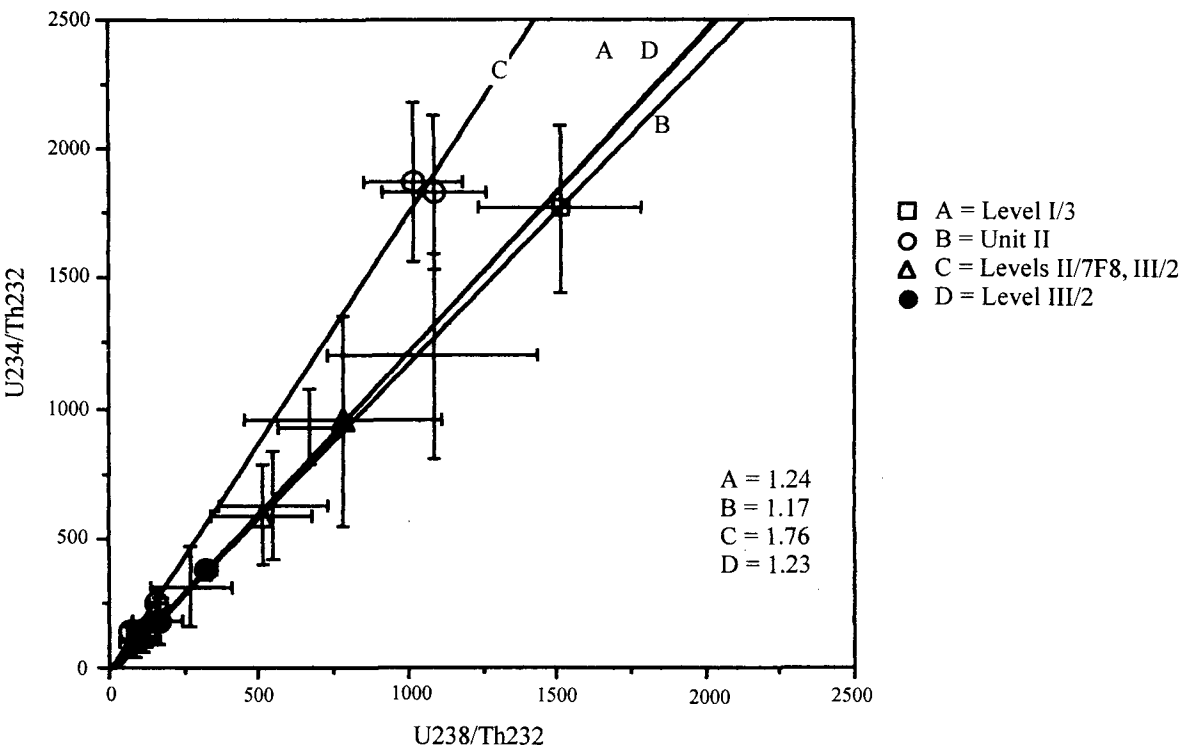


Fig. 14-5—Kabazi II, Plot of $\text{U}^{234}/\text{Th}^{232}$ and $\text{U}^{238}/\text{Th}^{232}$.

TABLE 14-1
Kabazi II

Unit/ Level	Sample Number	Uranium ppm	Thorium ppm	U^{234} / U^{238}	Th^{230} / Th^{232}	Th^{230} / U^{234}	Age <i>K</i> years BP
I 3	221-281-E-3	4.1 ± 0.1	0.12 ± 0.04	1.04 ± 0.03	27.3	0.22 ± 0.02	27. ± 1/1
I 3	224-289-E-3	2.8 ± 0.1	0.04 ± 0.01	1.08 ± 0.03	44	0.25 ± 0.01	31. ± 1.5/1.5
I 3	127-289-D-1	1.1 ± 0.06	<0.01	1.16 ± 0.08	104	0.28 ± 0.03	34.7 ± 4.5/4.4
II 1	58-282-E-2	2.2 ± 0.1	<0.01	1.17 ± 0.04	549	0.31 ± 0.02	40.1 ± 5/4.7
II 1	225-290-E-3	3.3 ± 0.1	0.02 ± 0.01	1.14 ± 0.03	89.4	0.14 ± 0.01	16.7 ± 0.6/0.5
II 1A	39-291-E-1	2.5 ± 0.2	<0.01	1.06 ± 0.09	43	0.26 ± 0.04	32.1 ± 6.5/6
II 1A	226-291-E-3	5.3 ± 0.1	0.01 ± 0.002	1.11 ± 0.02	153	0.13 ± 0.003	14.7 ± 0.4/0.4
II 7	199-288-E-3	0.6 ± 0.1	0.02 ± 0.01	1.2 ± 0.2	36.7	0.35 ± 0.05	46.5 ± 8/7
II 7F8	222-283-E-3	3.4 ± 0.1	0.03 ± 0.01	1.14 ± 0.03	36.4	0.12 ± 0.01	13.9 ± 0.3
II 7F8	37-293-E-1	0.4 ± 0.1	<0.01	1.8 ± 0.7	50	0.37 ± 0.1	48.3 ± 17/15
II 7F8	228-293-E-3	1.8 ± 0.1	0.04 ± 0.01	1.11 ± 0.02	64.8	0.46 ± 0.01	65.5 ± 2.5/2.4
III 2	63-284-E-2	0.8 ± 0.1	<0.01	1.4 ± 0.1	640	0.69 ± 0.04	117. ± 13/12
III 2	210-284-E-3	2.3 ± 0.04	0.02 ± 0.01	1.22 ± 0.02	379.2	0.40 ± 0.01	53.9 ± 2/2
III 2	56-285-E-2	0.9 ± 0.1	<0.01	1.7 ± 0.3	613	0.34 ± 0.04	43. ± 7/6
III 2	223-285-E-3	10.6 ± 0.2	0.06 ± 0.01	1.16 ± 0.02	240.3	0.41 ± 0.01	55.8 ± 2/2
III 2	65-292-E-2	0.5 ± 0.02	<0.01	1.84 ± 0.07	606	0.32 ± 0.02	41.1 ± 2/2
III 2	227-2923	3.1 ± 0.06	0.1 ± 0.02	1.11 ± 0.03	46	0.48 ± 0.01	69.7 ± 3/3

contiguous uranium uptake, but, sample 127-289-D-1 has the same uranium content as its associated enamel, suggesting a similar geochemical history and indicating the site is stratigraphically a closed system. They had an average age of $31,000 \pm 3,000$ years BP. The plots (figs. 14-4A and 14-5A) indicated that for Level I/3 (A) an age ratio of 0.3 and uranium ratio of 1.24 is equivalent to an age of $38,000 \pm 2,000$ (using the average error of the samples).

Kabazi II, Levels II/1, II/1A, II/7, and II/7F8

Six tooth enamels were processed from Level II/1 (58-282-E-2; 225-290-E-3), Level II/1A (39-291-E, 226-291-E-3), Level II/7 (199-288-E-3), and Level II/7F8 (222-283-E-3, 37-293-E-1, 228-293-E-3). Four enamels (58, 39, 199, 228) averaged $46,000 \pm 14,000$ BP, whereas three enamels (225, 226, 222) had younger ages averaging $15,000 \pm 500$ years BP. A replicate of 39-291-E-1, sample 226-291-E-3, produced a young age, probably reflecting dentine or other contamination. They were not used in the plots for this level (figs. 4-4B and 14-5B), nor was sample 37 (see below). The plots indicated for Levels II/1, II/1A, II/7, and II/7F8 (figs. 14-4B, 14-5B) an age ratio of 0.31 and uranium ratio of 1.17, equivalent to an age of $39,800 \pm 5,000$ years BP.

The thickness of the deposits and differences in the cultural remains in Unit II would suggest that the period of accumulation was not a rapid event. Unit II may be split into an upper zone (Levels II/1 and II/1A) and a lower zone (Level II/7 and II/7F8). Plotting these separated zones was not possible, since the data point dispersion was not great enough to form a unique linear association. Grouping Level I/3 with Level II/1 and Level II/1A produces an isochron (not shown) that is not significantly different from that of Unit I alone (41,000 BP), suggesting that these units succeeded each other relatively rapidly. Grouping Level II/7 and Level II/7F8 together with Unit III produces an isochron that has the same slope as the isochron for Unit II ($54,000 \pm 3,000$ years BP). Splitting Kabazi II, Unit II and regrouping the levels with those above and below indicates that Unit II could have been deposited over about 15,000 years.

Kabazi II, Levels II/7F8 and III/2

Four tooth enamels from Level II/7F8 (37-293-E-1) and Level III/2 (63-284-E-2; 56-285-E-2; 65-292-E-2) probably were contaminated by foreign uranium from incompletely cleaned ion exchange resins. They have similar uranium ratios that are higher than the average for the Kabazi II and were all processed at the same time. They had an average age of $44,000 \pm 7,000$ years BP (excluding 63). The plots (figs. 14-4C and 14-5C) indicated an age ratio of 0.34 and uranium ratio of 1.76 is equivalent to an age of $45,000 \pm 7,000$ years BP (using the average error of the samples). This age is probably a minimum for Level III since uranium was gained without any ^{230}Th .

Kabazi II, Level III/2

Three tooth enamels were processed from Level III/2 (210-284-E-3; 223-285-E-3; 227-292-E3). They had an average age of $60,000 \pm 3,000$ years BP. The plots (figs. 14-4D and 14-5D) indicated for Level III/2 an age ratio of 0.4 and uranium ratio of 1.23 is equivalent to an age of $54,000 \pm 3,000$ years BP (using the average error of the samples).

Summary of Kabazi II Results

The age of Level I/3 is $38,000 \pm 2,000$ years BP. The age of Unit II *as a single unit* is $39,800 \pm 5,000$ years BP, which, considering the thickness of the deposit, sterile strata separating the cultural levels, and its cultural variability, is probably too short an interval of deposition. Separating Unit II into upper and lower zones produced ambiguous results because of poor data point dispersion. The results of regrouping the upper levels of Unit II with Unit I suggest that these were deposited in rapid succession, since an isochronal age of $41,000 \pm 3,000$ years BP is generated. On the other hand, when Level II/7, and Level II/7F8 are grouped with Unit III, they produce an isochron that is the same as that generated for Unit III alone ($54,000 \pm 3,000$ BP), thus indicating that Unit II accumulated over as much as 15,000 years.

STAROSELE

Twelve teeth and one bone were submitted for dating from the four levels at Starosele. The analyses were conducted over three years, as each tooth was analyzed up to three times. Previously, Starosele had been unreliably dated with uranium series on bone by Cherdyntsev (1956) because he could not analyze for ^{234}U . In general, Starosele had uranium ratios that were higher than those at Kabazi II, and uranium contents that were lower (fig. 14-3). The uranium content of Starosele dentine (137-314-D-1) when measured was 20 to 50 times the concentration found in the enamels. The difference in uranium content contributed to problems from incomplete separation of dentine and enamel. Generally, use of heavy liquids produce enamel purities of 99+%. At this purity, enamel is usually unaffected by the 1/10% remaining dentine, however, at Starosele the lower uranium content enamels (<1 ppm) would be dramatically affected because the dentine not only had a higher uranium content, but a very young age. Contaminating dentine would thus tend to lower the age of any enamel. The young age of 137-314-D-1 indicates that, unlike Kabazi II where enamels and dentine have the same uranium content and ages, a closed system exists stratigraphically, Starosele has evidence that, at least in the dentine, late uranium uptake occurred. The same techniques to graphically remove the effects of low level contamination as demonstrated in Kabazi II data (figs. 14-4 and 14-5) has successfully removed some of the distortions (figs. 14-6 and 14-7) in the Starosele data.

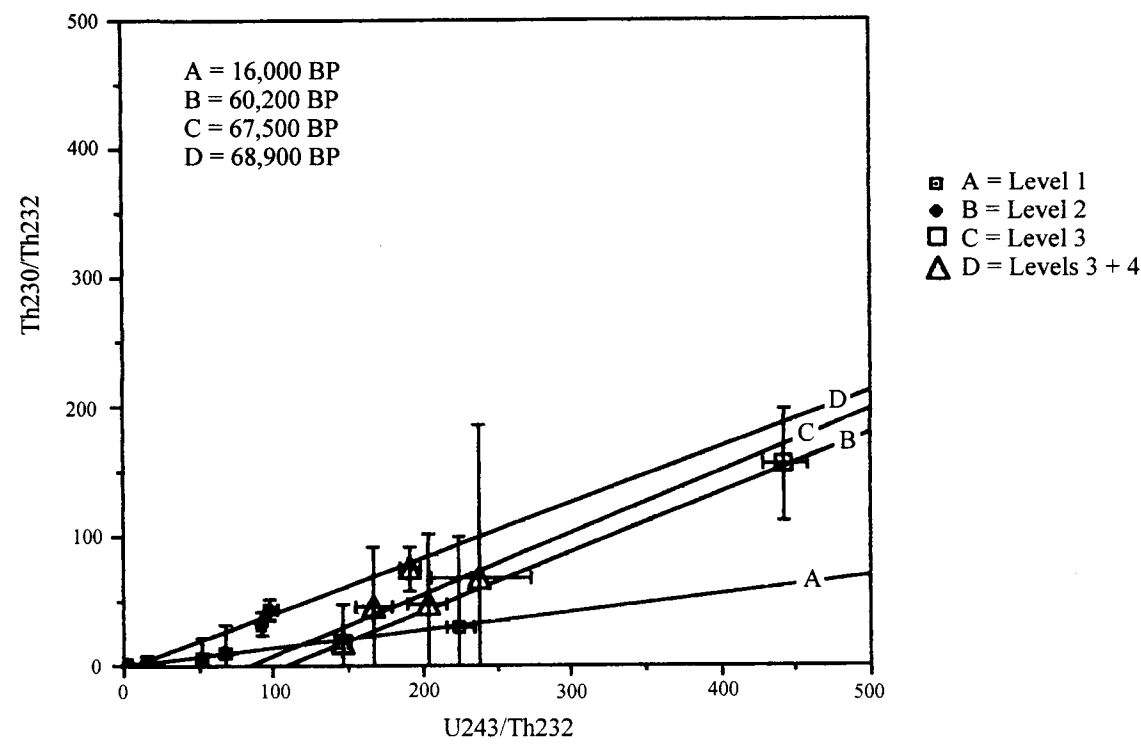


Fig. 14-6—Starosele, Plot of $\text{Th}^{230}/\text{Th}^{232}$ and $\text{U}^{238}/\text{Th}^{232}$.

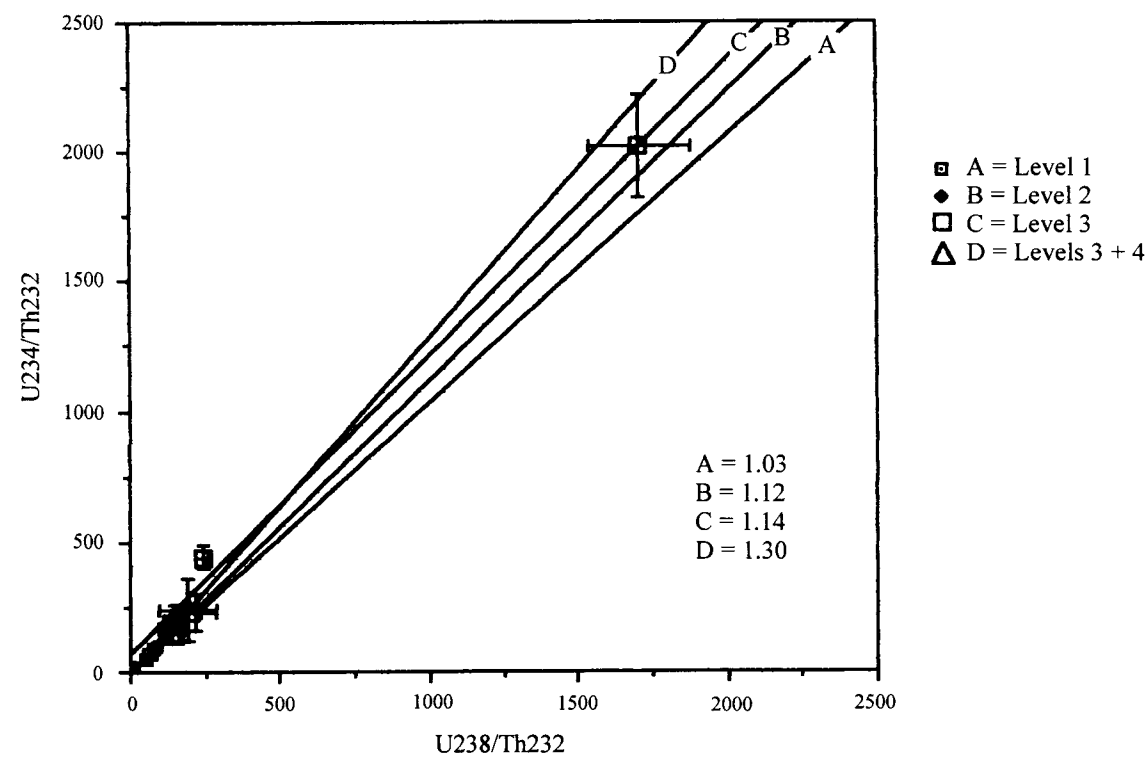


Fig. 14-7—Starosele, Plot of $\text{U}^{234}/\text{Th}^{232}$ and $\text{U}^{238}/\text{Th}^{232}$.

TABLE 14-2
Starosele

Level			Uranium	Thorium	U^{234}	Th^{230}		Age K Years
Square	Sample		ppm	ppm	/U ²³⁸	/Th ²³²	Th ²³⁰ /U ²³⁴	BP
1	I22	192-271-E-3	2.0 ± 0.1	0.17 ± 0.06	1.09 ± 0.06	9.2	0.14 ± 0.02	15.7 ± 2/2
1	J23	193-272-E-3	3.0 ± 0.2	0.04 ± 0.01	1.04 ± 0.07	31	0.14 ± 0.01	15.7 ± 1.3/1.3
1	I22	211-313-E-3	1.4 ± 0.1	0.08 ± 0.05	1.01 ± 0.10	6.3	0.12 ± 0.03	13.6 ± 3.5/3.4
2	H22	212-275-E-3	0.16 ± 0.02	<0.01	1.08 ± 0.15	33	0.36 ± 0.07	47.5 ± 13/11
2	G22	61-297-E-1	2.3 ± 0.08	0.24 ± 0.06	1.19 ± 0.06	44	0.45 ± 0.07	63 ± 5/4
3	F20	208-315-E-3	1.24 ± 0.08	0.0 ± 0.01	1.23 ± 0.12	17.5	0.12 ± 0.01	14 ± 1.4/1.4
3	F21	137-314-D-1	21.1 ± 0.5	<0.004	1.18 ± 0.03	222	0.11 ± 0.01	12.1 ± 0.9/0.9
3	F21	57-274-E-1	0.54 ± 0.03	<0.01	1.83 ± 0.03	155	0.35 ± 0.03	45.8 ± 5.1/4.9
4	H21	9-276-E-1	0.75 ± 0.01	0.04 ± 0.04	1.26 ± 0.9	75	0.39 ± 0.05	80 ± 10/8
4	H21	196-276-E-3	0.35 ± 0.02	0.01 ± 0.01	1.23 ± 0.2	67	0.28 ± 0.02	34.9 ± 3/2
4	I23	230-353-E-1	1.28 ± 0.08	0.02 ± 0.01	1.35 ± 0.09	49	0.24 ± 0.02	29.4 ± 2.1/2.0
4	I23	231-354-E-1	0.54 ± 0.03	0.0 ± 0.01	1.27 ± 0.08	45	0.27 ± 0.02	33.1 ± 2.4/2.3

Starosele, Level 1

The geochronology of Starosele begins with Unit III at Kabazi II which dated to 54,000 years BP. Thus a constraining age of Starosele Level 1 should be between 40,000 (Kabazi II, Unit II) and 54,000 years (Kabazi II, Unit III). Results from three enamels, (192-271-E-3; 193-272-E-3; 211-313-E-3) suggest that this level is only about 15,000 years BP, an age that is too young compared to the Kabazi II chronology. Several factors are probably at work here: late uranium uptake in Level 1 related to its position in a geochemically active soil horizon, or simply the inability to purify enamel with current techniques. Plotting these data (figs 14-6A and 14-7) indicates for Level 1 an age ratio of 0.137 and uranium ratio of 1.03 is equivalent to an age of 16,000 ± 3,500 years BP. The young age suggested by these enamels is not supportable by the lithic technology which is, without doubt, Middle Paleolithic.

Starosele, Level 2

Two tooth enamels from Level 2 (212-275-E-3; 61-297-E-1) produced ages from 47,500 to 63,000 years BP. The plots (figs. 14-6B and 14-7B) indicate for Level 2 an age ratio of 0.42 and uranium ratio of 1.12 is equivalent to an age of 60,000 years BP. Because of only two teeth being plotted, this is an unreliable result. Electron spin resonance dating of tooth enamel and radiocarbon dating suggest this level dates to around 45,000 years BP (personal communication A. Marks). This is consistent with the uranium series results and suggests that the results from Levels 1 and 2 are minimum age.

Starosele, Level 3

Two enamels and a dentine were processed from Level 3 (208-315-E-3; 57-274-E-3, 137-314-D-1). The plots (figs. 14-6C and 14-7C) indicated for Level 3 an age ratio of 0.46 and uranium ratio of 1.14, equivalent to an age of 67,500 years BP. As in Level 2, only two enamels were plotted, too few to produce a reliable result. Only 57 is consistent with Level 2 and ESR data (Marks et al. 1997) at 45.6 ± 5.1/4.9. A published 46,000 years BP uranium series age for this enamel (57) was in error (Marks et al. 1997). The dentine had high uranium content (21 ppm) and a young age (12,100 ± 900 years BP), indicating that late uranium uptake is occurring. This could cause enamel ages to be younger, and is probably causing 208 to be too young either from late uranium uptake, or contamination from dentine, since the uranium content (1.24 ppm) is also higher than other enamels. A simple correction of the

uranium content of 208 to that of 57 produces an age of 35,000 years BP, suggesting that late uranium uptake is the problem.

Starosele, Level 4

Four enamels were processed from Level 4 (9-276-E-1; 196-276-E-3; 30-353-E-1; 231-354-E-1). These enamels were geochemically similar, and since they had a poor data point dispersion, an isochron plot could not be generated. The sample data are combined with Level 3 to better define a geochemical association. The apparent ages span the expected duration of Staroselian occupation and have some distortion from initial ^{232}Th either from dentine or clastic contamination (no clastic material was noted during the cleaning phase). The plots (figs. 14-6D and 14-7D) indicated for Levels 3 and 4 an age ratio of 0.47 and uranium ratio of 1.3 is equivalent to an age of $68,900 \pm 10,000$ years BP. Because of multiple samples (five including 57) this is the most reliable estimate of the age of lower Starosele (Levels 3 and 4). One result (9) suggests that this level began forming more than 80,000 years ago (assuming some post-depositional uranium uptake). An earlier preliminary result from 9, suggesting this level may have started forming as early as $104,000 \pm 8,500$ years BP (Marks et al. 1997), has been lowered to 80,000 BP after a longer counting period. The formation of the lowest level of Starosele during the Last Interglacial is a possibility since uranium uptake is occurring throughout the site; thus, most, if not all, ages should be considered minimums.

Summary of Starosele Results

The ages for Level 1 are too young since Starosele should be roughly contemporaneous with Kabazi II, Unit II and Kabazi V, Complex C (Levels II/4A and II/7) and Complex D (Levels III/I, III/1A, and III/2) (see Chapter 15). The uranium contents of the Level 1 enamels are three to four times that of the lower uranium content enamels, whose ages are reasonable. Thus, Level 1 enamels have gained uranium recently either by being affected by the same geochemical conditions that are increasing uranium in the dentines, or by the effect of small amounts (1/10 of 1%) of dentine mixed with the enamel from imperfect separation techniques. Levels 2 and 3 do not have enough data points for definitive linear plots, but do produce ages consistent with expectations. Certainly, Levels 2 and 3 have ages at about 45,000 BP, consistent with ESR and AMS dating, but the linear plots suggest that these are minimum ages. Level 4 enamels do not have a unique solution because of low data point dispersion. Combining these points with Level 3, which may represent a continuation of the same occupation with an interval of abandonment, produces an age near 70,000 years BP. At least one sample (9-276-E-1) dates near $80,000 +10,000/-8,000$ years BP, indicating that Level 4 may represent a long period of accumulation.

KABAZI V, LEVEL III/1

Four tooth enamels were processed from Kabazi V, Level III/1 (59-300-E-1; 210-300-E-3; 64-304-E-3; 214-312-E-3; 202-311-E-3). Uranium contents were low (<1.5 ppm), as were the uranium ratios (1.04 to 1.2). Enamels 59 and 210 are replicates that are very different; an average of these samples is shown on Figure 14-8. This result indicates that these samples were statistically opposite outliers of a normal distribution. The plots (figs. 14-8 and 14-9) indicated for Level III/1 an age ratio of 0.49 and uranium ratio of 1.15 is equivalent to an age of $73,300 \pm 6,000$ years BP. Kabazi V, Level III/1 is, therefore, chronologically equivalent to lower Starosele.

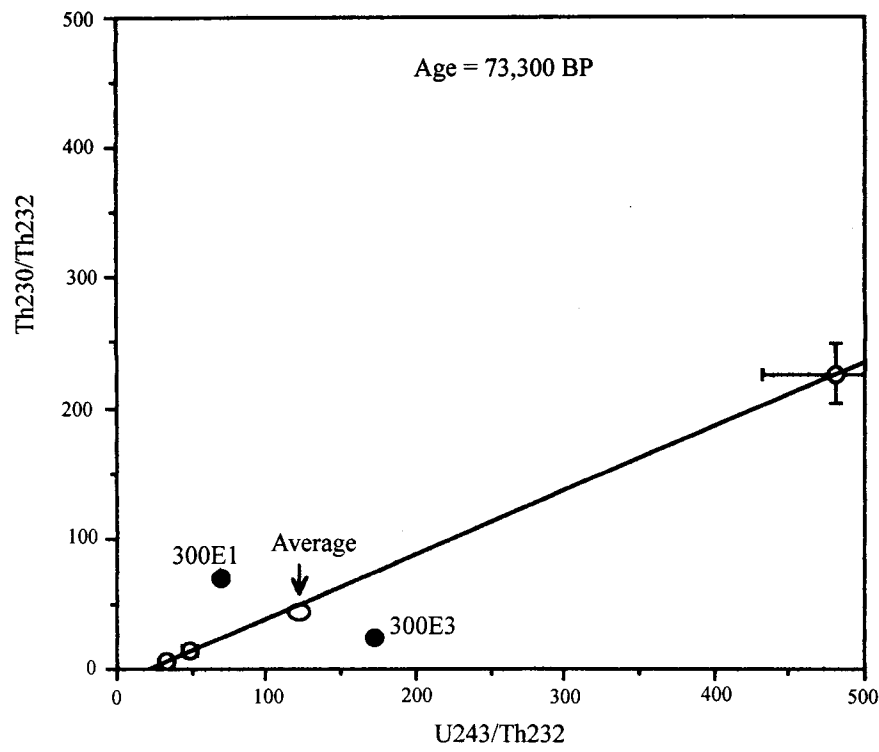


Fig. 14-8—Kabazi V, Level III/1, Plot of $\text{Th}^{230}/\text{Th}^{232}$ and $\text{U}^{234}/\text{Th}^{232}$.

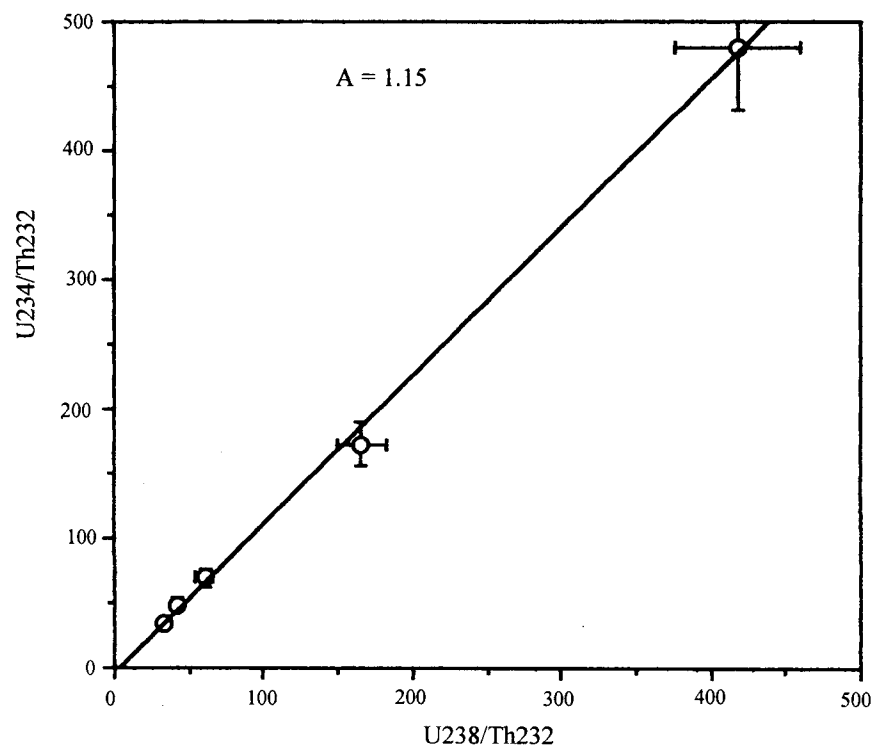


Fig. 14-9—Kabazi V, Level III/1, Plot of $\text{U}^{234}/\text{Th}^{232}$ and $\text{U}^{238}/\text{Th}^{232}$.

TABLE 14-3
Kabazi V

Unit Level	Sample Number	Uranium ppm	Thorium ppm	U^{234}/U^{238}	Th^{230}/Th^{232}	Th^{230}/U^{234}	Age K years BP
III 1	64-304-E-3	0.93 ± 0.02	<0.01	1.15 ± 0.04	226	0.42 ± 0.03	$58.7 \pm 6/5$
III 1	59-300-E-1	2.3 ± 0.03	<0.01	$1.14 \pm .02$	75	1.01 ± 0.02	>350,000
III 1	210-300-E-3	1.4 ± 0.1	<0.01	1.04 ± 0.1	38	0.13 ± 0.02	$15.4 \pm 2/2$
III 1	214-312-E-3	0.45 ± 0.03	<0.01	1.2 ± 0.1	14	0.29 ± 0.04	$37.2 \pm 5/5$
III 1	202-311-E-3	0.51 ± 0.04	0.05 ± 0.02	1.04 ± 0.1	6.1	0.18 ± 0.02	$21.6 \pm 3/3$

GABO, LAYER 1

A single tooth from Layer 1 of GABO was submitted for dating. Of three replicates, only one had good uranium and thorium spectra for analysis. Uranium content was high (3.4 ppm) and ²³²Th was low, which suggests this date is undistorted by dentine contaminate or late uranium uptake. The age is $69,600 \pm 2,000$ years BP; chronologically equivalent to lower Starosele. This result could change with additional analysis of new teeth.

TABLE 14-4
GABO, Layer 1

Sample Number	Uranium ppm	Thorium ppm	U^{234}/U^{238}	Th^{230}/Th^{232}	Th^{230}/U^{234}	Age K years BP
214-287-E-3	3.4 ± 0.04	0.01 ± 0.01	1.23 ± 0.02	514	0.48 ± 0.01	$69.6 \pm 2./2.$

CONCLUSION

The four Crimean localities presented here represent cultural activity that spans roughly the time from the Last Interglacial to about 35,000 years BP. Kabazi II and Kabazi V are the most reliably dated, whereas Starosele, because of a high uranium content in dentine relative to enamel, has the most problems. Starosele Levels 1 and 2 are constrained by Kabazi II, Unit II uranium series ages and minimum radiocarbon dates. Starosele Levels 3 and 4 are constrained by uranium series to at least 68,900 years BP. GABO is represented by one sample and is tentatively 69,600 years BP.